PHONOLOGICAL MEDIATION IN READING: A THEORETICAL FRAMEWORK

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ABSTRACT

PHONOLOGICAL MEDIATION IN READING: A THEORETICAL FRAMEWORK

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A set of perceptual and cognitive processes at various levels, from low-level visual perception to high-level discourse comprehension, underlie reading. Accordingly, research on reading focuses on different aspects of reading ranging from prelexical processing and word recognition to syntactic parsing, sentence comprehension, and discourse comprehension with various technical and theoretical tools including behavioral experiments, neuroimaging techniques, and computational models of eye movement controlling, which reflect the variety of the levels involved during reading. The focus of the current study was the early prelexical and lexical processing and postlexical integration processes involved in the word recognition process during text reading from a perspective of eye-movement control modeling. A framework for a computational model of *guidance by attentional gradient* (GAG) eye-movement control model that includes the role of phonological processes during reading was presented. The assumptions of the framework were tested by two sets of linear mixed models (LMMs) with data from Turkish Reading Corpus: (1) an LMM of fixation speech interval (FSI), and three LMMs of eye movement measures among oral reading data, and (2) three LMMs of eye movement measures among silent reading data. The results of the LMMs were compatible with the canonical findings frequently reported in the literature. Influences of the neighboring words on eye movement measures in the current study were mixed. The results indicated an effect of prelexical phonological processing on eye movements and the involvement of phonological representations on postlexical processing.

Keywords: reading, eye-movement control, eye-voice span

ÖZ

OKUMADA FONOLOJİK DOLAYIM: TEORİK BİR ÇERÇEVE

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Okumanın temelini, alt-seviye görsel algıdan üst-seviye söylem kavramaya kadar bir dizi algısal ve bilişsel süreçler oluşturmaktadır. Dolayısıyla okuma üzerine yapılan araştırmalar, okuma ile ilişkili farklı seviyelerdeki bu çeşitliliği yansıtacak şekilde okumanın, kelime-öncesi işleme ve kelime tanımadan sözdizimsel ayrıştırma, cümle kavrama ve söylem kavramaya kadar farklı yönlerine, davranışsal deneyler, nöro-görüntüleme teknikleri ve göz hareketi kontrolünün berimsel modellemesini de içeren çeşitli teknik ve teorik araçları kullanarak odaklanmaktadır. Mevcut çalışmanın odağında göz hareketi kontrol modellemesi perspektifinden metin okuma sırasında kelime tanıma sürecine dahil olan kelime-öncesi ve kelime işleme ile kelime-sonrası entegrasyon süreci bulunmaktadır. Okuma sırasındaki fonolojik süreçlerin rolünü de içeren bir *dikkat gradyanı ile yönlendirme* (GAG) berimsel göz hareketi kontrol modeli için bir teorik çerçeve sunulmuştur. Bu çerçevenin varsayımları, Türkçe Okuma Derlemi'nden alınan veri ile iki grup doğrusal karma modelle (LMM) test edilmiştir: (1) sesli okuma verisi üzerinden bir adet sabitleme-söyleme aralığı (FSI) doğrusal karma modeli ile üç adet göz hareketi ölçütü doğrusal karma modeli ve (2) sessiz okuma verisi üzerinden üç adet göz hareketi ölçütü doğrusal karma modeli. Sonuçlar, literatürde sıkça raporlanan standart bulgularla uyumluydu. Bu çalışmada komşu kelimelerin göz hareketleri üzerindeki etkileri karma idi. Sonuçlar, göz hareketleri üzerinde kelime-öncesi fonolojik işlemenin etkilerini ve kelime-sonrası işlemede fonolojik temsillerin dahlini işaret etmekteydi.

Anahtar Sözcükler: okuma, göz-hareketi kontrolü, göz-ses aralığı

To my mother Halime Özkan and my dear İpek Özkan,

and

To the memory of my father Aydemir Özkan, the memory of my dear friend Ekim Haşar, and the memory of my niece Elmas Gündüz

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LIST OF ABBREVIATIONS

LF	Long-Frequent words condition
LI	Long-Infrequent words condition
SF	Short-Frequent words condition
SI	Short-Infrequent words condition
A_{pc}	Audio recording start time in terms of display PC time
$A_{tracker}$	Audio recording start time in terms of tracker time
$FF_{tracker}$	First fixation start time relative to tracker start time
FF_{trial}	First fixation start time relative to trial start time
IA	Interest Area
t_{pc}	The current time of display PC at the start of audio recording
$t_{tracker}$	The current time of tracker at the start of audio recording
t_{trial}	Trial start time relative to tracker start time
P0	Predictability of word n
SF0	Stem frequency of word n
WL0	Word length of word n
SC0	Suffix count of word n
TF0	Trigram frequency of word n
VH0	Vowel harmony of word n
EVS	Spatial eye voice span
FSI	Fixation speech interval
RFLP	Relative first landing position
LS0	Launch site of word n
P1	Predictability of word n-1
SF1	Stem frequency of word n-1
WL1	Word length of word n-1
SC1	Suffix count of word n-1
P2	Predictability of word n+1
SF2	Stem frequency of word n+1
WL2	Word length of word n+1
SC2	Suffix count of word n+1
TF2	Trigram frequency of word n+1
VH2	Vowel harmony of word n+1
LS2	Launch site of word n+1

CHAPTERS

1. INTRODUCTION

The processes that are involved in reading comprise an interplay between various levels of processes, from low-level oculomotor processes to high-level discourse comprehension. Research on processes in reading heavily relies on the analysis of eye-movement data. Eye movement patterns provide robust data that may give insight to understanding the underlying cognitive processes, such as the identification of words and allocation of covert attention (i.e., attention without moving the eyes) during the course of reading. There is a general agreement on often reported eye-movement measures, based on extensive evidence indicating that the underlying cognitive processes during reading have an effect on oculomotor processes. In particular, lexical and postlexical processes are assumed to have an effect on *when to move eyes* (i.e., fixation durations), whereas low-level visual processes, such as detecting the word boundaries, are assumed to have an effect on *where to move eyes* (i.e., saccades) (Radach & Kennedy, 2013; Warren, Reichle & Patson, 2011; Rayner, Pollatsek, Ashby, & Clifton, 2012; Reichle, 2006). Although computational models and empirical studies of eye-movements during reading provide ample evidence that eye-movements are influenced by ongoing cognitive processes, the nature of the so-called *eye-mind link* has been an ongoing debate (Reichle, 2006). It is still controversial whether *saccade generation results from a serial attention shift* (Reichle, Pollatsek, Fisher, & Rayner, 1998), or *an autonomous saccade generation process is delayed by cognitive processes as a function of the difficulty of the text* (Engbert, Longtin, & Kliegl, 2002). A related debate has been going on regarding whether lexical processes in reading are guided serially or in a distributed manner (cf. parallel processing). Even though there exists a consensus on the ongoing processing of the previous text, there is also a debate on the degree of the processing of the next word during a fixation on the current word – i.e., does the lexical processing of the next word start that early, or is it just prelexical processing of it (Rayner et al., 2012; Radach & Kennedy, 2013; Rayner, 1998; Reichle, 2006)

Another characteristic of reading is that it entails the transformation of orthographic representations to phonological representations. Essentially writing systems map symbols (or a combination of them) to *sounds*. Even in writing systems in which characters represent morphological units rather than phonological units, sounds are mostly represented through phonetic compounds (e.g., 90% of the characters in Chinese). Therefore, studies on the role of sound coding in reading focus on both *silent reading* and *reading aloud*. Although the nature of the relationship between reading and sound coding has not been fully understood, there is a general consensus that there *is* an effect of sound coding in reading (Rayner et al., 2012; Frost, 1998, 2005; Rastle & Brysbaert, 2006; Rayner, 1998). Studies in reading aloud mainly focus on the distance between the articulation of the text and the fixation point on the text at the time of articulation, or the time interval between the time of the articulation of the piece of the text and the fixation time of that piece of text, or both (cf., *the eye-voice span*) (Inhoff, Solomon, Radach & Seymour, 2011; Laubrock & Kliegl, 2015).

Buswell (1920) conducted early investigations of the eye-voice span, which revealed that the eyes move approximately 15-17 characters, or two to three words, ahead of the voice. Subsequent research on the eye-voice span has been in agreement with Buswell (1920), with a time interval of approximately 500 ms between the eyes and the voice (Inhoff et al., 2011; Laubrock & Kliegl, 2015). Although the explanation provided by researchers differ, studies on subvocal articulation that use techniques directly measuring muscle movements in the speech tract during silent reading to indirectly investigating the effect of sound coding via manipulating phonological properties of text show that there is evidence of an articulatory process during silent reading as well (Rayner et al., 2012; for a review of techniques used to study inner speech in general see, Guerrero, 2005). It was observed that reading tongue twisters took longer than matched control sentences in silent reading, as well as in reading aloud (Haber and Haber 1982); listening to an irrelevant sound or articulatory suppression during reading influence(s) eye-movement measures (Eiter & Inhoff, 2010; Inhoff, Connine, Eiter, Radach, & Heller, 2004); the muscle activity while reading a difficult text was increased, and the suppression of subvocalization during reading difficult text resulted in poor comprehension (Hardyck & Petrinovich, 1970 as cited in Rayner et al., 2012). The findings suggest that the articulatory component in silent reading is tied to the reading process itself. However, the relationship between silent reading and reading aloud is still mostly unknown. Several studies have shown that the relationship between oral and silent reading is not straightforward, at least concerning parafoveal processing in reading (Ashby, Yang, Evans & Rayner, 2012), and in the developmental context (Vorstius, Radach & Lonigan, 2014).

As mentioned above, a set of perceptual and cognitive processes at various levels are known to underly reading. Those processes form an assembly at different levels, from low-level visual perception to high-level discourse comprehension. Accordingly, reading research encompasses a spectrum of studies, with the topics of single word recognition out of context at one edge, and discourse comprehension at the other (Rayner, 1998; Rayner et al., 2012; Clifton, Ferreira, Henderson, Inhoff, Liversedge, Reichle & Schotter, 2016). The current study follows the line of reading research that focuses on relatively early lexical processes and postlexical integration processes involved in word recognition during *text reading*. Therefore, processes involved in single word recognition out of context or in syntactic and high-level discourse comprehension are beyond the scope of the current study.

On the other hand, the present study focuses on both silent reading and oral reading, i.e., the relationship between sound coding and eye-movements during reading. An attentional gradient model of eye-movement control with a component for phonological processing was proposed (i.e., **P**honological-Mediation in **G**uidance by **A**ttentional **G**radient model of reading – P-GAG). The model is basically a framework for a computational model. To test the basic assumptions of the model, Turkish Reading Corpus data (Acartürk et al., 2017a) were statistically analyzed by providing Linear Mixed Models of several eye-movement measures (i.e., first fixation duration, gaze duration, and relative first landing position), and of fixation speech interval (i.e., temporal interval between the first fixation on a word, and the articulation of that word).

In the next chapter, background information will be provided. The P-GAG model will be introduced in the third chapter. The subsequent two chapters will present the empirical study and its methodology, the analyses employed, the details of the linear mixed models, and the results. In the last chapter, the conclusions derived from the study will be discussed in the context of the P-GAG model.

2. BACKGROUND

Over the past few decades, research on reading has focused on various aspects of the phenomenon, from oculomotor control, word recognition, and comprehension in skilled reading to reading skill acquisition and the effect of aging (e.g., Rayner, 1998, 2009a for skilled reading; Blythe & Joseph, 2011 for developmental aspects; Li, Li, Wang, McGowan, Liu, Jordan & Paterson, 2017 for aging). Reading research has employed a set of tools including behavioral experiments, neuroimaging techniques, and computational models of eye movement controlling during reading with a focus on various levels of the underlying processes, ranging from prelexical processing and word recognition to syntactic parsing, sentence comprehension, and discourse comprehension (see Rayner, 1998, 2009a; Rayner et al., 2012 for reviews). The focus of the current study is the relatively early prelexical and lexical processes, and postlexical integration processes involved in word recognition during *text reading* from a perspective of eye-movement control modeling. The aim here is to provide a framework for a computational model of eye-movement control that includes the role of phonological processes during reading. Therefore, the current chapter focuses on the studies that rely on eye-movement data, studies on the role of sound coding during reading, as well as eye-movement control models of reading.

2.1. Attention and Oculomotor System

Reading is, in its most basic form, the extraction of information embedded in a configuration of written symbols. Essentially, we *attend* to the content of the text via attentional mechanisms to extract information. Additionally, we exploit the oculomotor system to *bring the text to the fovea* most of the time during reading. Therefore, in addition to proposed word identification mechanisms, the relationship between the attentional and oculomotor systems is one of the important components of eye-movement control models of reading. Moreover, the nature of the attentional system and its relationship with the oculomotor system is central to most of the debates in reading research, especially among those that employ a computational modeling approach. Since research on the attentional system *per se* is beyond the scope of the current study, the focus of the current section is on the relationship between covert visual spatial attention (rather than other modalities and visual search) and its relationship with oculomotor and word recognition systems.

According to the theory of visual spatial orienting of attention, proposed in Posner (1980), there is a distinction between the overt orienting of attention (i.e., head and eye movements) and the covert orienting of attention (i.e., orienting attention without moving eyes or head by a central control mechanism internal to the organism with or without external stimulus). Four possible relationships between these mechanisms were suggested: (1) complete dependence (i.e., eye-movement and attention systems are identical), (2) efference theory (i.e., eye-movements are programmed by attention), (3) functional relation (i.e., eye-movements and attention have common triggers, and hence a close functional relationship but no intrinsic physiological relationship), and (4) complete independence (Posner, 1980, p.13). The relationship has been investigated through a set of experiment series that employed different combinations of detecting a luminance increase and moving eyes to a target, both presented peripherally and emerged with differing latencies, in the presence and absence of neutral, congruent, or incongruent central cues. The results showed that participants were able to move covert attention while their eyes were fixed, and attention could move in the opposite direction of eyes. On the other hand, there was a strong tendency of moving attention to the target prior to an eye movement, even when luminance increases to be detected was on the opposite side with higher probability. These results suggested that the overt orienting of attention and covert orienting of it were loosely coupled in these tasks. On the other hand, although the relationship was not strong enough to support (1) and (2), it was not completely independent (Posner, 1980). Hence, the author concluded that the relationship was a functional one with a dependency on "the presentation of an important peripheral event" (Posner, 1980, p. 19). Subsequent empirical studies and computational models on visual attention followed the assumption of distinct but functionally tied mechanisms devoted to attentional processes and oculomotor processes with evidence from neuroimaging studies that support the claim of two systems of overt and covert orienting of attention with a functional relationship (e.g., Koch & Ullman 1985; Henderson, 1992; Kean & Lambert, 2003; for reviews of neuroimaging studies see Petersen & Posner, 2012, and Buschman & Kastner, 2015; but see Corbetta, Akbudak, Conturo, Snyder, Ollinger, Drury, Linenweber, Petersen, Raichle, Van Essen, Shulman, G L, 1998 for overlapping brain regions).

In reading research, the relationship between higher-level cognitive processes and eye movements investigated through experiments in which participants were allowed to move their eyes freely while their eye movements were recorded. In text reading, a dissociation between the allocation of attention and eye-movements is less obvious than relatively simple tasks such as orienting attention to an increased luminance in the peripheral visual field without moving the eyes. However, most of the successful eye-movement control models of reading take the dissociation given with a close relationship between covert attention and eye movements (e.g., Engbert et al., 2002; Reichle et al., 1998).

The main body of evidence for such a dissociation between covert attention and eye movements with a functional relationship comes from the studies which employed the *contingent display technique* (McConkie & Rayner, 1975). The contingent display change paradigms provide the investigation of *perceptual span* during reading (i.e., the region from which useful information intake is possible during one fixation – called *attentional span* in Henderson, 1992, p. 263). In the *gaze-contingent moving-window* technique introduced by McConkie & Rayner (1975), the amount of text visible to the participants was manipulated through differing sized *windows* defined by the experimenter. The opposite of the moving-window technique is the *gaze-contingent moving-mask* technique in which the text is visible outside of the mask (Rayner & Bertera, 1979). In both techniques, the place of the window/mask is dependent on the fixation detected by the eye-tracker, and available parafoveal information was manipulated by window or mask sizes. It was expected that the less parafoveal information was available prior to fixating the word, the longer fixation durations on the word. Another technique used to investigate the perceptual span is the *gaze-contingent invisible boundary* technique (Rayner, 1975). In this technique, a target word is replaced by another word or by a non-word until eyes crossed an invisible boundary. It is assumed that any inconsistency between the target word and the replaced word/non-word would influences the processing time of the target word depending on the available parafoveal information of the target word before crossing the boundary. Studies using moving-window techniques showed that comprehension was not influenced by window size unless the window size was one character. Increasing mask size, on the other hand, was more detrimental to comprehension such that as the mask size increased, words reported correctly was decreased – a mask size over 13 characters made almost impossible to report words correctly. Reading speed and eye-movement measures were influenced by both the window and the mask size. As the window size decreased or mask size increased, reading speed and saccade lengths decreased, the duration and the count of fixations increased (Rayner, 1975; McConkie & Rayner, 1975; Rayner & Bertera, 1979). McConkie and Rayner (1975) found that participants read at normal speed with intact comprehension if the window was at least 31 characters, which means 15 characters to each side of the fixation. The results of a later study, in which the stimulus letters outside of the center of vision were larger, were compatible with the finding, implying that the main factor influencing the perceptual span is not acuity limitations (Miellet, O'Donnell, & Sereno, 2009). Another important aspect of the perceptual span is its asymmetrical nature. Earlier research shows that readers obtain useful information 14-15 characters to the right of fixation and 3-4 characters to the left of it (McConkie & Rayner, 1976; Rayner, Well, & Pollatsek, 1980; but see Jordan, McGowan, Kurtev & Paterson, 2016, and Jordan, McGowan, Kurtev & Paterson, 2017 for conflicting findings). Cross-linguistic studies confirm this finding (DenBuurman, Boersma, & Gerrissen, 1981; Häikiö, Bertram, Hyönä, & Niemi, 2009; O'Regan, 1983). However, the asymmetry of the perceptual span was dependent on the direction of the writing system, as a study in Hebrew showed that the span was larger to the left of the fixation (Pollatsek, Bolozky, Well, & Rayner, 1981; see Jordan, Almabruk, Gadalla, McGowan, White, Abedipour & Paterson, 2014 for Arabic). Besides, studies on vertically printed Japanese text show that the perceptual span was extended five to six characters to the vertical direction of reading (Osaka & Oda, 1991; Osaka, 1993; see Su, Yin, Bai, Yan, Kurtev, Warrington, McGowan, Liversedge & Paterson, 2020 for asymmetric perceptual span both horizontally and vertically in the reading direction in Mongolian). The writing system influenced the size of the perceptual span, as well. Studies in Chinese showed that the perceptual span is narrower in Chinese with one character to the left of the fixation and 2-3 characters to the right of the fixation (Chen & Tang, 1998; Inhoff & Liu, 1998). While words in Chinese consists mostly of two letters, there are many one-letter words and some three-letters and four-letters words. The characteristics of Chinese in which characters represent syllables and morphemes imply that readers obtain an amount of information from the right of a fixation similar to the information obtained in English reading. Similarly, studies in Japanese Kanji (a script with morphemic characters) and Kana (a script with syllabic characters) scripts confirm the narrower perceptual span than English with even narrower when the text consists of primarily Kanji script (Osaka, 1987, 1992). Although a full comparison is not possible, considering these findings from different languages and writing systems together, the perceptual span is extended in the reading direction, approximately two to three words, including the fixated word.

The findings listed above suggest that the perceptual span is not determined solely by visual acuity constraints, but also by attentional mechanisms. Henderson (1992) suggests two possible non-attentional mechanisms that might be the source of the asymmetrical nature of the perceptual span: (1) lateralization of the function in the hemispheres and (2) developing a perceptual module specific to reading as a part of learning to read. According to (1), since mostly left hemisphere is dominant in language processing, and there is a contralateral connection of visual field and retinal receptor cells, there might be a processing advantage for text in the right visual field. However, as mentioned above, the perceptual span is not extended to the right visual field for all writing systems; rather, it is asymmetrically extended depending on the reading direction. According to the second possibility for a non-attentional explanation of the phenomenon, there is an automatized or hard-wired module that takes advantage of the information available in the visual field, depending on the reading direction. The module could have emerged during learning to read and specific to the writing system. If the explanation was correct, bilingual readers of right-to-left writing systems and left-to-right writing systems should have two modules and switch between modules as they switch between writing systems. However, in Inhoff, Pollatsek, Posner, and Rayner (1989), the effects of the manipulation on the reading direction of English text on perceptual span showed that even in the reverse order, the perceptual span was asymmetrical to the direction of the text. Since the participants could hardly develop a module for the novel reading direction, the results were detrimental to the possible explanation (2) mentioned above. Therefore the assumption that perceptual span is asymmetrical to reading direction due to covert attention directed accordingly was supported strongly by empirical evidence (Henderson, 1992).

The nature of the information obtained within the perceptual span (i.e., *parafoveal benefit*) is controversial in reading research – e.g., is it a lexical or prelexical influence? The controversial status of parafoveal benefit and its relation to serial vs. parallel processing of words were discussed in the section, *Eye-movement Control Models* (for a review see, Rayner, 1998, 2009a; Rayner et al., 2012).

2.2. Characteristics of eye-movements

The eyes do not move smoothly during the perception of a static stimulus (e.g., a text, a picture, etc.). Rather, they move with jumps, i.e., *saccades*, with relatively still periods called *fixations*. Saccades bring stimuli into the *fovea*, which has the highest acuity in the visual field. The *parafovea*, on the other hand, has a poorer acuity that provides limited information (e.g., word boundaries in reading). In reading, the eyes jump to different locations through the text in about 20-40 ms and then stand still (viz. fixation). The eyes are 'blind' between fixations due to *saccadic suppression* (Matin, 1974), i.e., information is extracted only during fixations, which last for 10-100 ms to 500 ms with a mean of 200-250 ms. Studies show that saccades and fixation durations during reading show a pattern dependent on several factors, like effects of prelexical, lexical, syntactic, or discourse processing, as well as readers' skill. Skilled readers tend to show saccadic movement mostly in the forward direction, while backward saccades, called *regressions*, occur when there is either comprehension difficulty or error in the programming of forward saccades. In addition to the direction of saccades, there is variability in the size of them. Saccade size highly depends on the length of the word, with an average of 7-8 letters between two fixations. Saccades may extend to 20 characters while very short words are frequently skipped, and long words tend to be fixated more than once – e.g., function words are skipped more than half of the time, and words that have eight letters or longer tend to receive *refixations* most of the time. The text type is another important factor that influences eye-movements. Earlier findings suggest that simpler texts like light fictions or newspaper articles are read with shorter average fixation durations, longer saccade lengths, fewer regressions, and more words per minute compared to texts that require expertise like texts on economics, physics, biology (Rayner, 1998, 2009a, 2009b; Rayner et al., 2012). Reading research and eye-movement control models focus mostly on word-by-word processing, although there are studies that investigate sentence-level and discourse-level processing during reading (see Staub & Rayner, 2007 for a review). Since the purpose of the current study is to provide a framework for including the phonological aspect of reading to existing eye-movement control models, the focus is on word-level processing.

The fact that the variability in saccades, fixation counts, and fixation durations during reading depends on the characteristics of the text necessitates a careful selection of measures in reading research. The variability in eye-movements also makes average fixation duration an insufficient measure for the study of reading. Reading research on eye movement control mostly focuses on saccade target selection and the time course of lexical processing during reading. Therefore, in addition to fixation position measures (e.g., *first landing position* – the position of the first fixation on the word), several first-pass reading times are selected for the estimate of early processing times, such as *first fixation duration* (the duration of the first fixation on a word in the first-pass), *single fixation duration* (the duration of the fixation on a word when the word received only one fixation in the first-pass), and *gaze duration* (the sum of the duration of all fixations on the word in the first-pass) (Rayner, 1998, 2009a). These mostly reported first-pass reading times, provide an approximate estimate of the time that is needed to process each word, and early effects of parafoveal processing on the processing of the foveal word (Rayner, 1998, 2009a; Kliegl, Nuthmann & Engbert, 2006; Kliegl, 2007). The processing time of a region that extends over more than one word is usually estimated by late eye-movement measures like second-pass reading time, *regression path duration* (or, *go-past time* which is the total duration between entering and leaving a region including intra-region regressions), and total reading time (Rayner, 1998, 2009a).

2.3. Eye-movement Control Models

The motivation behind the development of eye-movement control models has been to provide an explanation of the relationship between lexical processes and eye-movements during reading – i.e., of the *eye-mind link*. Rayner (2009b) deems the emergence of computational models of eye-movement control as the fourth era of reading research. The first era included initial observations about the basic facts about eye movements during reading, the second era included surface properties of eye movements under the influence of behaviorist movement in experimental psychology, and the third era was characterized by investigation of cognitive processes underlying reading with advanced eye-tracking technologies and novel techniques such as gaze-contingent display change paradigm (Rayner, 1998, 2009a, 2009b). State of the art in reading research since the late 1990s has been investigating the validity of eye-movement control models of reading and their predictions. These models, with their theoretical explanation of the eye-mind link, provided an account for counterintuitive findings and novel predictions that lead empirical studies (Rayner, 2009b).

The models have various assumptions about the nature of the relationship between lower-level processes of the oculomotor system and higher-level processes of the lexical processing system. The models essentially simulate eye movement patterns given their proposed *mechanism* for lexical processing and its relationship with the oculomotor system during reading. In doing so, the models aim to account for and predict frequently reported effects of word characteristics on eye movement measures, under their assumptions. The models included in this section (i.e., E-Z Reader, SWIFT, and Glenmore) have different assumptions about the eye-mind link. These models are selected due to their successful predictions of eye-movements dependent on characteristics of words and their representativeness of the main assumptions.

The basic assumptions of the early eye-movement control models accepted eye-movements as either the result of the completion of a cognitive event (e.g., completion of lexical processing) or result of the oculomotor system and low-level visual information. The first group of models is called *cognitive-control models* or *processing models*, and the second group of models is called *oculomotor-control models, primary oculomotor models*, or *oculomotor models* (Rayner, 1998, 2009b; Reichle, 2006; Reingold, Reichle, Glaholt, & Sheridan, 2012). The early cognitive-control models assume that readers immediately start processing a word as soon as they fixate on it (i.e., *immediacy-of-processing assumption*), and their eyes stay on the word until the processing is completed, including text integration (i.e., *eye–mind assumption*). Therefore, the first-pass reading time of a word reflects its processing time (Just & Carpenter, 1980). Several eye-movement characteristics were puzzling under these assumptions, like very short fixations, fixations between words, skipping, and refixation. Oculomotor control models, on the other hand, assume that eyes guided primarily by the oculomotor system and lexical processing can influence eye movements only during very long fixations – i.e., lexical processing effects emerge very late (Rayner, 2009b). However, there is abundant evidence of the influence of lexical processing on eye-movements, such as the systematic effects of frequency and predictability of words on fixation durations. Therefore successful eye-movement control models assume a mixture of these mechanisms with different weights on cognitive-control mechanisms. In a model with the *process-monitoring assumption* (Morrison, 1984), although eye-movements are guided by serial attention shifts as a result of lexical access, rather than complete lexical processing, those shifts have a delayed effect on saccades (Kliegl et al., 2006). According to this conception of the reading process, after the foveal word (word n) processing reaches a certain level (e.g., lexical access), attention shifts to the next word (word n+1) in the parafovea, and a saccade programming starts. Since the attention was already shifted to the next word, the processing of word n+1 starts before eyes move to that word (i.e., *parafoveal processing*). The next word can be completely processed before eyes move to that word (as it is the case for function words). In that case, the saccade program can be modified, and word n+1 can be skipped with a cost that is manifested in longer fixation duration on word n+2 (Rayner, 1998). Although this conception could explain several irregular eye-movements, like skipping, it fell short in explaining refixations on a word. The E-Z Reader model (Reichle et al., 1998; Reichle, Pollatsek, & Rayner, 2006;

Reichle, Warren, & McConnell, 2009), which implements the process-monitoring assumption, permit a limited distribution of processing of words by assuming that a saccade program can start upon lexical access, or before lexical access. According to the assumption, processing word n can continue while fixating word n+1. In contrast to the process-monitoring assumption, the SWIFT model (Engbert et al., 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005; Richter, Engbert & Kliegl, 2006; Schad & Engbert, 2012; Risse, Hohenstein, Kliegl & Engbert, 2014) assumes that the process-monitoring system interferes in essentially autonomous oculomotor system, only when necessary (Kliegl et al., 2006; Reingold et al., 2012). In SWIFT, attention is not allocated to one word in a serial manner; rather, it is a gradient with the highest activation level for the foveal word. Therefore, in SWIFT, words are processed in parallel within the perceptual span. Another parallel processing model is Glenmore (Reilly & Radach, 2003, 2006), which leaves the assumption of cognitive control in addition to the role of covert attention in guiding eye movements. In this neural network model, the saccade generation mechanism is influenced by a general activation level of word units, which changes due to the information intake during a fixation, as well as low-level oculomotor processes (Reilly & Radach, 2006). Details and predictions of these three models (i.e., Glenmore, E-Z Reader, and SWIFT) are provided in the sub-sections below.

2.3.1. Glenmore

Glenmore is an interactive activation model of eye movement control in reading (Reilly & Radach, 2002; 2003; 2006). Although the model allows the effects of linguistic processing on eye movements, the model does not include the concept of covert attention. According to the model, eye movements are determined by the interplay of low-level oculomotor processes and ongoing cognitive processing. The model consists of an input module, a word processing module, a fixate center (following Findlay & Walker, 1999), a saliency map, and a saccade generator. The saliency map holds low-level visual information as a saliency vector, which allows target selection and triggering of a saccade without the influence of cognitive processes, at the beginning of each fixation. During a fixation, the saliency values are updated by feedback from word units through letter units, depending on the information from linguistic processing. The letter and word units comprise the linguistic processing module within an interactive activation framework (Grainger & Jacobs, 1998). From the letter units, the information transferred from visual inputs and word units is transferred to a fixate center (FC). The activity in the FC triggers a saccade directed to the location determined by the saliency map and executed by a saccade generator, which is the non-connectionist component of the model.

Input units in the model comprised of 30 character spaces with the fovea at position 11, reflecting the perceptual span. The asymmetry of the perceptual span is implemented by a probability density function of the gamma distribution. The letters present within the perceptual span are linked to letter units. Activation in a letter unit indicates the presence of the corresponding letter among the letter units. Another connection from input units is directed to the saliency map. The initial activation in the salience map is modified by the feedback from the letter units. Letter units transfer information with another set of connections to word units (determined by the model) and receive feedback from word units. The activity in word units is influenced by recurrent connections that implement word frequency and inhibitory connections between words that implement competition between words. Accordingly, the activation of the region in the saliency map is determined by both low-level oculomotor processes and high-level linguistic processes, which is implemented by the connections between input units, saliency map, letter units, and word units. The target of a saccade is determined by the activity in the salience map. Another connection from letter units to FC determines the activity in FC. When the activity in FC falls below a threshold, a saccade is triggered.

The model predicts the positive relationship between word length and fixation durations that empirical findings indicate. The predictions of the model regarding the relationship between word frequency and fixation durations were mixed. Among short words, model predictions and data were compatible, as presented in Reilly and Radach (2006). However, predictions of the model regarding the effect of word frequency and that of data were not compatible among medium length and low-frequency words, and among long and low- and medium frequency words. On the other hand, simulations of the model did not show any IOVP effect. Besides, when launch sites were small, an OVP effect was observed (Reilly & Radach, 2006). As the authors admit, the model does not include an account for saccadic errors, which result in short fixation durations, corrective saccades, and hence the IOVP effect.

The illustration of the model in Figure 2.1, Panel A is a simplified reproduction of the Figure 21.1 in Reilly and Radach (2003, p. 432) and Figure 1 in Reilly and Radach (2006, p. 37), and Panel B is a simplified reproduction of Figure 21.2 in Reilly and Radach (2003, p. 437) and Figure 2 in Reilly and Radach (2006, p. 39).

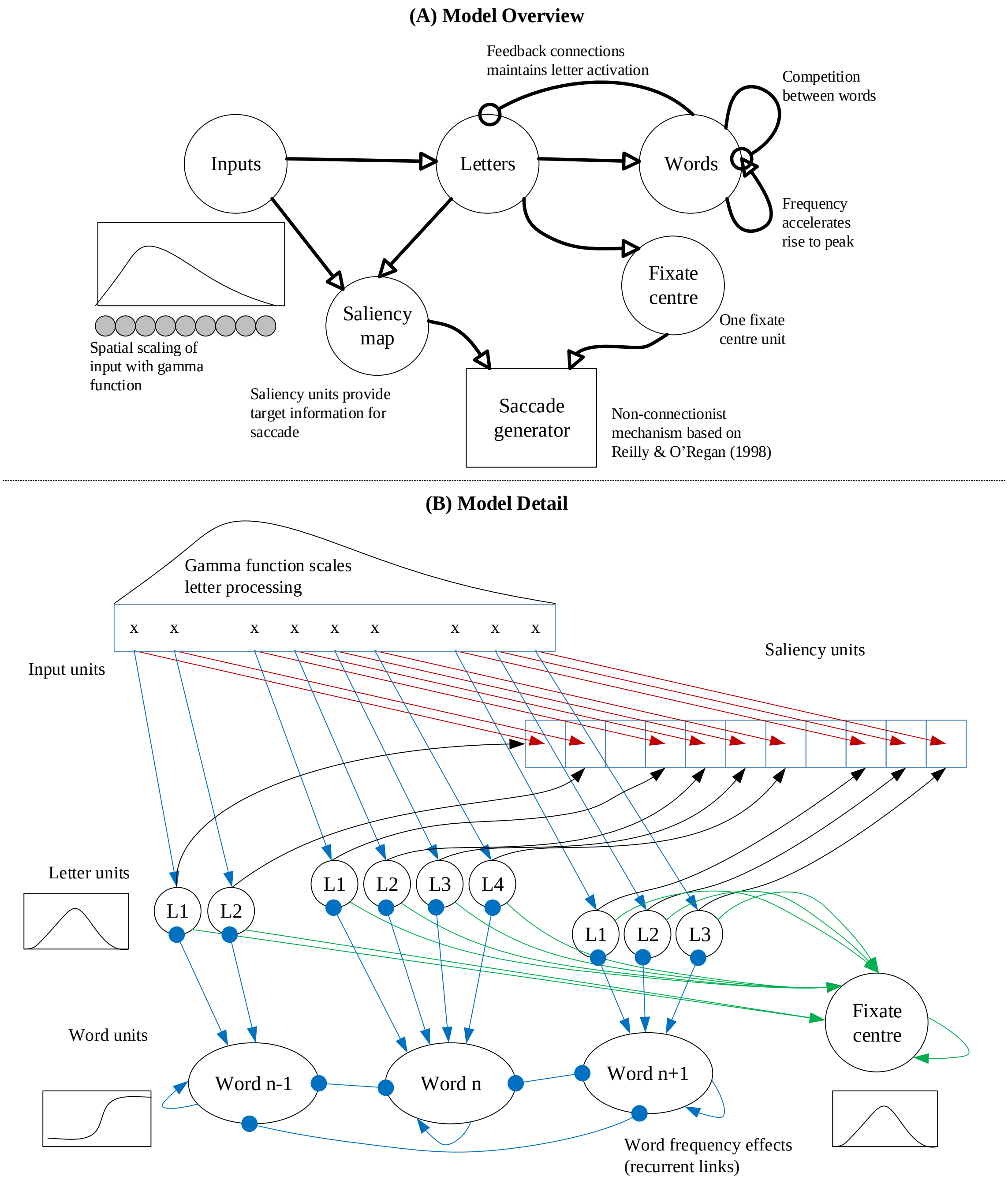


Figure 2.1 Illustration of *Glenmore*. Panel A is a simplified reproduction of the Figure 21.1 in Reilly and Radach (2003, p. 432) and Figure 1 in Reilly and Radach (2006, p. 37); Panel B is a simplified reproduction of Figure 21.2 in Reilly and Radach (2003, p. 437) and Figure 2 in Reilly and Radach (2006, p. 39).

2.3.2. E-Z Reader[1]

The E-Z Reader is a *Serial Attention Shift* (SAS) cognitive control model. According to the core assumptions of the model, attention from one word to the next shifts in a strictly serial manner, and both saccadic programming and attention shifts are governed by lexical processing, in a decoupled fashion.

According to the model, the completion of an early stage of lexical processing triggers the oculomotor system to program a saccade to the next word. However, spatial attention-shift to the next word is triggered upon completion of lexical access (Reichle et al., 2006). Saccades are generated in two stages within the oculomotor system, such that (a) the labile stage (M_1) and (b) the non-labile stage (M_2). A labile stage can be canceled, and a new saccade program can be started if a word is processed parafoveally during that stage. When the system passes a point-of-no-return, the non-labile stage starts. A saccade at the non-labile stage cannot be canceled even if the processing of word is completed during this stage, causing saccadic errors. Saccades are generated upon the completion of the non-labile stage. The visual system processes low spatial-frequency information (e.g., word boundaries) and high spatial-frequency information, which allow individual words to be identified. Low spatial-frequency information is used by the oculomotor system to select the next target location. High spatial-frequency information of a word is available only when attention shifts to that word, and the information is passed to the word identification system for identification of the word. The word identification system consists of two stages. The first one (L_1) is the *familiarity check* stage, which begins upon the completion of lexical access of the previous word (i.e., parafoveal processing that started upon the attention shift to the current word). The second stage (L_2) is the *completion of lexical access* that begins upon the completion of L_1. The completion of L_2 sends a signal to the visual system for a shift of attention, and the postlexical integration of the word begins. However, shifting attention is not an instantaneous process, but requires time. Lexical processing and postlexical processing are independent and parallel processes, and postlexical processing goes on in the background with little influence on eye movements. Although *the default reading process* (Reichle et al., 2009, p. 7) continues in the forward direction without postlexical processing difficulty, any failure in the postlexical integration stage would direct the attention and the eyes back to the point of difficulty.

The time required to complete L_1 can be zero for highly predictable words to account for empirical findings that show highly predictable words are skipped most of the time. If the word is not a highly predictable word, the mean time required to complete L_1 is a function of frequency and predictability of word with negative parameters to account for the requirement of longer durations to process a difficult word (i.e., low-frequency and less-predictable words). The actual time required to complete L_1 is adjusted as a function of mean *eccentricity* (i.e., the distance) between the fixation point and the letters of the word. Although the time required to complete L_2 is also a function of frequency and predictability of the word with a negative relationship, this time

[1] The explanation of E-Z Reader in this sub-section was mainly based on E-Z Reader 10 (Reichle et al., 2009) which was based on E-Z Reader 9 (Reichle et al., 2006; Pollatsek, Reichle & Rayner, 2006). For previous versions of the model see Reichle et al. (1998); Reichle, Rayner, & Pollatsek (1999, 2003); Pollatsek, Reichle, & Rayner (2003) as cited in Reichle et al. (2006).

duration cannot be zero. Upon completion of L_1 of word n, a saccade will be programmed while the process of L_2 of it continues. Attention will be still on word n until L_2 is completed. When L_2 is completed, attention shifts to word n+1, and parafoveal processing of it starts (i.e., L_1 of word n+1). If M_1 is completed before L_1 of word n+1 is completed, M_2 starts, and eyes are directed to word n+1. If L_1 of word n+1 is completed before M_1 is completed, M_1 will be canceled, and a new saccade will be programmed for word n+2. This specification of the model predicts longer fixation durations prior to a skip (i.e., skipping cost). Saccade lengths in the model were specified with an *intended saccade length* and two error components (i.e., *systematic error* and *random error*). Intended saccade length is the distance between the current fixation and the center of the word that eyes are directed, under the assumption that saccades are always directed toward the center of words. Systematic error is a function of the difference between an optimal saccade length (it is 7 in the model) and intended saccade length, and the duration of the fixation on the launch site. The random error component is a random deviate that is sampled from a Gaussian distribution with μ = 0 and σ as a function of the intended saccade length. Lastly, the probability of refixation in the model is a function of the absolute difference between landing position and saccade target (i.e., the center of the word that eyes are directed to) (Reichle & Sheridan, 2015). The mathematical specification of the relationships explained above is beyond the scope of the current study (see Reichle et al., 2009 and Reichle & Sheridan, 2015, for a detailed description of E-Z Reader 10).

Model predictions were mostly in line with most empirical findings. As the frequency of word increased, simulated fixation durations (first fixation duration, single fixation duration, and gaze duration) decreased, and the simulated probability of skipping increased, and that of fixating decreased. Predictability of words and simulated fixation durations showed a negative relationship, while it showed a positive relationship with simulated probabilities of skipping. As the length of words increased, fixation durations and the probability of refixating increased, and the probability of skipping decreased. Although discrepancies were observed for very high-frequency words, the relationship between word characteristics and eye movement measures were qualitatively similar, and for low-frequency words, observation and simulation were almost identical (Reichle & Sheridan, 2015; Reichle et al., 2006, Reichle et al., 2003).

The schematic diagram of the model in Figure 2.2, Panel A is a reproduction of Figure 3 in Reichle et al. (2003, p. 451) with a modification to include the postlexical integration process introduced in E-Z Reader 10; that of Panel B is a reproduction of Figure 1-B in Reichle et al. (2009, p. 3). In the diagram presented in Panel B, the box labeled *V* stands for visual processing, *A* stands for attention, and *I* stands for postlexical integration. Labels L_1, L_2, M_1, and M_2, are the stages of the lexical processing and saccade generation process, as explained above.

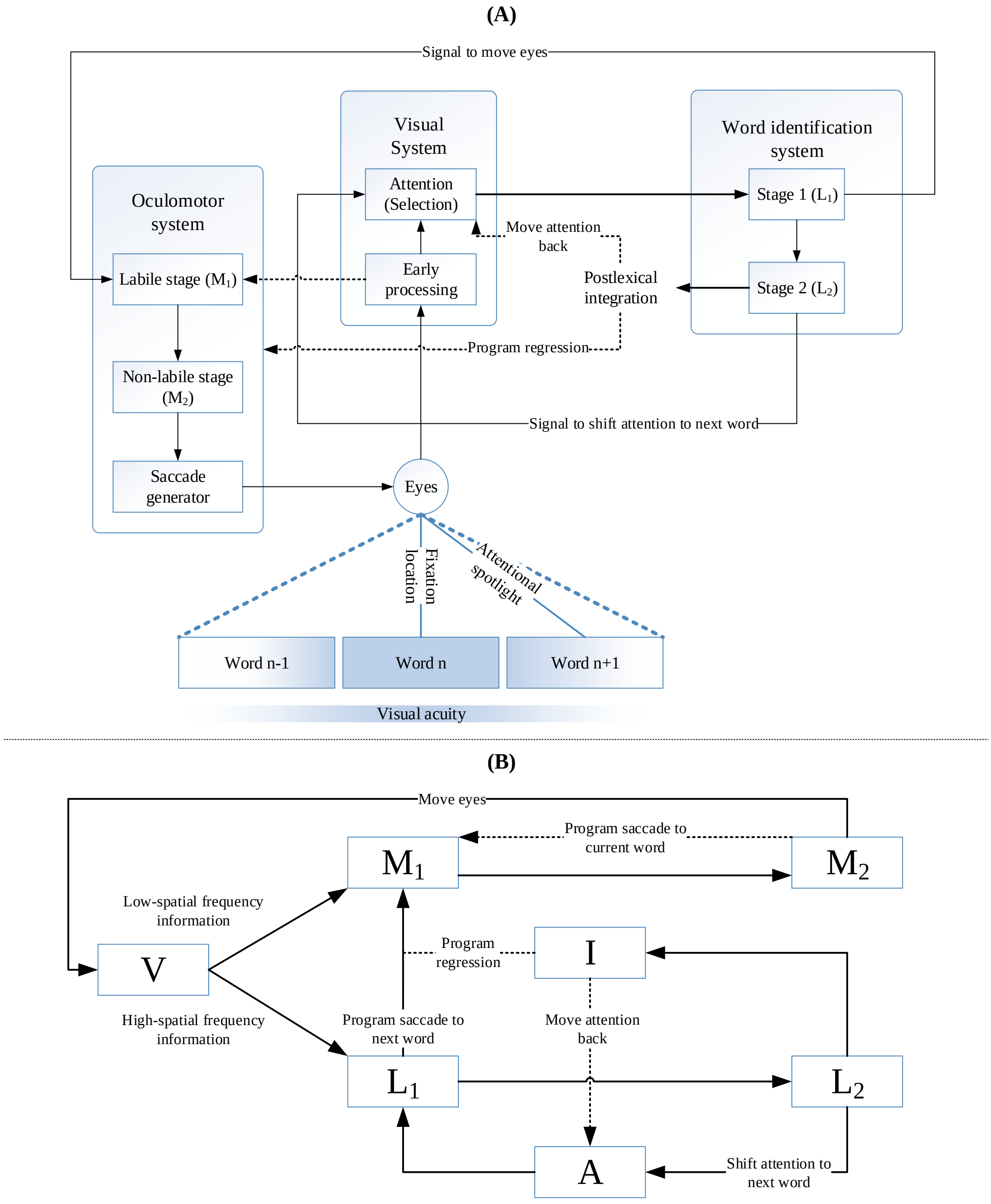


Figure 2.2 Illustration of *E-Z Reader 10*. Panel A is a reproduction of Figure 3 in Reichle et al. (2003, p. 451) with a modification to include postlexical integration; Panel B is a reproduction of Figure 1-B in Reichle et al. (2009, p. 3).

2.3.3. SWIFT[2]

The SWIFT is a *guidance by attentional gradient* (GAG) model of eye movement control in reading. In SWIFT, attention is conceptualized as a gradient, rather than a *spotlight* that moves serially. Inspired by the dynamic field theory of movements preparation proposed by Erlhaen and Schöner (2002), and the framework of saccade generation proposed by Findlay and Walker (1999), SWIFT proposes a lexical activation field for word targets. Foveal words have higher activation values than words in the parafovea as a processing gradient. Therefore, words are attended to and processed in parallel within the perceptual span, depending on the activation value. The seven core principles of SWIFT as presented in Engbert et al. (2005) are such that (1) the activation field processing is spatially distributed and saccade target selection is dependent on the competition among words with different activation values, (2) there are separate pathways for saccade timing, and saccade target selection, (3) saccades are generated autonomously with an inhibition by foveal targets to allow the influence of lexical processing on saccade generation, (4) saccade programming consists of labile and non-labile stages, (5) saccade lengths are influenced by random errors inherent to the oculomotor system and systematic errors as a function of launch-site distances, (6) mislocated fixations are corrected immediately by a corrective saccade program, and (7) intended saccade amplitude influences the saccade latency.

The illustration of the model overview in Figure 2.3, Panel A is a slightly modified reproduction of the illustration of SWIFT in Figure 9 in Reichle et al. (2003, p. 462), and Panel B is a reproduction of Figure 1 in Richter et al. (2006, p. 26).

[2] In this sub-section, the explanation of SWIFT (i.e., Saccade-generation With Inhibition by Foveal Targets) model (Engbert et al., 2002), was based on the second version of the model (i.e., SWIFT-2, Engbert et al., 2005; Richter et al., 2006). Therefore, the main reference of the sub-section is Engbert et al. (2005). The citations from other resources are mentioned in the text. SWIFT-3 includes several parameter adjustments to account for the *zoom lens effect* (Eriksen & St.James, 1986; LaBerge & Brown, 1989; Schad, Nuthmann & Engbert, 2010 as cited in Schad & Engbert, 2012) and is a variant of SWIFT-2 differing in parameter values only (Schad & Engbert, 2012). Therefore, SWIFT-3 and its assumptions mentioned but not explained further in the sub-section.

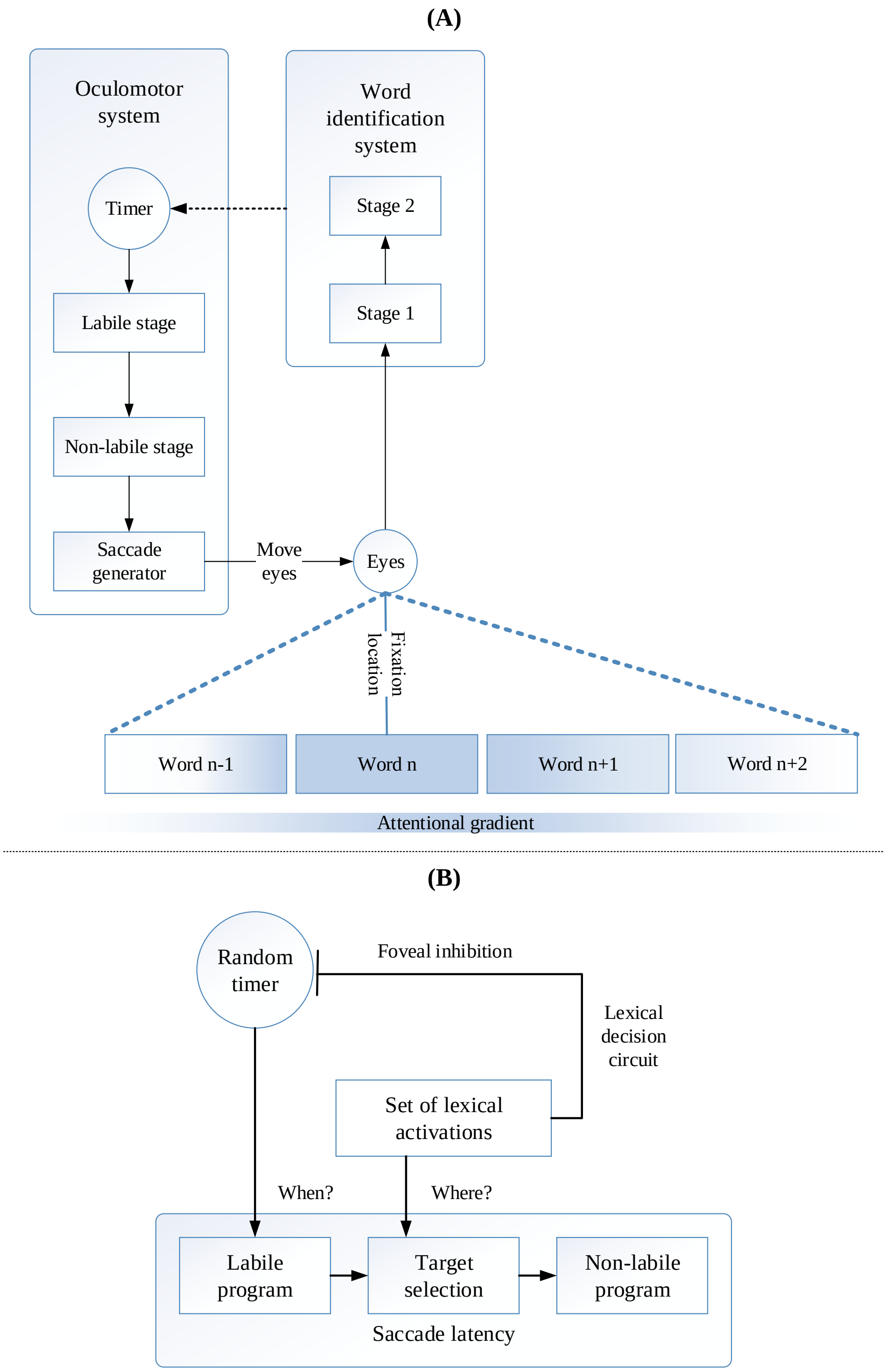


Figure 2.3 Illustration of *SWIFT*. Panel A is a slightly modified reproduction of Figure 9 in Reichle et al. (2003, p. 462); Panel B is a reproduction of Figure 1 in Richter et al. (2006, p. 26).

According to the conception of reading in SWIFT, the oculomotor system generates saccades randomly to possible targets that are constrained by a dynamic field of activations of words. The maximum activation of a word is limited by the difficulty of that word (i.e., its frequency), while the lexical processing rate of the word is a function of its eccentricity (i.e., its distance to the current fixation location). The word identification process consists of two stages: (1) *preprocessing stage* during which the activation value reaches its maximum value, and (2) during *lexical completion*, the activation decays to zero until the word is completely processed. The temporal evolution of activations is influenced by the predictability of the word in a way that highly predictable words reach their maximum activation during the parafoveal preprocessing stage, which results in skipping of them. The probability of selection of a word as a saccade target is a function of its relative lexical activation. The next command for starting a saccade program is a stochastic process with a top-down inhibitory signal from lexical processing and dependent on the foveal activation. Therefore, any difficulty in the word identification system results in a delay in the oculomotor system through the word difficulty effect that limits the maximum activation values of the words. Saccades programmed in two stages: (1) during the *labile stage,* the saccade can be canceled, and (2) the *non-labile stage* starts upon the completion of the labile stage and passing a point-of-no-return. Since preprocessing require continuous visual input while lexical completion does not require new visual input, preprocessing pauses during saccades due to saccadic suppression (Matin, 1974), but lexical completion continues. Mislocated fixations due to systematic error or random error are corrected with a new saccade program immediately (Engbert et al., 2005). A more detailed description of SWIFT was provided in the third chapter of the current study.

The model predicts the frequently reported effects of word characteristics such that together with a decrease in frequency and an increase in word length, simulations of the model produced increased fixation durations, and decreased skipping instances, and increased multiple fixation instances. The interaction effect of word length and launch site on first landing position was compatible with experimental findings such that among short words, eyes tended to land on the right edge of the word if the launch site was small, tended to land around the center if launch site was medium length, and tended to land towards the left edge if launch site was high. For longer words (i.e., words that have six letters or eight letters), fixations mostly landed around the center of words with a tendency towards the right edge for short lunch sites and a tendency towards the left edge for long launch sites. The model was more successful in qualitatively predicting the fewer fixation counts of relatively short words (i.e., words that have six letters or less) that had an initial landing position around the center of the words than other positions. However, for longer words, there were discrepancies between the observations and model predictions (Richter et al., 2006).

A study on shuffled text reading (i.e., reading a text created by using randomly selected words from the Potsdam Sentence Corpus, Kliegl, Grabner, Rolfs, & Engbert, 2004; Kliegl et al., 2006) revealed that eye movements during shuffled text reading were influenced by the expected successor- and lag-effects while the effects of word characteristics were reversed (Schad et al., 2010 as cited in Schad & Engbert, 2012). That is, words were fixated longer on short words and frequent words than that of long words and infrequent words, which was a contradictory finding regarding experimental findings in normal text reading. For the explanation of these counterintuitive effects, Schad et al. (2010) proposed that these effects were the result of the zoom lens of attention (i.e., dynamical modulation of perceptual span by foveal word difficulty) (Schad & Engbert, 2012). According to them, the zoom lens of attention effect should be more pronounced during shuffled text reading than during normal text reading due to less influence of ongoing lexical processing during shuffled text reading. To give an account for these findings and hypotheses, in SWIFT-3, parameters of SWIFT-2 was modified. SWIFT-3 was not explained further in the current study (see Schad & Engbert, 2012, for a detailed explanation of SWIFT-3).

2.4. The Role of *Sound*

The influence of phonological processing in reading is not surprising if one takes the phonological characteristics of writing systems into account. In alphabetical writing systems (e.g., English, Turkish) and syllabic writing systems (e.g., Japanese *Kana*), graphemes are mapped onto phonological representations, although the mapping is not one-to-one correspondence in most writing systems. Even in logographic writing systems, such as Chinese, in which characters represent morphological units rather than phonological units, the sound is represented with 90% of the characters, which are phonetic compounds. Mapping a phonological or orthographical representation onto meaning, on the other hand, is arbitrary (Frost, 1998). Given that oral language acquisition is an earlier process, reading acquisition is essentially learning rules that map graphic representations to phonological representations (Milledge & Blythe 2019).

The developmental aspect of reading is beyond the scope of the current study. However, the changing role of sound coding in reading development is the core of controversies on the nature of the phonological processing during reading. The role of phonological processing in lexical identification during the acquisition of reading skill was not disputed much. That is, the initial attempts in learning to read are constructing the associations between orthographic representations of words and words in the oral vocabulary, which was acquired before learning to read. The learning process continues with learning grapheme to phoneme correspondences to the point where nature phonological processing changes, and supposedly the function of it in lexical access decreases (Milledge & Blythe, 2019; Jared, Ashby, Agauas & Levy, 2016 for reviews). However, the role of phonological processing from that point, i.e., in skilled reading, is controversial.

Several experimental paradigms have been employed to study the role of sound coding in skilled reading, including masked phonological priming, articulatory suppression, distraction by auditory input, electromyography recordings of articulatory muscles, gaze-contingent boundary paradigm that accompany tasks such as naming, lexical decision, semantic categorization, and sentence or text reading (e.g., Slowiaczek & Clifton, 1980; Van Orden, 1987; Guerrero, 2005; Inhoff et al., 2004; Eiter & Inhoff, 2010; Ashby, Treiman, Kessler, & Rayner, 2006). The findings provide converging evidence that there *is* a role of sound coding in the reading process (see Frost 1998, 2005; Leinenger, 2014; Rayner et al., 2012; Rastle & Brysbaert, 2006; Rayner, 1998 for reviews). However, there is conflict on the degree and timing of the involvement of phonological processing in the skilled reading process, and accordingly, the point in time when the sound coding is at play in the process. That is whether words are accessed only through phonological representations even by skilled readers (i.e., strong phonological theory), or is there a structural change in skilled reading with an addition of a route which provides direct access from the orthography of a word to its lexical entry (i.e., weak phonological theory, or dual-route model). The weak phonological theory suggests that words are accessed in skilled reading by a dual-route mechanism with one route for direct access to the semantic system and phonological output lexicon, one route for indirect access through prelexical grapheme-to-phoneme rules (Frost, 1998, 2005; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Rayner et al., 2012). Although there are findings for a structural change due to learning to read (e.g., Dehaene, Pegado, Braga, Ventura, Filho, Jobert, Dehaene-Lambertz, Kolinsky, Morais & Cohen, 2010; Vorstius et al., 2014; see Blythe & Joseph, 2011 for a review), several behavioral studies imply that phonological processing changes from slow, overt processing to a more quick, covert one as reading is acquired, rather than elimination of phonological processing for some words (e.g., Milledge & Blythe 2019; Jared et al., 2016).

Strong phonological theory, on the other hand, proposes a single mandatory prelexical phonological processing mechanism which is the only way to lexical access (Frost, 1998, 2005; Coltheart et al., 2001; Rayner et al., 2012). It is worth to note that the dispute is on an early phase in reading, which is lexical access, the process of finding a *lexical entry* in the *mental lexicon*, rather than the detailed and complete lexical representation that includes the meaning and detailed phonological representation of the word, at a later stage of lexical processing. Another caution is on the conception of the mental lexicon and lexical entry: This is a localized conception of words in mind, independent of their theoretical specifications. In other words, the discussion applies well to finding the word in the mental lexicon as *a list of lexical entries organized according to their frequency*, or as a *localized interactive distributed system with inhibitory or excitatory connections to word nodes*. Therefore, lexical access in this context means finding the relevant entity (i.e., the word) in mind before reaching its meaning and detailed phonological representation (Frost, 1998). On the other hand, the dispute is not mainly on the role of inner speech in post lexical processing, which has somewhat clearer evidence than its mandatory involvement in the lexical access phase (Rayner et al. 2012; Inhoff et al., 2004; Eiter & Inhoff, 2010; Inhoff et al., 2011; Laubrock & Kliegl, 2015).

Being *mandatory* is crucial in the discussion. That is because both approaches (i.e., weak vs. strong phonological theory of reading) include phonological processing (see Leinenger, 2014, for a review). However, they differ in the mandatory status. According to the dual-route conception of reading of the weak phonological theory, there is a route in which skilled readers access words directly from the visual presentation of words unless the task requires a clear phonological computation (e.g., reading a low-frequency word or a pseudoword). In the model, there is also an additional indirect phonologically mediated communication between letter level, orthographic lexicon, and semantic component. Strong phonological theory, on the other hand, suggests that prelexical phonological processing is the default procedure and required in lexical access. Hence, there is no direct access through orthographic lexicon without phonological mediation to words, and phonological representations are always constructed by prelexical phonological processing (Frost, 1998, Coltheart et al., 2001). Another important aspect of early phonological processing in reading is the effect of orthographic depth in alphabetical writing systems. Both approaches claim a lexical aspect in phonological processing in deep orthographies such as in English, be it the direct orthographic route in weak phonological theory or lexical top-down shaping of impoverished phonological representations in strong phonological theory. Besides, both theories claim that there is more prelexical influence than a lexical influence on phonological processing in shallow orthographies such as in Turkish that contrasts to the dominance of the lexical aspect of phonological processing in deep orthographies such as English (Frost, 2005; Coltheart et al. 2001). If the proposed effect of orthographic depth is correct, then the lexical characteristics of words should have a weaker effect on the phonological processing of words in shallow orthographies. The hypothesis was tested by cross-linguistic studies, and stronger effects of lexical characteristics (e.g., frequency of the word, semantic priming) on response times were found in deeper orthographies in naming tasks (Frost, 2005). In a study on sentential pseudoword reading in Turkish, which has a shallow orthography, several letter frequency measures showed significant effects on eye-movement measures. Significant effects of word center consonant collocation frequencies and word boundary frequencies of six letters' length pseudowords on fixation duration values, and a significant interaction effect of vowel harmony collocation frequency (reflecting vowel harmony rules which restrict vowel sequences in Turkish words) and word boundary collocation frequency on regressive eye-movements to the pseudowords were observed. Since these letter frequency measures were related to pseudowords in which case lexical characteristics such as word frequency and predictability were eliminated, the observed effects on eye-movement measures were interpreted as effects of phonotactics in Turkish reading (Acartürk, Kılıç, Kırkıcı, Can & Özkan, 2017b).

Before the explanation of the approach adopted in the current study, another role of the phonological representation in reading should be noted: the involvement of phonological representations in postlexical processing. With its fluid characteristic, working memory, especially the phonological loop, is assumed to be a crucial system involved in reading (Laubrock & Kliegl, 2015). According to Baddeley (2003a), working memory consists of four main components: (1) a visuospatial sketchpad which integrates visual and spatial information and provides a unified representation, (2) a phonological loop which enables registration of visual or auditory input to the system, provided that the visual input can be named, (3) an episodic buffer which is the short-term store that provides a connection to the crystallized system of long term memory, and (4) a central executive which is a limited capacity attentional system that controls the other three components. The phonological loop consists of several sub-components that provide two pathways to the phonological output buffer, which provide information for spoken output. Auditory input reaches to phonological output buffer through a phonological analysis and a short-term phonological store, while visual input reaches to phonological output buffer through a short-term store for visual analysis and orthographic to phonological recoding process. The phonological loop provides retention of auditory and visual inputs in working memory and registering them to long term memory by a rehearsal process. While auditory input to the rehearsal process has a direct route without the mediation of phonological output buffer, visual input is registered through a path that is mediated by phonological output buffer (Baddeley, 2003a, 2003b; Baddeley & Hitch, 2019). The working principles of the phonological loop are consistent with a conception of the role of sound coding in reading that includes early detection of phonological codes from the visual input and later retention of words as phonological representations for text integration. However, it should be noted that there are several models of working memory in which the phenomena were explained in a different way (e.g., working memory as a component of a multicomponent model vs. working memory as a part of long-term memory; see Morey, Rhodes & Cowan, 2019; Logie, 2019; and Morey, Rhodes & Cowan, 2020 for a recent discussion on working memory models; see Baddeley, 2012 for a comprehensive review). Since a comprehensive discussion of working memory models is beyond the scope of the current study, the focus will be on the acoustic nature of retention of words within short periods of time in the memory (e.g., Baddeley & Hitch, 2019; Buchsbaum & D'Esposito, 2019) – for text integration in the case of the reading process. The effect of phonological representations in postlexical processing in reading was investigated empirically by several studies, and it is found that a direct registration of auditory input (Inhoff et al., 2004) and its combination with articulatory suppression as a secondary task (Eiter & Inhoff, 2010; Slowiaczek & Clifton, 1980) influence subsequent fixation durations and comprehension of the text. Studies on the eye-voice span (EVS) during reading aloud, on the other hand, show that there is a dynamic modulation of EVS by eye-movements to keep a constant distance between the eyes and the voice, implying retention of a manageable number of items in working memory (Inhoff et al., 2011; Laubrock & Kliegl, 2015; and see Rayner et al. 2012; Rayner, 1998; Leinenger, 2014 for a review of the role of sound coding in postlexical processing in reading).

To sum up, both weak and strong phonological theories suggest that there is the involvement of phonological processing early in the reading process, at the phase of lexical access. Although attributed strength and mandatory status of the prelexical phonological processing change according to each theory, both theories expect prelexical phonological processing to be stronger in a shallow orthography than it is in a deep orthography. Besides, empirical studies provide a similar picture. On the other hand, studies mentioned above show that there is a role of phonological representations in postlexical processing in reading. Words are stored as phonological representations during the text integration process.

The current study proposes a framework for an eye-movement control model that accounts for the effect of sound coding during reading. The **P**honological-Mediation in **G**uidance by **A**ttentional **G**radient (P-GAG) model of reading, proposed here, is not a *model* in the computational sense, rather a model of a framework for a computational model that includes phonological processing. The details of the P-GAG model are explained in the next chapter. The underlying assumptions of P-GAG were tested by the statistical analysis of an empirical study, which is explained in the fourth and fifth chapters.

3. PHONOLOGICAL MEDIATION IN READING: A THEORETICAL FRAMEWORK

The **P**honological-Mediation in **G**uidance by **A**ttentional **G**radient (P-GAG) model of reading proposed here, as the name suggests, is an attentional gradient model. In other words, it is assumed that words within the perceptual span are processed *in parallel*. The saccade generation mechanism of the P-GAG model mainly depends on the assumption of the SWIFT model, which suggests foveal inhibition on autonomous oculomotor processes (Engbert et al., 2002; Engbert et al. 2005; Richter et al., 2006; Schad & Engbert, 2012).

3.1. Principles of SWIFT

A complete mathematical description of the model is beyond the scope of the current study. However, the theoretical framework presented in the current study mainly depends on SWIFT. Therefore, several notions presented in Engbert et al. (2005) which are necessary to explain the working principles of the model are presented as follows:

Dynamic field of activations. In SWIFT, potential saccade targets are computed from a field of activations, i.e., $\{a_n(t)\}$, for words $n = 1, 2, 3, \ldots, N$ at time t. Although there is not a pre-specified limit on the number of words that have an activation value, as a result of the dynamics of the model, $\{a_j(t)\}$ for $j \geq n + 4$ would be typically close to zero when word n is the foveal word. Therefore, possible saccade targets are constrained by the dynamics of the model. The change in the activation field over time depends on the word recognition and fixation position through its influence on word recognition. In the preprocessing stage of word n, $\{a_n(t)\}$ starts to build up, and it decreases during the lexical completion process.

Word difficulty. In SWIFT, word difficulty limits the maximum activation of a word. As widely accepted in reading research, word frequency and its predictability from the sentence context are regarded as the sources of word difficulty. In E-Z Reader, the combined effect of word frequency and predictability on word processing difficulty is conceptualized as additive. In SWIFT, on the other hand, frequency and predictability are not conceptualized as a combined source of word difficulty. That is because of the temporal characteristics of the effects of these word characteristics – i.e., the effect of predictability would influence eye movements earlier than frequency, and the influence of predictability would not need visual input. Therefore, in contrast to E-Z Reader, in SWIFT, word difficulty is estimated from word frequency alone, and predictability influenced the temporal evolution of activations. The specification of these word characteristics in SWIFT enables the emergence of the effect of predictability earlier than that of frequency.

Lexical processing rate. According to SWIFT, the lexical processing rate of a word is a function of the *eccentricity* of that word (i.e., the distance of a word to the current position of fixation). The eccentricity of a word is a function of the eccentricities of all letters of the word, which is the distance of each letter to the position of fixation. The relationship between processing rate and eccentricity is formulated as an asymmetric Gaussian function to reflect the asymmetry of the perceptual span. The asymmetry of the distribution of the processing rate results in a shift of the maximum lexical rate to the left of the word center, which is compatible with findings such as *preferred viewing location* (PVL), and *optimal viewing position* (OVP) (see Rayner, 1998, 2009a, and 2009b for reviews). The total lexical processing rate is bounded between 0 and 1. The processing rate of a word is calculated from the set of processing rates of its letters with a parameterized function. By doing so, SWIFT allows the processing rate of a word as the sum of all its letter processing rates (an additional letter facilitates the processing), and as the mean of its letter processing rates (an additional letter leads to processing cost), as special cases. The simulations of the model show that the processing rate of a word is an intermediate between these two extreme cases.

Temporal evolution. Within the activation field, a word has a zero activation, (1) before processing (i.e., when it is unknown), and (2) after processing (i.e., when it is completely processed). During the *preprocessing stage*, the activation value reaches its maximum value, which is dependent on the difficulty of the word. In the second stage of word processing, *lexical completion*, the activation decays to zero until it is completely processed. The temporal evolution of activations is dependent on three processes such that (1) a preprocessing factor, (2) a stochastic variable for processing rate, and (3) a global decay strength. The preprocessing factor is modulated by the predictability of word with an asymmetry between preprocessing and lexical completion such that activation increases fast and decreases slow. During preprocessing, which is an early stage of processing, words are added to the set of possible targets (i.e., the set of words that have activation value greater than zero). The influence of the predictability on processing rate depends on the point in time of processing such that for a highly predictable word, during parafoveal preprocessing (i.e., before the word is fixated), processing rate decreases. Therefore, highly predictable words skipped with a high probability as empirical findings suggest. However, once a word is in its lexical completion state, the processing rate of the word increases with its predictability. The lexical completion is implemented as a stochastic memory retrieval process in the model. Finally, the global decay process induces a slow decrease in activations at a constant rate. The decay factor is interpreted as a memory leakage by the modelers.

Saccade target selection. Saccade targets are selected among words that have activation values greater than zero with a stochastic process. The probability of selection of a word as a saccade target is the relative lexical activation of that word with an exponent parameter for the measure for the stochasticity. The value of the parameter determines the degree of parallel processing of words with two extreme cases such that (1) target selection probabilities for all words within the set of possible targets are the same, and (2) target selection is a deterministic process with the winner-takes-all rule.

Control of fixation duration by foveal inhibition. According to SWIFT, the time interval between two saccade programs is stochastic with a predefined mean that depends on the reading rate of the reader. However, the interval is influenced by a top-down inhibitory signal from lexical processing. Therefore, the next command for starting a saccade program is dependent on the foveal activation. Since the saccade generation is a faster process than word recognition, the top-down inhibition influences the saccade program with a delay, which potentially explains lag effects.

Saccade programming. The saccade generation process consists of a two-stage saccade programming process and saccade execution. The stages of saccade programming are the labile stage, during which the saccade can be canceled, and a new saccade can be programmed, and the non-labile stage, which starts upon the termination of the labile stage and passing a point-of-no-return. The saccade target selection process is triggered by the transition from labile to the non-labile stage. Preprocessing is paused during saccades to account for *saccadic suppression* (Matin, 1974). Since lexical completion would not need new visual input, the model assumes that lexical completion continues during saccades.

Oculomotor errors in saccade generation. In the model, the intended saccade length is accepted as the distance to the optimal viewing position. The actual saccade length is the sum of intended saccade length and two error terms – i.e., *saccade range error* (systematic error) and random error (a Gaussian distribution with zero mean and a standard deviation dependent on intended saccade length). The systematic error depends on the difference between the intended saccade length and an optimal saccade length.

Mislocated fixations and error correction. The model assumes an immediate correction of mislocated fixations with a new saccade program. To implement the assumption, a vanishing intersaccadic interval is introduced to the model for mislocated fixations, which shortens the interval between two saccade programs. The conceptualization of mislocated fixations and error corrections results in shorter fixation durations when a saccade target selection is undershot or overshot (i.e., fixations located at the edges of the word). Therefore, the model provides an account of the IOVP effect (Vitu, McConkie, Kerr, & O'Regan, 2001).

Saccade latency modulation. In SWIFT, saccade programming time is a stochastic process that is modulated by intended saccade amplitude, after target selection. That is, the model assumes that the non-labile stage of saccade programming is influenced by intended saccade length such that saccade latency decreases with an increase in intended saccade amplitude. The functional relation between time for non-labile stage and intended saccade amplitude influences the IOVP effect for short amplitudes (i.e., less than or equal to four characters, mostly intraword saccades), whereas it influences successor effects for longer amplitudes (i.e., greater than or equal to six characters, mostly interword saccades). The IOVP effect is influenced such that the closer fixation to the edge of the word, the higher the intended saccade length to the center of the word, and the less fixation duration. For interword saccade, the functional relation produces shorter fixation durations for long parafoveal words than for short ones.

Stochasticity in saccade programming. Upon the completion of the non-labile stage, the saccade will be executed. The model assumes a fixed mean execution time (i.e., 25 ms). To simulate the noise in the saccade programming process, the model uses a gamma distribution.

According to the dynamics in SWIFT, words are processed in parallel within the perceptual span. Therefore, the model predicts lag- and successor effects (i.e., the effects of the characteristics of neighboring words on eye movement measures), the effect of visual acuity (i.e., the interaction effect of the length of the foveal word and next word characteristics), and the effect of dynamical modulation of the perceptual span (i.e., the foveal load hypothesis – the interaction effect of neighboring word difficulties) on eye movement measures, in addition to the canonical effects of foveal word characteristics and oculomotor measures (Kliegl et al., 2006; Kliegl, 2007).

3.2. Phonological Mediation and Postlexical Processing in P-GAG

In the P-GAG model, the phonological processing of a word starts at Stage 1 (i.e., prelexical phonological processing and preprocessing), and a detailed phonological representation of it is accessed upon lexical completion. There is the involvement of prelexical phonological processing in the word identification system to capture the influence of phonological processing in lexical access (see Section 2.4). It was assumed that prelexical phonological processing influences the activation value of words similar to word difficulty by influencing the limit of maximum activation of the word. The two-way relationship between preprocessing and prelexical phonological processing is meant to capture (i) the influence of prelexical phonological processing in lexical access, (ii) lexical influences in phonological processing, especially in deep orthographies. Both prelexical phonological processing and preprocessing have connections to lexical completion. That is because (1) according to SWIFT, the lexical processing rate of words is influenced by the visual processing (i.e., spatial distance to the current fixation), and (2) according to P-GAG, prelexical phonological processing is required for lexical access. Therefore, the connection between preprocessing and lexical completion captures (1) while the connection between prelexical phonological processing and lexical completion captures (2). Lastly, prelexical phonological processing influences the saccade target selection process through its influence on the activation values, which is represented by a connection between prelexical phonological processing and preprocessing. In other words, we assume an early influence of prelexical phonological processing during parafoveal and early foveal lexical processing and the saccade selection process. Accordingly, in addition to the effects predicted by SWIFT, we expected the effects of prelexical characteristics of words that represent phonotactics in Turkish (Acartürk et al., 2017b) on fixation durations and first fixation locations, as it was described in detail in the chapters devoted to empirical study.

An additional component, the *memory buffer,* is a short-term store that includes postlexical processing and motor planning for articulation in oral reading, as proposed in Laubrock and Kliegl (2015). The two-way relationship between lexical completion and postlexical processing is inhibitory. The inhibitory connection from postlexical processing to lexical completion captures longer fixation durations and regressions due to delayed lexical completion that results from the difficulties in the integration process or increased memory load. The inhibitory connection from the word identification system to the memory buffer is meant to capture the interference of the difficulties faced during the word identification process to postlexical and motor planning processes, manifested in delayed articulation.

The phonological representation of a word is held in the memory buffer until its integration to text and preparation for articulation gets completed in oral reading. As soon as the word is articulated, it is removed from the buffer. Accordingly, the time interval between the beginning of the first fixation on a word and the beginning of the articulation of it (*Fixation Speech Interval* – FSI – following Inhoff et al., 2011) reflects the time course from prelexical phonological processing to postlexical integration of a word. Since FSI is restricted by the completion of postlexical integration, it is a good candidate to assess the effect of postlexical processing on eye-movements. The insight from FSI analyses could extend to the text integration role of sound coding in silent reading (i.e., subvocal articulation). However, to the best of our knowledge, current eye-movement control models of reading lack the proposed phonological aspect of the reading process. We suggest that the investigation of FSI might provide a basis for the introduction of one of the phonological aspects of reading to the eye-movement control models of reading – i.e., its influence in a memory component.

The existence of prelexical effects on FSI can be accepted as evidence of an effect of early prelexical phonological processing on the postlexical integration process. Although the existence of lexical effects on FSI would not provide direct evidence for the hypothesis on the involvement of phonological representation in postlexical processing, the absence of them could weaken the hypothesis. In that case, the effect of FSI on eye-movements should be investigated cautiously. In the current analysis, a statistical control approach was adopted, rather than experimental control of phonological aspects of words. Since the data in this study is from Turkish Reading Corpus (Acartürk et al., 2017a), experimental control was on the length and the frequency of target words, and morphological complexity (i.e., suffix count). It is assumed that statistical control of factors that may influence FSI in a linear mixed model (LMM) could provide insight on the degree of the involvement of prelexical and lexical processing of words in the reading process. Lexical and prelexical properties of words as covariates in an LMM of FSI would provide their contribution to the variation of FSI. Investigation of the relationship between FSI, prelexical properties, and eye-movements, as a second step, would reveal a clearer picture of the role of sound coding in reading.

Another measure of the distance between articulation and viewing of a word was the spatial measure of the eye-voice span (i.e., EVS in terms of character count). It was assumed that EVS of a word represents the memory load until that word was removed from the memory buffer. The relationship between EVS and FSI and those two and eye movement measures in oral reading would provide an insight into the effect of the memory load.

The illustration of P-GAG is presented in Figure 3.1. The arrows at the end of links represent information direction, and the dots represent inhibitions that result in a delay. The dashed red lines represent components involved in oral reading. The other components related to phonological processing are involved in both oral and silent reading. The figure implies that the word *n-2* is articulated while the fixation is on the word *n*. Although this depiction is compatible with the eye-voice span measures (i.e., two to three words), it should be taken as an approximation.

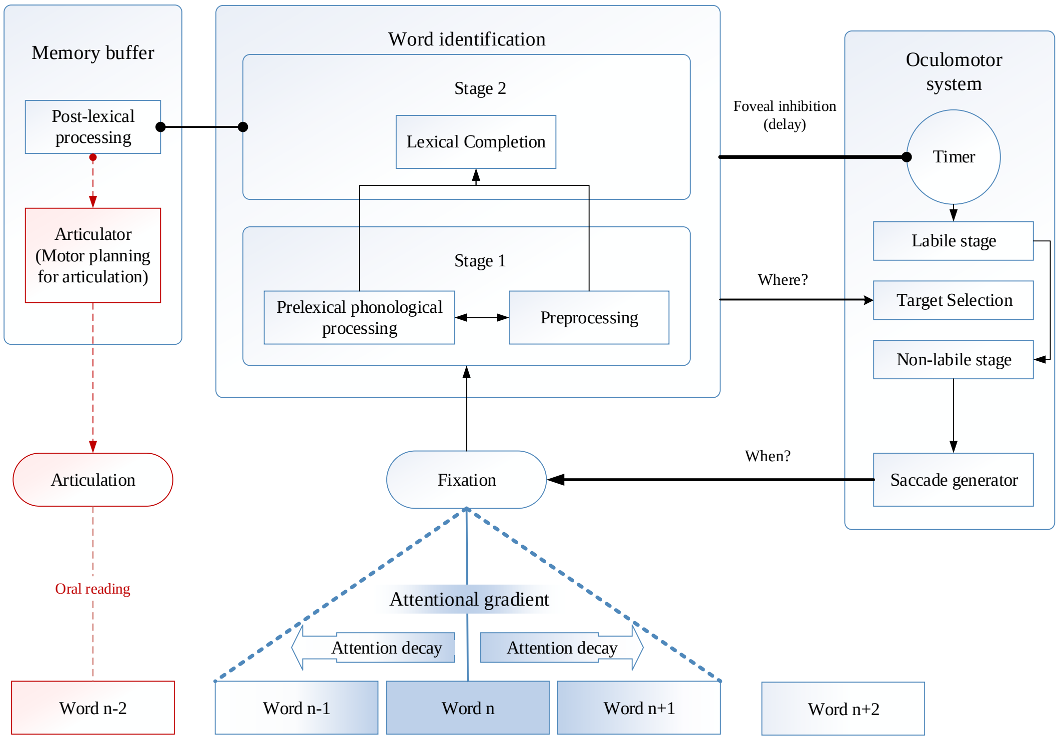
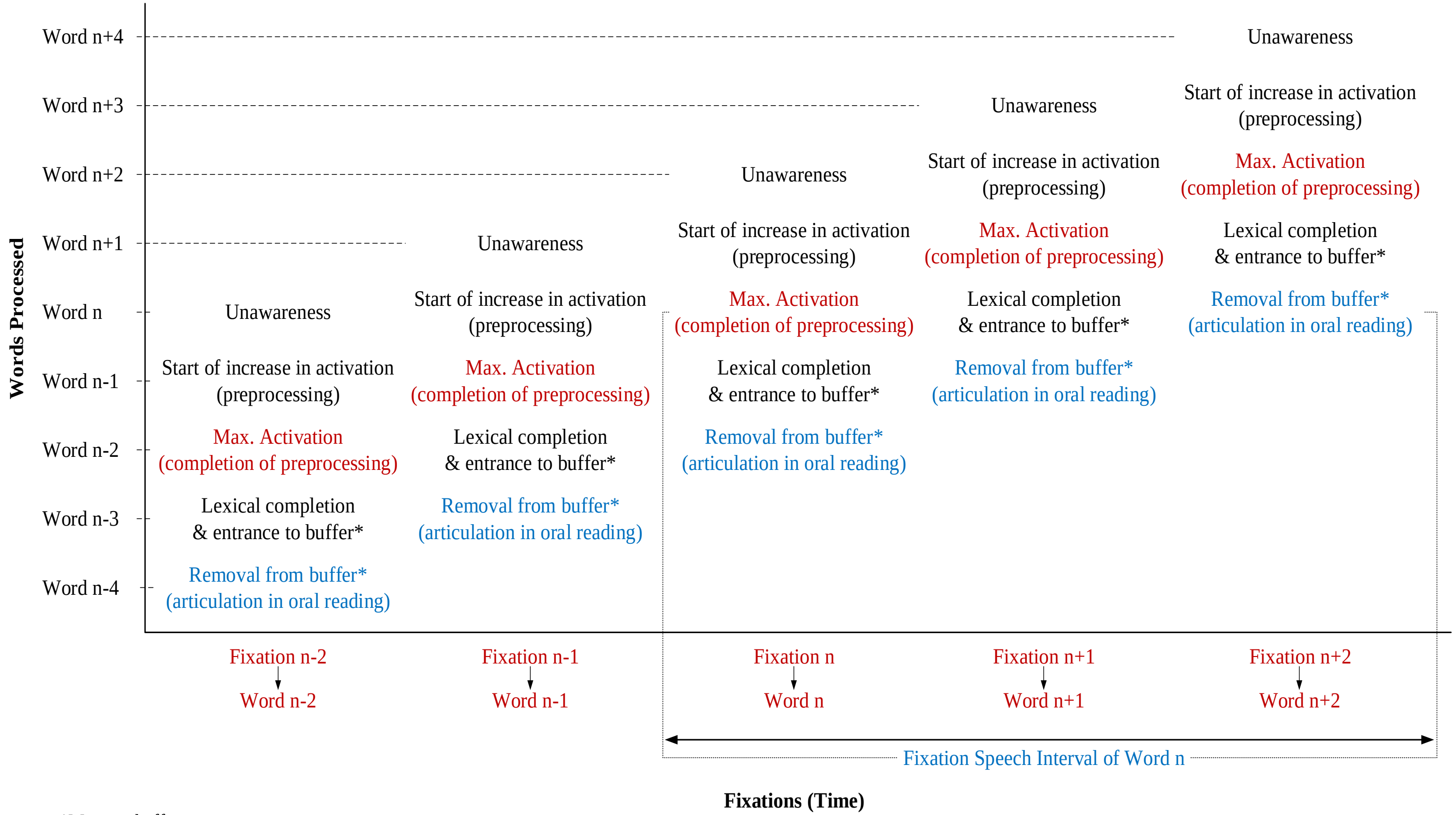


Figure 3.1 Illustration of the P-GAG (**P**honological-Mediation in **G**uidance by **A**ttentional **G**radient) model of reading.

Processing in five successive fixations on five successive words, according to P-GAG, is illustrated in Figure 3.2, for the cases in which there is a single fixation on each word without regression and skipping. In the figure, the x-axis represents successive fixations (time of processing), and the y-axis represents words that are processed. Word n stands for the word which receives the current fixation, i.e., *Fixation n*. For fixations and words, *n-1* stands for the previous fixation (or word), and *n-2* stands for the one before previous fixation (or word). Any difficulty in lexical completion of word n-1 or completion of preprocessing of word n would result in a longer fixation n and limitation in preprocessing of word n+1. The approximate fixation speech interval of word n is showed below fixations, which is linked to the fixation n on word n and to the articulation of word n during fixation n+2. Horizontally, the Figure illustrates the processing stages of each word through successive fixations. Vertically, the Figure illustrates the processing stages of successive words within one fixation.



*Memory buffer

Figure 3.2 Illustration of processing in five successive fixations on five successive words according to P-GAG.

4. EMPIRICAL STUDY

4.1. Methodology

4.1.1. Participants

A total of 215 participants (*M* = 22.72, *SD* = 2.61 years old; 102 female) participated in the experiment for a monetary compensation of 20 TRY (approximately 5 USD). Participants signed an informed consent form and completed a demographic data form before the session started, and were informed that they could leave the experiment any time they liked. Each session was composed of two parts (for details, please see Section 4.1.4) and lasted approximately 1.5 hours. Two memory tests (a *Corsi Block* test and a digit span test) and a familiarity test were also conducted within the experimental session. We excluded the data from 15 participants since they were not eligible for the analyses: (i) the native language of one participant was not Turkish, (ii) eight participants were bilingual, (iii) two participants reported that they had dyslexia, (iv) two participants used contact lenses during the experiment, and (v) two participants read the 50% of the stimulus text twice due to technical problems (data loss 7.5%; *M* = 23.13, *SD* = 2.36 years old; seven females). Data were collected from an additional 15 participants (*M* = 21.67, *SD* = 2.23 years old; nine females) to compensate for the loss of data collected from these participants. Inspection of the data before the analyses revealed that data collected from four more participants were not eligible for the analyses due to technical problems during the experiments or low data quality (data loss 2%; *M* = 21.00, *SD* = 2.08 years old; two female). Accordingly, the data collected from 196 participants were included in the analyses (98% of 200 participants; *M* = 22.72, *SD* = 2.64 years old; 93 females).

4.1.2. Materials

4.1.2.1. Target Word Properties

Target words were selected according to their frequency and length values from the BOUN web corpus. The BOUN web corpus includes 1,337,898 distinct words (types) and 383,224,629 word tokens (Sak, Güngör & Saraçlar, 2008; Bilgin, 2016). The surface frequency of a word was calculated according to word tokens such that the surface count is the sum of all occurrences of the exact form of that word in the corpus. Frequency per million refers to the token counts/million.

Target words were selected according to their stem lengths and frequencies. Short target words have four letters (e.g., *masa*, ‘table’), while long words have ten letters (e.g., *bilgisayar*, ‘computer’) in their stem forms. Short and long words were divided into two groups according to their base frequency values (low frequency vs. high frequency). Accordingly, the target word set was specified in four conditions according to their word length and base frequency values: Short-Infrequent words (SI), Long-Infrequent (LI) words, Short-Frequent (SF) words, and Long-Frequent (LF) words (conditions, hereafter).

There were 16 words in each condition. The suffixed forms of the target words, with the suffixes *-de / -da / -te / -ta* (i.e., allomorphs of *-DA*), and the suffixes *-deki / -daki / -teki / -taki* (i.e., allomorphs of *-DAki*) were also included into the stimulus set. In total, the target word set consisted of 192 words (see APPENDIX A for the full list of the target words).

The analysis of the target words for frequency revealed no significant differences between the frequency values of short and long words within relevant frequency groups, which was the desired finding for the validity of the experiment design. The four conditions, in other words, were constructed such that characteristics of the target words (i.e., word length and frequency per million) were homogeneous within each condition. The mean surface frequency values (per million) of the stem and suffixed versions of words and ANOVA results are presented in Table 4.1.

Table 4.1 The mean surface frequency values of words within conditions and ANOVA results.

	Surface frequency per million			
	Stems			
	Frequent Words		**Infrequent Words**	
Short Words	26.02 (18.93)	$F(1,30) = 1.98, p > .05$	0.07 (0.09)	$F(1,30) = 2.27, p > .05$
Long Words	47.63 (58.45)		0.14 (0.17)	
	Words with one suffix			
	Frequent Words		**Infrequent Words**	
Short Words	7.73 (14.72)	$F(1,30) = 0.72, p > .05$	0.001 (0.002)	$F(1,30) = 0.64, p > .05$
Long Words	4.22 (7.58)		0.002 (0.004)	
	Words with two suffixes			
	Frequent Words		**Infrequent Words**	
Short Words	1.10 (2.19)	$F(1,30) = 2.52, p > .05$	0.0003 (0.001)	$F(1,30) = 0.00, p > .05$
Long Words	0.22 (0.33)		0.0003 (0.001)	

Values in the parenthesis represent standard deviations.

4.1.2.2. Stimulus Texts

The stimulus texts were selected from a set of resources, including the BOUN Corpus (Sak et al., 2008), METU Turkish Corpus (Say, Zeyrek, Oflazer, & Özge, 2002), and the Turkish National Corpus (Aksan, Aksan, Koltuksuz, Sezer, Mersinli, Demirhan, Yılmazer, Atasoy, Öz, Yıldız, Kurtoğlu, 2012). The stimulus texts that were designed to include some of the infrequent words, especially their suffixed versions which were not found in these corpora, were located using publicly available resources (by Google search) for likely use in web pages. In case of a lack of a target word in any of the resources, the texts that included more frequent synonyms of that target word were found, and the synonym was replaced with the target word. This methodology allowed us to use available text, instead of creating sentences for the experiment, thus improving the ecological validity of the experiment (see APPENDIX A for a complete list of the stimuli). In addition to stimulus texts, four paragraphs were used as filler material. The paragraphs were excerpted from a novel (Bıçakçı, 2006).

The resulting stimuli have the following characteristics:

1. Word counts (*M* = 15.33, *SD* = 2.88 words) and character counts (*M* = 125.13, *SD* = 20.78 characters) of texts were not significantly different among the experimental conditions ($F(3,188) = 1.00$, $p > .05$, $F(3, 188) = 2.20$, $p > .05$, respectively).

Table 4.2 Word and character counts of texts.

	Infrequent Words	Frequent Words
	Word Count	
Short Words	15.48 (3.05)	15.73 (2.55)
Long Words	14.75 (3.05)	15.35 (2.82)
	Character Count	
Short Words	121.00 (20.17)	124.65 (18.95)
Long Words	123.54 (22.12)	131.33 (20.99)

Values in the parenthesis represent the standard deviation.

2. Character counts of the lines that included a target word were not significantly different among the conditions (*M* =60.92, *SD* = 4.50, $F(3,188) = 0.65$, $p > .05$).

3. The target words were always located approximately in the middle of a line. The character count of the line on the left of the target word: *M* = 26.66, *SD* = 8.52; the character count of the line on the right of the target word: *M* = 25.77, *SD* = 7.93.

4. The target words were always located approximately in the middle of the text. The character count of the text from the beginning of the text to the beginning of the target word: *M* = 56.70, *SD* = 27.85; the character count of the text from the end of the target word to the end of the text: *M* = 59.43, *SD* = 22.93.

5. Some of the stimulus texts consisted of more than one sentence (155 texts include a single sentence, 34 texts include two sentences, and three texts include three sentences). There were at least two words between the target words and the beginnings or the ends of the sentences. If there was a conjunction in the sentence, there were at least two words between the target word and the conjunction.

6. There was no punctuation mark around the target words.

7. The words that precede the target words and the words that succeed the target words were composed of at least five characters.

8. Each text included only one target word. Each target word appeared only in one text, and once in a text. Hence, each target word and its suffixed forms appeared once in the stimulus text set.

9. Each text was presented in at least two lines (107 of 192 texts) and at most three lines (85 of 192 texts).

4.1.3. Apparatus

The eye-movements of the participants were recorded monocularly (right eye) with the SR Research EyeLink 1000 (1000 Hz) eye tracker system with a tower mount (see, Figure 4.1). Stimuli were presented on a 17-inch CRT monitor with 1024 x 768 resolution with a VGA connection on a computer running at 3.0 GHz under a Windows XP operating system. Audio files were recorded for each text and paragraph (as filler material) using a Creative Labs Sound Blaster Audigy 2 ZS sound card. The participants were seated 62 cm away from the display screen with their heads positioned on a forehead rest. The stimuli were presented using 18 pt monospace font (`Courier New`), each letter corresponding 14.03 pixels, and approximately 0.46 degrees of visual angle. Since the experiment included oral reading blocks, to minimize head movements, a chinrest was not used.

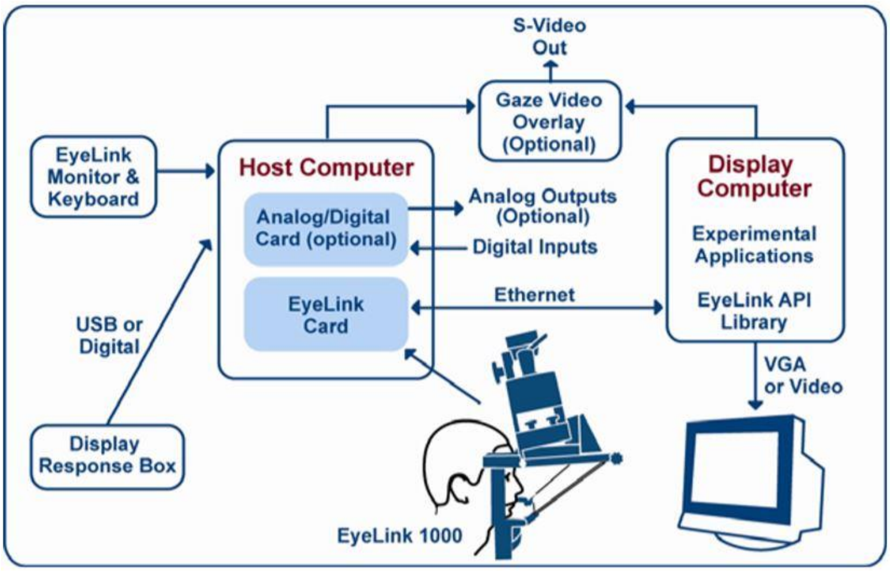


Figure 4.1 SR Research EyeLink 1000 Tower Mount (EyeLink 1000 User Manual version 1.5.0, Figure 1-1, p. 2).

The participants answered questions and proceeded with the experiment after breaks, calibrations, and reading instructions by using a Microsoft USB Sidewinder gamepad (see Figure 4.2). They were instructed to answer a question as “False” by using the back-left button and as “True” by using the back-right button. These instructions appeared at the bottom of each question in parentheses.

Figure 4.2 Microsoft USB Sidewinder gamepad.

4.1.4. Experimental Design and Procedure

The experiment was designed using Experiment Builder 1.10.1630, the software provided by the eye tracker manufacturer.

The experiment was composed of two parts, with 96 stimulus texts in each part. Within each part, there was one silent reading and one oral reading block. Participants were informed that they could participate in the second part on another day. Most of the participants completed both parts of the sessions on the same day, whereas two participants preferred to participate in the second part on another day. The experiment was conducted in a within-subject design. The *reading modality* of the texts (i.e., oral vs. silent reading) and the order of the experiment blocks was counterbalanced among participants with 48 combinations of the texts, conditions, reading modality, and block order. Accordingly, each text was read both silently and aloud by different participants. In other words, each participant read half of the stimuli silently and the remaining half of the stimuli aloud (see APPENDIX B for the counterbalancing procedure). Figure 4.3 illustrates the design of the parts and blocks.

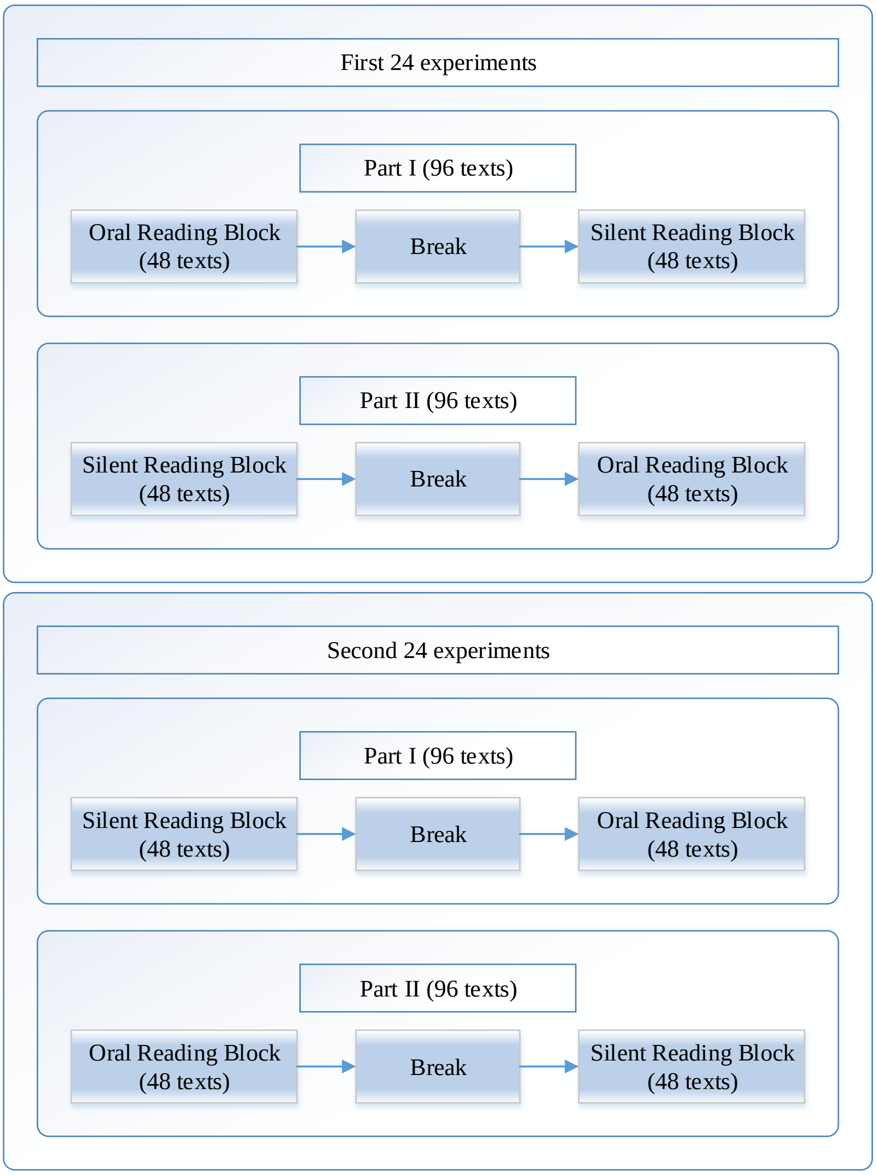


Figure 4.3 Experimental design. The order of reading modality was counterbalanced among participants.

The blocks were composed of a practice session, a paragraph session as filler material, and the text reading session. Four practice texts and two practice questions in the practice session were presented to the participants, and one paragraph in the paragraph session was presented at the beginning of each block. Accordingly, there was a total of 16 practice texts and four paragraphs in one experiment session. The text reading sessions were composed of 48 stimuli (four target words x three suffix versions x four conditions) within each block, and 24 true-or-false comprehension questions within each part, summing up to 192 stimulus texts and 48 questions in the whole experiment session. The comprehension questions were prepared for each text to be presented in a pseudo-random order to the participants such that the correct answer of 94 of them was *False*; the correct answer of 98 of them was *True*. The participants correctly answered 88.84% of the questions (*SD* = 5.89%). There was one break after every 16 texts and between blocks, summing up to five breaks in one part and ten breaks in the whole experiment session. Figure 4.4 illustrates the procedure within one block.

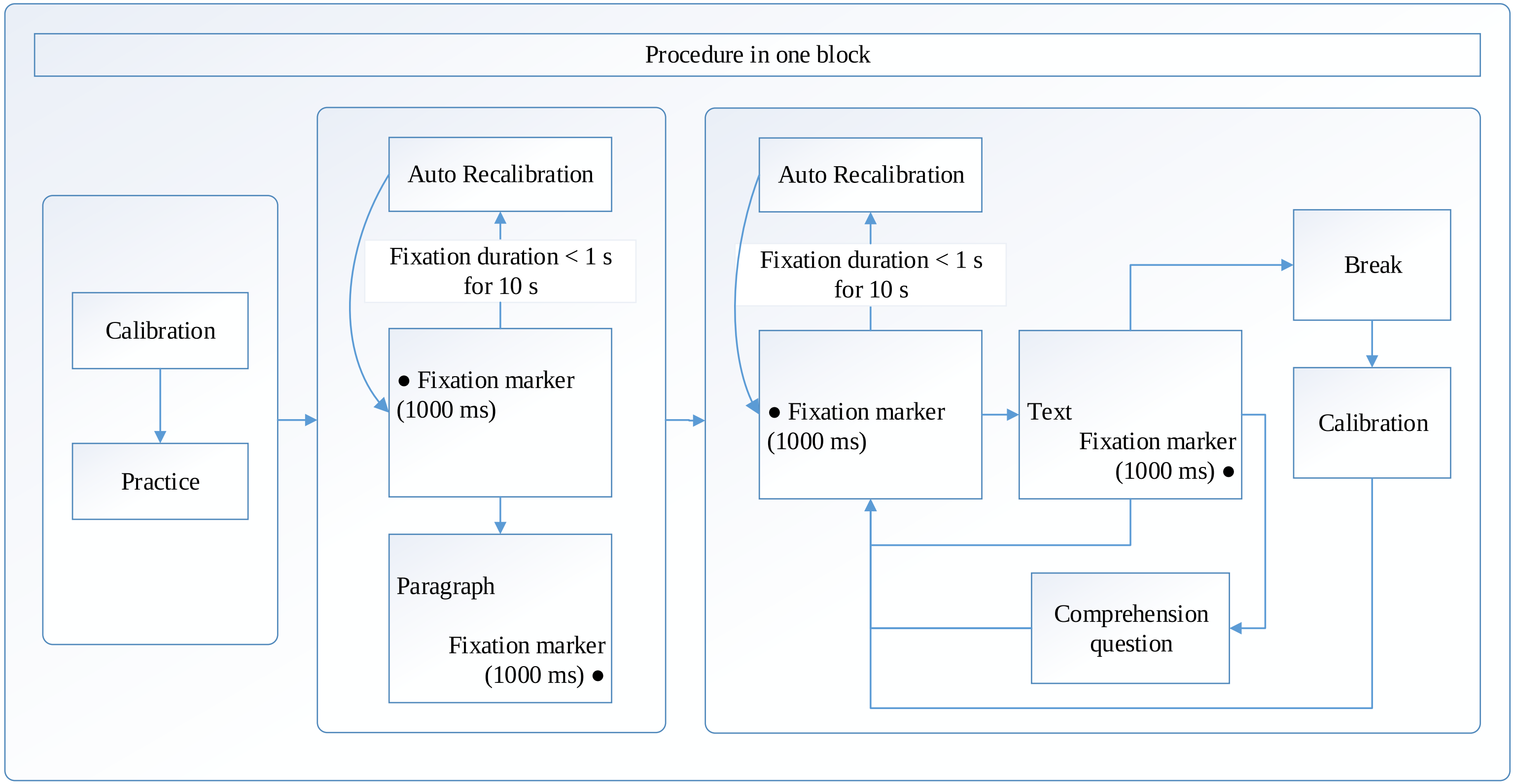


Figure 4.4 Procedure of one block. The procedure of silent block and that of oral block were identical. Texts were followed by (i) a comprehension question, (ii) a fixation marker for the next text, or (iii) a break.

At the beginning of the parts, general instructions were presented to the participants, which provided information about the study, in general. At the beginning of each block, there were short instructions for the practice session that presented information about the reading modality (silent vs. oral reading) of the block. After the practice instructions, a nine-point standard calibration and validation were performed.[3] Following the practice session, at the beginning of the text reading session, the participants were instructed to read the texts at their normal reading pace for comprehension, either silently or aloud, depending on the reading modality of the block. On the left of the screen, a gaze-contingent fixation marker (a circle with a diameter of 32 pixels) was displayed, in a blank screen, before the presentation of a stimulus on the screen. The coordinates of the fixation marker were (42, 250) for texts and practices, and (28, 150) for paragraphs (the 0, 0 coordinate is the top left). There was an IA (Interest Area) with a diameter of 150 pixels around the fixation marker, which was invisible to the participants. Following a fixation duration of 1000 ms within the IA of the fixation marker, the stimulus appeared on the screen with the first letter on the same coordinates as the coordinates of the fixation marker. If any fixation within the IA of the fixation marker did not reach the duration of 1000 ms for 10 seconds, an auto-calibration process was triggered for re-calibration with the same standards as described above. Together with the texts, there was another fixation marker, and an IA on the right bottom of the screen that had the same size as the size of the previous fixation marker, as well as an IA that belonged to the fixation marker (the coordinates were (982, 700) for texts and practice texts, and (981, 715) for paragraphs). This second fixation marker was gaze-contingent, as well, used for proceeding with the next screen. Automatic re-calibration was not triggered for the second fixation marker to avoid limiting the reading duration of participants. If any fixation within the IA of the fixation marker that was displayed together with the stimulus did not reach a duration of 1000 ms, the screen changed manually from the keyboard of Host PC (i.e., the computer that controls the eye tracker). Hence, the automatic re-calibration process linked to the IA of the fixation marker that appeared on a blank screen was started. For the analyses, each word in texts was marked as an Interest Area (IA) by using the *Use Runtime Word Segment InterestArea* function of Experiment Builder software. The IAs for fixation markers were constructed manually. Multiple versions of the IA sets were constructed depending on the purpose of the analysis. Since the IAs for fixation markers were used only during experiments for their gaze-contingent functions, the IAs for fixation markers were removed from the IA sets for the analyses.

4.1.5. Memory and Familiarity Tests, and Predictability

In addition to experiment sessions of both experiments, there were two memory tests (a Corsi Block test and a digit span test). Following the experiment, participants completed an additional seven-point Likert-scale familiarity test for a measurement of the familiarity degree of the target words.[4] The mean values of the Corsi test and digit

[3] The calibration and validation was renewed after each break.

[4] All of the tests were programmed in Experiment Builder 1.10.1630 as non-EyeLink experiments. Digit sequences in digit span test were increased up to eight digits. Corsi test was a modified version of an example experiment designed by SR Research Team depending on another study (Dreher, et al., 2001).

span test results that were collected from the participants above mentioned are presented in Table 4.3.

Table 4.3 The mean scores of the digit span and Corsi tests.

	Digit span test	Corsi test*
Mean	6.99	5.73
SD	1.07	0.68

* Data obtained from 195 participants since data from one participant was not recorded due to technical problems.

The relationship between memory test results and the capacity of memory buffer was investigated by a Baseline-Category Logit Model (BCLM) of the number of words held in the buffer before articulation. The levels were (1) *one-word* level that represents the cases that the word is articulated before eyes left the word (i.e., one word in the buffer), (2) *two words* level that represents the cases that the word is articulated while fixating the word n+1 (i.e., two words in the buffer), (3) *more than two words* level that represents the cases that the word is articulated while fixating any word on the right of word n+1 (i.e., more than two words in the buffer), and (4) *regression* level represents the cases that the word is articulated during a regressive fixation on word n (i.e., regressions). The details and the results of the BCLM were presented in APPENDIX D.

The familiarity test was given after the experiment session was finished to prevent participants from seeing the target words prior to the experiment. However, participants were instructed before the test to think of their familiarity degrees of the target words before the experiment and to select one for *I have never heard the word* and seven for *I know the meaning of the word*. The stem frequency of words and the familiarity scores of them were 41.21% correlated. The mean familiarity scores within conditions are presented in Table 4.4.

Table 4.4 The mean familiarity scores of the target words on a seven-point Likert-scale.

	Infrequent Words	Frequent Words
Short Words	2.79 (1.52)	6.96 (0.02)
Long Words	4.02 (2.14)	6.95 (0.04)

Values in the parenthesis represent the standard deviation.

The interaction of familiarity scores and prelexical characteristics of words were included in LMMs to test the dual-route hypothesis. The scores converted to a categorical variable such that a score smaller than five regarded as unfamiliar. The details were presented in the subsequent sections of this chapter.

The example Corsi test was retrieved from SR Research Support site and modified such that square sequences lit up to six squares, gradually and delay conditions were removed from the original example experiment (https://www.sr-support.com/forum/experiment-builder/examples/663-temporal-order-and-spatial-memory?618-Temporal-order-and-spatial-memory=). In both memory tests, the test was finished whenever the participant was not able to replicate the order twice for a sequence.

Predictability scores for target words[5] and its neighboring words in stimulus text were collected from 105 participants with 35 predictions for each word (M = 24.9, SD = 5.2 years old, ten participants did not report their birth year; 71 female). Participants were asked to predict the following word (either word n (target word), word n-1, or word n+1) given the context in the part of the text prior to the target word. Correct predictions scored as 1, and incorrect predictions scored as 0. The probability (p) of correct prediction was calculated using (4.1) where n = 35 (i.e., the number of predictions for each word).

$$p = \textit{number of correct predictions} / n \qquad (4.1)$$

4.2. Analyses and Data Selection

4.2.1. Eye-movement Data Inspection and Cleansing

Eye-movement data were inspected, cleansed, and corrected where necessary, as described in this section. The eye-movement measures were retrieved by the Data Viewer, the data analysis software provided by the eye tracker manufacturer.[6]

A manual inspection of gaze data revealed two types of calibration problems: (i) all fixations were above or below the lines, namely the *offset* problem (see Figure 4.5 for an example), (ii) fixations were upward or downward sloping (see Figure 4.6 for an example).

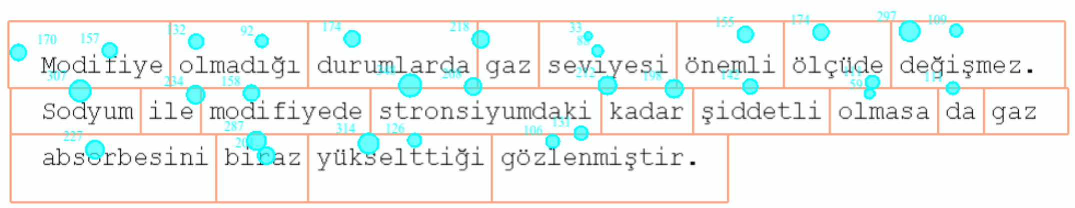


Figure 4.5 Example of calibration problem (type i). Fixations were above the lines. The problem was solved by selecting all fixations and moving them downwards.

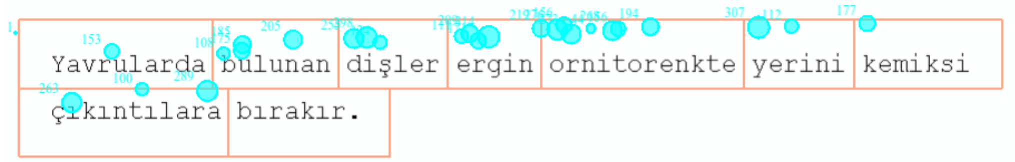


Figure 4.6 Example of calibration problem (type ii). Fixations were upward sloping. The problem was solved by using the *Drift Correct* function of the Data Viewer.

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[5] Predictability scores for target words were collected from 122 participants for Turkish Reading Corpus (Acartürk et al., 2017a). However, the neighboring words were predicted by 35 participants. Therefore, for statistical purposes a randomly selected sample that includes predictability scores of target words collected from 35 participants was included in the analyses. Predictability scores of 192 target words from 122 participants and that of the selected 35 participants were not significantly different ($F(1,382) = 0.00004$, $p > .05$).

[6] Eye movement data inspection and analyses were started by using Data Viewer version 2.3.22. During the analyses, the software was updated to version 2.6.1.

These calibration problems were solved by (1) selecting all fixations and moving them downwards or upwards, (2) selecting the fixations which belonged to the same line and aligning them by using the *Drift Correct* function of the Data Viewer software, or (3) using a combination of (1) and (2). The fixations were moved only vertically when necessary, and none of the fixations were moved horizontally (i.e., the coordinates of the fixations along the X-axis were not changed) by following the analysis previously reported in the literature (Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & Van de Weijer, 2011). When any of the solutions were not applicable for a trial (i.e., a stimulus together with fixations) that have calibration problems, that trial was removed from the analyses. Similarly, when data loss because of a technical problem was detected in a trial during manual data inspection, that trial was removed from the analyses, as well. A total of 60 trials of 37632 trials from 196 participants were eliminated (0.16%). During six experiment sessions, the experiment canceled after some of the stimuli were presented because of technical or electricity supply problems. A total of 156 trials in which stimuli were read twice by the same participant were removed from the analyses (0.41%). The last two version of data loss due to low-quality data or technical problems was 216 of 37632 trials (0.57%).

4.2.2. Eye-movement Measures

The fixations that were made after the first fixation on the last word (i.e., re-readings) and words that received the first fixation after fixating a word on the right (i.e., skipped words) were removed from the analyses. A set of first-pass eye-movement measures included in the analyses. The eye-movement measures are either retrieved from Data Viewer software or calculated by using several variables provided by the software. The explanation of the eye-movement measures included the analyses are as follows:

First Fixation Duration (FFD) is the duration of the first fixation on a target word, regardless of the fixation count. The example presented in Figure 4.7 shows two successive fixations, highlighted. It is clear that the first fixation on *enfeksiyon* 'infection' is on the second *e*, which has a duration of 186 ms. Therefore, the FFD value for *enfeksiyon* is 186 ms. A natural logarithmic transformation was applied to FFD values.

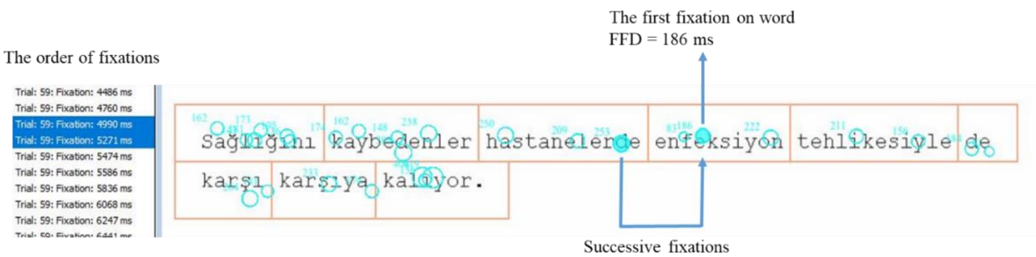

Figure 4.7 Example of First Fixation Duration (FFD).

Gaze Duration (GD) is the sum of all fixation durations on a target word in the first pass. The example presented in Figure 4.8 shows the fixations in the first pass on the target word, *enfeksiyon* 'infection', highlighted. In this example, the target word received all fixations in the first pass (i.e., the word was not viewed after eyes left the word). However, it is not the case for all instances. If there were fixations on the word which were not in the first pass, they would not be included in GD. The sum of all fixation durations (i.e., GD) was 491 ms in this example. A natural logarithmic transformation was applied to GD values.

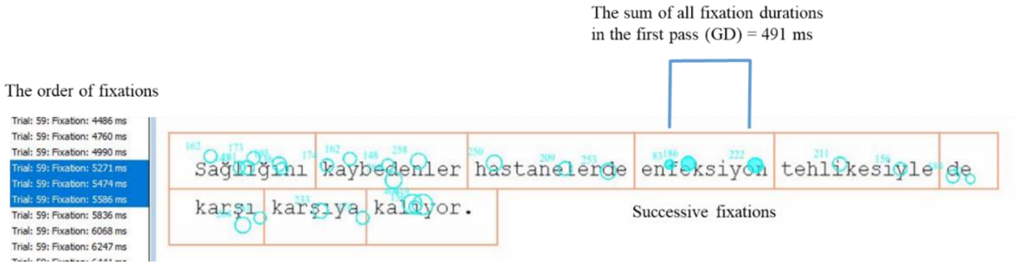

Figure 4.8 Example of Gaze Duration (GD).

First Landing Position (FLP) is the distance between the first letter of the word and the location of the first fixation on the word. The example presented in Figure 4.9, the first fixation on *enfeksiyon* 'infection', which is on the second *e*. There are four letters from the beginning of the word to the location of the first fixation on that word. Therefore, FLP, in this example, is four characters. Instead of raw FLP values, *Relative FLP* values were included in the analyses.

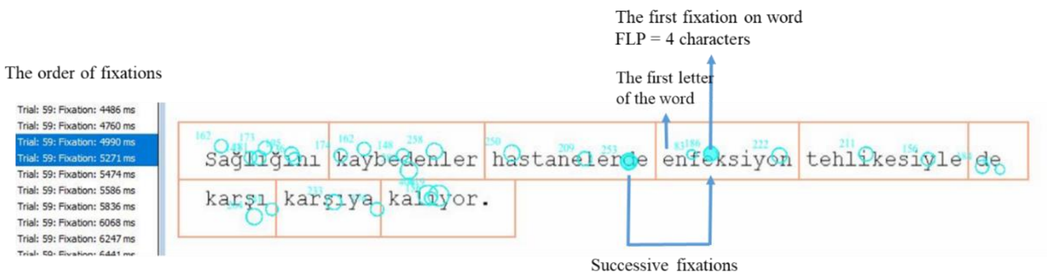

Figure 4.9 Example of First Landing Position (FLP).

Relative First Landing Position (RFLP) is the FLP values relative to the target word center. Relative fixation positions were transformed to reflect word-relative FLPs on words by (4.1). The negative RFLP values indicate the first half of the word, the positive RFLP values indicate the second half of the word, and 0 indicates the middle of the word (Hohenstein, Matuschek, & Kliegl, 2017).

$$RFLP = (FLP/(Word\ Length + 1)) - 0.5 \qquad (4.1)$$

Launch Site (LS) is the distance between the first letter of a word and the location of the fixation prior to the first fixation on that word. The example presented in Figure 4.10, the location of the fixation prior to the first fixation on the target word, *enfeksiyon* 'infection', is on *d* of the word *hastanelerde* 'in the hospitals'. There are three characters from *d* of *hastanelerde* to the beginning of the target word. Therefore, LS, in this example, is three characters. Although it was not the case in all instances, in this example, the fixation prior to the first fixation on the target word is on the previous word. The launch site of the target word (LS) and the launch site of the word n+1 (LS2) included in the analyses. The log-transformed (base 2) values of LSs were included in the analyses.

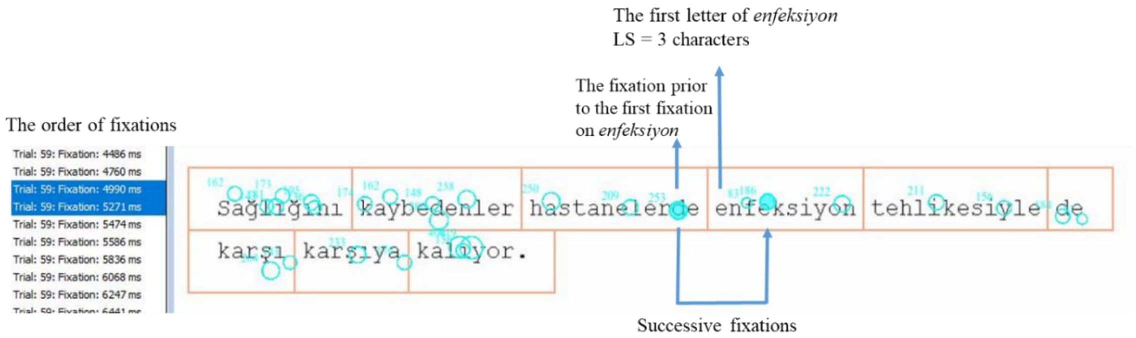

Figure 4.10 Example of Launch Site (LS).

4.2.3. Audio Recording Analyses

The texts and paragraphs that were read aloud by the participants were recorded as waveform audio files (`.wav`) files, separately for each trial. Articulation start times and articulation end times of the target words were annotated manually by the ELAN software, as illustrated in Figure 4.11 (Brugman & Russel, 2008).

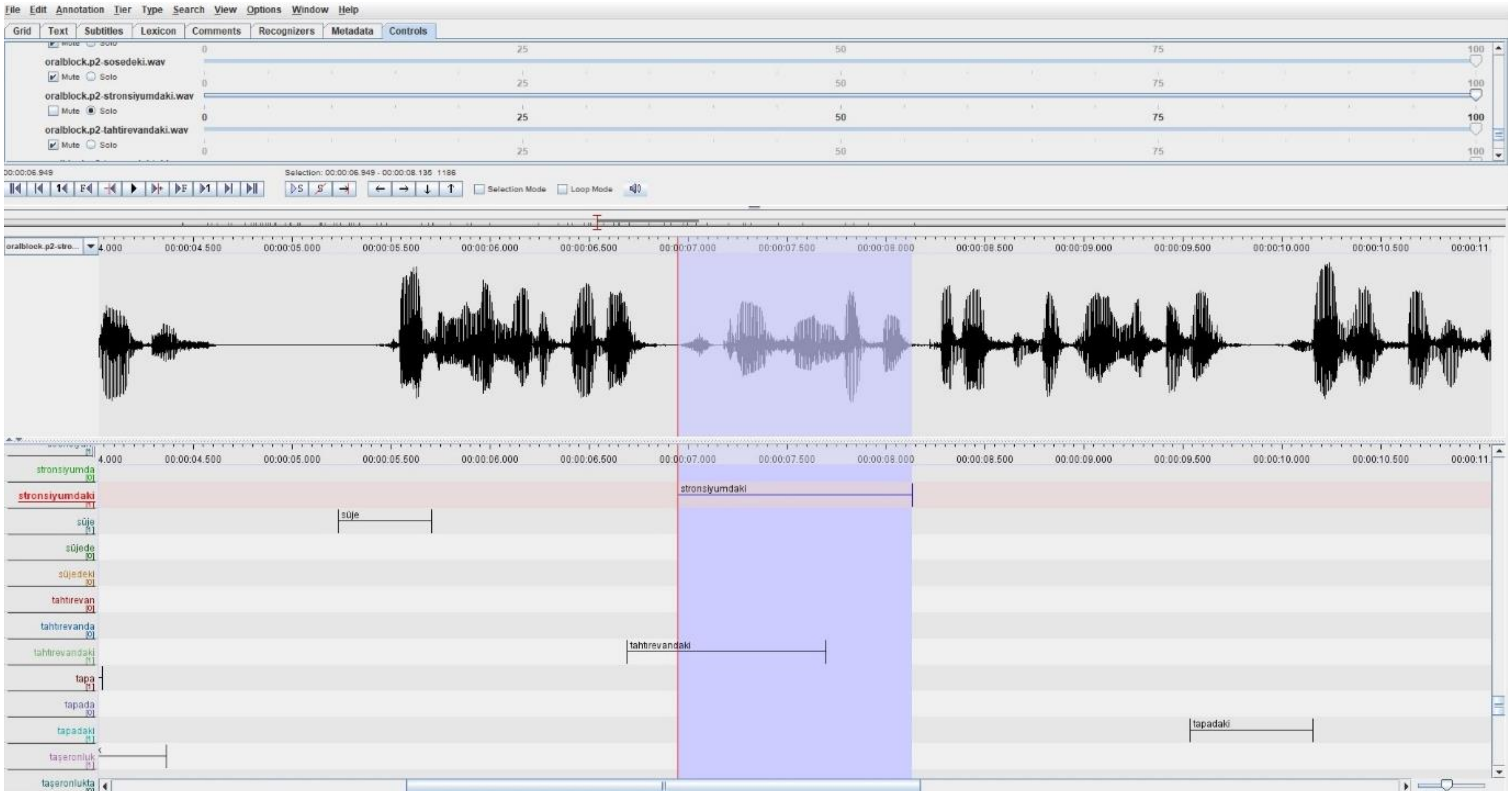

Figure 4.11 Audio annotation in ELAN. In this example, the beginning and the end times of the articulation of the target word *stronsiyumdaki* ‘in strontium’.

The beginnings and the ends of the articulations were determined by listening to the audio files and marking the wave beginnings in the ELAN. The tier sets included one tier for each target word and imported to the ELAN file (.eaf) that was created for each participant. ELAN annotations were entered on these tiers. If a target word was not articulated correctly in a trial (e.g., saying a different word than the written one, reading the target word more than once, stuttering while reading the target word), the audio file of that trial was not annotated, and hence removed from the analyses. 92.39% of the audio recording annotations were controlled and refined by a second annotator.

The annotations provided time stamps of the start and the end of an articulation, which allowed the synchronization of the articulation times and eye-movements. For synchronization, audio recording start times and first fixation start times were calculated according to eye tracker time using (4.2) and (4.3).

$$A_{tracker} = A_{pc} - t_{pc} + t_{tracker} \tag{4.2}$$

$$FF_{tracker} = FF_{trial} + t_{trial} \tag{4.3}$$

By (4.2), the audio recording start time was calculated. In equation (4.2), $A_{tracker}$ stands for the audio recording start time in terms of the eye tracker time. The A_{pc} is the audio recording start time in terms of the display PC time, which was recorded during experiments in a variable defined in the experiment. The t_{pc} is the current time of the display PC, which was recorded in a variable defined in the experiment. Finally, the $t_{tracker}$ is the current eye tracker time at the time t_{pc} value is updated, which was also recorded during experiments in a variable defined in the experiment. Since the fixation start and the end times were provided by the Data Viewer software relative to trial start time, the first fixation start time relative to the tracker start time was calculated using (4.3), where $FF_{tracker}$ is the first fixation start time relative to the eye tracker start time, the FF_{trial} is the first fixation start time relative to the trial start time, and the t_{trial} is the trial start time relative to the eye tracker start time. The variables that were used to calculate the $FF_{tracker}$ were provided by the Data Viewer software.

4.2.4. The Eye-voice Span

Two eye-voice span measures were included in the analyses: (i) the distance between the first letter of the target word and the character that is fixated at the beginning of the articulation of the target word, in terms of character count (i.e., EVS), and (ii) the time interval between the beginning of the articulation of a word and the first fixation time on the target word (i.e., *Fixation Speech Interval* – FSI – following the definition in Inhoff et al., 2011).

In the example illustrated in Figure 4.12, at the start time of the articulation of the target word *jeodinamik* 'geodynamics', there was a fixation on the second *i* of *karakterinin* 'of character'. Accordingly, the EVS value in this example consists of 22 characters. A logarithmic transformation (base 2) was applied to EVS values.

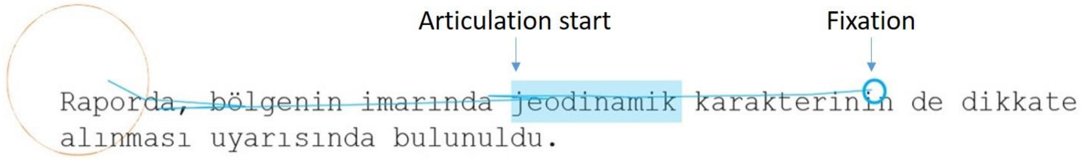

Figure 4.12 The Eye-voice Span in terms of character count (EVS)

In the example of FSI illustrated in Figure 4.13, the first fixation on the target word *jeodinamik* started after 2900 ms passed from the beginning of the trial. The articulation of the same word, in this example, started after 3839.54 ms passed from the beginning of the trial. As a result, FSI, in this example, is 939.54 ms. A natural logarithmic transformation was applied to FSI values.

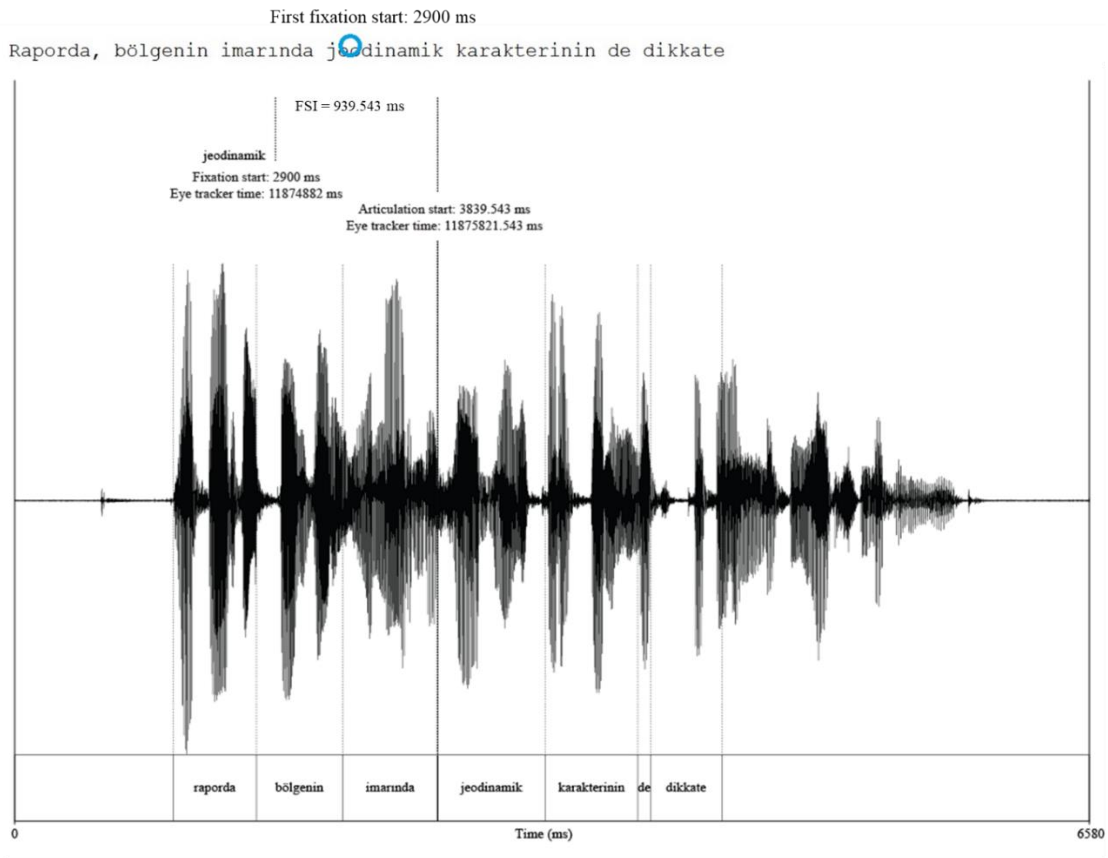

Figure 4.13 The Eye-voice Span in terms of time interval (FSI).

Following the practice in the literature, data eliminated further according to criteria related to the eye-movement measures (Kliegl et al., 2004; Yan, Zhou, Shu, Yusupu, Miao, Krügel & Kliegl, 2014; Kliegl et al., 2006; Kliegl, 2007; Field, 2009). A further elimination was required according to several criteria related to audio recordings, FSI, and EVS (Inhoff et al., 2011; Laubrock & Kliegl, 2015; Field, 2009). The additional elimination criteria and data loss are presented in Table 4.5.

Table 4.5 Elimination of the data according to eye-movement measures and articulation related criteria

	Criteria	Oral Reading	Oral Reading Percent (relative to 1)	Silent Reading	Silent Reading Percent (relative to 1)	Total	Total Percent (relative to 1)
1	All data from 196 participants	18816	-	18816	-	37632	-
2	Re-readings	24	0.13	132	0.7	156	0.41
3	Low-quality data	22	0.11	38	0.2	60	0.16
4	Valid data	18770	99.76	18646	99.1	37416	99.43
5	Skipped words	1213	6.46	1500	8.04	2713	7.25
6	Remaining data	17557	93.54	17146	91.96	34703	92.75
	Criteria	**Oral Reading**	**Oral Reading Percent (relative to 6)**	**Silent Reading**	**Silent Reading Percent (relative to 6)**	**Total**	**Total Percent (relative to 6)**
6	Previous and next fixations were on a different line than that of the target	121	0.69	92	0.54	213	0.61
7	Regressions (in & out)	1627	9.27	1612	9.4	3239	9.33
8	LS0 related elimination (Fixation n-1 was on the space on the left of the target, or LS0 was greater than 9 characters)	1227	6.99	1707	9.96	2934	8.45
9	LS2 related elimination (Fixation n+1 was on the space on the right of the target, or LS2 was greater than 9 characters)	710	4.04	1437	8.38	2147	6.19
10	Articulation errors	2567	14.62	-	-	2567	7.4
11	Fixation at the beginning of articulation was on a different line than that of the target	29	0.17	-	-	29	0.08
12	Fixation at the beginning of articulation was not on a word	3	0.02	-	-	3	0.01
13	Negative FSI values	1	0.01	-	-	1	0
14	Negative EVS values	13	0.07	-	-	13	0.04
15	Outlier FSI durations (FSI<136.4, FSI>1211.7 according to IQR calculations)	806	4.59	-	-	806	2.32

16	Outlier EVS lengths (EVS<0.5, EVS>20.5 according to IQR calculations)	122	0.69	-	-	122	0.35
17	Fixation duration related elimination (GD<60, GD>1000, single fixation duration>800)	2704	15.4	1107	6.46	3811	10.98
18	Fixation after the last fixation on the word was not on a word	4	0.02	2	0.01	6	0.02
19	Remaining data	11081	63.11	12225	71.3	23306	67.16

The sum of elimination percents is not the percent of the total eliminated data because of overlapping criteria (e.g., a regressive single duration shorter than 60 ms, or a target word that has both outlier FSI and outlier EVS values). For LS, values that were greater than the upper quartile plus 1.5 times interquartile range accepted as outliers. For FSI and EVS, values that were greater than upper quartile plus 1.5 times the interquartile range, or less than lower quartile plus 1.5 times interquartile range accepted as outliers. The other cutoff points either statistical/theoretical necessity (e.g., negative values, articulation errors), or depend on the literature (e.g., duration cutoff points, except an elimination according to the first fixation duration).

The remaining data after the elimination process mentioned above was 67.16% of all non-skipped valid data, 63.11% of all non-skipped valid oral reading data, and 71.3% of all non-skipped valid silent reading data.

4.2.5. Lexical and Prelexical Characteristics

The approach in the current study assumes a distributed processing of words during reading, as mentioned. Therefore, to test the effects of the characteristics of neighboring words, in addition to the lexical and prelexical characteristics of the target word (*word n*), those of the word on the left of the target word (*word n-1*), and the word on the right of the target word (*word n+1*) were included in the analyses.

4.2.5.1. Lexical Characteristics

Stem Frequency (SF) was selected as lexical frequency covariate because the stimuli were organized according to their stem frequency values. It was the surface frequency values obtained from BOUN corpus (Bilgin, 2016; Sak et al., 2008; see Section 4.1.2.1 for a detailed explanation). Lexical frequencies per million were log-transformed (base 10) after a Laplace smoothing method applied by (4.4) (Brysbaert & Diependaele, 2013) since there were zero frequency values.

$$Fpm = ((Count + 1)/(Token + Type))*1{,}000{,}000 \qquad (4.4)$$

In (4.4), *Fpm* stands for frequency per million, *Count* stands for the count of occurrences of a word in the corpus, *Token* stands for the count of word tokens in the corpus (383,224,629), and *Type* stands for the count of word types in the corpus (1,337,898). For figures, a word was accepted as infrequent whenever its frequency was below 1.17, following the criterion for stimuli design.

Predictability (P) scores of the words were also included in the analyses, to take the effect of sentential context into account (see Section 4.1.5 for details). Logit-based predictability values were used in the analyses (Kliegl et al., 2004). The probability (*p*) of correct prediction was calculated using (4.5) where *n* = 35. Predictabilities of zero and one were replaced according to (4.6), and logit predictability values were defined as (4.7).

$$p = \text{number of correct predictions} / n \tag{4.5}$$

$$p = \begin{cases} \frac{1}{2*n} & \text{if } p=0 \\ \frac{(2*n)-1}{2*n} & \text{if } p=1 \\ p & \text{otherwise} \end{cases} \tag{4.6}$$

$$\text{Logit}\ (p) = 0.5 * \ln\ (p / (1 - p) \tag{4.7}$$

Word Length (WL), as another word-level variable, was included in the analyses. Reciprocal values of absolute word length values (i.e., 1/WL) included in the analyses (Kliegl, et al., 2006; Kliegl, 2007; Hohenstein et al., 2017).

4.2.5.2. Prelexical Characteristics

Prelexical covariates were selected depending on the phonological characteristics of Turkish as follows.

Vowel Harmony (VH). In Turkish, there are eight vowels that are grouped according to the height of the tongue, the roundedness of the lips, and the frontness of the tongue during articulation (see Table 4.6). Vowel distribution in Turkish words is highly restricted according to the rules of VH. Sequences are allowed to be in one of the groups in Table 4.6 depending on the vowel in the previous syllable, to the extent that vowels in most suffixes agree with the last syllable of the word to preserve VH, although there exceptional suffixes that do not agree with the last syllable (e.g., -ki, one of the suffixes selected for this study).

Table 4.6 Vowels in Turkish

	Rounded		**Unrounded**	
	Front	**Back**	**Front**	**Back**
High	ü	u	i	ı
Non-high	ö	o	e	a

In Table 4.7, sequences allowed according to VH are presented. Most of the exceptions to VH are loan words (Göksel & Kerslake, 2005).

Table 4.7 Vowel sequences allowed according to vowel harmony

	The vowel of the syllable	The allowed vowel of the next syllable
Back	Unrounded (a, ı)	Unrounded (a, ı)
	Rounded (o, u)	Unrounded & Non-high (a)
		Rounded & High (u)
Front	Unrounded (e, i)	Unrounded (e, i)
	Rounded (ö, ü)	Unrounded & Non-high (e)
		Rounded & High (ü)

The variable, VH, was included in the analyses as a categorical covariate with two levels, which show whether the rule was broken or not. Since we are primarily interested in the effect of a broken rule, words that respect VH were accepted as base category (i.e., respected VH rule was labeled as 0, and broken VH rule was labeled as 1). Hence, the dependent variable values of words that respect the VH rule were included in the intercept of the model, while the coefficient of the variable showed the change in the dependent variable value when the rule was broken.

Trigram Frequency (TF) values were assumed to capture the phoneme environment. That is because different pronunciations of phonemes (i.e., allophones) are context-dependent. For example, /h/ is pronounced as a voiceless palatal fricative when precedes a front vowel, like a voiceless velar fricative when a back vowel precedes it, like a voiceless glottal fricative when precedes a back vowel, and sometimes it is silent between two identical vowels (Göksel & Kerslake, 2005). The average adjacent trigram frequencies were included in the analyses as covariates. Because of the restrictions of letter clusters at word-initial and word-final positions, trigrams were divided into three subgroups: word-initial, word-final, and between these two. For each group, frequency values were obtained from the BOUN corpus separately, depending on the place of the trigram in the word (Bilgin, 2016). Therefore, another restriction, boundary frequency (i.e., the frequency of letters at word-initial and word-final positions) assumed to be captured by TF calculated as explained. Trigram frequency values were calculated as occurrences per million. Since there was not any zero frequency value for trigram frequency, the Laplace smoothing method was not applied. Average trigram values were used as a covariate, rather than three covariates for each trigram frequency, to avoid too much complexity. The averages of frequency per million values were log-transformed (base 10).

Familiarity included in the model as a categorical variable such that familiarity scores below five regarded as unfamiliar. The main purpose of the inclusion of familiarity in the model was to provide a test for the dual-route hypothesis. To test the hypothesis, the interaction between prelexical covariates and familiarity was included in the model with unfamiliar instances coded as 1 and familiar instances coded as 0.

4.3. Linear Mixed Models

In the current study, two different sets of *Linear Mixed Models* (LMM) with the `lme4` package (version 1.1-15; Bates, Maechler, Bolker, Walker, 2015) in the R environment (version 3.4.2, 64-bit build; R Core Team, 2017) are provided: (i) oral reading LMMs, (ii) silent reading LMMs. Within the first group of LMMs, FSI, FFD, GD, and RFLP are modeled. The next group of LMMs had the same dependent variables, except FSI. A similar strategy was applied to both LMMs to test the assumptions of P-GAG. The processing status of five successive words during fixation n according to assumptions of P-GAG is illustrated in Figure 4.14.

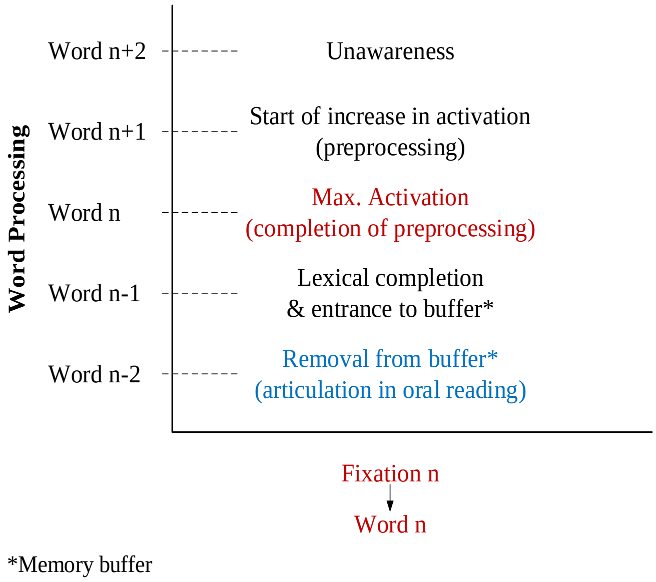

Figure 4.14 Processing five successive words during fixation n according to assumptions of P-GAG.

In Figure 4.14, it is assumed that there is a single fixation on each word without regression and skipping. Word n receives the current fixation, i.e., fixation n. Any difficulty in the completion of lexical completion of word n-1 or completion of preprocessing of word n would result in a longer fixation n and limitation in preprocessing of word n+1. On the other hand, preprocessing of word n+1 starts during fixation n. These effects were tested by investigating the effects of several lexical and prelexical characteristics of words on eye-movement measures.

4.3.1. Dependent Variables

Fixation speech interval (FSI). Fixation speech interval was the time interval between the first fixation on word n and the beginning of the articulation of it. In P-GAG, similar to SWIFT, the activation of a word can reach its maximum and decay to zero parafoveally, and hence, the word can be skipped. However, since only the fixated words were included in the LMM, according to P-GAG, FSI of a word covers the time required to complete preprocessing, lexical completion and entrance to the memory buffer, and removal from the buffer stages of processing that word. Therefore, FSI was considered mainly as a measure for the time required to complete postlexical processing in the memory buffer, which does not require new visual input. Therefore, the LMM of FSI consisted of lexical and prelexical characteristics of words and the spatial measure of the eye-voice span (EVS). In other words, there were not any eye-movement measures as a covariate in the LMM of FSI.

Fixation durations. To test the assumptions of P-GAG related to top-down foveal inhibition due to lexical processing, two fixation duration measures were modeled statistically, separately for each reading modality (i.e., silent and oral reading). One of those fixation duration measures was the first fixation duration (FFD). It was assumed that the LMMs of FFD would provide insight for early influences of lexical and prelexical processing, and the influences of oculomotor measures (i.e., relative first landing position and launch sites of word n and word n+1) on lexical processing times. Since long words tended to receive multiple fixations, LMMs of an additional fixation duration measure, gaze duration (GD), were provided. All of the four LMMs of fixation duration measures included all lexical, prelexical, and oculomotor covariates and the interactions, as explained in the following sub-sections. In addition to those covariates, the LMMs of FFD and GD for oral reading included FSI and EVS as covariates.

Relative first landing position (RFLP). To test the assumptions of P-GAG related to the saccade target selection process, the influences of lexical and prelexical characteristics of words and launch sites of word n and word n+1 on RFLP were modeled with two LMMs for each reading modality. In the LMM of RFLP for oral reading, there were FSI and EVS as covariates.

4.3.2. Assumptions Underlying the Selection of Covariates

The assumptions underlying the inclusion of covariates are presented in the following sub-sections. All continuous covariates were centered on common means of the relevant covariate before the construction of LMMs (see APPENDIX C for details).

4.3.2.1. Common Covariates and Interactions

Canonical lexical effects. The frequently reported effects of the predictability (P0), length (WL0), and frequency (SF0) of word n were included in the model. The selection of stem frequency rather than word frequency was because of the experimental design – i.e., the stimulus words were selected according to their stem frequencies. An interaction between WL0 and SF0 was included in the model (Kliegl et al., 2006; Kliegl, 2007). The expectation was to observe canonical findings in the results of the current study (e.g., the observation of an increase in fixation durations together with an increase in WL0).

Prelexical phonological processing as an early process. To account for phonological lexical processing, two covariates were included in the model (see Section 4.2.5.2): vowel harmony and trigram frequency of words. Since it was assumed that prelexical phonological processing influences eye movements early in the processing, any lag effect (i.e., the effect of the characteristics of word n-1 on eye movements of the foveal word) related to prelexical processing was not expected. Therefore, vowel harmony of word n (VH0), that of word n+1 (VH2), trigram frequency of word n (TF0), and that of word n+1 (TF2) were included in the model as prelexical characteristics of words. The expectation was to observe the influence of prelexical word characteristics similar to that of frequency, because of the assumption of the P-GAG that prelexical phonological difficulty contributes to the word difficulty.

Lag (spillover) effects. A difficulty in the lexical completion of word n-1 would be observed in eye movement measures and FSI of the foveal word. To test the assumption, predictability, length, and frequency of word n-1 were included in the model (P1, SF1, and WL1, respectively).

Successor (parafoveal-on-foveal) effects. Due to the assumption of distributed processing of words within the perceptual span, the characteristics of word n+1 were expected to influence eye movements and FSI of word n. To test the assumption, predictability, length, and frequency of word n+1 were included in the model (P2, SF2, and WL2, respectively).

Morphological complexity. Although there are several possibilities of determining a measure for morphological complexity, in the current study, the number of inflectional suffix counts were included in the LMMs as a measure of morphological complexity. Accordingly, suffix count of word n (SC0), suffix count of word n-1 (SC1), and suffix count of word n+1 (SC2) were included in the LMMs. It was expected that increased morphological complexity would show the effects of the increased difficulty of words.

Visual acuity hypothesis. According to the visual acuity hypothesis, the length of the foveal word influences the successor effects due to acuity limitations (Kliegl et al., 2006; Kliegl, 2007). In the current study, it was assumed that the effects of SF2, TF2, and VH2 are influenced by the restriction of visual acuity depending on the length of word n. Therefore, three interactions were included in the model to test the assumption. They were the interaction between WL0 and SF2, that of WL0 and TF2, and that of WL0 and VH2. The expectation was the weaker effects of SF2, TF2, and VH2 on the dependent variables among words that have higher WL0 values.

Foveal load (dynamical modulation of the perceptual span) hypothesis. According to the assumption of dynamical modulation of the perceptual span, there is a restriction of parafoveal information intake due to *foveal-load* (Henderson & Ferreira, 1990; Kliegl et al., 2006). According to the foveal-load hypothesis, the perceptual span should be restricted if there is an increased cognitive load because of the difficulty of the foveal stimulus. In the current study, it was assumed that the foveal load on word n would influence the effect of the difficulty of word n+1 (measured by SF2, TF2, and VH2) on dependent variables. The assumption was tested with three interactions such that the interaction between SF0 and SF2, that of SF0 and TF2, and that of SF0 and VH2. It was expected that an increased foveal load on word n (i.e., low SF0 values) would shrink the perceptual span and result in weaker effects of SF2, TF2, and VH2 on the eye movement measures and FSI of word n.

Another source of dynamical modulation of perceptual span would be due to the difficulty of word n-1 (i.e., SF1). The interactions SF1 x SF0, SF1 x TF0, and SF1 x VH0 were included in the model to assess the second type of foveal load. The expectation was that an increased foveal load on word n-1 would result in less parafoveal benefit for word n. Therefore, for lower SF1 values, the influences of SF0, TF0, and VH0 on dependent variables should be weaker.

Mandatory status of prelexical phonological processing. According to P-GAG, foveal and parafoveal prelexical phonological processing is mandatory for lexical access, not only for infrequent/unfamiliar words or non-words but also for familiar words. To test the mandatory status of prelexical phonological processing, we assumed that testing the influence of familiarity on the effect of prelexical characteristics of words would be informing. Therefore, the interaction between familiarity (as a categorical variable) and TF0, and that of familiarity and VH0 included in the model. It was expected that the effects of TF0 and VH0 should be observed among unfamiliar words, but they should be weaker.

4.3.2.2. Covariates and Interactions Specific to Oral Reading

The spatial measure of the eye-voice span (EVS). The distance between the first letter of word n and the letter on which fixation was located at the beginning of the articulation of word n was assumed to represent memory load during the postlexical processing of word n. Therefore, it was expected that an increased EVS would indicate an increased memory load and would result in longer FSI values. On the other hand, words that require less processing times would allow memory buffer to hold more items, which would be observed as a negative relationship between EVS and fixation durations.

Fixation speech interval (FSI). According to P-GAG, postlexical processing influences the lexical processing and hence, eye movement measures indirectly. Therefore, FSI was included in LMMs of eye movement measures. Since a difficulty in postlexical processing would increase the time required for lexical processing, it was expected that higher FSI values would be accompanied by longer fixation durations.

Interactions. An interaction between WL0 and EVS was included in the LMM of FSI to understand if there was an influence of the length of a word on the effect of memory load on FSI. Interaction between EVS and FSI was included in the LMM of GD to account for regressive eye movements for very long FSI values (Inhoff et al., 2011). An FSI value greater than GD while the fixation was on the word n during its articulation (i.e., a short EVS) would indicate a regressive eye movement during postlexical processing.

4.3.2.3. Covariates and Interactions Specific to LMMs of Eye Movement Measures

The launch site is the distance between the last fixation prior to viewing a word and the first letter of the word. Two launch site measures included in the LMMs of eye movement measures: launch site of word n (LS0) and launch site of word n+1 (LS2). In addition to the frequently reported influence of the LS0 on eye movement measures (Rayner, 1998, 2009a; Rayner et al., 2012 for a review), to account for the influence of the distance of the next word. That was mainly to test the effect of the distance on the successor effects. Therefore, there were two interaction terms in the LMMs: the interaction between LS2 and SF2, and LS2 and P2. An additional interaction between WL1 and LS0 was included in the models to account for skipping costs.

Relative first landing position and its quadratic component were included in fixation duration models to account for a frequently reported robust effect of inverted optimal viewing position (IOVP) (Vitu et al., 2001).

4.3.3. Construction of Linear Mixed Models

In the first stage of the construction of LMMs, all covariates, and interactions, as explained above, included in the base LMMs as fixed factors. At this stage, there was only IOVP curvature (a quadratic component of RFLP) included in the LMMs of FFD and GD as a nonlinear component. Participants and words were selected as random factors. Since only eye-movements on the target word of each text included in the analyses, sentences were not included as a random factor. The random structures of base LMMs were intercept-only random factors. All base LMMs were converged.

In the second stage, the random slopes of the LMMs were determined in a bottom-up manner (Barr, Levy, Scheepers, & Tily, 2013). Several linear covariates were included in the model as random slopes for *participant* and for *word* one by one. At each step, if the model did not fail to converge, the LMM that includes a new random slope was tested against the base LMM using the `anova`() function with a model selection α-level of likelihood ratio test of 0.2 (i.e., the *p*-value for model selection was set to 0.2) to balance Type I error and model power (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017). If the result of `anova`() indicated a contribution of the random slope, the new LMM was evaluated for unnecessary complexity with a principal component analysis using the `rePCA()` function of the `RePsychLing` package (Baayen, Bates, Kliegl, & Vasishth, 2015), following the *parsimonious mixed models approach* of Bates, Kliegl, Vasishth, & Baayen (2015). A random slope included in the model if the model complexity related to the random structure did not exceed the principal component count that cumulatively accounts for 100% of the variance.

The inclusion and evaluation of random slopes for the *participant* were in the following order: (1) word n characteristics (i.e., P0, WL0, and SF0), (2) word n-1 characteristics (i.e., P1, WL1, and SF1), (3) word n+1 characteristics (i.e., P2, WL2, and SF2), (4) suffix counts (SC0, SC1, and SC2), (5) oral reading specific covariates (i.e., EVS for all LMMs, and FSI for LMMs of eye movement measures), (6) covariates specific to LMMs of eye movements (i.e., oculomotor measures: LS0 and LS2 for all LMMs of eye movement measures, and RFLP for LMMs of fixation durations), (7) prelexical characteristics of words (i.e., TF0, TF2, VH0, and VH2), and (8) familiarity.

The purpose of the random slope is to take variability in the effects of covariates dependent on a random factor into account. Since the lexical and prelexical characteristics of words are constant for words, the tested random slopes for words were comprised of only oral reading specific covariates (i.e., EVS for all LMMs, and FSI for LMMs of eye movement measures), and covariates specific to LMMs of eye movements (i.e., oculomotor measures: LS0 and LS2 for all LMMs of eye movement measures, and RFLP for LMMs of fixation durations).

In the third stage, the covariates were inspected for their relationships with dependent variables visually with `ggplot2` package (Wickham, 2009), not to miss a nonlinear relationship. In graphics, linear, quadratic, and cubic relationships were allowed. If a graphical inspection indicated accordingly, the nonlinear component of the covariate was included in the model and tested for its contribution with the same criteria as the criteria for the inclusion of a random slope, except the principal component analysis. However, the inclusion of a new nonlinear component was tested for multicollinearity with variance inflation factors (VIFs) (Lefcheck, 2012). If the VIF value of the new component exceeded the threshold value of ten, it was not included in the model (Field, 2009; for more conservative threshold values, see Zuur, Ieno, & Elphick, 2010).

Finally, the models were re-evaluated for their complexity in the random structure and fixed structure with principal component analysis and VIFs, respectively. There was not any model that exceeded the principal component count of random factors that cumulatively accounts for 100% of the variance. There were no multicollinearity problems, given that none of the VIF values were higher than six, and the average tolerance values (i.e., 1/VIF) for all models were higher than 0.2 (Field, 2009). Residuals of the models were distributed close to normal distribution.

In the next chapter, the results of LMMs were reported with *p* values obtained using the `lmerTest` package (version 2.0-36; Kuznetsova, Brockhoff, & Christensen, 2017). Partial effects for graphs obtained using the `remef` package (Hohenstein & Kliegl, 2015), and graphs were constructed using the `ggplot2` package (Wickham, 2009). The stage-by-stage model construction process and related evaluations (e.g., model comparison tables, chi-square results for model comparisons, VIF, and PCA results) were reported in APPENDIX C.

5. RESULTS

In this chapter, the results of the empirical study are reported. First, descriptive statistics are presented, and then the results of the LMM analyses are presented. At the end of each section, the assumptions of the P-GAG model are evaluated within the framework of the findings.

5.1. Descriptive Statistics

The stimuli of the current study consisted of 192 texts with one target word in each organized according to their frequencies and lengths in four conditions: short-frequent (SF), short-infrequent (SI), long-frequent (LF), and long-infrequent (LI) words. In Table 5.1, a summary of the findings is presented among valid instances included in the analyses after the elimination (see Table 4.5 for elimination criteria and percents and APPENDIX E for a more detailed table of descriptive statistics).

Table 5.1 Summary of the findings broken by conditions

	Short Words		Long Words		
	Frequent Words	Infrequent Words	Frequent Words	Infrequent Words	All Conditions
Oral Reading					
Fixation Counts (Number of instances & percents)					
Valid data	3350	2906	3137	1688	11081
Single fixations	2187 (65.28%)	1535 (52.82%)	339 (10.81%)	60 (3.55%)	4121 (37.19%)
Multiple fixations	1163 (34.72%)	1371 (47.18%)	2798 (89.19%)	1628 (96.45%)	6960 (62.81%)
First fixation duration (ms)	281.16 (107.48)	316.84 (134.14)	256.73 (92.26)	279.83 (113.73)	283.4 (114.39)
Gaze duration (ms)	366.82 (155.08)	467.31 (200.32)	596.82 (185.31)	714.78 (165.84)	511.29 (216.55)
Relative first landing position (0-1)	0.41 (0.18)	0.4 (0.18)	0.33 (0.13)	0.33 (0.13)	0.37 (0.16)
Fixation speech interval	613.72 (158.61)	681.91 (170.31)	606.32 (146.03)	628.13 (137.16)	631.7 (158.28)
Eye-voice span (letters)	11.81 (3.17)	9.77 (3.43)	12.35 (3.74)	9.49 (3.67)	11.07 (3.69)
Eye-voice span (words)	1.02 (0.43)	0.83 (0.45)	0.41 (0.49)	0.19 (0.39)	0.67 (0.55)
Saccade amplitude (letters)					
Last saccade	6.87 (1.56)	6.72 (1.47)	8.3 (1.88)	8.19 (1.8)	7.43 (1.82)
Next saccade	6.83 (1.77)	6.68 (1.92)	7.48 (1.95)	7.59 (2.13)	7.09 (1.95)
Silent Reading					
Fixation Counts (Number of instances & percents)					
Valid data	3294	3157	3209	2565	12225

	Short Words		Long Words		All Conditions
	Frequent Words	Infrequent Words	Frequent Words	Infrequent Words	
Single fixations	2590 (78.63%)	2157 (68.32%)	1050 (32.72%)	596 (23.24%)	6393 (52.29%)
Multiple fixations	704 (21.37%)	1000 (31.68%)	2159 (67.28%)	1969 (76.76%)	5832 (47.71%)
First fixation duration (ms)	239.45 (83.35)	266.26 (108.52)	228.55 (71.37)	256.16 (94.2)	247.02 (91.26)
Gaze duration (ms)	284.45 (124.25)	354.8 (179.55)	401.88 (172.1)	508.8 (211.97)	380.51 (189.5)
Relative first landing position (0-1)	0.44 (0.19)	0.43 (0.19)	0.34 (0.14)	0.33 (0.13)	0.39 (0.17)
Saccade amplitude (letters)					
Last saccade	7.71 (1.93)	7.37 (1.73)	9.14 (2.1)	8.77 (1.93)	8.22 (2.06)
Next saccade	7.53 (1.9)	7.36 (2.06)	8.79 (2.41)	8.93 (2.51)	8.11 (2.33)

Note: Descriptive statistics were calculated over valid data included in LMMs. For fixation counts, values in the table indicate the number of instances, values in the parenthesis indicate percents; for continuous variables, values in the table indicate means, values in the parenthesis indicate standard deviations. Values belong to target words (i.e., word n).

The percentage of multiple fixations among valid instances increased (1) as the length of the word increased (i.e., oral reading: from 41% to 92%; silent reading: from 26% to 72%), (2) as the frequency of word decreased (i.e., oral reading: from 61% to 65%; silent reading: from 44% to 52%), and (3) among oral reading instances (i.e., 48% for silent reading, 63% for oral reading). The mean first fixation durations and gaze durations were greater for oral reading instances than that of silent reading instances. The mean first landing positions were slightly left of the word center, and saccade amplitudes were approximately seven characters for oral reading, approximately eight characters for silent reading. These findings were compatible with the literature on several languages (for reviews: Rayner, 1998, 2009a, 2009b; Rayner et al., 2012; example studies: English: Inhoff et al., 2011; German: Kliegl et al., 2006; Kliegl, 2007; Laubrock & Kliegl, 2015; Finnish: Pollatsek, Hyönä & Bertram, 2000; Hyönä & Pollatsek, 1998; Järvilehto, Nurkkala & Koskela, 2009; Uighur: Yan et al., 2014; Hebrew: Deutsch & Rayner, 1999; Arabic: Paterson, Almabruk, McGowan, White & Jordan, 2015; Turkish: Özkan, Beken Fikri, Kırkıcı, Kliegl, Acartürk, 2020). The mean values of FSI were greater than 600 ms within all conditions (M = 632, SD = 158.3), which was greater than that of English and German (486 ms in Inhoff et al., 2011 for English; 561 ms in Laubrock & Kliegl, 2015 for German), but close to FSI of Finnish words (625 ms in Järvilehto et al., 2009). The mean values of EVS (i.e., the spatial measure of the eye-voice span in terms of character count), on the other hand, were less in all conditions (M = 11, SD = 3.7 characters) than the findings reported in the literature (15-17 characters in Buswell, 1920; 16 characters which were computed from first fixation onset in Laubrock & Kliegl, 2015). In Turkish, approximately one more word was viewed during FSI of short words while the eyes tended to be on the same word at the beginning of its articulation for long words (see APPENDIX D for a detailed analysis). We suggest that the discrepancy observed in eye-voice span measures in Turkish sentence reading with the literature (except for Finnish) resulted from its shallow orthography. The distance between the eyes and the voice might be a function of phoneme count, rather than character count. On the other hand, the inflated FSI might be an indicator of increased prelexical phonological processing for languages with shallow orthographies (Frost, 1998, 2005). However, these claims require further investigation with cross-linguistic studies.

5.2. Fixation Speech Interval (FSI)

Fixation speech interval (FSI) is the difference between the beginning of the first fixation on the target word (i.e., *word n*) and the beginning of the articulation of it. According to the P-GAG model, FSI reflects the time course of the processing of word n, from its prelexical phonological processing to postlexical processing in the memory buffer. Assuming that there is a single fixation on each word for demonstration, the processing states of word n-1, word n, and word n+1 during FSI of word n are illustrated in Figure 5.1 (see Chapter 3).

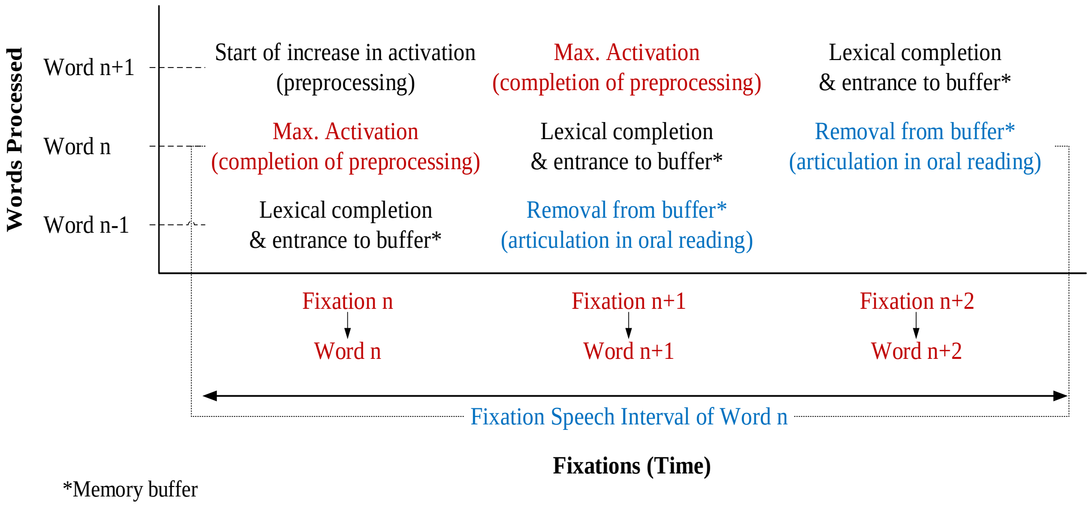

Figure 5.1 Illustration of the processing of word n-1, word n, and word n+1 during FSI of word n according to P-GAG assumptions.

According to the depiction in Figure 5.1, during FSI of word n (i) lexical completion of word n-1 is finished, it is entered to the memory buffer, articulated, and removed from the memory buffer, (ii) preprocessing and lexical completion of word n is finished, it is entered to the memory buffer, articulated, and removed from the memory buffer, and (iii) increase in the activation of word n+1 started, preprocessing of word n+1 is completed, and lexical completion of word n+1 started. To test the assumptions of P-GAG, the LMM of FSI of word n (FSI, hereafter) reported below included (i) lexical characteristics of word n-1, (ii) lexical and prelexical characteristics of word n, and (iii) prelexical and lexical characteristics of word n+1. In addition to the characteristics of words, several assumptions were tested with interactions, as presented below.

The effect of spatial measure of the Eye-Voice Span (EVS).

The spatial measure of the eye-voice span (EVS) is the distance between the first letter of word n and the fixated letter at the beginning of the articulation of word n. Therefore, it reflects the capacity of the buffer. It was expected that as the items held in the buffer increased, the processing load and hence FSI increased. The positive relationship between EVS and FSI was significant (b = 0.06, SE = 0, t = 15.5, p < .001). (see Figure 5.2).

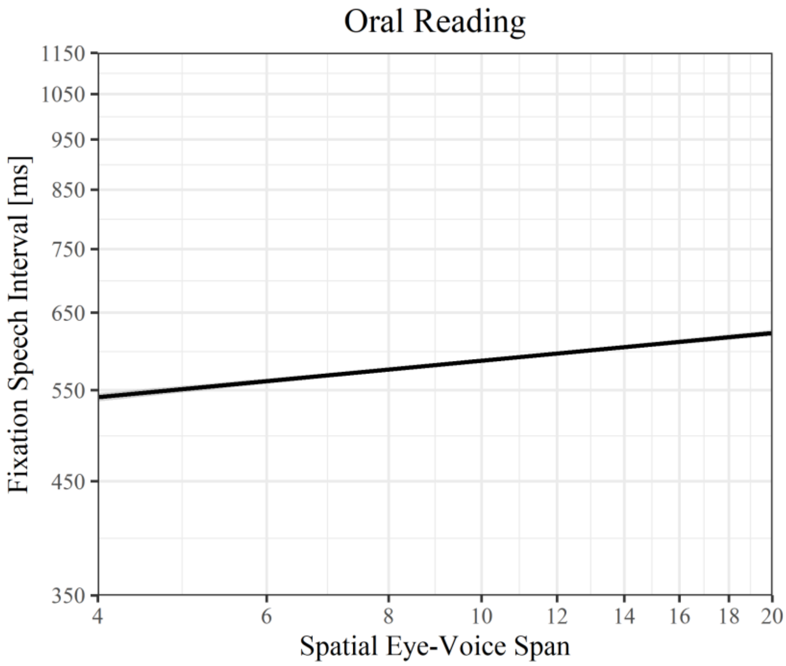

Figure 5.2 The effect of EVS on FSI values. Units of EVS on the x-axis and of FSI on the y-axis are log-transformed values of EVS (base 2) and FSI. Line and 95% confidence band are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Immediate effects of the characteristics of word n.

The effects of lexical characteristics and that of the predictability of word n on FSI were mixed. The predictability of word n (P0) and stem frequency of it (SF0) influenced FSI significantly (b = -0.08, SE = 0.02, t = -3.86, p < .001; b = -0.03, SE = 0.01, t = -4.15, p < .001, respectively). The effects were negative. In other words, less predictable words and infrequent words (i.e., more difficult words) required more processing time (i.e., higher FSI values) than more predictable and frequent words required (see Figure 5.3).

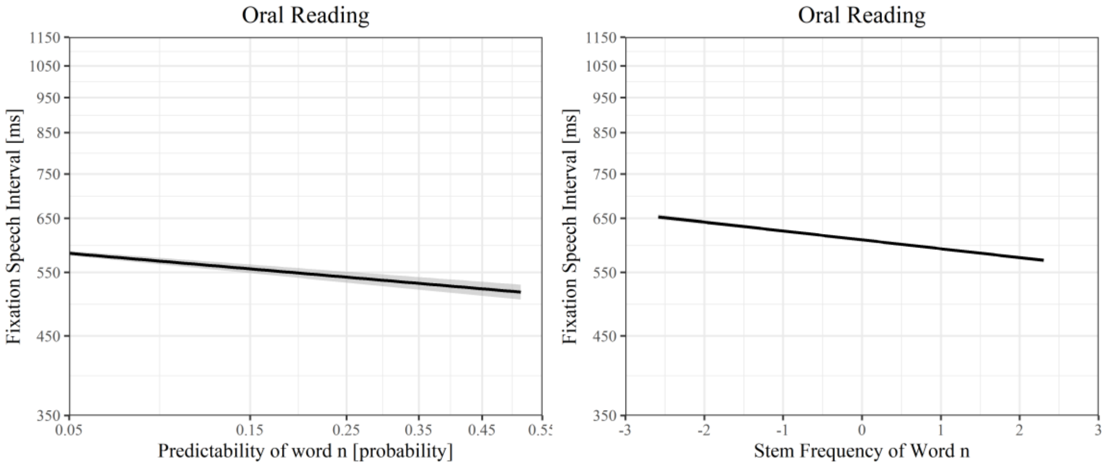

Figure 5.3 The effects of P0 and SF0 on FSI values. Units of FSI on the y-axis are log-transformed values of FSI. Units of SF0 on the x-axis are log-10 transformed values of frequency per million. Units of P0 on the x-axis are logit-transformed values of probabilities. Line and 95% confidence band (shown in gray) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The effect of the length of word n (WL0) and the effect of the interaction of WL0 and SF0 on FSI were not significant (b = 0.31, SE = 0.21, t = 1.47, p = 0.14; b = -0.04, SE = 0.07, t = -0.57, p = 0.57, respectively).

Lag- and successor-effects.

The effects of the lexical characteristics and that of the predictabilities of neighboring words (i.e., *word n-1* and *word n+1*) on FSI were not significant (P1: b = 0.01, SE = 0.01, t = 1.41, p = 0.16; SF1: b = -0.01, SE = 0.01, t = -0.78, p = 0.44; WL1.c: b = -0.3, SE = 0.23, t = -1.3, p = 0.19; P2: b = -0.02, SE = 0.01, t = -1.59, p = 0.11; SF2: b = 0.01, SE = 0.01, t = 1.39, p = 0.17; WL2: b = 0.43, SE = 0.23, t = 1.82, p = 0.07).

Prelexical phonological processing effects.

Prelexical characteristics of words were selected as the measures of prelexical phonological processing difficulty. Prelexical processing was assumed as an early process. Therefore, the prelexical effects of word n and word n+1 were included in the models. They were vowel harmonies (i.e., VH0 and VH2), and trigram frequencies (i.e., TF0 and TF2). Among effects of those prelexical characteristics only the effect of TF2 on FSI was significant (b = -0.06, SE = 0.02, t = -2.96, p < .01). Increased FSI values, together with a decrease in TF2 values, imply a significant effect of parafoveal prelexical phonological processing on FSI (see Figure 5.4).

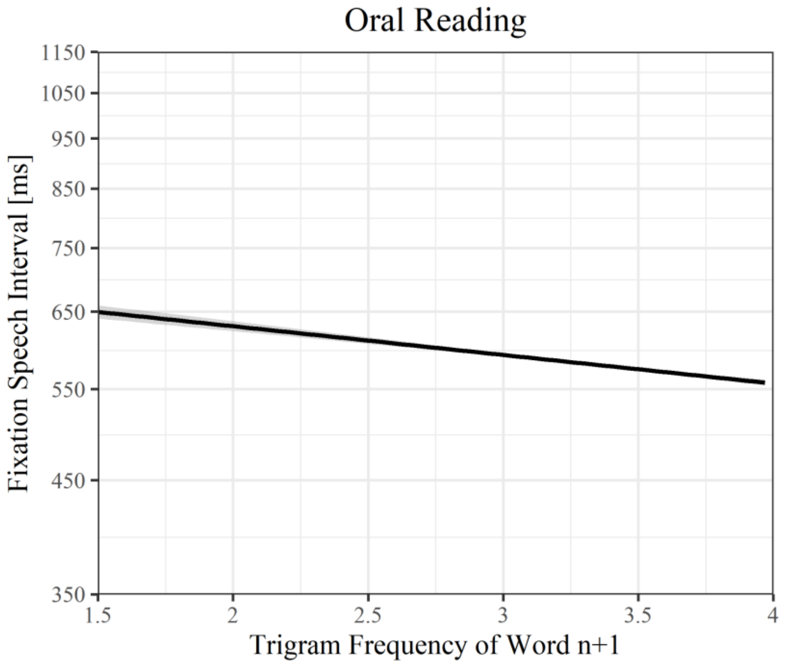

Figure 5.4 The effect of TF2 on FSI values. Units of FSI on the y-axis are log-transformed values of FSI, and units of TF2 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The relationship between FSI and TF2 can be construed as a supporting observation regarding the preprocessing timing of words. The relationship implies that preprocessing of the next word starts during FSI. The negative relationship indicates that difficulty in preprocessing of word n+1 resulted from low TF2 values interferes with the lexical and postlexical processing of word n. Although it was not a significant effect, VH2 showed a similar effect such that an increase in FSI value together with broken vowel harmony rule for word n+1 (b = 0.02, SE = 0.02, t = 1.17, p = 0.24). The reversed, non-significant effects of TF0 and VH0, together with the effects of prelexical characteristics of word n+1, imply that early phonological processing of words started parafoveally and did not have a strong influence on FSI (TF0: b = 0.0003, SE = 0.02, t = 0.02, p = 0.99; VH0: b = -0.01, SE = 0.01, t = -0.58, p = 0.57).

Visual acuity hypothesis.

According to the visual acuity hypothesis, the effects of the characteristics of word n+1 are influenced by the length of the foveal word, with a weaker effect of the characteristic of word n+1 among long foveal words (Kliegl et al., 2006; Kliegl, 2007). Although the hypothesis (and other hypotheses tested here) are mainly about the relationship between eye-movement measures and lexical characteristics of words, we have tested those effects for prelexical characteristics and FSI, as well. There were three interaction terms in the LMM of FSI to test the visual acuity hypothesis: (1) WL0 x SF2, (2) WL0 x VH2, and (3) WL0 x TF2. The significant negative effect of TF2 on FSI was weaker among long foveal words (b = -0.81, SE = 0.3, t = -2.76, p < .01). Figure 5.5 illustrates the interaction effect of WL0 and TF2 on FSI.

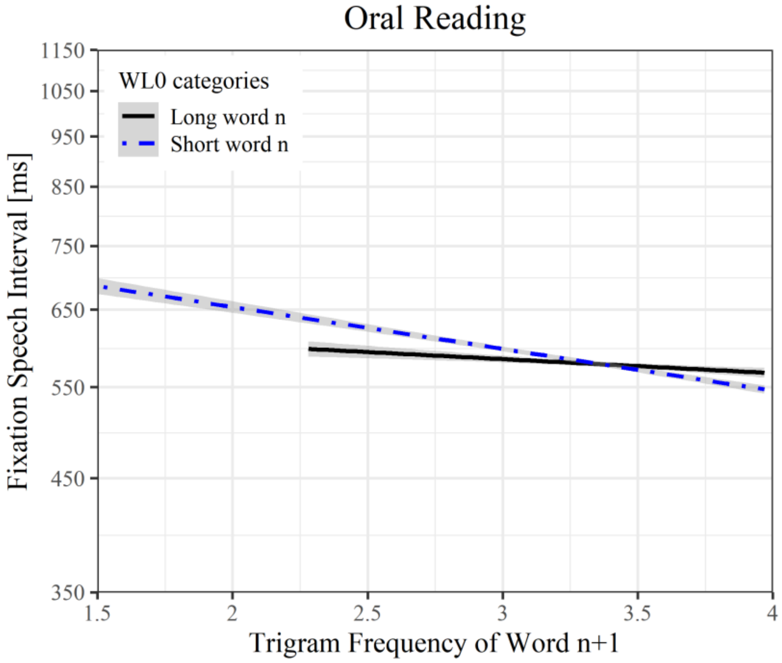

Figure 5.5 The interaction effect of WL0 and TF2 on FSI values. Units of FSI on the y-axis are log-transformed values of FSI, and units of TF2 on the x-axis are log-10 transformed values of frequency per million. The categories of WL0 are short word n (4-8 characters), and long word n (10-14 characters). Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Although slightly weaker effects of SF2 and VH2 on FSI were observed among long foveal words than their effects among short foveal words, these interaction effects were not significant (WL0 x SF2: $b = 0.02$, $SE = 0.1$, $t = 0.18$, $p = 0.86$; WL0 x VH2: $b = 0.06$, $SE = 0.23$, $t = 0.24$, $p = 0.81$).

Foveal load hypothesis.

According to the *foveal load hypothesis* (Henderson & Ferreira, 1990; Kliegl et al., 2006; Kliegl, 2007), the effects of the characteristics of words are influenced by the frequency of the previous word. The rationale behind the hypothesis is the restriction of the perceptual span while processing a difficult word. In the current context, difficult words are infrequent words. The hypothesis, as visual acuity hypothesis, is mainly about eye-movement measures and lexical characteristics of words. In the current study, we have tested the hypothesis (1) for the influence of the frequency of word n-1 (SF1) on the effects of the lexical and prelexical characteristics of word n on FSI, and (2) for the influence of the frequency of word n (SF0) on the effects of the lexical and prelexical characteristics of word n+1 on FSI. Therefore, two sets of three interaction terms added to the LMM of FSI as follows:

(1) The effect of foveal load resulted from the difficulty of word n-1: SF1 x SF0, SF1 x TF0, and SF1 x VH0. For an infrequent word n-1, stronger effects of word n characteristics due to less parafoveal processing of word n were expected.

(2) The effect of foveal load resulted from the difficulty of word n**:** SF0 x SF2, SF0 x TF2, and SF0 x VH2. For infrequent word n, weaker effects of word n+1 characteristics due to less parafoveal-on-foveal effect resulted from the shrinkage of the perceptual span were expected.

Among these interaction terms, only the interactions between SF values and TF values had significant effects. The relationship between FSI and TF0 was positive among frequent previous words while it is negative among infrequent words (SF1 x TF0: b = 0.02, SE = 0.01, t = 2.4, p < .05). As mentioned before, results imply that prelexical phonological processing started parafoveally. Less parafoveal processing of word n due to low SF1 values resulted in increased FSI values for low TF0 values. However, contrary to our expectation, the negative relationship between FSI and TF2 values, on the other hand, was slightly weaker among frequent foveal words (b = -0.02, SE = 0.01, t = -2.38, p < .05). The significant interaction effects are illustrated in Figure 5.6.

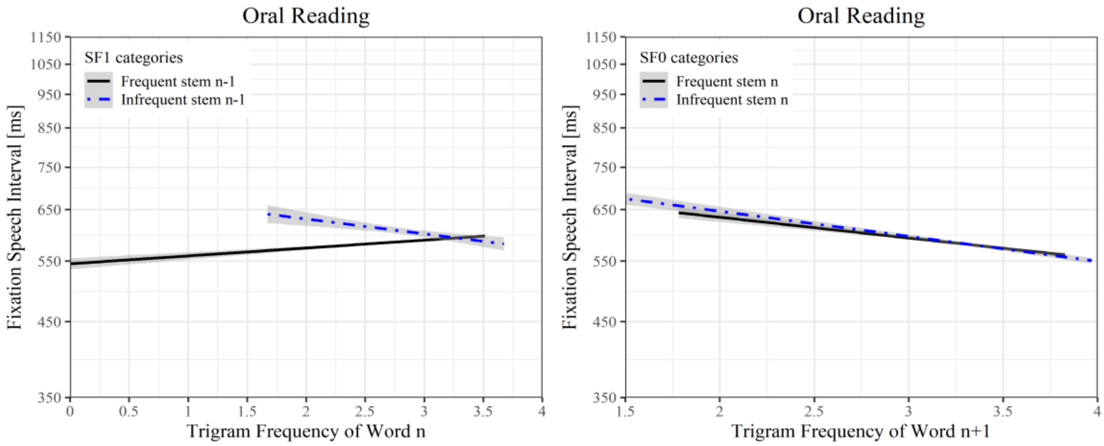

Figure 5.6 Interaction effects of SF1 x TF0 and SF0 x TF2 on FSI (foveal load hypothesis). Units of FSI on the y-axis are log-transformed values of FSI. Units of TF0 and TF2 on the x-axis are log-10 transformed values of frequency per million. Categories of stem frequencies are frequent stems (SF > 1.17) and infrequent stems (SF < 1.17). Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Mandatory status of prelexical phonological processing.

According to the dual-route hypothesis (Coltheart et al., 2001), there are two routes from orthography to lexical access. One of them is a direct route from written symbols to lexical access, and the other route from written symbols to lexical access mediated by grapheme-to-phoneme rules for non-words (i.e., prelexical phonological processing in the current study). Although there was not any non-word in our stimulus set, we have assumed that the influence of familiarity of a word on the effects of prelexical characteristics of it would provide insight. To test the hypothesis, two interactions with familiarity scores (transformed as a categorical covariate as *familiar* and *unfamiliar* with familiar as the base category) included in the LMMs: (1) familiarity x TF0, and (2) familiarity x VH0.

The effects of the interactions on FSI were not significant (familiarity x TF0: b = -0.001, SE = 0.01, t = -0.06, p = 0.95 familiarity x VH0: b = 0.01, SE = 0.02, t = 0.81, p = 0.42). However, the main effect of familiarity was significant (b = 0.03, SE = 0.01,

$t = 2.06$, $p < .05$) such that FSI was higher among unfamiliar words than it is among familiar words (see Figure 5.7).

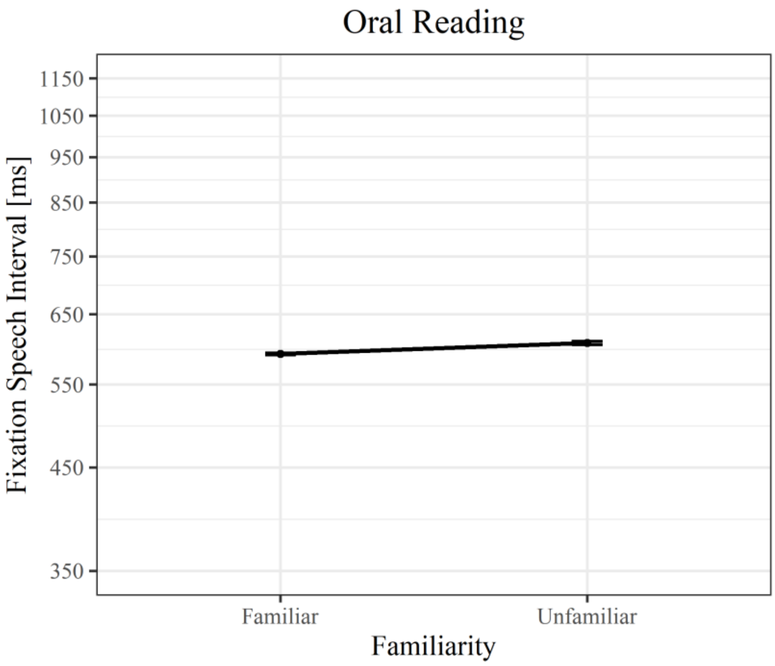

Figure 5.7 The effect of familiarity on FSI values. Units of FSI on the y-axis are log-transformed values of FSI. The partial effect of familiarity was retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Morphological complexity.

In the current study, inflectional suffix counts (SC) were included in the LMMs as a measure of morphological complexity. Among the suffix counts of words n, n-1, and n+1, only the suffix count of word n-1 (SC1) influenced FSI values negatively ($b = -0.02$, $SE = 0.01$, $t = -2.08$, $p < .05$). An increase in the suffix count of word n-1 decreased FSI values, which implies a facilitatory effect of SC1 on FSI values (see Figure 5.8). However, word length was a confounding factor in understanding the effect of suffix count. Therefore, to study further the relationship between SCs and FSI, a more controlled experiment should be designed to eliminate the effect of WLs as a confounding factor

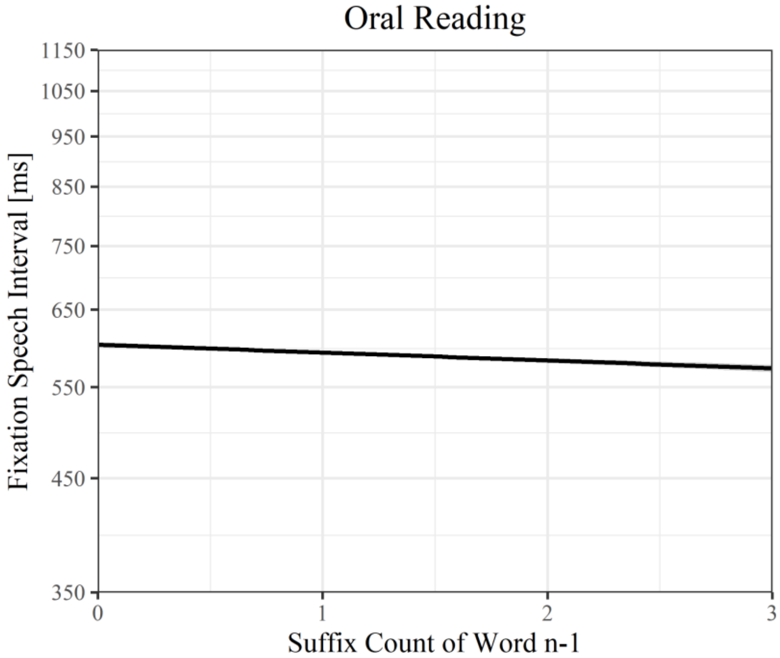

Figure 5.8 The effect of SC1 on FSI values. Units of FSI on the y-axis are log-transformed values of FSI. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Discussion.

The negative effects of predictability and frequency of word n on FSI imply that postlexical processing during FSI, which require word retention in the working memory, was influenced by the difficulty of word n (Inhoff et al., 2004; Eiter & Inhoff, 2010; Inhoff et al., 2011; Laubrock & Kliegl, 2015). The positive relationship between EVS and FSI supported the assumption that increased memory load would delay the completion of postlexical processing. The interplay between the characteristics of words their relation to memory load required further investigation. Therefore, the influence of the characteristics of word n and memory capacity of participants (i.e., results of the memory tests explained in Section 4.1.5) investigated with an additional baseline-category logit model (BCLM) of memory buffer with staying on the same word during articulation of it (i.e., one-word condition) as the base category as explained in APPENDIX D. Although the effect of the length of word n (WL0) on FSI was not significant, the results of BCLM showed that the strongest effect on the retention of words in the buffer was the effect of WL0. The probability of holding two words (i.e., articulating word n while fixating word n+1) and more than two words increased among short words. The probability of holding one word because of articulating the word before leaving it or regressing to it while articulating was increased among long words. The results of the LMM of FSI and that of BCLM imply that the effect of WL0 on FSI was indirect through the effect of EVS. The negative (but not significant) influence of WL0 on FSI indicates that while articulating short words, there were more words in the memory buffer resulting in more distance between the eyes and the voice and longer postlexical processing times due to increased memory load. While the effects of SF0 and digit span test results on the capacity of memory buffer was significant for all categories, the effects of Corsi-block test results and predictability were mixed. In general, an increase in the probability of staying on the same word during articulation was observed together with the increased difficulty of words and lower short term memory capacity of participants (see APPENDIX D for the details of BCLM analysis). Together with the results of BCLM analysis, the influences of the characteristics of words and EVS on FSI values can be construed as any difficulty in postlexical processing resulted from either the difficulty of the word (SF0) and the context of the text (P0) or the increased memory load (EVS) resulted in longer processing times (i.e., longer FSI durations).

The results of the LMM of FSI did not provide supporting evidence for the effects of prelexical characteristics of word n, and lexical characteristics of neighboring words on FSI. Interactions of the familiarity and prelexical characteristics of word n were investigated to test the dual-route hypothesis (Coltheart et al., 2001), which were not significant. These results imply that the effect of prelexical phonological processing during the time period between viewing a word and articulation of it (i.e., FSI) was not strong enough to influence FSI values. Together with the significant effect of a prelexical characteristic of word n+1 (i.e., TF2), these results suggest that prelexical phonological processing starts and probably finishes at an early phase of processing – mostly parafoveally. On the other hand, the effect of TF2 was restricted dependent on the length of word n, which strengthens the interpretation of parafoveal prelexical phonological processing. Follow-up studies with stimulus words controlled for their phonological aspects would reveal a clearer picture.

Although it was assumed that FSI covers the time from the early processing of words to late postlexical processing of them, the possibility of the dominance of postlexical processing demands over prelexical processing demands should be considered. Therefore, the analyses of First Fixation Duration (FFD) and Gaze Duration (GD), presented in the next sections, provide finer measures of early prelexical and lexical processing (Rayner, 1998, 2009a). In the LMMs of FFD and GD constructed over oral reading instances, the eye-voice span measures were accepted as an indicator of memory load and postlexical processing difficulty, as the results of FSI analyses indicate accordingly.

In Table 5.2, estimates of all LMM parameters for FSI are presented with their significance status in the rightmost column. The effects that significantly influenced FSI were presented above.

Table 5.2 LMM parameter estimates for Fixation Speech Interval (FSI)

Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status
Intercept	**6.38**	**0.02**	**272.1**	**320.24**	**< 2E-16**	**p < .0001**
Predictability of word n (P0)	**-0.08**	**0.02**	**175.6**	**-3.86**	**1.58E-04**	**p < .0001**
Stem frequency of word n (SF0)	**-0.03**	**0.01**	**235.5**	**-4.15**	**4.62E-05**	**p < .0001**
Word length of word n (WL0)	0.31	0.21	191.7	1.47	0.14	NS
Suffix count of word n (SC0)	-0.003	0.01	189.6	-0.30	0.76	NS
Trigram frequency of word n (TF0)	0.0003	0.02	200.6	0.02	0.99	NS
Vowel harmony of word n (VH0)	-0.01	0.01	220	-0.58	0.57	NS
Familiarity	**0.03**	**0.01**	**5216**	**2.06**	**0.04**	**p < .05**
Spatial eye voice span (EVS)	**0.06**	**0.004**	**10980**	**15.50**	**< 2E-16**	**p < .0001**
Predictability of word n-1 (P1)	0.01	0.01	185.6	1.41	0.16	NS
Stem frequency of word n-1 (SF1)	-0.01	0.01	184.4	-0.78	0.44	NS
Word length of word n-1 (WL1)	-0.30	0.23	184.4	-1.30	0.19	NS
Suffix count of word n-1 (SC1)	**-0.02**	**0.01**	**187.7**	**-2.08**	**0.04**	**p < .05**
Predictability of word n+1 (P2)	-0.02	0.01	183.3	-1.59	0.11	NS
Stem frequency of word n+1 (SF2)	0.01	0.01	177.6	1.39	0.17	NS
Word length of word n+1 (WL2)	0.43	0.23	188.9	1.82	0.07	NS
Suffix count of word n+1 (SC2)	0.01	0.01	186.4	1.44	0.15	NS
Trigram frequency of word n+1 (TF2)	**-0.06**	**0.02**	**181.4**	**-2.96**	**0.003**	**p < .001**
Vowel harmony of word n+1 (VH2)	0.02	0.02	177.8	1.17	0.24	NS
WL0 x SF0	-0.04	0.07	215.4	-0.57	0.57	NS
WL0 x SF2	0.02	0.10	187.4	0.18	0.86	NS
WL0 x TF2	**-0.81**	**0.30**	**192.6**	**-2.76**	**0.01**	**p < .001**
WL0 x VH2	0.06	0.23	188.6	0.24	0.81	NS
SF0 x SF2	0.003	0.003	185.5	0.96	0.34	NS
SF0 x TF2	**-0.02**	**0.01**	**198.3**	**-2.38**	**0.02**	**p < .05**
SF0 x VH2	0.01	0.01	189.4	1.33	0.19	NS
SF1 x SF0	-0.01	0.003	190	-1.94	0.05	NS
SF1 x TF0	**0.02**	**0.01**	**183.2**	**2.40**	**0.02**	**p < .05**
SF1 x VH0	-0.004	0.01	189.6	-0.44	0.66	NS
Familiarity x TF0	-0.001	0.01	9031	-0.06	0.95	NS
Familiarity x VH0	0.01	0.02	3730	0.81	0.42	NS
WL0 x EVS	-0.06	0.07	4915	-0.90	0.37	NS

Random effects:			
Groups	Name	Variance	Std.Dev.
Participant	Intercept	0.0138	0.12
Participant	Stem frequency of word n (SF0)	0.0004	0.02
Participant	Word length of word n (WL0)	0.0359	0.19
Word	Intercept	0.0048	0.07
Residual		0.0378	0.19

The number of obs: 11081, groups: Participant, 196; Word, 192

An x between variables indicates interaction. Significant coefficients were set bold (NS: not significant). VH estimates belong to category 1 (violation of the rule), and Familiarity estimates belong to category 1 (unfamiliar).

5.3. Fixation Durations (First Fixation Duration and Gaze Duration)

According to the assumptions of the P-GAG model, any difficulty in processing stages of word identification (i.e., preprocessing, lexical completion, and prelexical phonological processing) would result in a delay in saccade generation mechanism and hence, longer fixation durations. On the other hand, since postlexical processing and lexical processing difficulties inhibit each other, postlexical processing difficulties result in longer fixation durations in an indirect way, through a delay in the word identification process.

In Figure 5.9, the processing of word n-1, word n, and word n+1 during fixation n, with an assumption that there is a single fixation on word n (see Chapter 3).

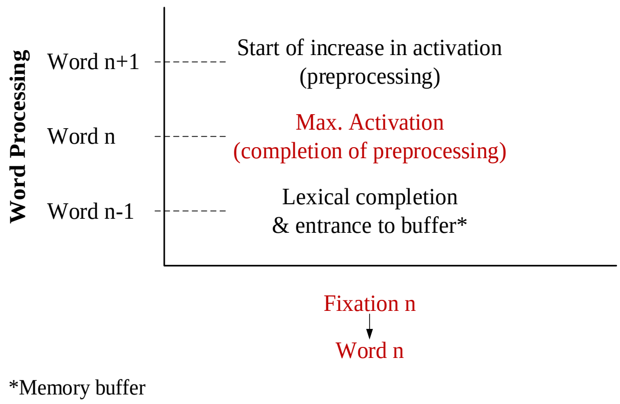

Figure 5.9 Illustration of processing of word n-1, word n, and word n+1 during fixation n, according to P-GAG assumptions.

According to P-GAG, during a single fixation on word n, lexical completion of word n-1 and preprocessing of word n are finished, and preprocessing of word n+1 started. However, preprocessing is not necessarily prelexical processing, exclusively. Therefore, it is assumed that during fixation n, lexical processing of it can be completed partially, and lexical processing of word n+1 can start. These assumptions of P-GAG on fixation durations were tested with four LMMs which are the LMMs of (1) first fixation duration (FFD) on target words during oral reading, (2) FFD on target words during silent reading, (3) gaze duration (GD) on target words during oral reading, and (4) GD on target words during silent reading. LMMs of FFD were assumed to capture the processing during the first fixation on word n. In single fixation cases (oral reading: 37%; silent reading: 52%; see Table 5.1 for details), FFD is the total fixation duration on a word. LMMs of GD were provided to capture the processing of words that receive more than one fixation.

5.3.1. Covariates and Interactions Specific to Oral Reading

The eye-voice span measures of oral reading instances included in the LMMs of fixation durations to test the assumptions of P-GAG regarding the interplay between word identification process and postlexical processing. Both eye-voice span measures showed significant effects on fixation durations. FSI influenced fixation durations positively with a significant quadratic component for GD (FFD: b = 0.16, SE = 0.02, t = 9.05, p < .001; GD linear: b = 0.65, SE = 0.02, t = 38.03, p < .001; GD quadratic: b = -0.08, SE = 0.03, t = -2.76, p < .01). As LMM of FSI suggests, FSI was mostly associated with postlexical processing difficulty, which was reflected in longer FSI values when the mentioned difficulty increased. Increased postlexical processing load due to word-specific difficulty manifested itself in the positive relationship between FSI and fixation duration values. That was a stronger relationship between FSI and GD. EVS reflects the items held in the memory buffer during FSI. EVS influenced fixation durations negatively (FFD: b = -0.03, SE = 0.01, t = -3.38, p < .001; GD: b = -0.16, SE = 0.005, t = -32.48, p < .001). Under the assumption that fixation durations reflect the time needed for word identification, words that require shorter identification times allow the buffer to hold more items (see Figure 5.10).

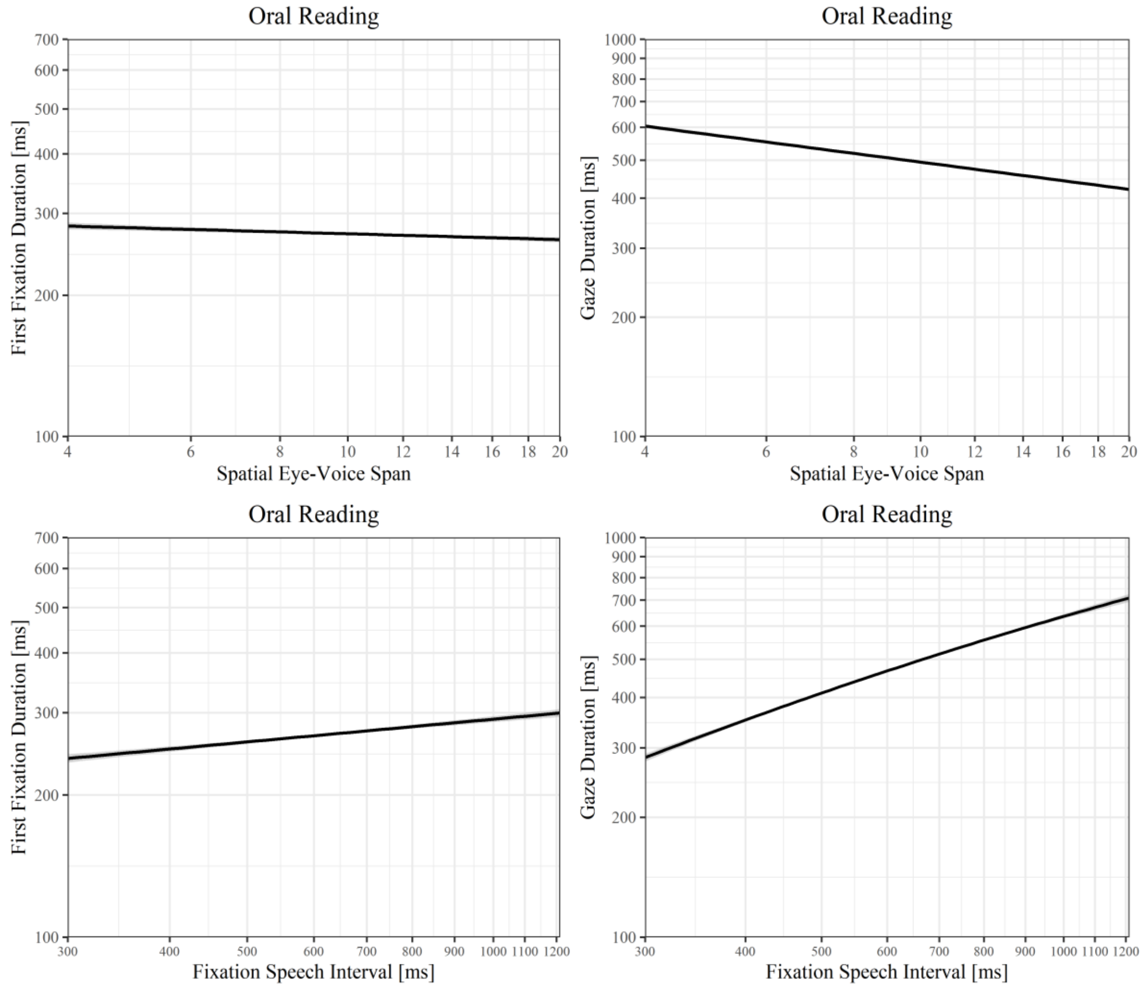

Figure 5.10 The effect of EVS and FSI on fixation duration values. Units of fixation durations on the y-axis and units of FSI and EVS on the x-axis are log-transformed values of them. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

To capture the regressive eye movements during articulation, the interaction between EVS and FSI included in the LMM of GD, assuming that regressive eye-movements to word n during FSI imply a processing difficulty. An FSI value that was greater than GD while eyes are on the word during articulation (i.e., EVS less than or equal to WL0) means that eyes left and returned to word n during FSI. The interaction term was significant (b = 0.11, SE = 0.02, t = 6.15, p < .001). The negative relationship between EVS and GD was the strongest among words that were articulated after the eyes left the word. The result supports the interpretation of the relationship between EVS and fixation durations that shorter identification times allow the buffer to hold more items (see Figure 5.11).

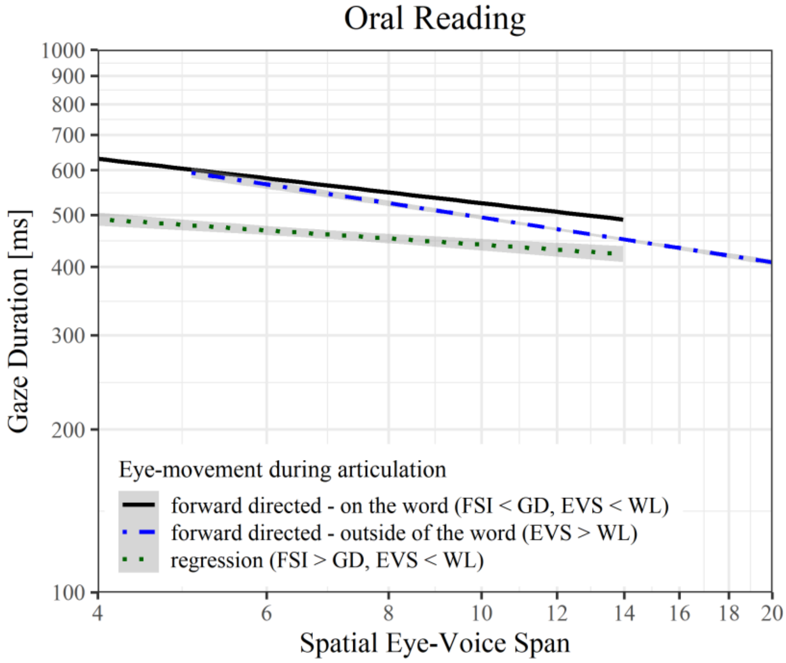

Figure 5.11 The interaction effect of EVS and FSI on GD. Units of GD on the y-axis and units of EVS on the x-axis are log-transformed values of them. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

5.3.2. Common Covariates and Interactions for Fixation Durations

Canonical effects – relative first landing position.

In the current study, relative first landing position (RFLP) influenced fixation durations significantly (oral reading FFD: b = 0.51, SE = 0.03, t = 18.61, p < .001; silent reading FFD: b = 0.24, SE = 0.02, t = 11.04, p < .001; oral reading GD: b = -0.1, SE = 0.02, t = -5.35, p < .001; silent reading GD: b = -0.32, SE = 0.02, t = -13.77, p < .001). The effect of quadratic component (i.e., IOVP curvature) was significant on all fixation durations, except on oral reading GD (oral reading FFD: b = -2, SE = 0.1, t = -19.18, p < .001; silent reading FFD: b = -2.1, SE = 0.08, t = -25.78, p < .001; oral reading GD: b = -0.08, SE = 0.07, t = -1.09, p = 0.28; silent reading GD: b = -0.2, SE = 0.09, t = -2.29, p < .05). In Figure 5.12 the effect of RFLP on fixation durations are illustrated for both reading modalities (i.e., oral vs silent reading).

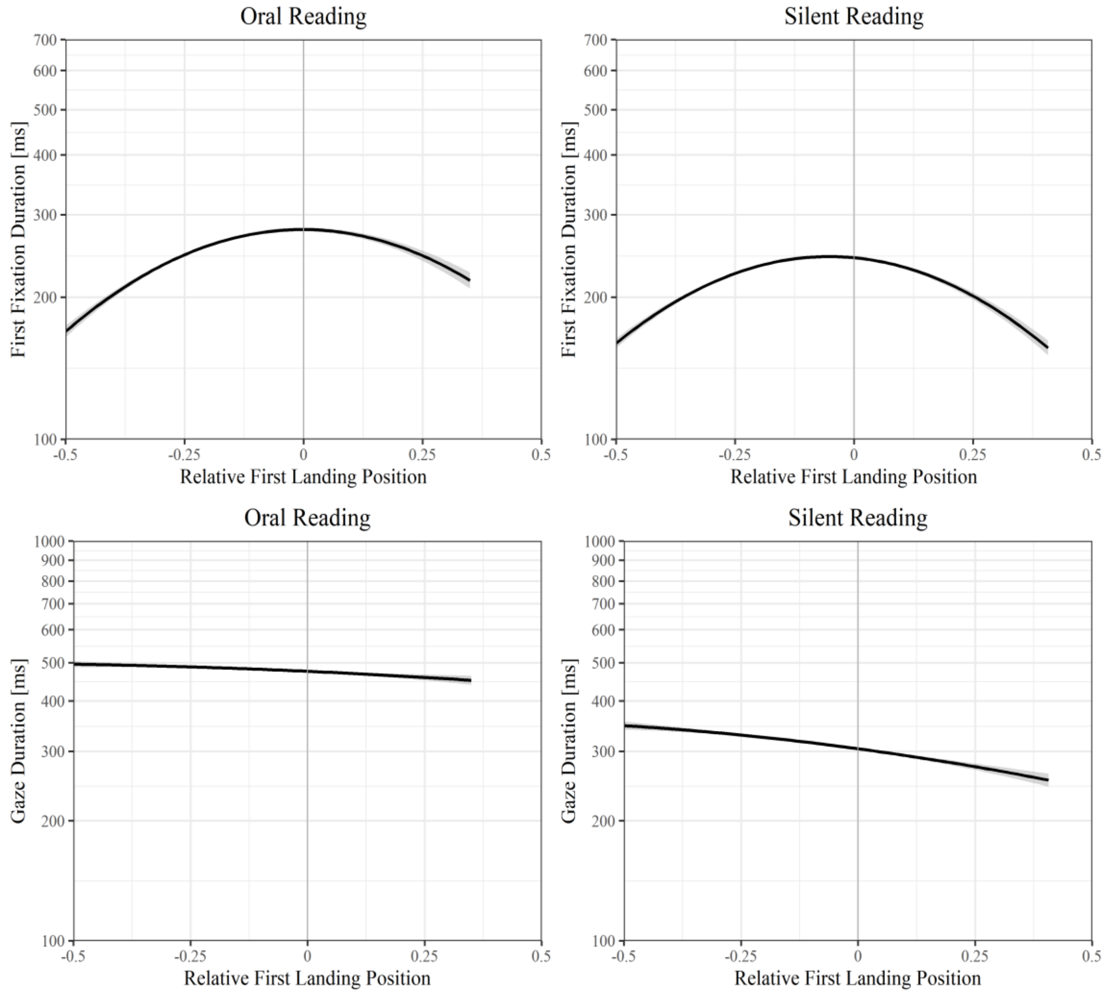

Figure 5.12 The effect of RFLP on fixation durations. Units of fixation durations on the y-axis are log-transformed values. RFLP values of 0 indicate the middle, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The influence of RFLP on FFD was compatible with the frequently reported *Inverted Optimal Viewing Position* (IOVP) effect, which was shown for several languages (Vitu et al., 2001; Kliegl et al., 2006 for German; Yan et al., 2014 for Uighur; and Hyönä, Yan, Vainio, 2018 for Finnish). Briefly, studies show that if eyes firstly land on the edges of a word due to saccadic error, it is corrected by successive fixations. As a result, the IOVP effect manifests itself as first fixations closer to the center of words that have longer durations than they have when they are on the edges. The results of the current study support the interpretation such that if the first fixation was on the edges of the word, FFD was shorter than it was when the first fixation was around the center of the word. The relationship between RFLP and GD was negative, indicating that the first fixations on closer to the left edge of a word, followed by multiple fixations on the word. As another supporting finding for the saccadic error interpretation, if RFLP was on the right half of the word (i.e., RFLP > 0), GD values were shorter, FFD values were higher (relative to FFDs of RFLP < 0, especially during oral reading), and skipping and single fixation probabilities increased. In Figure 5.13, the probability of skipping a word, of single fixation on a word, and of multiple fixations on a word calculated from raw data are presented as a function of RFLP.

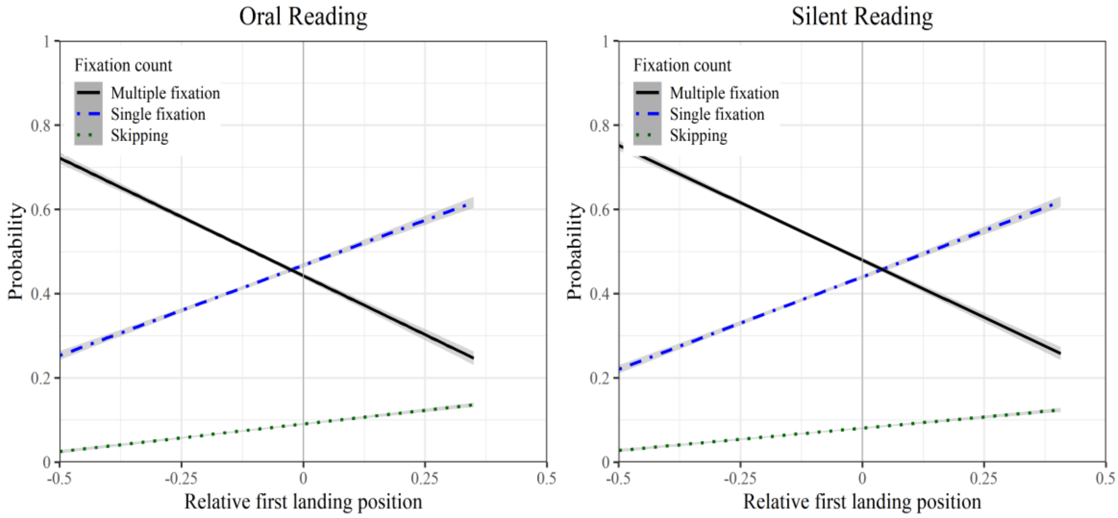

Figure 5.13 The relationship between fixation count probabilities and RFLP. RFLP values of 0 indicate the middle, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Line and 95% confidence band (shown in grey) are calculated over raw data using the `ggplot2` package (Wickham, 2009).

Canonical effects – launch site.

The relationship between launch site (LS0) and fixation durations were significantly positive (oral reading FFD: $b = 0.02$, $SE = 0.01$, $t = 2.62$, $p < .01$, silent reading FFD: $b = 0.03$, $SE = 0.01$, $t = 4.44$, $p < .001$, oral reading GD: $b = 0.03$, $SE = 0.01$, $t = 5.84$, $p < .001$, silent reading GD: $b = 0.04$, $SE = 0.01$, $t = 7.48$, $p < .001$). The relationship show that greater distance between the last fixation before viewing the word and the beginning of the word result in longer fixation durations due to less parafoveal preview benefit (see Figure 5.14).

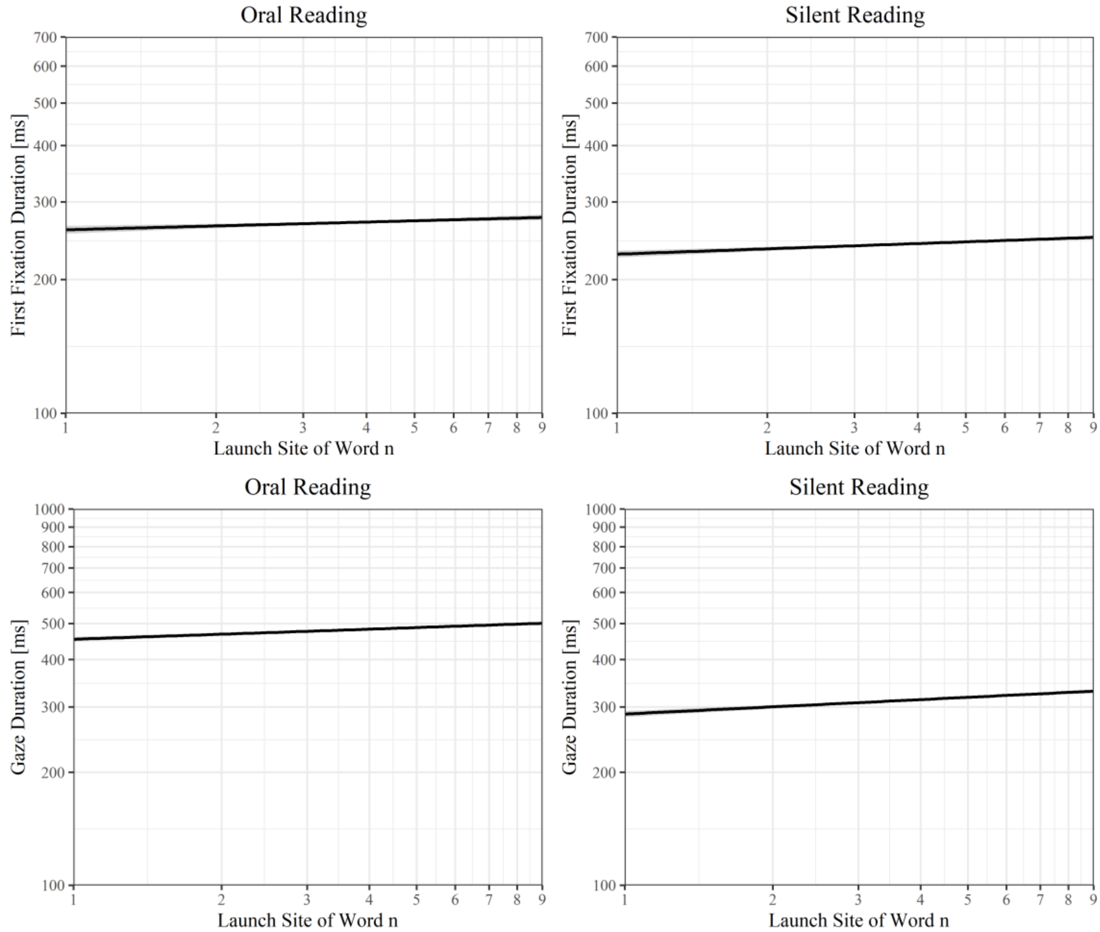

Figure 5.14 The effect of LS0 on fixation durations. Units of fixation durations on the y-axis are log-transformed values. Units of LS0 on the x-axis are log-transformed (base 2) values. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The significant positive effect of LS on fixation durations indicated the effect of parafoveal processing benefit during the last fixation before word n was viewed. In other words, the further the previous fixation, the less parafoveal benefit was obtained from the word n, and hence, the longer processing time was needed for word n.

The relationship investigated further by including the interaction between LS0 and the length of word n-1 (WL1) in the model to understand the cost of skipping the previous word[7]. The interaction term was significantly influenced FFD during reading aloud (b = 0.48, SE = 0.18, t = 2.72, p < .01). The highest FFD values were observed among words that have previous short words and long LS0 values, which implies a skipped

[7] The skipping cost in SAS models indicate increased fixation duration prior to skipping a word. That is because in those models the default target of next saccade is word n+1 and skipping can only happen if the next saccade is cancelled. In GAG models on the other hand, saccades generated autonomously and saccade target selection is the result of competition between words within the attentional gradient that have different activations. In contrast to SAS models, in GAG models skipping instances are the result of longer fixation durations and increased parafoveal processing, rather than being a saccade cancellation process (Engbert et al., 2005, pp. 795-796). Therefore, a cost of skipping word n-1 which manifested itself as longer fixation durations on word n, implies less parafoveal processing of word n, rather than a saccade cancellation.

word n-1 (see Figure 5.15). The influence of the interaction term on the other fixation duration measures was not significant.

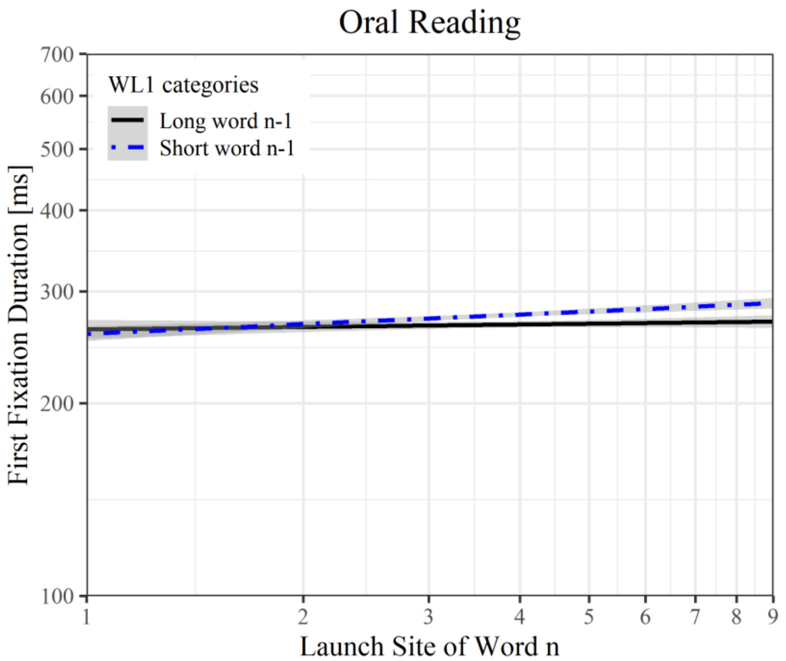

Figure 5.15 The interaction effect of WL1 and LS0 on FFD during oral reading. Units of FFD on the y-axis are log-transformed values. Units of LS0 on the x-axis are log-transformed (base 2) values. The categories of WL1 are short word n (8 characters and shorter), and long word n (9 characters and longer) Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Canonical effects – immediate effects of word n characteristics.

The effect of SF0 on fixation durations was significant (oral reading FFD: b = -0.02, SE = 0.01, t = -2.55, p < .05; silent reading FFD: b = -0.03, SE = 0.01, t = -5.85, p < .001; oral reading GD: b = -0.06, SE = 0.01, t = -7.98, p < .001; silent reading GD: b = -0.09, SE = 0.01, t = -9.63, p < .001). Less frequent words (i.e., more difficult words) received longer fixation durations as observed in previous studies (Rayner, 1998, 2009a, 2009b; Rayner et al., 2012). The effect was stronger during silent reading (see Figure 5.16).

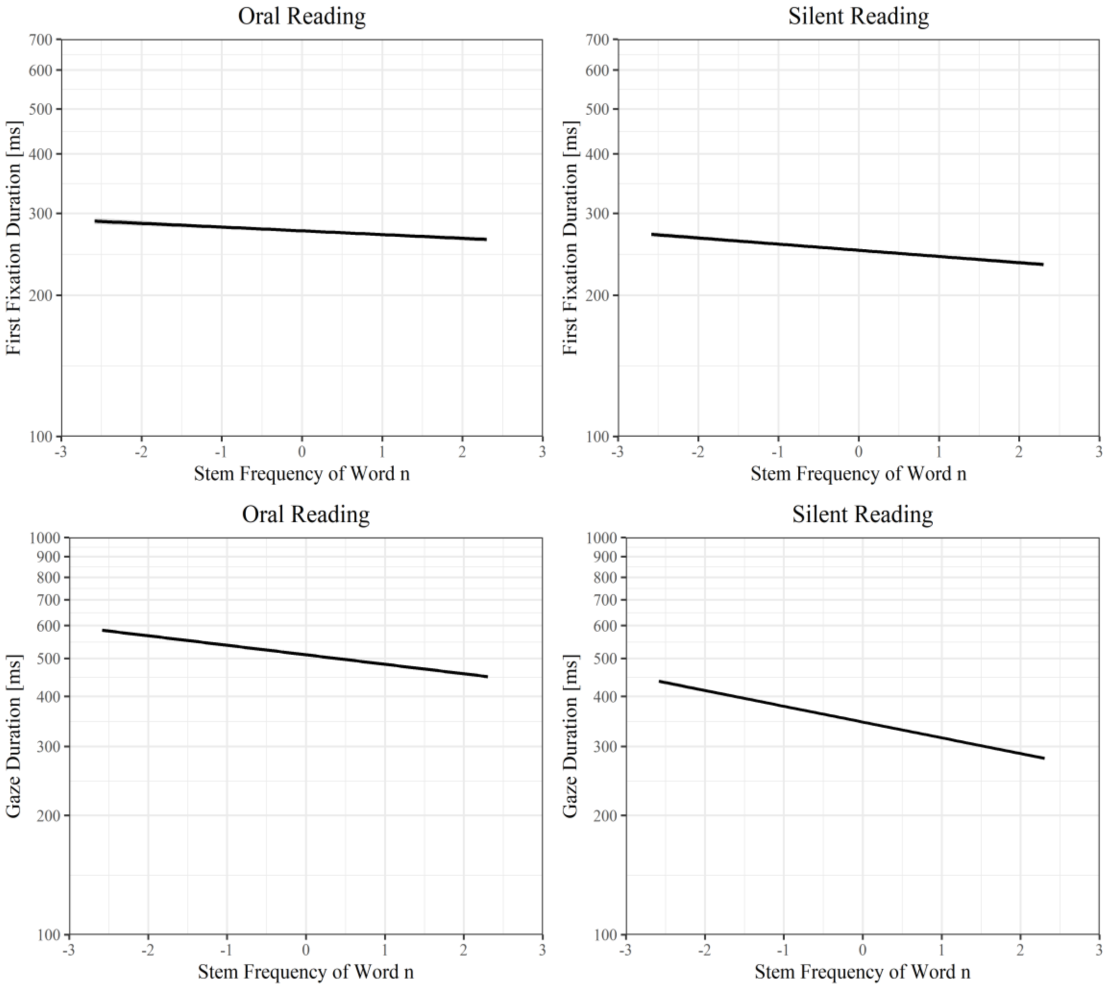

Figure 5.16 The effect of SF0 on fixation durations. Units of fixation durations on the y-axis are log-transformed values, and units of SF0 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The significant effect of the length of word n on first fixation duration values was negative with a significant quadratic component for silent reading (oral reading FFD: $b = 0.78$, $SE = 0.22$, $t = 3.49$, $p < .001$; silent reading FFD, linear: $b = 1.03$, $SE = 0.18$, $t = 5.62$, $p < .001$; quadratic: $b = -10.97$, $SE = 1.53$, $t = -7.17$, $p < .001$). The relationship was positive between WL0 and GD values (oral reading GD: $b = -6.22$, $SE = 0.23$, $t = -27.2$, $p < .001$; silent reading GD: $b = -4.4$, $SE = 0.3$, $t = -14.72$, $p < .001$).[8] The relationship between fixation durations and WL0 show that shorter first fixation durations were compensated with subsequent fixations among long words, which was manifested in shorter first fixation durations and longer gaze durations on long words than they were on short words (see Figure 5.17).

[8] Since WL0 values are reciprocal word lengths, a negative estimate indicates a positive relationship, and vice versa.

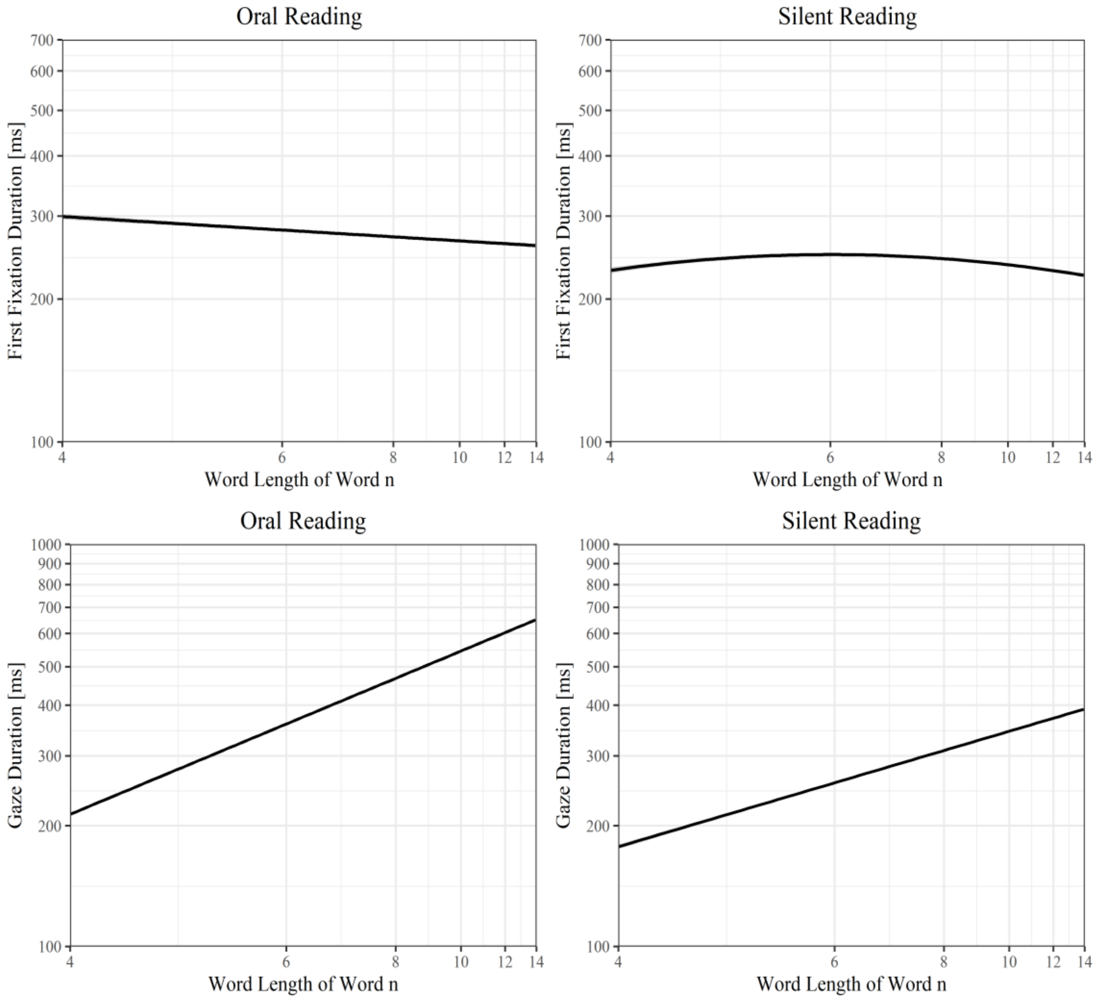

Figure 5.17 The effect of WL0 on fixation durations. Units of fixation durations on the y-axis are log-transformed values. Units of WL0 on the reversed x-axis are reciprocal word lengths. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The effect of the interaction of WL0 and SF0 was significant on GD among silent reading instances (b = 0.32, SE = 0.1, t = 3.23, p < .01). The positive relationship between GD and WL0 was slightly stronger if the word was an infrequent word (see Figure 5.18).

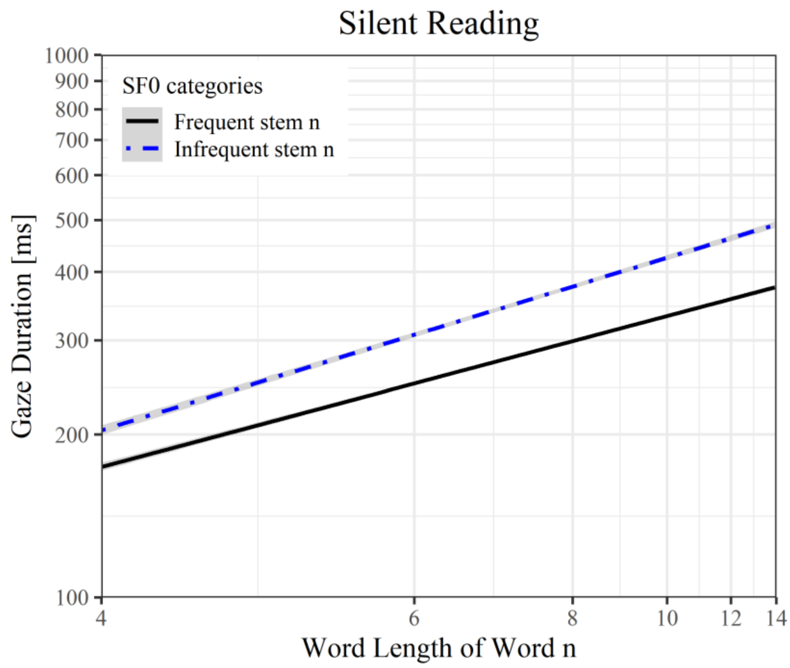

Figure 5.18 The interaction effect of WL0 and SF0 on GD during silent reading. The units of GD on the y-axis are log-transformed values. Units of WL0 on the reversed x-axis are reciprocal word lengths. Categories of SF0 are frequent stems (SF0 > 1.17), and infrequent stems (SF0 < 1.17). Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The effect of predictability of word n (P0) on fixation durations was not significant (oral reading FFD: b = -0.02, SE = 0.02, t = -0.83, p = 0.41; silent reading FFD: b = -0.03, SE = 0.02, t = -1.81, p = 0.07; oral reading GD: b = 0.01, SE = 0.02, t = 0.24, p = 0.81; silent reading GD: b = -0.04, SE = 0.03, t = -1.46, p = 0.15). However, an expected decreasing effect was observed, except the effect on GD during oral reading.

Lag- and successor-effects.

The effects of the characteristics of words n-1 and n+1 on fixation durations were mixed. Among lexical characteristics of word n-1, predictability of it (P1) influenced FFD and GD significantly during silent reading, and length of it (WL1) influenced FFD during oral reading (P1 - silent reading FFD: b = -0.02, SE = 0.01, t = -3.79, p < .001; P1 - silent reading GD: b = -0.04, SE = 0.01, t = -2.96, p < .01; WL1 - oral reading FFD: b = 0.6, SE = 0.24, t = 2.57, p < .05). During silent reading, fixation duration values were longer if the previous word was a less predictable word, which implies that processing of less predictable words spilled over. During oral reading, on the other hand, FFD was slightly longer if the previous word was a short word. As short words are more often skipped, the result might be the result of skipping costs. An investigation of data showed that all of the skipped words n-1 were short words (350 instances during oral reading). In Figure 5.19, lag-effects are illustrated.

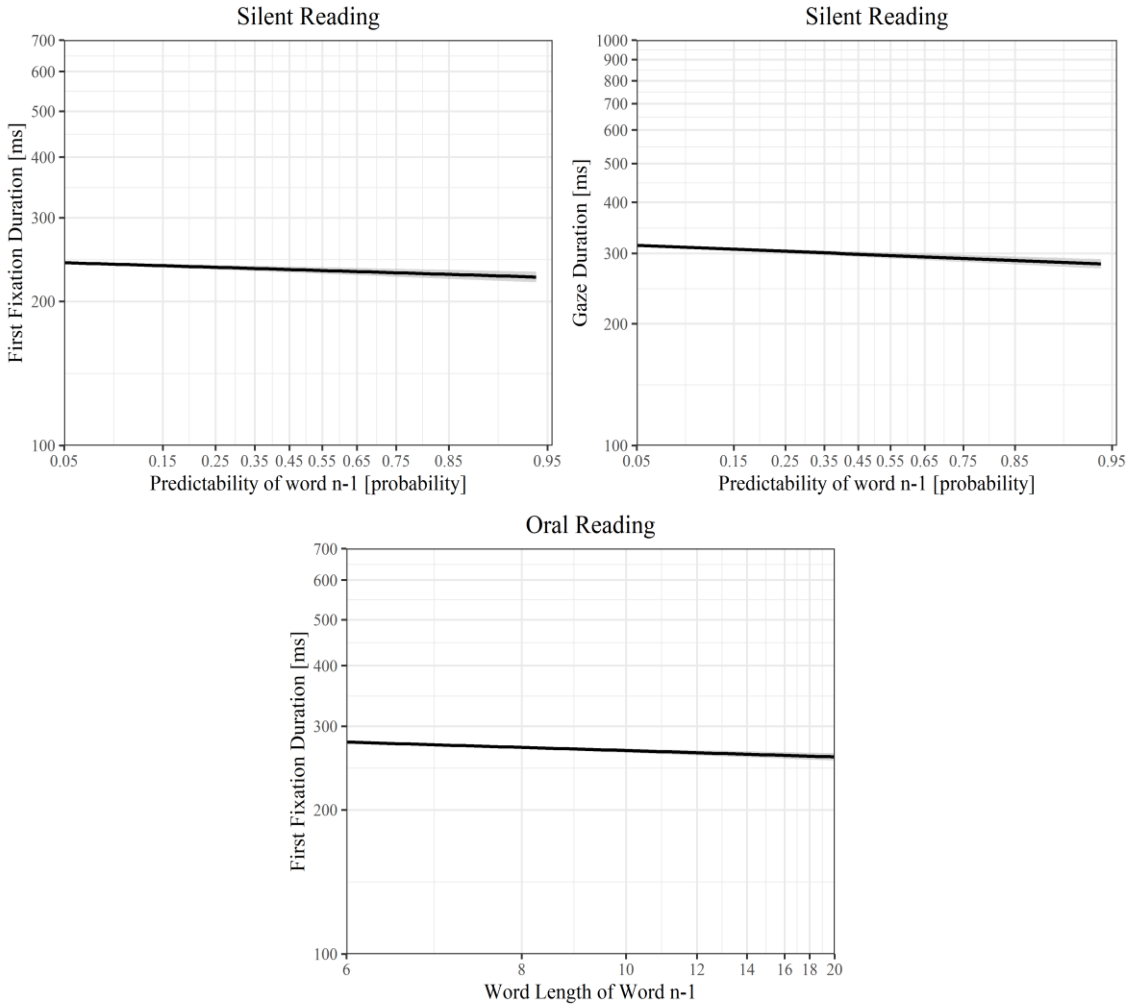

Figure 5.19 Lag-effects on fixation durations. Units of fixation durations on the y-axis are log-transformed values. Units of WL1 on the reversed x-axis are reciprocal word lengths and of P1 logit-transformed. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Among successor effects, only the effect of the length of word n+1 (WL2) on GD during silent reading was significant ($b = 0.83$, $SE = 0.32$, $t = 2.61$, $p < .01$). An increase in WL2 accompanied a decrease in GD during silent reading. The result may be conceived as an indicator of the increase in the activation of the next word and hence the attraction of attention to it due to its length.

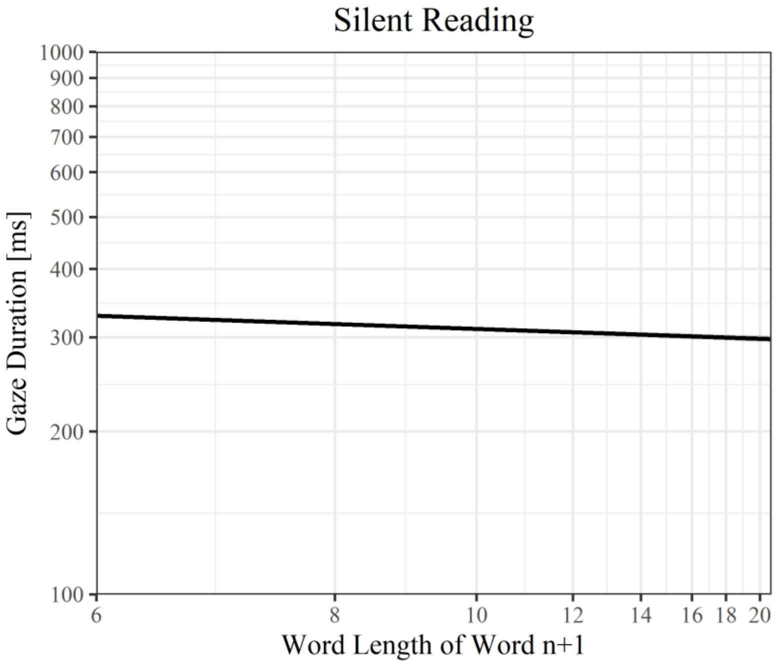

Figure 5.20 The effect of WL2 on GD during silent reading. The units of GD on the y-axis are log-transformed values. Units of WL2 on the reversed x-axis are reciprocal word lengths. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Prelexical phonological processing effects.

The effects of prelexical characteristics of words on fixation durations were mixed. The effects of TF0 on fixation durations during oral reading and on GD during silent reading were significant (oral reading FFD: $b = 0.04$, $SE = 0.02$, $t = 2.55$, $p < .05$; oral reading GD: $b = -0.04$, $SE = 0.02$, $t = -2.14$, $p < .05$; silent reading GD: $b = -0.06$, $SE = 0.02$, $t = -2.45$, $p < .05$). The positive influence on FFD and negative influence on GD imply that a difficulty in prelexical processing due to low TF0 values compensated by subsequent fixations during oral reading (see Figure 5.21). Among silent reading instances, the effect was significant only on GD and negative on FFD but not significant ($b = -0.01$, $SE = 0.01$, $t = -0.45$, $p = 0.65$).

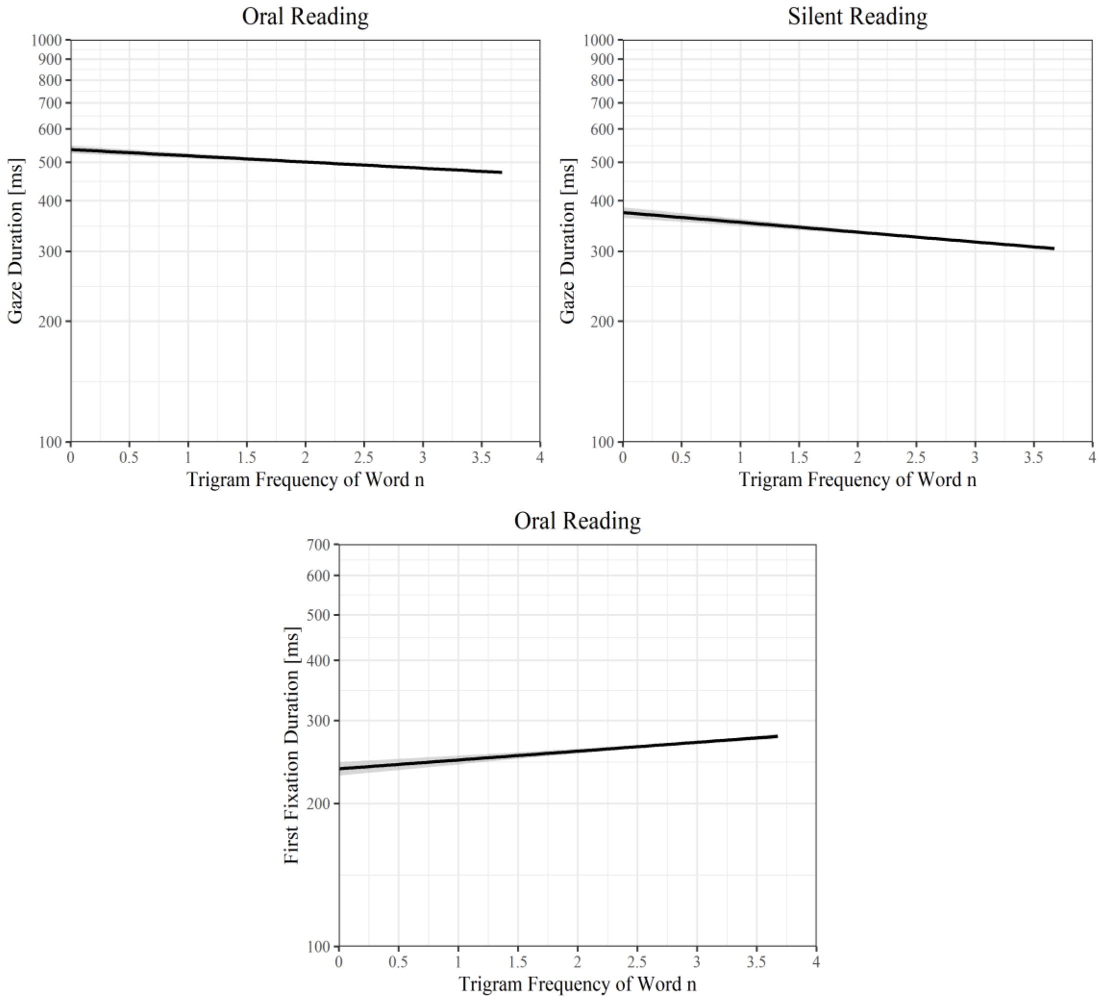

Figure 5.21 The effect of TF2 on fixation durations. Units of fixation durations on the y-axis are log-transformed values, and units of TF0 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The effects of VH2 on GD during oral reading (oral reading GD: $b = 0.06$, $SE = 0.02$, $t = 3.4$, $p < .001$), and on fixation durations during silent reading (silent reading FFD: $b = 0.03$, $SE = 0.01$, $t = 2.41$, $p < .05$; silent reading GD: $b = 0.08$, $SE = 0.02$, $t = 3.39$, $p < .001$) were significant. A broken rule increased fixation durations during silent reading implying a parafoveal-on-foveal effect of prelexical processing of word n+1 (see Figure 5.22). The result was compatible with the findings in previous studies which indicated a parafoveal processing of vowels during silent reading (e.g., Ashby et al., 2006).

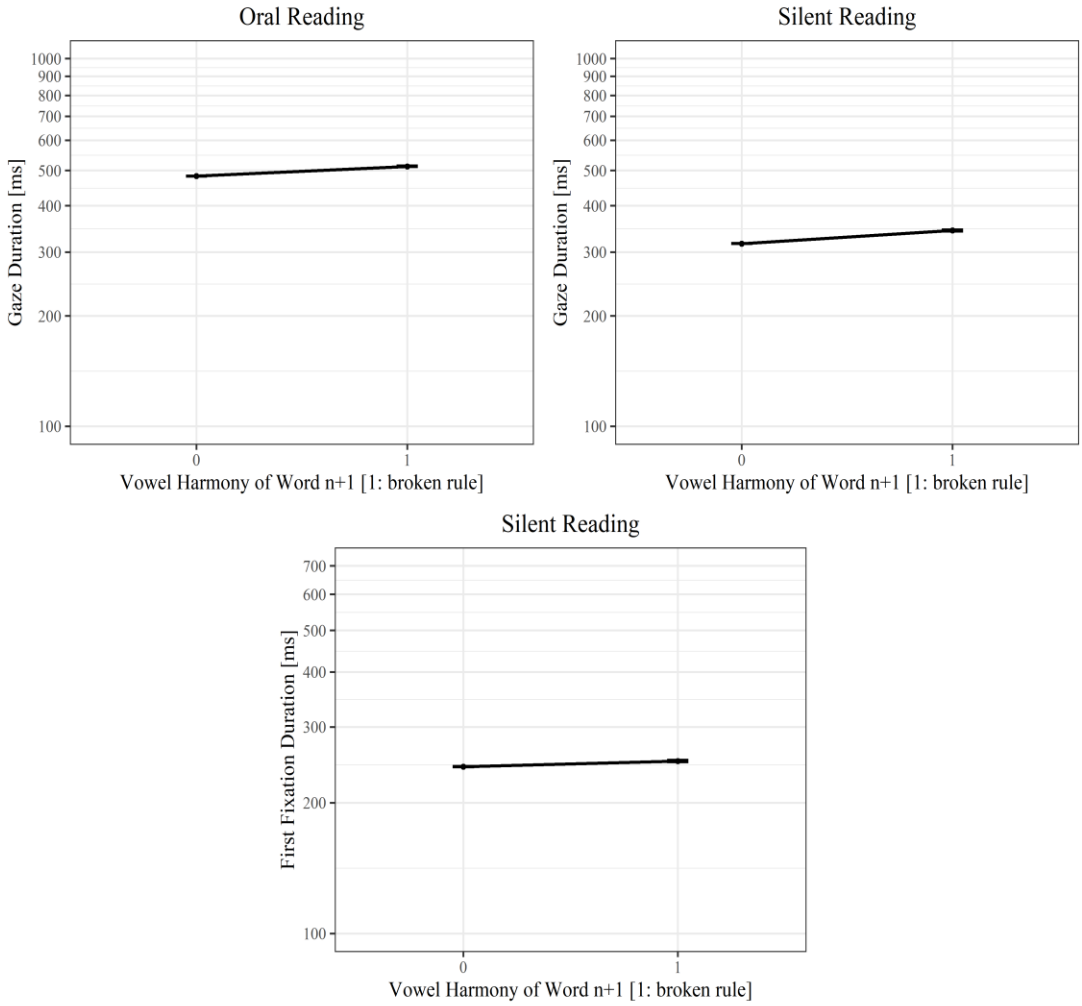

Figure 5.22 The effect of VH2 on fixation durations. Units of fixation durations on the y-axis are log-transformed values. The partial effect of VH2 was retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Visual acuity hypothesis.

According to the hypothesis, the length of the foveal word would influence the parafoveal-on-foveal effects of the characteristics of the next word. To test the hypothesis, the interactions between WL0 and prelexical characteristics and stem frequency of word n+1 (i.e., TF2, VH2, and SF2) included in the eye-movement measure models. An additional covariate, the launch site of word n+1 (LS2), as a measure of the distance of the next word and its interactions with SF2 and predictability of word n+1 (P2), included in the models.

Among the interaction terms that include WL0, only the interaction between WL0 and TF2 influenced FFD significantly during reading aloud (b = -1.19, SE = 0.3, t = -3.91, p < .001). The effect of TF2 was negative among short foveal words, while it was positive among long foveal words. The pattern indicated parafoveal prelexical processing during FFD but dependent on the length of the foveal word among oral reading instances (see Figure 5.23).

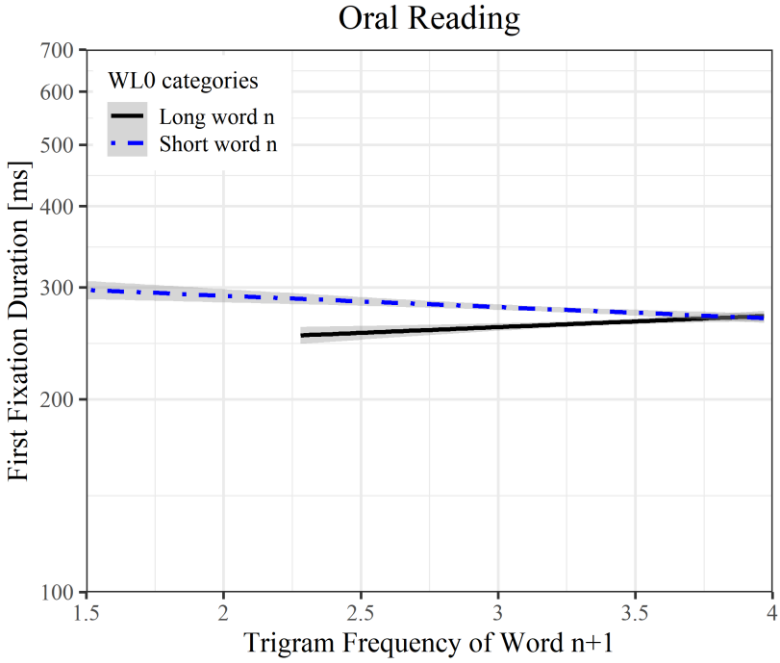

Figure 5.23 The interaction effect of WL0 and TF2 on FFD during oral reading. The units of FFD on the y-axis are log-transformed values, and units of TF2 on the x-axis are log-10 transformed values of frequency per million. The categories of WL0 are short word n (4-8 characters), and long word n (10-14 characters). Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The distance of the next word influenced fixation durations significantly (oral reading FFD: $b = 0.02$, $SE = 0.01$, $t = 2.49$, $p < .05$; oral reading GD: $b = -0.14$, $SE = 0.01$, $t = -25.79$, $p < .001$; silent reading GD: $b = -0.17$, $SE = 0.01$, $t = -23.57$, $p < .001$), except FFD among silent reading instances ($b = -0.01$, $SE = 0.01$, $t = -1.45$, $p = 0.15$). The effect was positive on FFD among oral reading instances and it was negative on the rest of fixation duration measures. Shorter FFD and longer GD were accompanied a shorter distance from the next word among oral reading instances. During silent reading the pattern observed only for GD (see Figure 5.24).

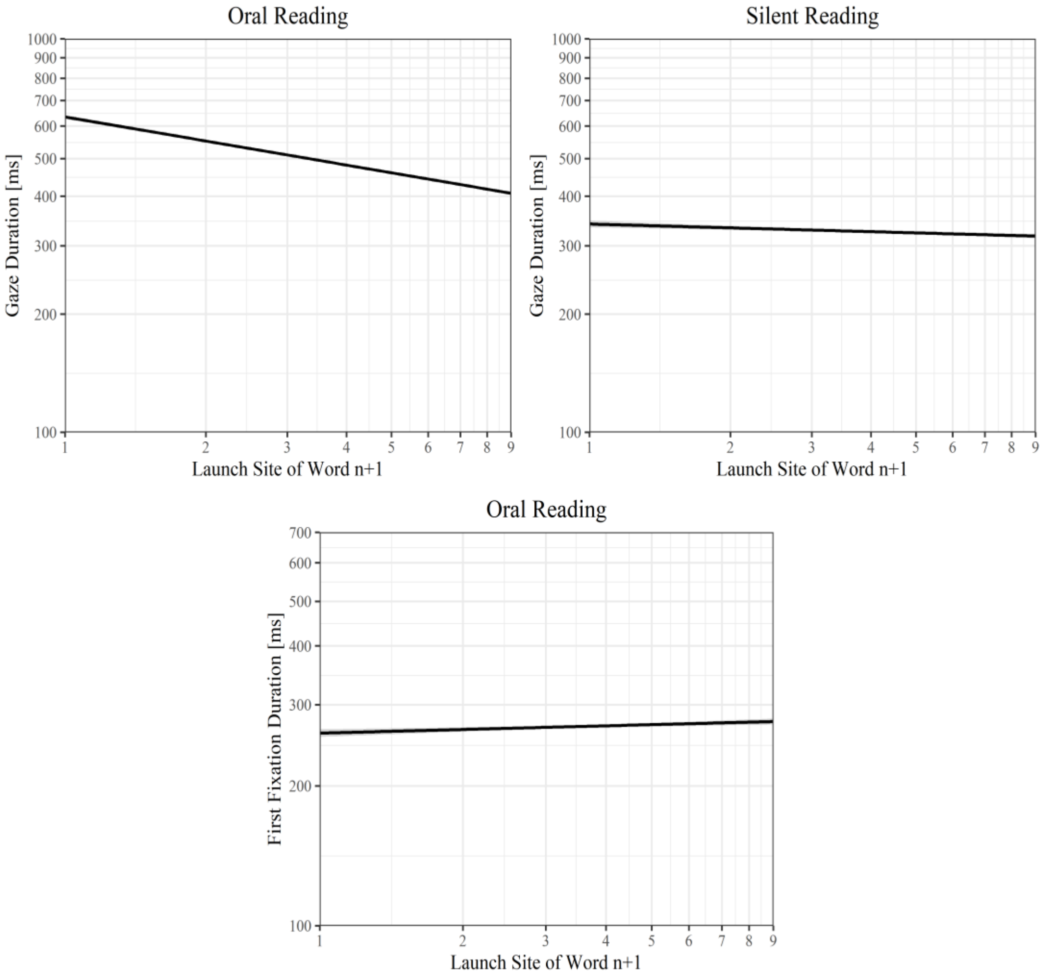

Figure 5.24 The effect of LS2 on fixation durations. Units of fixation durations on the y-axis are log-transformed values. Units of LS2 on the x-axis are log-transformed (base 2) values. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Among silent reading instances, although neither SF2 nor LS2 influenced FFD significantly, a positive effect of SF2 on FFD was observed when LS2 values are longer, while the effect was lost when the eyes were close to the next word. The effect was small but significant ($b = 0.01$, $SE = 0.004$, $t = 2.02$, $p < .05$) (see Figure 5.25).

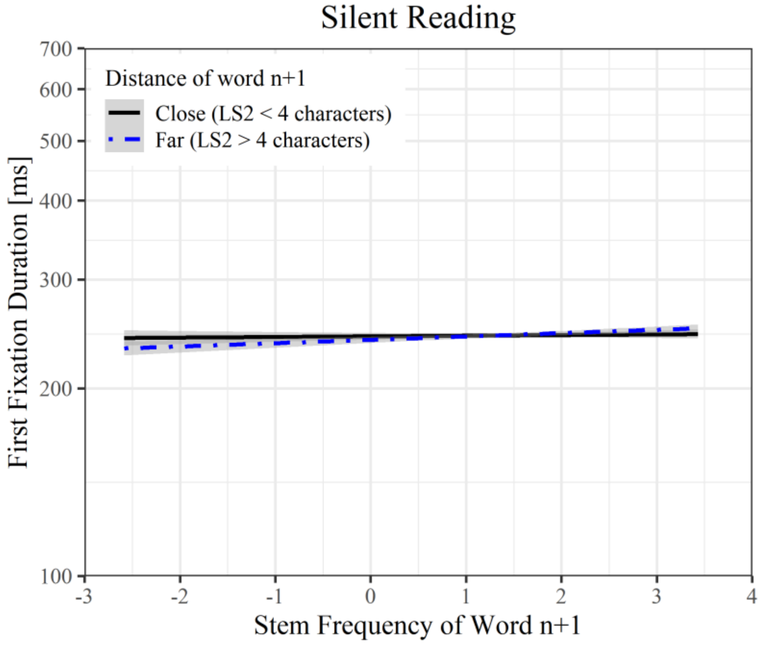

Figure 5.25 The interaction effect of LS2 and SF2 on FFD during silent reading. Units of FFD on the y-axis are log-transformed values, and units of SF2 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The interaction effect of LS2 and P2 was small but significant for both reading modalities (oral reading GD: $b = -0.02$, $SE = 0.01$, $t = -2.13$, $p < .05$; silent reading GD: $b = -0.03$, $SE = 0.01$, $t = -3$, $p < .01$). The positive effect of P2 on GD observed when the eyes were close to the next word was lost when LS2 values were greater (see Figure 5.26).

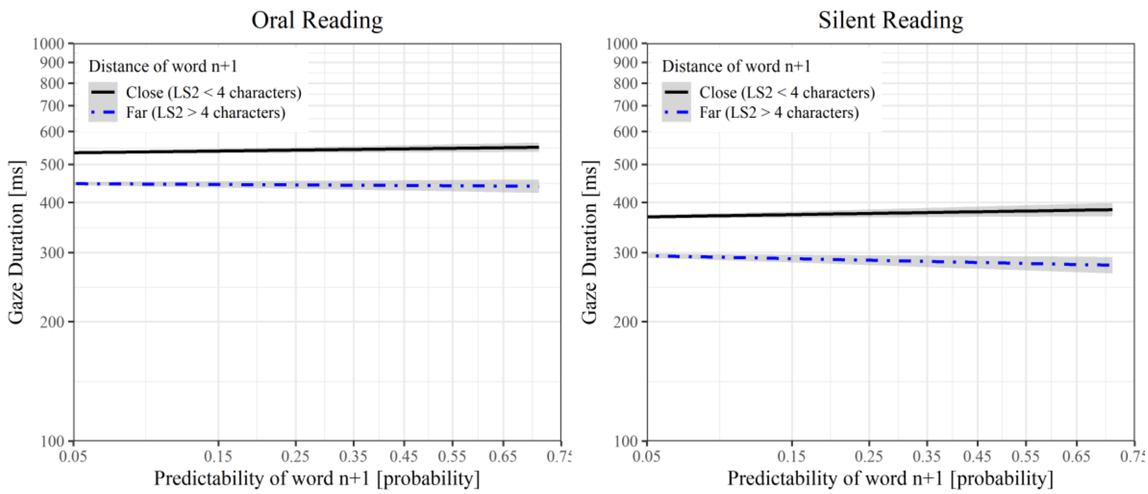

Figure 5.26 The interaction effect of LS2 and P2 on GD during silent reading. The units of GD on the y-axis are log-transformed values, and units of P2 on the x-axis are logit-transformed values. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Foveal load hypothesis.

As a reminder, two sets of three interaction terms added to LMMs to test the foveal load hypothesis as follows:

(1) The effect of foveal load resulted from the difficulty of word n-1: SF1 x SF0, SF1 x TF0, and SF1 x VH0. The expectation was stronger effects of word n characteristics due to less parafoveal processing of word n for an infrequent word n-1.

(2) The effect of foveal load resulted from the difficulty of word n**:** SF0 x SF2, SF0 x TF2, and SF0 x VH2. The expectation was weaker effects of word n+1 characteristics due to less parafoveal-on-foveal effect resulted from the shrinkage of the perceptual span for an infrequent word n.

Among silent reading instances, SF1 influenced the effects of the prelexical characteristics of word n (i.e., TF0 and VH0) on fixation durations significantly while the effects of these interactions were not significant among oral reading instances. For both reading modalities, SF1 did not influence the relationships between fixation durations and SF0 significantly.

An infrequent word n-1 together with a low TF0, resulted in short FFDs on word n which was compensated by refixations manifested in longer GDs, during reading silently. If the word n-1 was a frequent word, word n received longer FFD and GD for low TF0 values. The pattern was significant (silent reading FFD: $b = 0.01$, $SE = 0.01$, $t = 2.1$, $p < .05$; silent reading GD: $b = 0.02$, $SE = 0.01$, $t = 2.02$, $p < .05$). If the word n-1 was an infrequent word a broken rule of VH0 resulted in shorter fixation durations while the effect was lost if the word n-1 was a frequent word. The effect was small but significant (silent reading FFD: $b = 0.01$, $SE = 0.01$, $t = 2.11$, $p < .05$; silent reading GD: $b = 0.03$, $SE = 0.01$, $t = 2.27$, $p < .05$). Figure 5.27 illustrates the interaction effect of SF1 and TF0, and that of SF1 and VH0.

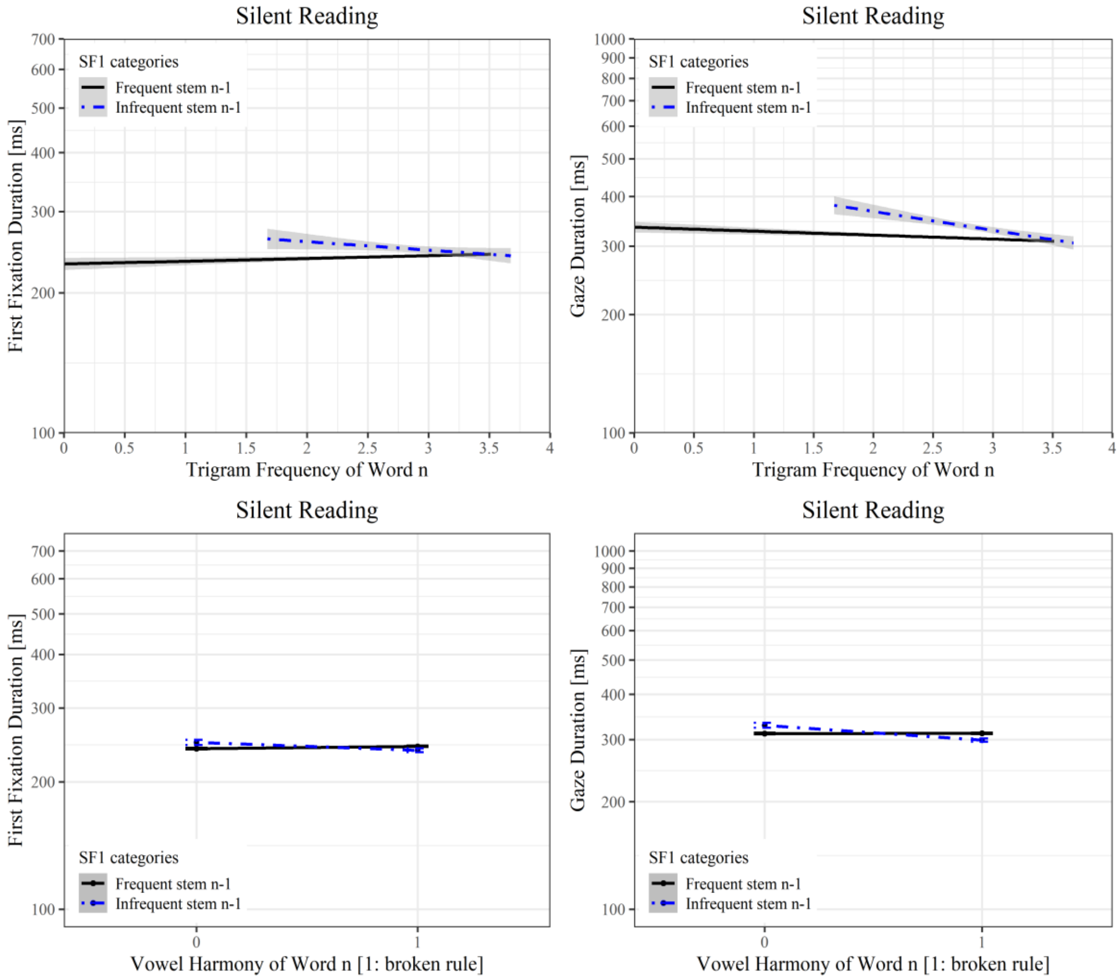

Figure 5.27 The interaction effect of SF1 and TF0, and that of SF1 and VH0 on fixation durations. Units of fixation durations on the y-axis are log-transformed values, and units of TF0 on the x-axis are log-10 transformed values of frequency per million. Categories of SF1 are frequent stems (SF1 > 1.17), and infrequent stems (SF1 < 1.17). Line and 95% confidence band (shown in grey) and the means in the categories of VH0 are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

On the other hand, SF0 influenced the effect of TF2 on FFD and the effect of VH2 on GD significantly only among oral reading instances. All other interaction effects included SF0 were non-significant. During reading aloud, increasing effect of TF2 on FFD among infrequent words was slightly decreasing among frequent words (b = -0.02, SE = 0.01, t = -2.46, p < .05). A broken rule of VH2 resulted in longer GD among frequent words during reading aloud while the effect was lost among infrequent words (b = 0.03, SE = 0.01, t = 2.2, p < .05). Figure 5.28 illustrates the significant interaction effects related to SF0.

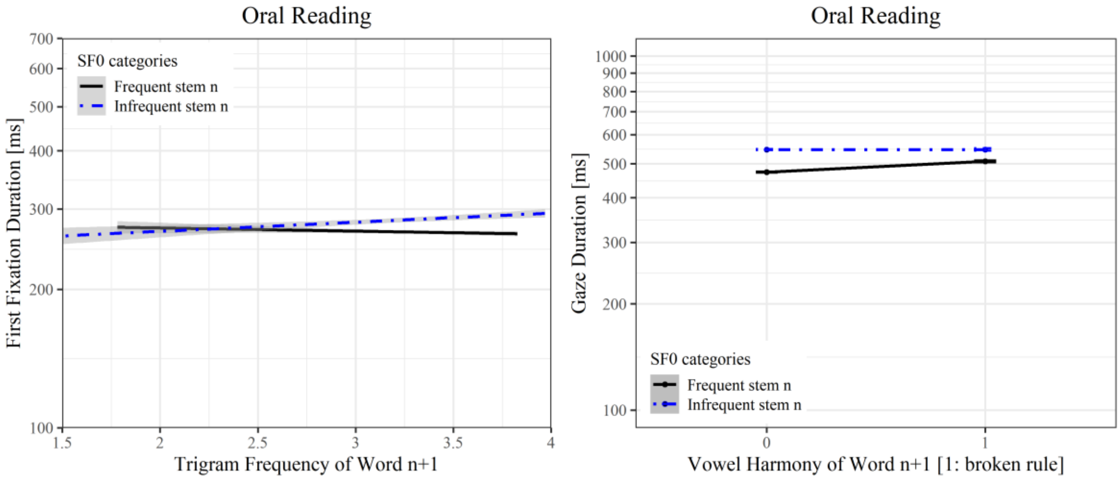

Figure 5.28 The interaction effect of SF0 and TF2 on FFD, and that of SF0 and VH2 on GD during reading aloud. Units of fixation durations on the y-axis are log-transformed values, and units of TF2 on the x-axis are log-10 transformed values of frequency per million. Categories of SF0 are frequent stems (SF0 > 1.17), and infrequent stems (SF0 < 1.17). Line and 95% confidence band (shown in grey) and the means in the categories of VH2 are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Mandatory status of prelexical phonological processing.

As a reminder, to test the mandatory status of prelexical phonological processing, two interactions with familiarity scores (transformed as a categorical covariate) included in the LMMs: (1) familiarity x TF0, and (2) familiarity x VH0.

While the effect of interaction (2) was not significant for any fixation duration, interaction (1) was significant among oral reading instances (oral reading FFD: b = -0.04, SE = 0.02, t = -2.28, p < .05; oral reading GD: b = -0.04, SE = 0.01, t = -3.27, p < .01). illustrates the interaction (1) among during reading aloud.

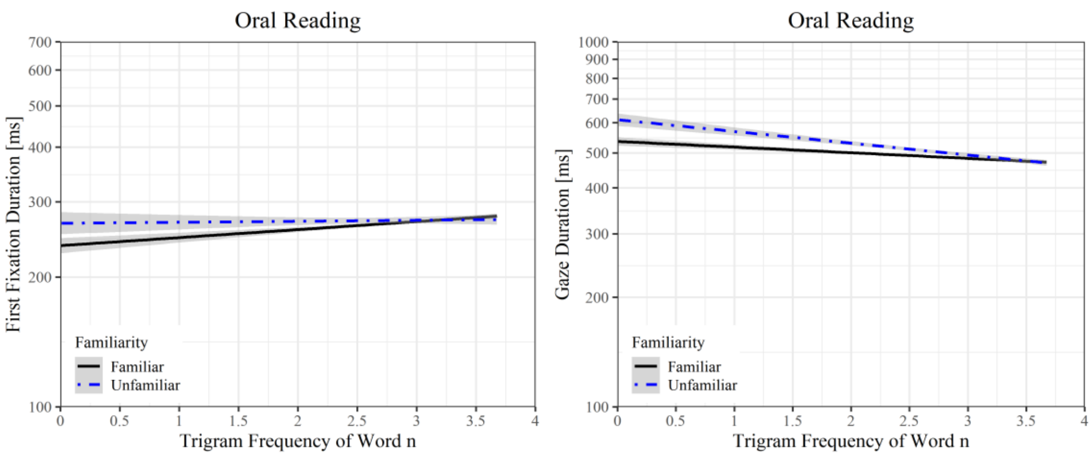

Figure 5.29 The interaction effect of familiarity and TF0 on fixation durations during reading aloud. Units of fixation durations on the y-axis are log-transformed values, and units of TF0 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey)

are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The effect of trigram frequency of familiar words on FFD was positive while the effect was negative on GD among oral reading instances, which implies that a difficulty due to TF0 of a familiar word resulted in multiple fixations with shorter FFD values. On the other hand, the pattern suggests that familiar words that have higher TF0 values tended to receive single fixations. The effect of TF0 among familiar words was similar to the main effect of TF0. Among unfamiliar words, the effect of TF0 on FFD was lost. However, a stronger negative effect of TF0 of unfamiliar words on GD was observed, which resembles the main effect of TF0 among silent reading instances. Among oral reading instances, the difference between fixation durations of familiar words and that of unfamiliar words almost disappeared when TF0 values were high. The results of the interaction between familiarity and TF0 and the main effect of TF0 suggest that prelexical phonological processing exists among both familiar and unfamiliar words with a stronger negative effect of prelexical processing among unfamiliar words during oral reading.

Morphological complexity.

The effect of suffix count of word n (SC0) on fixation durations was significant (oral reading FFD: $b = 0.04$, $SE = 0.01$, $t = 4.49$, $p < .001$; silent reading FFD: $b = 0.02$, $SE = 0.01$, $t = 3.95$, $p < .001$; oral reading GD: $b = 0.03$, $SE = 0.01$, $t = 3.1$, $p < .01$; silent reading GD: $b = 0.04$, $SE = 0.01$, $t = 3.21$, $p < .01$). An increase in SC0 resulted in an increase in fixation durations. Among suffix counts of neighboring words (i.e., SC1 and SC2) only SC1 influenced FFD slightly negatively during reading silently. The effect was small but significant ($b = -0.01$, $SE = 0.01$, $t = -2.16$, $p < .05$). However, as stated previously, word length was a confounding factor in the current study. Figure 5.30 illustrates the effects of suffix counts on fixation durations.

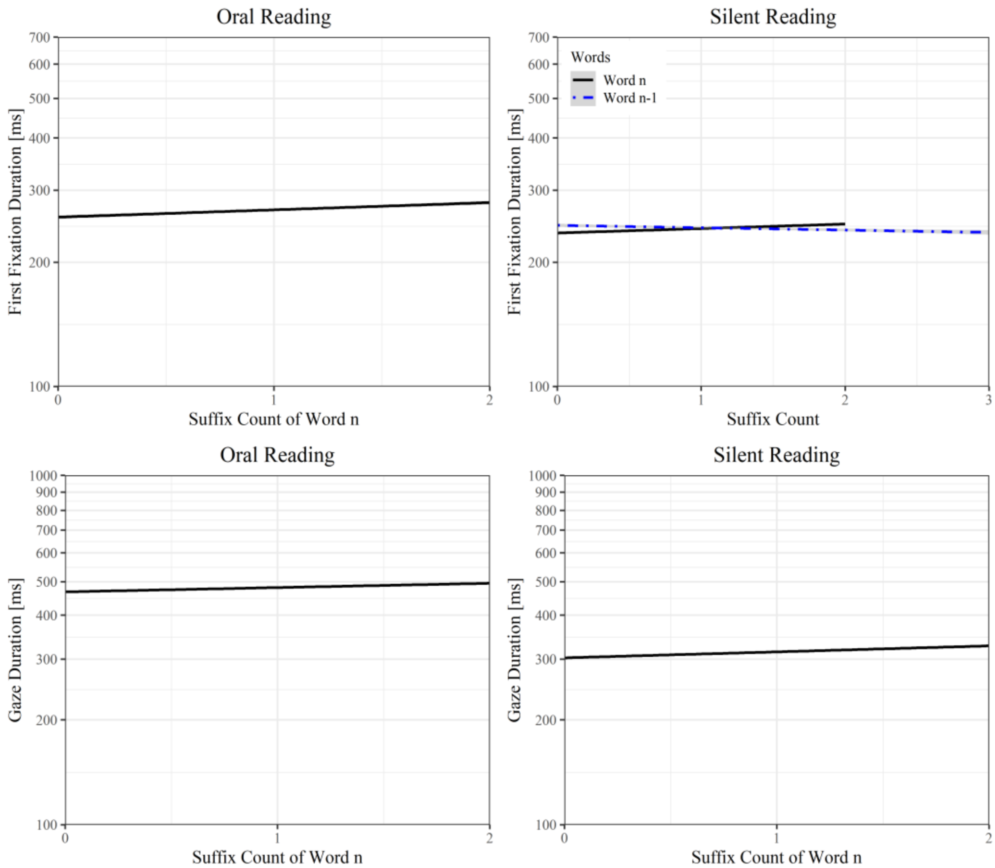

Figure 5.30 The effects of suffix counts on fixation durations. Units of fixation durations on the y-axis are log-transformed values. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

5.3.3. Discussion on the Results of the LMMs of Fixation Durations

The assumption of P-GAG that any difficulty resulted in the processing of a word from its preprocessing to postlexical integration would influence fixation durations through a delay in the saccade generation mechanism was tested with four LMMs of fixation durations.

A frequently reported effect, *inverted optimal viewing position* (IOVP – Vitu et al., 2001), was observed in the current study. That is, first fixations were longer, and gaze durations were shorter when eyes firstly landed around the center of words than they were landed at the edges. These results indicate that when the first fixation was landed around the center of words, fixation counts tended to decrease, indicating successive corrective saccades preceded by oculomotor errors. The effect was observed in the studies on several languages in addition to English (Vitu et al., 2001), including German (Kliegl et al., 2006), Finnish (Hyönä et al., 2018), Uighur (Yan et al., 2014), and Turkish (Özkan et al., 2020). Frequently reported effects of the characteristics of the words and launch site were observed in the current study, as well (for reviews, see Rayner, 1998, 2009a, 2009b; Rayner et al., 2012). Eyes tended to stay longer on words which were longer (i.e., higher word lengths), less predictable from the context (i.e., lower predictabilities), have low-frequency values (i.e., lower frequencies), and received the first fixation from a far previous fixation (i.e., greater launch sites).

The effect of morphological complexity was measured by the number of inflectional suffixes of words, although there might be finer measures. The suffix count of the foveal word influenced fixation durations positively. In other words, an increase in the number of suffixes of the foveal word accompanied by an increase in fixation durations. The effect of the suffix count of the previous word was decreasing on the first fixation duration on the foveal word during reading silently. Although the findings were compatible with the previous studies on morphologically rich languages (e.g., Yan et al., 2014; Hyönä et al., 2018; results of the LMM of a quasi-experimental subset of single fixation durations in Özkan et al., 2020), the effects of the number of suffixes should be interpreted cautiously because of the confounding word length effect, as a limitation of the current study. Further investigation of the relationship between fixation durations and morphological complexity is required with a stimulus set controlled for word length and suffix count.

As the indicators of distributed processing of words within the perceptual span, the effects of the characteristics of neighboring words were included in the LMMs of fixation durations (Kliegl et al., 2006; Kliegl, 2007). The effects of the neighboring words were mixed. The predictability of the previous word influenced the fixation durations on the foveal word such that a less predictable previous word increased the fixation duration on the foveal word while reading silently. The result implied continuing processing of a difficult-to-predict previous word during the processing of the foveal word. The effect of the predictability of the previous word on the fixation durations on the foveal word was not observed among oral reading instances. The length of the previous word influenced the first fixation duration on the foveal word negatively during reading aloud. Since longer words tended to receive multiple fixations, a previous long word would result in closer previous fixation prior to the first fixation on the foveal word. That would result in increased parafoveal processing of the foveal word and hence, shorter first fixation on it. This effect was not observed among silent reading instances. Lastly, the length of the next word influenced gaze duration during reading silently. Decreased gaze durations on foveal words when the next word was a long word was interpreted as the attraction of attention due to increased activation of a long next word. The positive effect of the predictability of the next word due to the memory retrieval process (Kliegl et al., 2006) was observed on gaze duration only when the next word was close to the last fixation on the foveal word (i.e., the launch site of the next word). There was not a significant effect of the frequencies of the neighboring words on the fixation durations of the foveal words with a negligible interaction effect of the launch site of the next word and the frequency of it on the first fixation of the foveal word.

The effects of prelexical phonological processing on fixation durations assumed by P-GAG were tested by two prelexical characteristics of words, which were the trigram frequency and vowel harmony of words. These covariates were selected to reflect phonotactics in Turkish (Acarturk et al., 2017b). The results were mixed, but there was evidence for foveal processing of trigram frequency. The processing of vowel harmony was mostly parafoveal compatible with the previous findings that indicated the parafoveal processing of vowels (Ashby et al., 2006). A low trigram frequency value was accompanied by increased gaze durations in both silent reading and oral reading instances. The decreased first fixation duration, together with increased gaze duration for low trigram frequency values while reading aloud, indicated increased fixation counts on words that have low trigram frequencies. Among familiar words during reading aloud, the decreasing effect of trigram frequency on gaze duration was weaker, though it was not lost, and its effect on first fixation duration was positive, which implies prelexical phonological processing with fewer fixation counts. If the previous word was an infrequent word, a decreasing effect of trigram frequency on the first fixation duration was observed, and the decreasing effect on gaze duration was stronger during reading silently. However, if the previous word was an infrequent word, a broken rule of vowel harmony resulted in shorter fixation durations. A broken rule of vowel harmony of the next word, on the other hand, increased fixation durations on the foveal word indicating parafoveal processing of vowels. The effect was lost if the foveal word was an infrequent word, implying less parafoveal processing due to increased foveal load. Trigram frequency of the next word influenced the first fixation durations during reading aloud positively if the foveal word was a long or an infrequent word and negatively if the foveal word was a short or frequent word. The result implies that if the foveal word was an easy word, there was room for parafoveal processing of the trigram frequency of the next word; however, if the foveal word was a difficult word, the parafoveal processing was observed only when the trigram frequency of the next word was high.

As a measure of postlexical processing difficulty, increased FSI values yielded longer fixation durations during reading aloud. In the current study, the spatial distance between the eyes and the voice during reading aloud (EVS) was selected as a measure of memory load in the memory buffer of P-GAG during postlexical processing. The results of the LMMs indicated that the relationships between EVS and fixation durations were negative, implying that words that require shorter identification time allow the buffer to hold more words. The weaker negative effect of EVS on gaze duration (GD) when the eyes were on the word during articulation of it supported the claim. The results were compatible with the results of a baseline-category logit model (BCLM) analysis presented in APPENDIX D. According to the results of BCLM, easier words (i.e., short and high-frequency words, and highly predictable words) and higher memory capacity of the participants (i.e., higher scores of Corsi-Block and digit-span tests) increased the probability of retaining more words in the buffer.

Up to this point, mostly, the significant estimates were interpreted. In Table 5.3, estimates of all LMM parameters for the first fixation duration for both reading modalities (i.e., oral vs. silent reading) are presented. In Table 5.4, the same table for gaze duration is presented.

Table 5.3 LMM parameter estimates for First Fixation Duration (FFD) in oral vs. silent reading

	Oral Reading						Silent Reading					
Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status
Intercept	**5.60**	**0.02**	**266.7**	**270.85**	**< 2E-16**	**p < .0001**	**5.49**	**0.02**	**347.1**	**330.71**	**< 2E-16**	**p < .0001**
Predictability of word n (P0)	-0.02	0.02	163.2	-0.83	0.41	NS	-0.03	0.02	167.3	-1.81	0.07	NS
Stem frequency of word n (SF0)	**-0.02**	**0.01**	**245.6**	**-2.55**	**0.01**	**p < .05**	**-0.03**	**0.01**	**255.8**	**-5.85**	**1.51E-08**	**p < .0001**
Word length of word n (WL0)	**0.78**	**0.22**	**206.5**	**3.49**	**5.83E-04**	**p < .0001**	**1.03**	**0.18**	**235.3**	**5.62**	**5.31E-08**	**p < .0001**
WL0 quad.							**-10.97**	**1.53**	**209.9**	**-7.17**	**1.24E-11**	**p < .0001**
Suffix count of word n (SC0)	**0.04**	**0.01**	**179.6**	**4.49**	**1.26E-05**	**p < .0001**	**0.02**	**0.01**	**180.3**	**3.95**	**1.12E-04**	**p < .0001**
Trigram frequency of word n (TF0)	**0.04**	**0.02**	**210**	**2.55**	**0.01**	**p < .05**	-0.01	0.01	243.7	-0.45	0.65	NS
Vowel harmony of word n (VH0)	-0.001	0.02	210.3	-0.05	0.96	NS	-0.002	0.01	235	-0.18	0.85	NS
Familiarity	0.01	0.02	1711	0.31	0.76	NS	0.02	0.02	1118	1.27	0.20	NS
Spatial eye voice span (EVS)	**-0.03**	**0.01**	**137.7**	**-3.38**	**9.54E-04**	**p < .0001**	-	-	-	-	-	-
Fixation speech interval (FSI)	**0.16**	**0.02**	**9686**	**9.05**	**< 2E-16**	**p < .0001**	-	-	-	-	-	-
Relative first landing position (RFLP)	**0.51**	**0.03**	**10910**	**18.61**	**< 2E-16**	**p < .0001**	**0.24**	**0.02**	**6917**	**11.04**	**< 2E-16**	**p < .0001**
RFLP quad.	**-2.00**	**0.10**	**10560**	**-19.18**	**< 2E-16**	**p < .0001**	**-2.10**	**0.08**	**8514**	**-25.78**	**< 2E-16**	**p < .0001**
Launch site of word n (LS0)	**0.02**	**0.01**	**207.1**	**2.62**	**0.01**	**p < .001**	**0.03**	**0.01**	**345**	**4.44**	**1.22E-05**	**p < .0001**
Predictability of word n-1 (P1)	-0.02	0.01	182.4	-1.93	0.06	NS	**-0.02**	**0.01**	**194**	**-3.79**	**2.04E-04**	**p < .0001**
Stem frequency of word n-1 (SF1)	0.01	0.01	169.7	0.73	0.47	NS	-0.01	0.01	192.3	-1.65	0.10	NS

Word length of word n-1 (WL1)	**0.60**	**0.24**	**184.8**	**2.57**	**0.01**	**p < .05**	0.18	0.17	216.3	1.05	0.29	NS
Suffix count of word n-1 (SC1)	0.01	0.01	176.7	1.17	0.24	NS	**-0.01**	**0.01**	**194.6**	**-2.16**	**0.03**	**p < .05**
Predictability of word n+1 (P2)	-0.01	0.01	184.3	-0.55	0.59	NS	-0.01	0.01	216.4	-0.49	0.63	NS
Stem frequency of word n+1 (SF2)	-0.001	0.01	165.2	-0.09	0.93	NS	0.01	0.01	183.7	1.93	0.05	NS
Word length of word n+1 (WL2)	0.07	0.24	174.4	0.28	0.78	NS	0.20	0.17	186.7	1.19	0.24	NS
Suffix count of word n+1 (SC2)	-0.004	0.01	178.5	-0.49	0.63	NS	0.01	0.01	186.4	0.76	0.45	NS
Trigram frequency of word n+1 (TF2)	-0.01	0.02	172.3	-0.52	0.61	NS	-0.01	0.02	182.5	-0.33	0.74	NS
Vowel harmony of word n+1 (VH2)	-0.01	0.02	160.8	-0.35	0.73	NS	**0.03**	**0.01**	**180.5**	**2.41**	**0.02**	**p < .05**
Launch site of word n+1 (LS2)	**0.02**	**0.01**	**10480**	**2.49**	**0.01**	**p < .05**	-0.01	0.01	232.6	-1.45	0.15	NS
WL0 x SF0	0.05	0.07	241.7	0.71	0.48	NS	0.08	0.06	257.8	1.46	0.15	NS
WL0 x SF2	0.11	0.10	188	1.08	0.28	NS	0.07	0.08	228.1	0.96	0.34	NS
WL0 x TF2	**-1.19**	**0.30**	**191.6**	**-3.91**	**1.29E-04**	**p < .0001**	-0.45	0.23	199.5	-1.97	0.05	NS
WL0 x VH2	0.19	0.24	184	0.82	0.42	NS	-0.16	0.18	204.6	-0.92	0.36	NS
SF0 x SF2	0.01	0.004	178.2	1.70	0.09	NS	-0.002	0.002	177.5	-0.62	0.54	NS
SF0 x TF2	**-0.02**	**0.01**	**195.6**	**-2.46**	**0.01**	**p < .05**	-0.0004	0.01	194.4	-0.07	0.95	NS
SF0 x VH2	-0.01	0.01	183.2	-1.31	0.19	NS	0.01	0.01	193.6	0.63	0.53	NS
SF1 x SF0	0.004	0.004	183.2	1.14	0.26	NS	-0.001	0.003	201.4	-0.51	0.61	NS
SF1 x TF0	0.01	0.01	181.1	0.62	0.54	NS	**0.01**	**0.01**	**209.4**	**2.10**	**0.04**	**p < .05**
SF1 x VH0	-0.002	0.01	178.5	-0.24	0.81	NS	**0.01**	**0.01**	**199**	**2.11**	**0.04**	**p < .05**
Familiarity x TF0	**-0.04**	**0.02**	**3625**	**-2.28**	**0.02**	**p < .05**	-0.02	0.01	2818	-1.68	0.09	NS
Familiarity x VH0	0.01	0.02	1024	0.37	0.71	NS	-0.01	0.02	686	-0.81	0.42	NS
WL1 x LS0	**0.48**	**0.18**	**142.2**	**2.72**	**0.01**	**p < .001**	0.14	0.12	10200	1.13	0.26	NS

LS2 x SF2	-0.001	0.01	10070	-0.13	0.89	NS	**0.01**	**0.004**	**198**	**2.02**	**0.04**	**p < .05**
LS2 x P2	-0.01	0.01	7432	-0.44	0.66	NS	-0.01	0.01	177.3	-0.81	0.42	NS

Random effects:		Oral Reading		Silent Reading	
Groups	Name	Variance	Std.Dev.	Variance	Std.Dev.
Participant	Intercept	0.0151	0.12	0.0161	0.13
Participant	Predictability of word n (P0)	-	-	0.003	0.06
Participant	Stem frequency of word n (SF0)	0.0003	0.02	-	-
Participant	Word length of word n (WL0)	0.2869	0.54	0.3653	0.6
Participant	Spatial eye voice span (EVS)	0.0016	0.04	-	-
Participant	Launch site of word n (LS0)	-	-	0.0014	0.04
Participant	Stem frequency of word n+1 (SF2)	-	-	0.0004	0.02
Word	Intercept	0.0031	0.06	0.0012	0.04
Word	Spatial eye voice span (EVS)	0.0017	0.04	-	-
Word	Launch site of word n (LS0)	0.0014	0.04	-	-
Word	Launch site of word n+1 (LS2)	-	-	0.0006	0.02

Residual		0.1285	0.36	0.0992	0.31
The number of obs.		11081		12225	
Groups	Participant	196			
	Word	192			

An x between variables indicates interaction. Significant coefficients were set bold (NS: not significant). VH estimates belong to category 1 (violation of the rule), and Familiarity estimates belong to category 1 (unfamiliar).

Table 5.4 LMM parameter estimates for Gaze Duration (GD) in oral vs. silent reading

	Oral Reading						Silent Reading					
Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status
Intercept	**6.18**	**0.02**	**238.5**	**311.77**	**< 2E-16**	**p < .0001**	**5.75**	**0.03**	**301.1**	**205.56**	**< 2E-16**	**p < .0001**
Predictability of word n (P0)	0.01	0.02	187.4	0.24	0.81	NS	-0.04	0.03	189.5	-1.46	0.15	NS
Stem frequency of word n (SF0)	**-0.06**	**0.01**	**226.5**	**-7.98**	**7.28E-14**	**p < .0001**	**-0.09**	**0.01**	**236.9**	**-9.63**	**< 2E-16**	**p < .0001**
Word length of word n (WL0)	**-6.22**	**0.23**	**218.8**	**-27.20**	**< 2E-16**	**p < .0001**	**-4.40**	**0.30**	**196.9**	**-14.72**	**< 2E-16**	**p < .0001**
Suffix count of word n (SC0)	**0.03**	**0.01**	**189.9**	**3.10**	**2.23E-03**	**p < .001**	**0.04**	**0.01**	**191.3**	**3.21**	**1.56E-03**	**p < .001**
Trigram frequency of word n (TF0)	**-0.04**	**0.02**	**206.9**	**-2.14**	**0.03**	**p < .05**	**-0.06**	**0.02**	**217**	**-2.45**	**0.02**	**p < .05**
Vowel harmony of word n (VH0)	0.01	0.02	225.9	0.42	0.67	NS	-0.02	0.02	229.6	-1.12	0.27	NS
Familiarity	0.02	0.02	3664	1.33	0.18	NS	0.02	0.02	3747	1.00	0.32	NS
Spatial eye voice span (EVS)	**-0.16**	**0.01**	**10950**	**-32.48**	**< 2E-16**	**p < .0001**	-	-	-	-	-	-
Fixation speech interval (FSI)	**0.65**	**0.02**	**253**	**38.03**	**< 2E-16**	**p < .0001**	-	-	-	-	-	-
FSI quad.	**-0.08**	**0.03**	**1897**	**-2.76**	**0.01**	**p < .001**	-	-	-	-	-	-

Relative first landing position (RFLP)	**-0.10**	**0.02**	**10840**	**-5.35**	**9.08E-08**	**p < .0001**	**-0.32**	**0.02**	**12120**	**-13.77**	**< 2E-16**	**p < .0001**
RFLP quad.	-0.08	0.07	10570	-1.09	0.28	NS	**-0.20**	**0.09**	**11510**	**-2.29**	**0.02**	**p < .05**
Launch site of word n (LS0)	**0.03**	**0.01**	**210.4**	**5.84**	**2.01E-08**	**p < .0001**	**0.04**	**0.01**	**12040**	**7.48**	**8.12E-14**	**p < .0001**
Predictability of word n-1 (P1)	-0.01	0.01	187.3	-1.02	0.31	NS	**-0.04**	**0.01**	**195.7**	**-2.96**	**3.46E-03**	**p < .001**
Stem frequency of word n-1 (SF1)	-0.003	0.01	184.1	-0.28	0.78	NS	-0.02	0.01	188.2	-1.31	0.19	NS
Word length of word n-1 (WL1)	0.19	0.24	190.3	0.79	0.43	NS	0.28	0.32	196.3	0.85	0.39	NS
Suffix count of word n-1 (SC1)	-0.01	0.01	189.3	-1.29	0.20	NS	-0.01	0.01	189.2	-0.89	0.37	NS
Predictability of word n+1 (P2)	0.001	0.01	194	0.08	0.94	NS	-0.01	0.02	198.9	-0.77	0.45	NS
Stem frequency of word n+1 (SF2)	0.01	0.01	185.3	1.60	0.11	NS	0.01	0.01	182.2	1.23	0.22	NS
Word length of word n+1 (WL2)	0.02	0.24	188.3	0.08	0.94	NS	**0.83**	**0.32**	**188.9**	**2.61**	**0.01**	**p < .001**
Suffix count of word n+1 (SC2)	0.002	0.01	187.9	0.22	0.83	NS	0.02	0.01	189.2	1.22	0.22	NS
Trigram frequency of word n+1 (TF2)	-0.004	0.02	182.9	-0.18	0.86	NS	-0.001	0.03	184.7	-0.04	0.97	NS
Vowel harmony of word n+1 (VH2)	**0.06**	**0.02**	**176.7**	**3.40**	**8.46E-04**	**p < .0001**	**0.08**	**0.02**	**184.4**	**3.39**	**8.42E-04**	**p < .0001**
Launch site of word n+1 (LS2)	**-0.14**	**0.01**	**426.7**	**-25.79**	**< 2E-16**	**p < .0001**	**-0.17**	**0.01**	**568.1**	**-23.57**	**< 2E-16**	**p < .0001**
WL0 x SF0	0.13	0.07	224.9	1.75	0.08	NS	**0.32**	**0.10**	**223.3**	**3.23**	**1.41E-03**	**p < .001**
WL0 x SF2	0.14	0.10	192.8	1.36	0.17	NS	0.11	0.14	199.3	0.79	0.43	NS
WL0 x TF2	0.14	0.31	195.7	0.45	0.65	NS	-0.15	0.41	193.1	-0.36	0.72	NS
WL0 x VH2	0.10	0.24	190.7	0.43	0.67	NS	-0.34	0.32	195.8	-1.06	0.29	NS
SF0 x SF2	0.0003	0.004	186.5	0.07	0.94	NS	0.002	0.01	183.2	0.51	0.61	NS
SF0 x TF2	0.01	0.01	202.5	0.51	0.61	NS	-0.0002	0.01	190.7	-0.02	0.99	NS

SF0 x VH2	**0.03**	**0.01**	**188.5**	**2.20**	**0.03**	**p < .05**	0.03	0.02	188.4	1.66	0.10	NS
SF1 x SF0	0.002	0.004	191.9	0.46	0.65	NS	0.0004	0.01	191.8	0.08	0.93	NS
SF1 x TF0	0.004	0.01	185.8	0.50	0.62	NS	**0.02**	**0.01**	**194.9**	**2.02**	**0.05**	**p < .05**
SF1 x VH0	0.003	0.01	190.4	0.29	0.77	NS	**0.03**	**0.01**	**190.5**	**2.27**	**0.02**	**p < .05**
Familiarity x TF0	**-0.04**	**0.01**	**7784**	**-3.27**	**1.09E-03**	**p < .001**	-0.02	0.02	8398	-0.99	0.32	NS
Familiarity x VH0	-0.01	0.02	2425	-0.38	0.70	NS	0.01	0.02	2379	0.60	0.55	NS
WL1 x LS0	0.05	0.12	145.1	0.41	0.68	NS	0.07	0.13	11940	0.54	0.59	NS
LS2 x SF2	-0.002	0.003	5563	-0.63	0.53	NS	-0.003	0.004	11890	-0.61	0.54	NS
LS2 x P2	**-0.02**	**0.01**	**8304**	**-2.13**	**0.03**	**p < .05**	**-0.03**	**0.01**	**8470**	**-3.00**	**2.75E-03**	**p < .001**
EVS x FSI	**0.11**	**0.02**	**5293**	**6.15**	**8.14E-10**	**p < .0001**	-	-	-	-	-	-

Random effects:		Oral Reading		Silent Reading	
Groups	Name	Variance	Std.Dev.	Variance	Std.Dev.
Participant	Intercept	0.0062	0.08	0.0313	0.18
Participant	Predictability of word n (P0)	0.0024	0.05	0.0019	0.04
Participant	Stem frequency of word n (SF0)	-	-	0.0007	0.03
Participant	Word length of word n (WL0)	0.577	0.76	-	-
Participant	Suffix count of word n (SC0)	-	-	0.0006	0.03
Participant	Fixation speech interval (FSI)	0.0075	0.09	-	-
Participant	Predictability of word n-1 (P1)	-	-	0.0009	0.03

Participant	Stem frequency of word n+1 (SF2)	0.0002	0.01	-	-
Participant	Suffix count of word n+1 (SC2)	-	-	0.0002	0.02
Participant	Launch site of word n+1 (LS2)	0.0009	0.03	0.0016	0.04
Word	Intercept	0.0047	0.07	0.009	0.09
Word	Fixation speech interval (FSI)	0.016	0.13	-	-
Word	Launch site of word n (LS0)	0.0007	0.03	-	-
Residual		0.0576	0.24	0.1107	0.33
The number of obs.		11081		12225	
Groups	Participant	196			
	Word	192			

An x between variables indicates interaction. Significant coefficients were set bold (NS: not significant). VH estimates belong to category 1 (violation of the rule), and Familiarity estimates belong to category 1 (unfamiliar).

5.4. Relative First Landing Position (RFLP)

As mentioned previously, P-GAG is based on SWIFT, a *guidance by attentional gradient* (GAG) model. Therefore, in the model, there is not any default target for the next saccade (Engbert et al., 2005; Richter et al., 2006), in contrast to *sequential attention shifts* (SAS) models in which the target of the next saccade is word n+1 (Reichle et al., 2006; Pollatsek et al., 2006). As it is the case for SWIFT, the target selection process in P-GAG is a probabilistic and competitive process depending on the activation levels of the words. Since P-GAG is a theoretical framework, rather than a computational eye-movement model, mathematical specification of the saccade generation process is beyond the scope of the current study. However, we assume that the word identification process and postlexical difficulty of a word influence the target selection process through the restriction put on the maximum values of the activations of words due to their difficulty. Accordingly, more difficult words would receive multiple fixations with the first fixation on closer to the beginning of the word.

The assumptions of P-GAG regarding saccade target selection were tested by an LMM for Relative First Landing Position (RFLP). As expected, in addition to low-level visual processing of word boundaries (i.e., word length) and Launch Site (LS), lexical and prelexical word characteristics and postlexical difficulty measures (i.e., the eye-voice span measures) influenced the location of the fixation on the word. The details of the results are presented in the following sub-sections.

5.4.1. Covariates Specific to Oral Reading

The effects of spatial measure of the eye-voice span (EVS) and fixation speech interval (FSI) on RFLP were significant (EVS: $b = 0.02$, $SE = 0.002$, $t = 6.65$, $p < .001$; FSI: $b = -0.06$, $SE = 0.01$, $t = -8.63$, $p < .001$). Greater EVS values and shorter FSI values accompanied first fixations closer to the center of the words (see Figure 5.31).

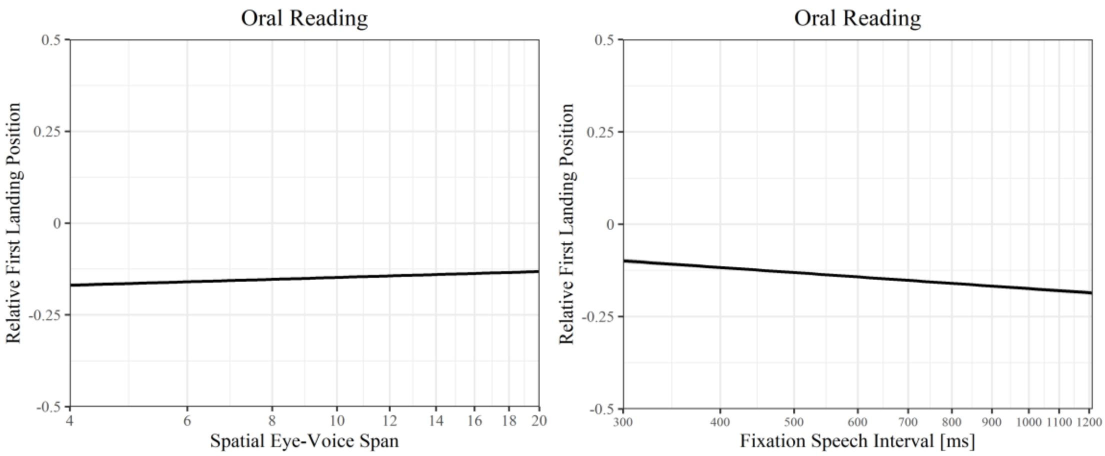

Figure 5.31 The effects of EVS and FSI on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of EVS and FSI on the x-axis are log-transformed values. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

As it was observed that first fixations closer to the left edge of the words associated with increased multiple fixation probability (see Figure 5.13), the result suggests that words that receive the first fixation closer to the left edge of them require longer postlexical processing times (i.e., longer FSI) and allow fewer items to be held in memory buffer during FSI (i.e., shorter EVS). The result suggests that postlexical processing difficulty and memory load influenced the target selection process during reading aloud.

5.4.2. Common Covariates and Interactions for Relative First Landing Position

Canonical effects – launch site.

Launch site (LS0) influenced RFLP significantly for both reading modalities (oral reading: b = -0.08, SE = 0.003, t = -27.06, p < .001; silent reading: b = -0.09, SE = 0.002, t = -39.94, p < .001). The interaction term included in the models to take the cost of skipping word n-1 into account (i.e., WL1 x LS0) was significant as well (oral reading: b = -0.38, SE = 0.08, t = -5.04, p < .001; silent reading: b = -0.41, SE = 0.05, t = -8.04, p < .001). As the distance between the previous fixation and the beginning of the word got longer (i.e., high LS0 values) first fixations tended to land closer to the left edge of the words while first fixations tended to land around the center of the words when LS0 got shorter. The stronger negative effect for short words n-1 imply a skipping cost for high LS0 values (see Figure 5.32).

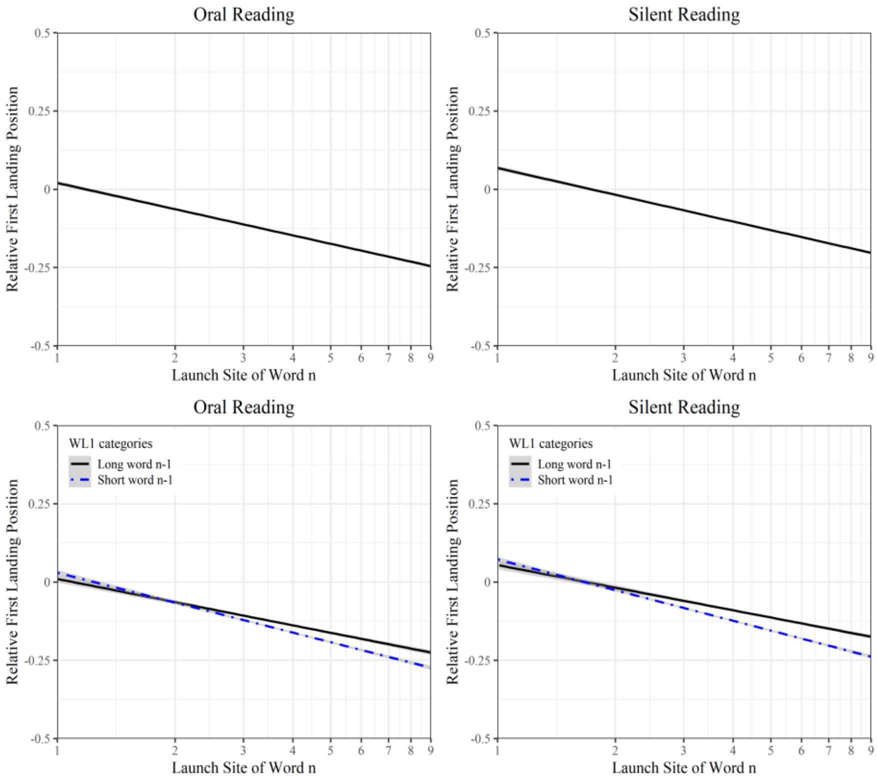

Figure 5.32 The effects of LS (first row of the figure), and its interaction with WL1 (second row of the figure) on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of LS on the x-axis are log-2 transformed values. Categories of WL1 are short words (8 characters and shorter) and long words (9 characters and longer). Line and 95% confidence band are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Canonical effects – immediate effects of word n characteristics.

Among lexical characteristics of word n WL0 influenced RFLP significantly (oral reading: $b = 0.77$, $SE = 0.08$, $t = 9.55$, $p < .001$; silent reading: $b = 0.77$, $SE = 0.09$, $t = 8.41$, $p < .001$). In addition to effect of WL0, the effect of SF0 on RFLP was significant, among silent reading instances ($b = 0.01$, $SE = 0.003$, $t = 2.59$, $p < .05$). Longer words received first fixations closer to their left edge, and shorter words received first fixations closer to their center in both reading modalities. Overall, first fixation locations were closer to the center among silent reading instances relative to oral reading instances. The effect of SF0 on RFLP during reading silently indicates that more difficult words (i.e., low SF0 values) received first fixations closer to their left edge. The result implies that the target selection process was not exclusively orthographic but influenced by lexical processing during reading silently (see Figure 5.33).

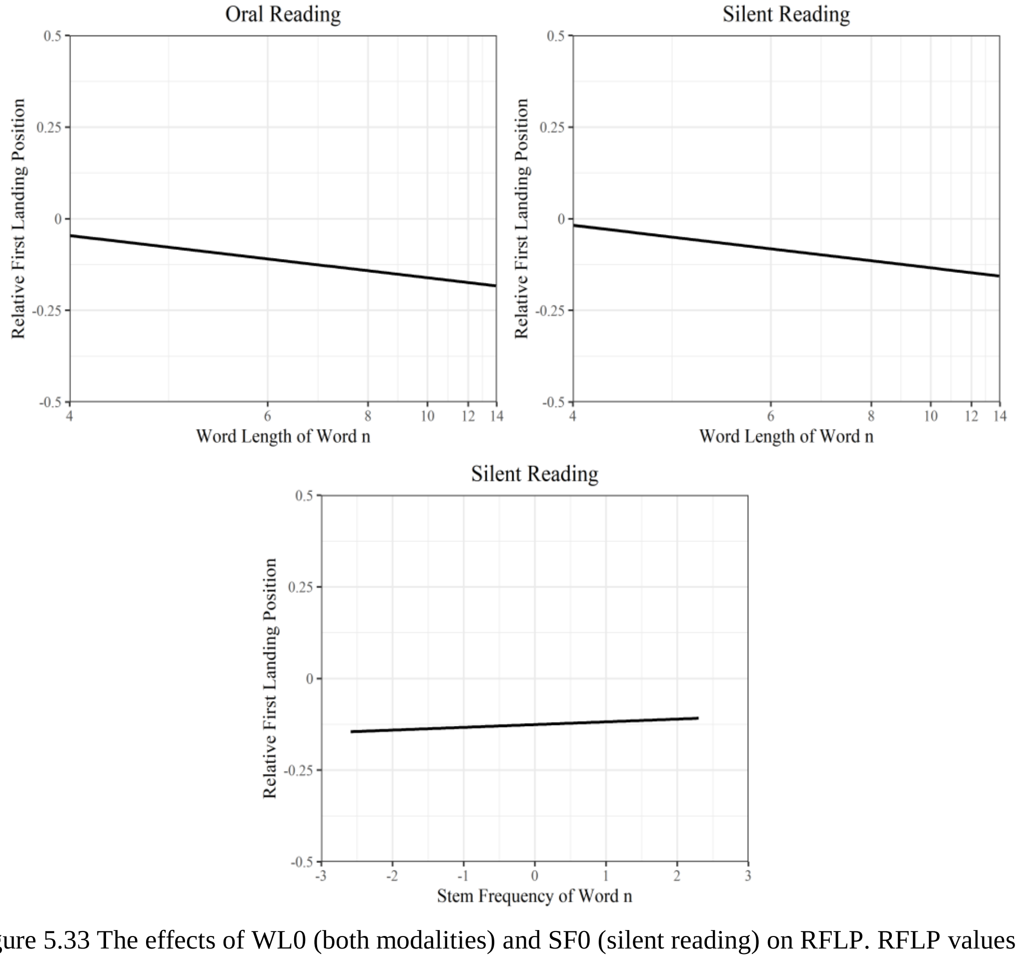

Figure 5.33 The effects of WL0 (both modalities) and SF0 (silent reading) on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of WL0 on the reversed x-axis are reciprocal lengths of word n. Units of SF0 on the x-axis are log-10 transformed values of frequencies per million. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Lag- and successor-effects.

Among lexical characteristics of word n-1, length of word n-1 (WL1) influenced RFLP significantly in both reading modalities (oral reading: $b = -0.43$, $SE = 0.09$, $t = -4.92$, $p < .001$; silent reading: $b = -0.7$, $SE = 0.1$, $t = -6.98$, $p < .001$). In addition to WL1, SF1 during reading aloud, and P1 during reading silently influenced RFLP significantly (oral reading, SF1: $b = -0.01$, $SE = 0.003$, $t = -2.32$, $p < .05$; silent reading, P1: $b = 0.01$, $SE = 0.004$, $t = 2.54$, $p < .05$). The first fixations on word n tended to be closer to the center of the word when word n-1 were words that tended to receive multiple fixations (e.g., long and low-frequency words n-1) and hence received closer last fixations to the foveal word. Since more predictable words tended to be skipped, whenever word n-1 was a predictable word first fixation on word n was closer to the center as a result of closer fixations to the right edge of word n-1 (see Figure 5.34).

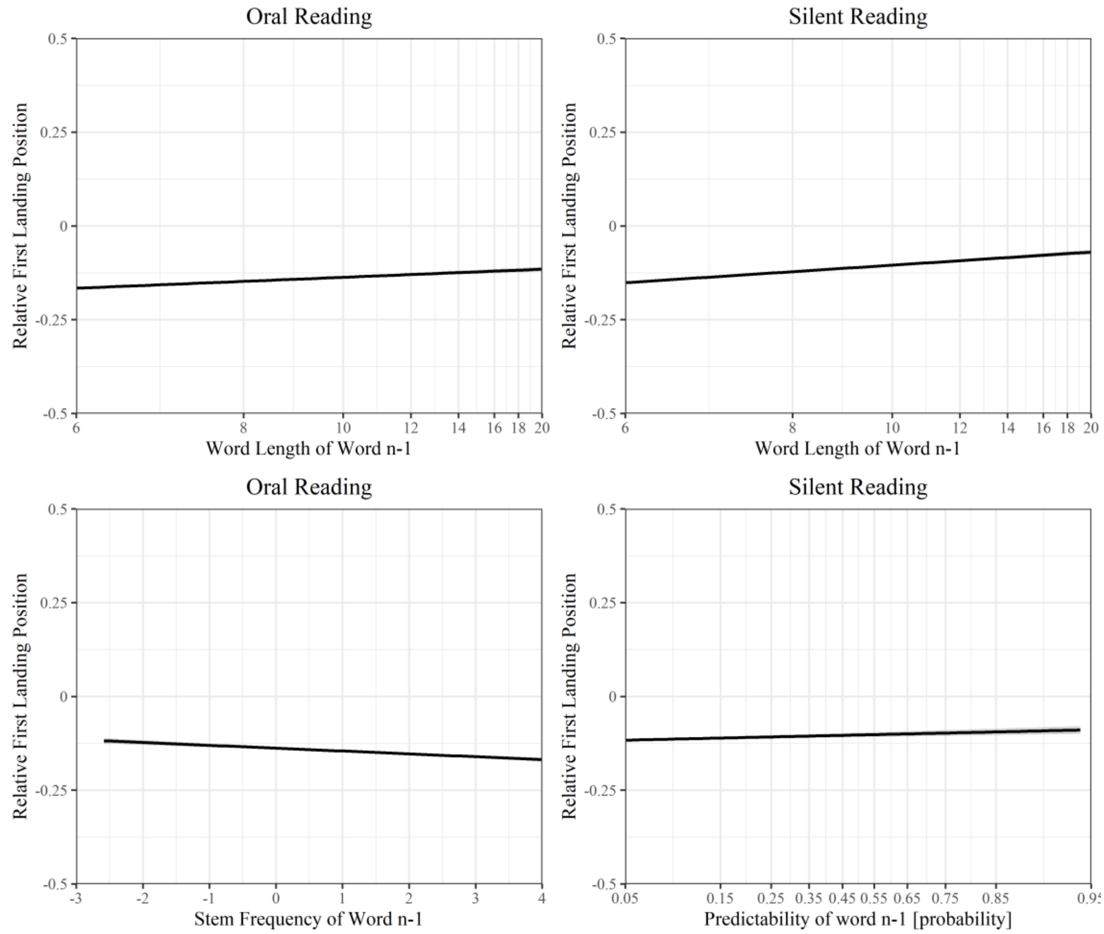

Figure 5.34 Lag-effects on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of WL1 on the reversed x-axis are reciprocal word lengths, of SF1 on the x-axis are log-10 transformed values of frequencies per million, and of P1 on the x-axis are logit-transformed. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Among successor effects, P2 influenced RFLP significantly in both reading modalities (oral reading: $b = -0.01$, $SE = 0.005$, $t = -2.43$, $p < .05$; silent reading: $b = -0.01$, $SE = 0.01$, $t = -2.08$, $p < .05$). In addition to P2, WL2 influenced RFLP significantly during oral reading (b = 0.22, SE = 0.09, t = 2.51, $p < .05$). Words that have less predictable next words tended to receive first fixations closer to their centers. Since predictability is mainly the effect of the context, the result implies that the target selection process was influenced by the context such that if the next word was a less predictable word, eyes tended to land closer to it. Additionally, during reading aloud, eyes tended to land closer to the center of word n if the next word was a short word (see Figure 5.35).

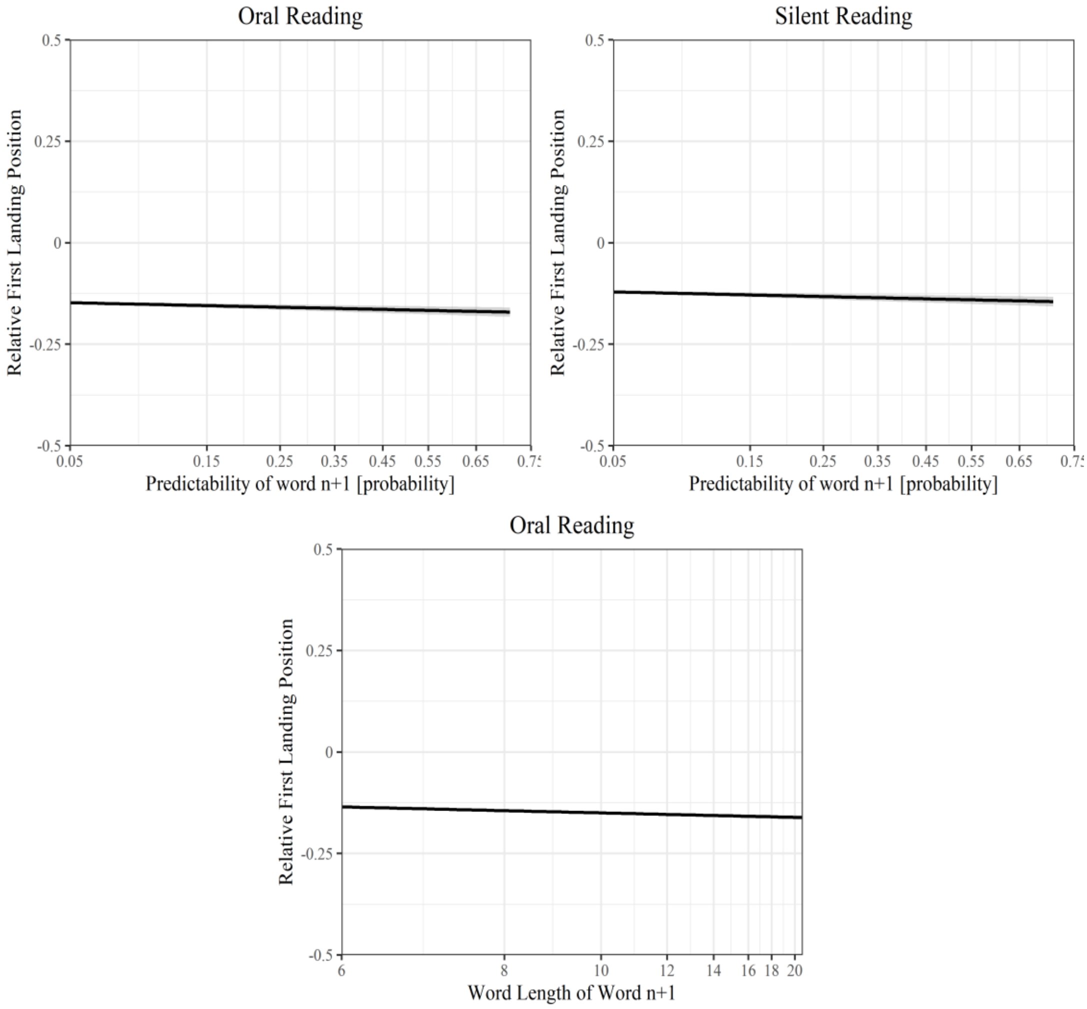

Figure 5.35 Successor-effects on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of P2 on the x-axis are logit-transformed, and of WL2 on the reversed x-axis are reciprocal word lengths. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Prelexical phonological processing effects.

Trigram frequency of word n (TF0) and vowel harmony of word n+1 (VH2) influenced RFLP significantly during both reading modalities (oral reading, TF0: b = 0.01, SE = 0.01, t = 2.27, $p < .05$; silent reading, TF0: b = 0.01, SE = 0.01, t = 2, $p < .05$; oral reading, VH2: b = -0.01, SE = 0.01, t = -2.27, $p < .05$; silent reading, VH2: b = -0.02, SE = 0.01, t = -2.22, $p < .05$). Words that had low TF0 values received first fixations closer to the left edge of them. The effect of a broken rule of VH2 on RFLP was a slightly closer first fixation to the left edge of the word (see Figure 5.36).

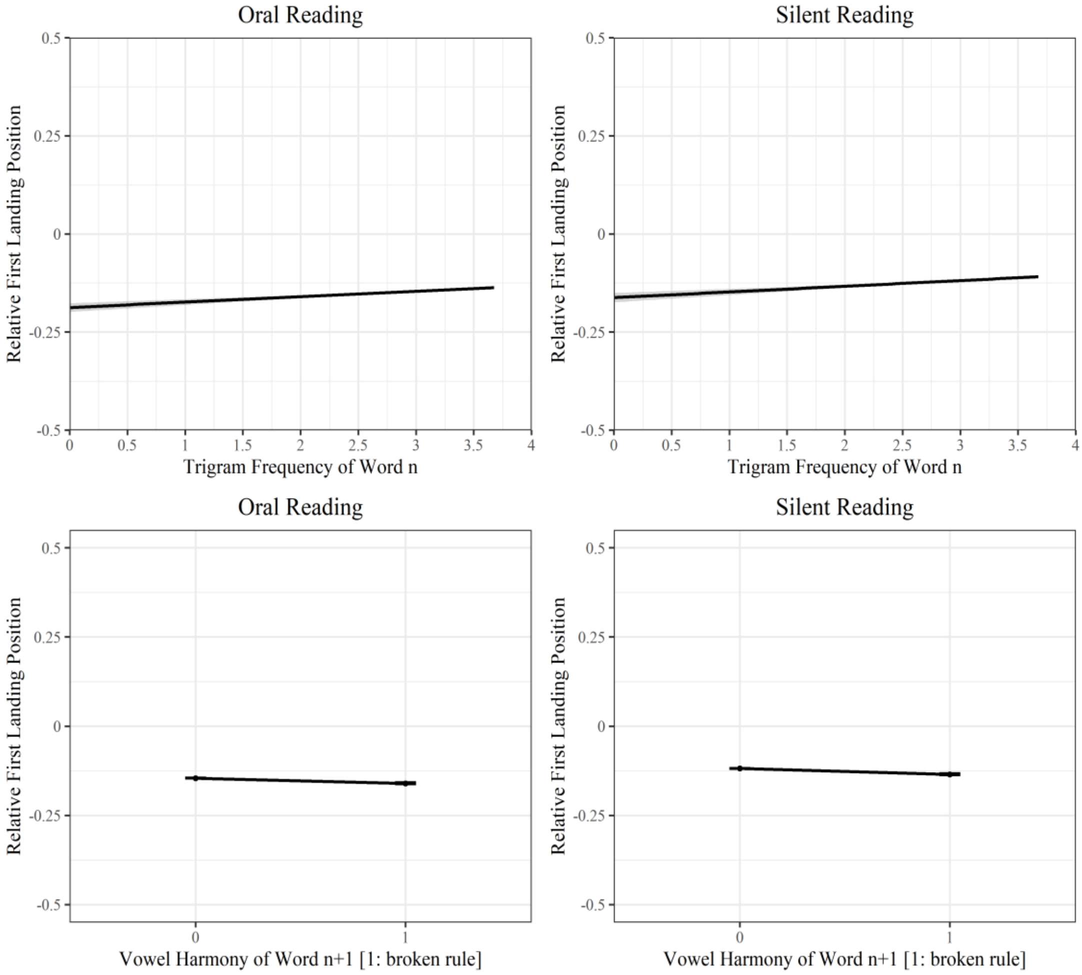

Figure 5.36 The effect of TF0 and VH2 on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of TF0 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey) are partial effects of TF0. The partial effects of TF0 and VH2 were retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Visual acuity hypothesis.

According to the hypothesis, the length of the foveal word would influence the parafoveal-on-foveal effects of the characteristics of the next word. To test the hypothesis, the interactions between WL0 and prelexical characteristics and stem frequency of word n+1 (i.e., TF2, VH2, and SF2) included in the eye-movement measure models. An additional covariate, the launch site of word n+1 (LS2), as a measure of the distance of the next word and its interactions with SF2 and predictability of word n+1 (P2), included in the models.

WL0 was significant. WL0 influenced the effect of SF2 on RFLP during reading silently (b = 0.1, SE = 0.04, t = 2.2, p < .05). As SF2 increased, short words tended to receive first fixations closer to their center while long words tended to receive first fixations closer to their left edge. In other words, the relationship between SF2 and RFLP was positive among short words while it was negative among long words. The result implies that an increased difficulty of word n+1 due to decreased SF2 resulted in closer first fixations to the left edge of the word n, which was associated with increased multiple fixations. The negative effect of SF2 on RFLP among long words was weak, probably due to the dominating effect of WL0 (see Figure 5.37).

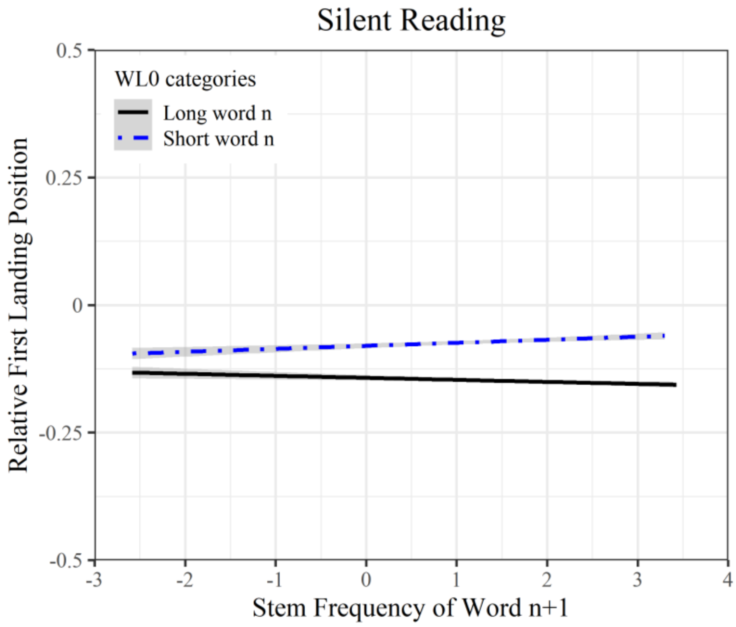

Figure 5.37 The interaction effect of WL0 and SF2 on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of SF2 on the x-axis are log-10 transformed values of frequency per million. Categories of WL0 are short words (4-8 characters) and long words (10-14 characters). Line and 95% confidence band (shown in grey) are partial effects retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

LS2 influenced RFLP and the effects of SF2 and P2 on RFLP significantly in both reading modalities. RFLP closer to left edge of words accompanied greater LS2 values (oral reading: b = -0.05, SE = 0.002, t = -20.92, p < .001; silent reading: b = -0.07, SE = 0.003, t = -23.5, p < .001). The result was not expected since the first fixations closer to the left edge of words were associated with refixations, which was expected to result in shorter LS2 values (see the first row of Figure 5.38). An investigation of the result by separating data according to WL0 revealed that the negative relationship between LS2 on RFLP was the result of the strong negative relationship between them among short words, which tend to receive single fixations (see the second row of Figure 5.38).

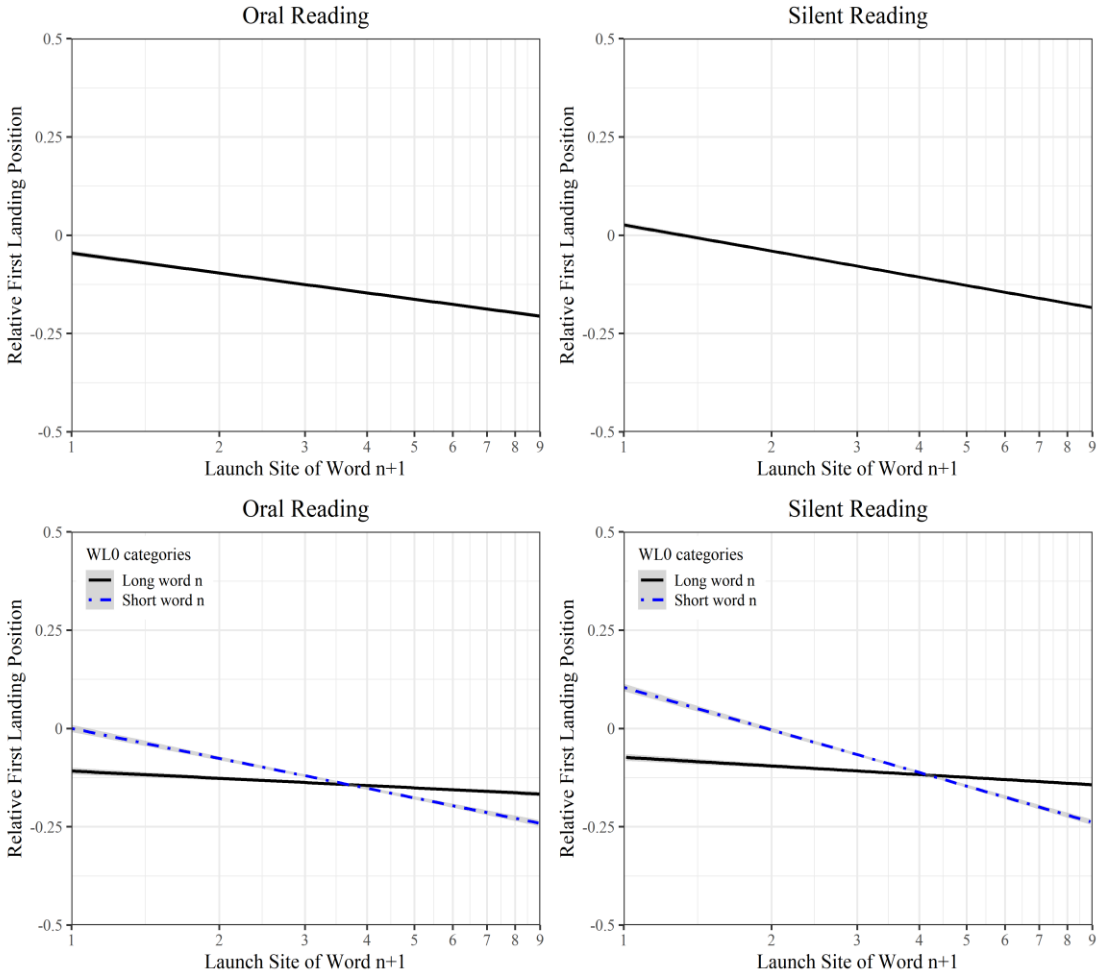

Figure 5.38 The effect of LS2 on RFLP (first row of the figure) and the effect of LS2 on RFLP broken by WL0 (second row of the figure). RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of LS2 on the x-axis are log-transformed (base 2) values. Categories of WL0 are short words (4-8 characters) and long words (10-14 characters). Line and 95% confidence band (shown in grey) are partial effects retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

The distance of the next word influenced the effect of P2 (oral reading: b = -0.02, SE = 0.004, t = -4.55, p < .001; silent reading: b = -0.02, SE = 0.004, t = -3.59, p < .001) and the effect of SF2 on RFLP significantly (oral reading: b = 0.003, SE = 0.002, t = 2.05, p < .05; silent reading: b = 0.01, SE = 0.002, t = 9.15, p < .001). Small negative effect of P2 on RFLP was lost among words that have greater LS2 values for both reading modalities. Slightly negative effect of SF2 on RFLP was relatively stronger among words that have less LS2 values than that of among words that have greater LS2 values, during reading aloud. Among silent reading instances, on the other hand, the effect of SF2 on RFLP was slightly positive among words that have greater LS2 values while the effect was stronger and negative among words that have less LS2 values (see Figure 5.39).

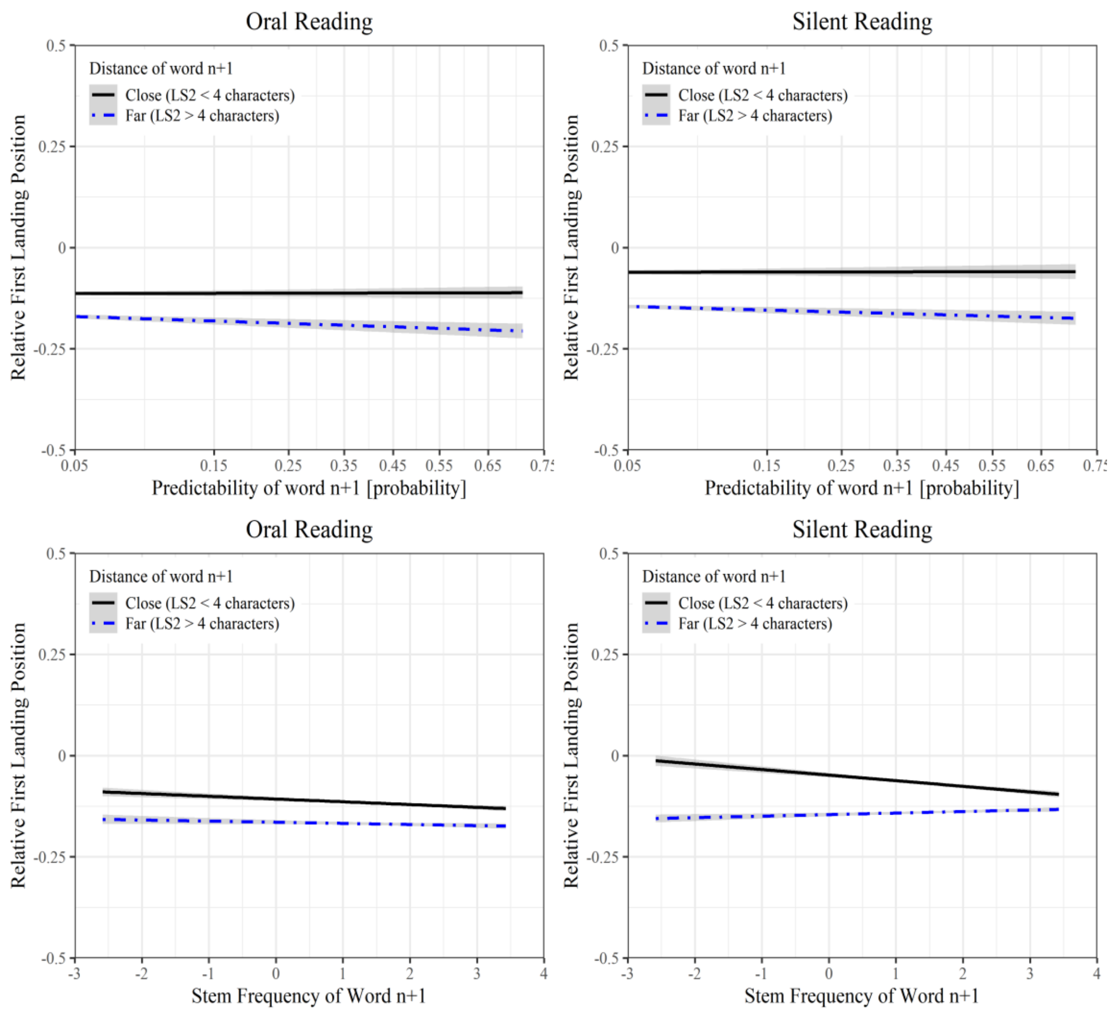

Figure 5.39 Interaction effects of LS2 and P2, and LS2 and SF2 on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of P2 on the x-axis are logit-transformed, and of SF2 on the x-axis are log-10 transformed values of frequency per million. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Foveal load hypothesis.

As a reminder, two sets of three interaction terms added to LMMs to test the foveal load hypothesis as follows:

(1) The effect of foveal load resulted from the difficulty of word n-1: SF1 x SF0, SF1 x TF0, and SF1 x VH0. The expectation was stronger effects of word n characteristics due to less parafoveal processing of word n for an infrequent word n-1.

(2) The effect of foveal load resulted from the difficulty of word n: SF0 x SF2, SF0 x TF2, and SF0 x VH2. The expectation was weaker effects of word n+1 characteristics due to less parafoveal-on-foveal effect resulted from the shrinkage of the perceptual span for an infrequent word n.

The effect of VH2 on RFLP was influenced by SF0 in both reading modalities (oral reading: $b = -0.01$, $SE = 0.004$, $t = -2.28$, $p < .05$; silent reading: $b = -0.01$, $SE = 0.005$, $t = -2.19$, $p < .05$). The negative effect of VH2 on RFLP was lost among infrequent words. SF1, on the other hand, influenced the effect of TF0 on RFLP only among oral reading instances ($b = -0.01$, $SE = 0.003$, $t = -2.16$, $p < .05$). If word n-1 was an infrequent word, the positive effect of TF0 was weaker during oral reading (see Figure 5.40).

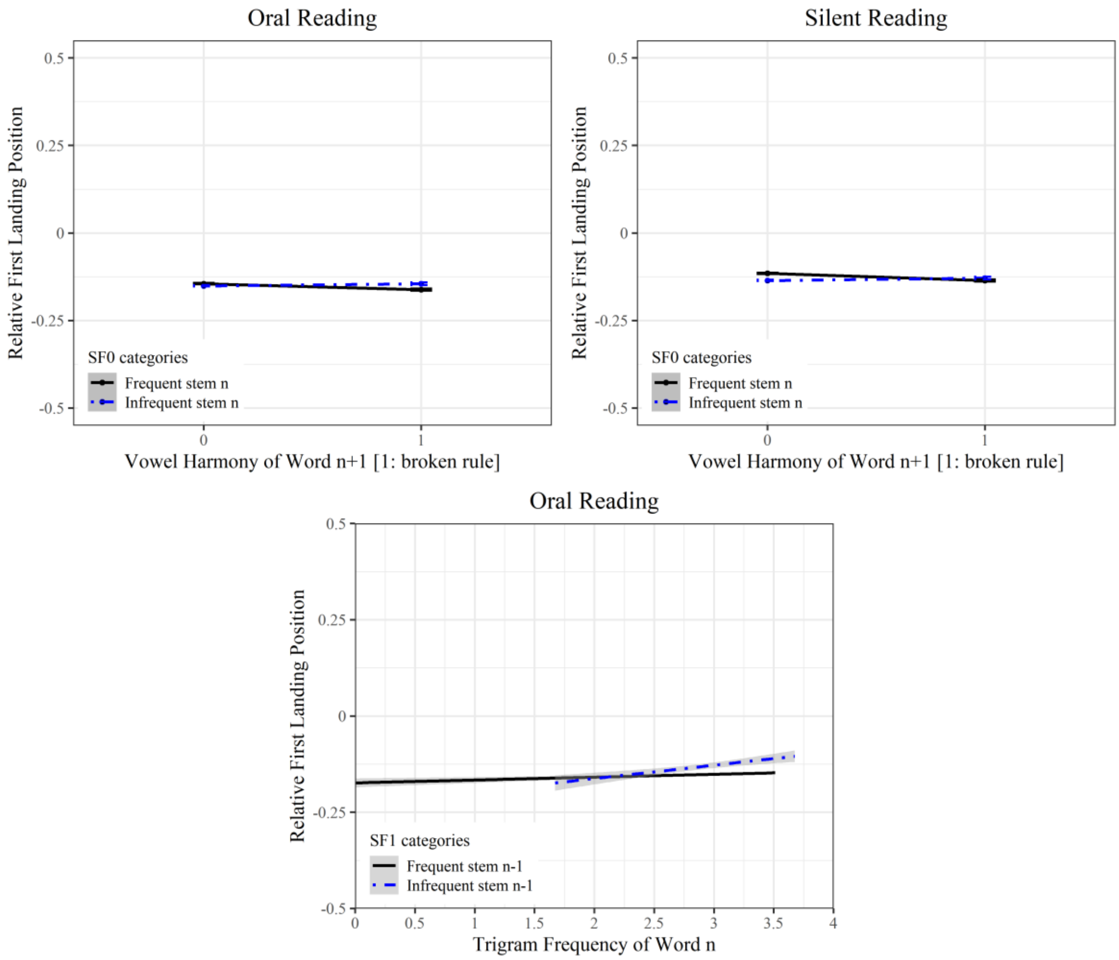

Figure 5.40 The interaction effects of SF0 and VH2, and SF1 and TF0 on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Units of TF0 on the x-axis are log-10 transformed values of frequency per million. Categories of SFs are frequent stems (SF > 1.17) and infrequent stems (SF <1.17). Line and 95% confidence band (shown in grey) are partial effects of TF0. The partial effects of TF0 and VH2 were retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Mandatory status of prelexical phonological processing.

As a reminder, to test the mandatory status of prelexical phonological processing, two interactions with familiarity scores (transformed as a categorical covariate) included in the LMMs: (1) familiarity x TF0, and (2) familiarity x VH0.

The effect of familiarity on RFLP and its influence on the effect of TF0 and VH0 on RFLP were not significant. Together with the significant influence of TF0 on RFLP, the result implies a prelexical phonological processing effect on RFLP independent of the familiarity of the words.

Morphological complexity.

Only the suffix count of word n (SC0) influenced RFLP significantly in both reading modalities (oral reading: $b = -0.01$, $SE = 0.003$, $t = -3.84$, $p < .001$; silent reading: $b = -0.01$, $SE = 0.004$, $t = -2.75$, $p < .01$). An increase in SC0 accompanied first fixations closer to the left edge of word n.

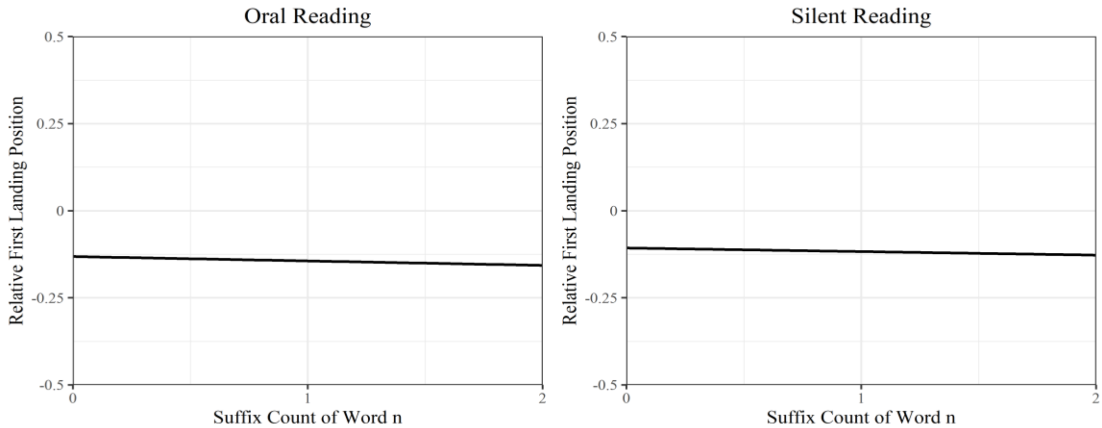

Figure 5.41 The effect of SC0 on RFLP. RFLP values of 0 indicate the center, RFLP values below 0 indicate the left half, and RFLP values above 0 indicate the right half of the word n. Line and 95% confidence band (shown in grey) are partial effects, retrieved from LMM estimates by using the `remef` package (Hohenstein & Kliegl, 2015).

Although the finding that first fixations closer to the beginning of words together with increased suffix counts was compatible with the previous research (Yan et al., 2014 for Uighur; and Hyönä et al. 2018 for Finnish), the effect in the current study should be interpreted cautiously due to confounding factor of WL0, as stated previously.

5.4.3. Discussion on the Results of the LMMs of Relative First Landing Position

The assumptions of P-GAG suggested that the target selection mainly depends on the eccentricities. However, the word identification process and postlexical difficulty of a word would influence the target selection process. Accordingly, the location of the fixation on a selected target should be influenced by the activation level of word n. More difficult words would receive multiple fixations with the first fixation on closer to the beginning of the word. The results of the LMM of RFLP were compatible with the canonical effects of low-level visual processing measured by word lengths and LS. Another effect regarding SC0 was compatible with the previous research (Yan et al., 2014 for Uighur; and Hyönä et al. 2018 for Finnish). As SC0 increased, the first fixation on the word tended to land closer to the left edge of the word. Among lexical effects, the effect of the frequency of word n on RFLP was significant with low-frequency words that received first fixations closer to their left edges.

The effects of TF0 on RFLP suggested that the prelexical phonological processing difficulty of a word influenced the location of the first fixation on that word. The effect was not influenced by the familiarity of the word but influenced by the frequency of the previous word such that the effect of TF0 on RFLP was stronger among infrequent previous words. The effects of characteristics of word n+1, on the other hand, showed that distributed processing of words had an influence on RFLP. Lastly, postlexical difficulty measures (i.e., the eye-voice span measures) influenced the location of the first fixation on the word. An increase in postlexical processing difficulty resulted in first fixation locations towards the left edge of the word, which in turn implied multiple fixations as fixation duration analyses suggested. The words that received first fixations closer to the left edge of the words tended to allow fewer items in the memory buffer.

In Table 5.5, estimates of all LMM parameters for relative first landing position for both reading modalities (i.e., oral vs. silent reading) are presented.

Table 5.5 LMM parameter estimates for Relative First Landing Position (RFLP) in oral vs. silent reading

	Oral Reading						Silent Reading					
Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status	Estimate	Std. Error	df	t value	Pr(>|t|)	Signif. Status
Intercept	**-0.15**	**0.01**	**303.8**	**-18.35**	**< 2E-16**	**p < .0001**	**-0.12**	**0.01**	**318.8**	**-13.40**	**< 2E-16**	**p < .0001**
Predictability of word n (P0)	0.01	0.01	170.4	1.19	0.24	NS	0.01	0.01	199.8	0.64	0.52	NS
Stem frequency of word n (SF0)	0.002	0.003	238.6	0.90	0.37	NS	**0.01**	**0.003**	**232.1**	**2.59**	**0.01**	**p < .05**
Word length of word n (WL0)	**0.77**	**0.08**	**193.8**	**9.55**	**< 2E-16**	**p < .0001**	**0.77**	**0.09**	**199.1**	**8.41**	**8.09E-15**	**p < .0001**
Suffix count of word n (SC0)	**-0.01**	**0.003**	**182.8**	**-3.84**	**1.68E-04**	**p < .0001**	**-0.01**	**0.004**	**184**	**-2.75**	**0.01**	**p < .001**
Trigram frequency of word n (TF0)	**0.01**	**0.01**	**211.8**	**2.27**	**0.02**	**p < .05**	**0.01**	**0.01**	**234**	**2.00**	**0.05**	**p < .05**
Vowel harmony of word n (VH0)	0.002	0.01	220.5	0.37	0.71	NS	0.0001	0.01	235.1	0.02	0.98	NS
Familiarity	0.01	0.01	1903	1.07	0.28	NS	0.01	0.01	2222	1.52	0.13	NS
Spatial eye voice span (EVS)	**0.02**	**0.002**	**10800**	**6.65**	**3.04E-11**	**p < .0001**	-	-	-	-	-	-
Fixation speech interval (FSI)	**-0.06**	**0.01**	**240.5**	**-8.63**	**8.43E-16**	**p < .0001**	-	-	-	-	-	-
Launch site of word n (LS0)	**-0.08**	**0.003**	**193.6**	**-27.06**	**< 2E-16**	**p < .0001**	**-0.09**	**0.002**	**11990**	**-39.94**	**< 2E-16**	**p < .0001**
Predictability of word n-1 (P1)	0.01	0.003	186.4	1.41	0.16	NS	**0.01**	**0.004**	**189**	**2.54**	**0.01**	**p < .05**
Stem frequency of word n-1 (SF1)	**-0.01**	**0.003**	**176.1**	**-2.32**	**0.02**	**p < .05**	-0.002	0.004	188.5	-0.43	0.67	NS
Word length of word n-1 (WL1)	**-0.43**	**0.09**	**193.1**	**-4.92**	**1.85E-06**	**p < .0001**	**-0.70**	**0.10**	**199.3**	**-6.98**	**4.19E-11**	**p < .0001**
Suffix count of word n-1 (SC1)	0.001	0.003	182.5	0.41	0.68	NS	-0.002	0.004	202.1	-0.55	0.58	NS
Predictability of word n+1 (P2)	**-0.01**	**0.01**	**188.6**	**-2.43**	**0.02**	**p < .05**	**-0.01**	**0.01**	**208.6**	**-2.08**	**0.04**	**p < .05**

Stem frequency of word n+1 (SF2)	-0.01	0.002	172.3	-1.92	0.06	NS	-0.001	0.003	179.1	-0.43	0.67	NS
Word length of word n+1 (WL2)	**0.22**	**0.09**	**179.6**	**2.51**	**0.01**	**p < .05**	-0.03	0.10	188	-0.26	0.79	NS
Suffix count of word n+1 (SC2)	0.004	0.003	181.7	1.21	0.23	NS	-0.001	0.004	188.9	-0.17	0.87	NS
Trigram frequency of word n+1 (TF2)	-0.01	0.01	178.2	-1.44	0.15	NS	-0.01	0.01	183.5	-1.39	0.17	NS
Vowel harmony of word n+1 (VH2)	**-0.01**	**0.01**	**168.9**	**-2.27**	**0.02**	**p < .05**	**-0.02**	**0.01**	**182.7**	**-2.22**	**0.03**	**p < .05**
Launch site of word n+1 (LS2)	**-0.05**	**0.002**	**10590**	**-20.92**	**< 2E-16**	**p < .0001**	**-0.07**	**0.003**	**388.5**	**-23.50**	**< 2E-16**	**p < .0001**
WL0 x SF0	0.04	0.03	238.3	1.54	0.12	NS	0.01	0.03	239.6	0.37	0.71	NS
WL0 x SF2	-0.02	0.04	189.7	-0.64	0.53	NS	**0.10**	**0.04**	**205.6**	**2.20**	**0.03**	**p < .05**
WL0 x TF2	0.08	0.11	195.3	0.76	0.45	NS	-0.14	0.13	195.9	-1.08	0.28	NS
WL0 x VH2	-0.03	0.09	189.7	-0.31	0.76	NS	0.07	0.10	200.5	0.68	0.50	NS
SF0 x SF2	0.001	0.001	182.3	0.42	0.68	NS	0.0001	0.001	180.1	0.04	0.97	NS
SF0 x TF2	-0.01	0.004	200	-1.65	0.10	NS	-0.01	0.004	190.8	-1.72	0.09	NS
SF0 x VH2	**-0.01**	**0.004**	**185.4**	**-2.28**	**0.02**	**p < .05**	**-0.01**	**0.01**	**188.4**	**-2.19**	**0.03**	**p < .05**
SF1 x SF0	0.0001	0.001	187.3	0.05	0.96	NS	0.001	0.001	193.9	0.42	0.67	NS
SF1 x TF0	**-0.01**	**0.003**	**181.2**	**-2.16**	**0.03**	**p < .05**	-0.002	0.004	201.6	-0.48	0.63	NS
SF1 x VH0	0.01	0.003	183.6	1.75	0.08	NS	0.001	0.004	191.7	0.36	0.72	NS
Familiarity x TF0	0.003	0.01	4383	0.55	0.58	NS	0.01	0.01	2079	0.88	0.38	NS
Familiarity x VH0	-0.003	0.01	1157	-0.41	0.68	NS	-0.01	0.01	1356	-0.92	0.36	NS
WL1 x LS0	**-0.38**	**0.08**	**170.3**	**-5.04**	**1.18E-06**	**p < .0001**	**-0.41**	**0.05**	**11630**	**-8.04**	**9.83E-16**	**p < .0001**
LS2 x SF2	**0.003**	**0.002**	**10650**	**2.05**	**0.04**	**p < .05**	**0.01**	**0.002**	**11850**	**9.15**	**< 2E-16**	**p < .0001**
LS2 x P2	**-0.02**	**0.004**	**7443**	**-4.55**	**5.45E-06**	**p < .0001**	**-0.02**	**0.004**	**5734**	**-3.59**	**3.37E-04**	**p < .0001**

Random effects:		Oral Reading		Silent Reading	
Groups	Name	Variance	Std.Dev.	Variance	Std.Dev.
Participant	Intercept	0.0032	0.06	0.0037	0.06

Participant	Predictability of word n (P0)	0.0004	0.02	0.0009	0.03
Participant	Trigram frequency of word n (TF0)	-	-	0.0002	0.01
Participant	Fixation speech interval (FSI)	0.0029	0.05	-	-
Participant	Word length of word n-1 (WL1)	0.0417	0.2	-	-
Participant	Suffix count of word n-1 (SC1)	-	-	0.0001	0.01
Participant	Predictability of word n+1 (P2)	-	-	0.0004	0.02
Participant	Suffix count of word n+1 (SC2)	-	-	0.00004	0.01
Participant	Launch site of word n+1 (LS2)	-	-	0.0005	0.02
Word	Intercept	0.0005	0.02	0.0007	0.03
Word	Launch site of word n (LS0)	0.0006	0.02	-	-
Residual		0.0152	0.12	0.0167	0.13
The number of obs.		11081		12225	
Groups	Participant		196		
	Word		192		

An x between variables indicates interaction. Significant coefficients were set bold (NS: not significant). VH estimates belong to category 1 (violation of the rule), and Familiarity estimates belong to category 1 (unfamiliar).

6. DISCUSSION AND CONCLUSION

A set of perceptual and cognitive processes form an assembly at different levels, from low-level visual perception to high-level discourse comprehension during reading. Accordingly, research on reading focused on various aspects of the phenomenon, from oculomotor control, word recognition, and comprehension in skilled reading to reading skill acquisition and the effect of aging (e.g., Rayner, 1998, 2009a; Blythe & Joseph, 2011; Li et al., 2017). The technical and theoretical tools employed in the reading research, including behavioral experiments, neuroimaging techniques, and computational models of eye movement controlling, reflect the diversity of the focus on various levels of the underlying processes, ranging from prelexical processing and word recognition to syntactic parsing, sentence comprehension, and discourse comprehension (see Rayner, 1998, 2009a; Rayner et al., 2012 for reviews). The focus of the current study was the early prelexical and lexical processes, and postlexical integration processes involved in word recognition during text reading from a perspective of eye-movement control modeling. A framework for a computational model of eye-movement control that includes the role of phonological processes during reading was provided.

In Rayner's terms (2009b), the emergence of the computational models of eye-movement control as the fourth era of reading research, preceded by initial observations about the basic facts about eye movements, exploring the surface properties of eye movements, and investigation of cognitive processes underlying reading with advanced eye-tracking technologies (Rayner, 1998, 2009a, 2009b). Since the late 1990's the focus of the reading research has been investigating the validity of eye-movement control models of reading and their predictions. The theoretical explanation of the *eye-mind link* (i.e., the relationship between lexical processes and eye-movements during reading) provided by eye-movement control models enabled novel predictions that lead empirical studies and account for counterintuitive findings (Rayner, 2009b).

In addition to proposed word identification mechanisms, a crucial aspect of eye-movement control models is their conception of attention and its relation with eye-movements. Reading is, essentially, the extraction of information embedded in a configuration of written symbols by exploiting attentional mechanisms and the oculomotor system. We *attend* the content of the text and exploit the oculomotor system to *bring the text to fovea* most of the time during reading. Therefore, the nature of the attentional system and its relationship with the oculomotor system is central to most of the debates in the reading research that employ a computational modeling approach.

Posner (1980) provided evidence for the dissociated but functionally tied systems of covert attention and eye movements. Evidence from neuroimaging studies supported the claim of two systems of overt and covert orienting of attention with a functional relationship (for reviews of neuroimaging studies, see Petersen & Posner, 2012, and Buschman & Kastner, 2015).

Since in the experiments designed to investigate text reading, participants mostly were allowed to move their eyes freely while their eye-movements were recorded, a dissociation between the allocation of attention and eye-movements is less obvious than relatively simple tasks such as orienting attention to an increased luminance in the peripheral visual field without moving the eyes (e.g., Posner, 1980). However, studies that employed *contingent display technique* (McConkie & Rayner, 1975) provided evidence for the dissociation between covert attention and eye movements. The contingent display change paradigms provide an investigation of *perceptual span* during reading (i.e., the region from which useful information intake is possible during one fixation). In the *gaze-contingent moving-window/mask* technique, the amount of text visible to the participants was manipulated through gaze-contingent windows or masks (McConkie & Rayner, 1975; Rayner & Bertera, 1979). In the other technique used to investigate the perceptual span, the *gaze-contingent invisible boundary* technique (Rayner, 1975), a target word is replaced by another word or by a non-word until the eyes crossed an invisible boundary. These techniques test the assumption that any restriction on the perceptual span would increase the processing times of words. Studies showed that as the window size decreased or mask size increased, reading speed and saccade lengths decreased, fixation durations and fixation counts increased (Rayner, 1975; McConkie & Rayner, 1975; Rayner & Bertera, 1979). Studies on perceptual span showed that readers obtain useful information 14-15 characters to the right of fixation and 3-4 characters to the left of it (McConkie & Rayner, 1976; Rayner et al., 1980; but see Jordan et al., 2016, 2017 for conflicting findings). Cross-linguistic studies confirm this finding (DenBuurman et al., 1981; Häikiö et al., 2009; O'Regan, 1983). The findings that indicate that the asymmetry of the perceptual span was dependent on the direction of the writing system such that the span was larger to the direction of reading (right to left direction (Hebrew and Arabic): Pollatsek et al., 1981; Jordan et al., 2014; vertical direction (Japanese): Osaka & Oda, 1991; Osaka, 1993; both horizontal and vertical direction (Mongolian): Su et al., 2020). On the other hand, the writing system influenced the size of the perceptual span, as well. Studies in Chinese showed that perceptual span is narrower in Chinese with one character to the left of the fixation and 2-3 characters to the right of the fixation (Chen & Tang, 1998; Inhoff & Liu, 1998; see Osaka, 1987, 1992 for a similar result for Japanese). The findings of an extended perceptual span in the reading direction accepted as evidence for the assumption that perceptual span is asymmetrical to reading direction due to covert attention directed accordingly (see Henderson, 1992 for a discussion). Therefore, most of the successful eye-movement control models of reading assume the dissociation between covert attention and eye movements with an asymmetric perceptual span (e.g., Engbert et al., 2002; Reichle et al., 1998).

The eye-movement control models essentially simulate eye movement patterns given their proposed *mechanism* for lexical processing, attentional system, and their relationship with the oculomotor system during reading. In doing so, the models aim to account for and predict frequently reported effects of word characteristics on eye movement measures, under their assumptions (Rayner, 1998, 2009a, 2009b; Rayner et al., 2012; Clifton et al., 2016).

The models of eye-movement control differ in their assumptions about (1) the role of the cognitive system, (2) the nature of the attentional system, and (3) the relationship between the oculomotor system and lexical processing. According to the first distinction, models are grouped as *cognitive-control models* (or *processing models*) and *oculomotor-control models* (or *primary oculomotor models*, or *oculomotor models*). In the extreme version of cognitive-control models, eyes stay on a word until its processing, including postlexical integration, completes, and in that of oculomotor-control models, eye movements are the result of the oculomotor system and low-level visual information, almost exclusively (Rayner, 1998, 2009b; Reichle, 2006; Reingold et al., 2012). Current eye-movement control models are at neither edge of the spectrum in the sense that they assume the influence of both the oculomotor system and lexical processing on eye movements, with a differing weight on each system. The second distinction between eye-movement control models depends on their conception of attention. According to *serial attention shift* (SAS) models, attention is conceptualized as a *spotlight* that moves over the text serially and monitors eye movements such that a saccade programming starts upon a shift of attention. According to the *guidance by attentional gradient* (GAG) models, attention is a gradient that guides eye movements rather than a spotlight that monitors eye movements. In SAS models, words are processed serially depending on the attentional shifts, while GAG models allow words to be processed in a distributed fashion within the perceptual span. The third distinction is a distinction related to the other two such that mostly SAS models usually assume an oculomotor system that is monitored by lexical processing while GAG models assume an indirect influence of linguistic processes on eye movements. Although the rough distinctions made here are relevant to the current study in which a framework for a GAG model was presented, these are not the only possible distinctions available (Rayner, 1998, 2009b; Reichle et al., 2003; Reichle, 2006; Reingold et al., 2012; Radach & Kennedy, 2013; Clifton et al., 2016).

The influence of phonological processing in reading is the other crucial aspect of the current study. The role of sound coding in reading studied (1) as early phonological processing and its role in lexical access, and (2) as a later phonological representation of words and its role in short term memory retention and postlexical processing during reading. Therefore, several experimental paradigms have been employed to study the role of sound coding in reading, including masked phonological priming, articulatory suppression, distraction by auditory input, electromyography recordings of articulatory muscles, gaze-contingent boundary paradigm that accompany tasks such as naming, lexical decision, semantic categorization, and sentence or text reading (e.g., Slowiaczek & Clifton, 1980; Van Orden, 1987; Guerrero, 2005; Inhoff et al., 2004; Eiter & Inhoff, 2010; Ashby et al., 2006).

There is almost consensus on the role of phonological representations in memory retention and postlexical processing (e.g., Inhoff et al., 2004; Eiter & Inhoff, 2010; Inhoff et al., 2011; Laubrock & Kliegl, 2015; for reviews Rayner et al. 2012; Rayner, 1998; Leinenger, 2014) and the role of early phonological processing in reading acquisition (Blythe & Joseph, 2011; Jared et al., 2016; Milledge & Blythe, 2019). However, the early role of phonological processing in lexical access for skilled reading is controversial. That is whether words are accessed only through phonological representations even by skilled readers (i.e., strong phonological theory), or is there a structural change in skilled reading with an addition of a route which provides direct access from the orthography of a word to its lexical entry (i.e., weak phonological theory, or dual-route model). Although both approaches include phonological processing in lexical access, they differ in the *mandatory* status of it. According to the dual-route conception of reading of the weak phonological theory, phonological computation is required when the task requires only (e.g., reading a low-frequency word or a pseudoword). Strong phonological theory, on the other hand, suggests that prelexical phonological processing is the default procedure in lexical access such that phonological representations are always constructed by prelexical phonological processing without direct access through orthographic lexicon to words (Frost, 1998, Coltheart et al., 2001). Both theories claim that there is more prelexical influence than a lexical influence on phonological processing in shallow orthographies that contrasts with the dominance of the lexical aspect of phonological processing in deep orthographies (Frost, 2005; Coltheart et al. 2001).

In the current study, a framework for a computational GAG model that includes the early and late roles of sound coding in reading was proposed. Therefore, the model proposed in the current study, Phonological-Mediation in Guidance by Attentional Gradient (P-GAG), was not a computational model but a framework for it. The model accepted the main assumptions of SWIFT, an eye-movement control model of reading (Engbert et al., 2002; Engbert et al., 2005; Richter et al., 2006; Schad & Engbert, 2012). As in SWIFT, in P-GAG, words are processed in a distributed fashion within the perceptual span with an indirect influence on eye movements through their inhibitory role on autonomous oculomotor processes. In SWIFT, eye movements are guided by an activation field of words. Activation of words mainly depends on their distance from the fixation (i.e., eccentricity), while the maximum activation of a word is limited by its difficulty (i.e., frequency). Activations start to build up parafoveally, reach their maximum during the preprocessing stage, and decay as a function of predictability until they are completely processed. Any word that has a non-zero activation value can be the target of a saccade.

The main distinction between SWIFT and P-GAG is the inclusion of phonological prelexical processing in word identification and a memory buffer for postlexical processing. Accordingly, a prelexical phonological processing component was added to the word identification system of SWIFT. The new component was linked to preprocessing and lexical completion, as postulated in SWIFT. It was assumed that prelexical phonological processing could be measured by prelexical word characteristics that reflect phonotactics (Acartürk et al., 2017b) and adds to the difficulty of words. Therefore, in addition to their frequencies, the maximum activation value is influenced by prelexical characteristics of words. According to P-GAG, upon their identification, words enter to the memory buffer for postlexical text integration and motor planning for articulation in oral reading. Accordingly, articulating a word during oral reading accepted as a clear indication of removal from the buffer. Therefore, fixation speech interval (FSI), which is the time interval between the beginning of the first fixation on a word and the beginning of the articulation of it assumed to represent the time course from prelexical phonological processing to postlexical integration of a word during oral reading. In addition to the inhibitory connection from the word identification system to the oculomotor system in SWIFT, in P-GAG, there are inhibitory connections from motor planning to postlexical processing, and between postlexical processing and second stage of word identification (i.e., lexical completion). Therefore, according to P-GAG, any difficulty in motor planning or word identification delays postlexical processing, and any difficulty or delay in postlexical processing interferes with word identification.

The assumptions of P-GAG, including those inherited from SWIFT, were tested by several Linear Mixed Models (LMMs) with data from Turkish Reading Corpus (Acartürk et al., 2017a). The stimulus target words of Turkish Reading Corpus were organized according to their lengths, stem frequencies, and suffix counts. Target words were presented to participants in texts for reading aloud or silently. The reading modality and conditions that depend on word characteristics were counterbalanced among participants.

There were seven LMMs in the current study to test the assumptions of P-GAG such that one LMM of FSI for oral reading, two LMMs of first fixation duration (FFD) for oral reading and silent reading, two LMMs of gaze duration (GD) for oral reading and silent reading, and two LMMs of relative first landing position (RFLP) for oral reading and silent reading. The assumptions of P-GAG related to the distributed processing of words, which were inherited from SWIFT, were tested by the inclusion of the characteristics of neighboring words and their interactions with target words in LMMs. The assumptions related to prelexical phonological processing were tested by the inclusion of prelexical characteristics of words (i.e., trigram frequencies and vowel harmonies of target and neighboring words) in LMMs. Lastly, the assumptions related to postlexical processing were tested for oral reading with an LMM of FSI and by the inclusion of FSI and the spatial measure of the eye-voice span (EVS) to LMMs for oral reading instances. It was assumed that FSI would increase with difficulties in postlexical processing and hence, would reflect difficulties faced during postlexical processing. On the other hand, the distance of the eyes from the target word at the beginning of articulation of the target word (i.e., EVS) was assumed to reflect the load in the memory buffer. To investigate the factors that influence the capacity of the memory buffer, a baseline-category logit model (BCLM) of the distance in terms of word count between the target word and the fixated word at the beginning of the articulation of the target word was provided in APPENDIX D.

The results of the LMMs were compatible with the frequently reported findings in the literature such that the mean first landing positions were slightly left of the word centers; saccade amplitudes were approximately 7 characters during reading aloud and approximately 8 characters during reading silently; mean first fixation duration was 283 ms among oral reading instances and 247 ms among silent reading instances; mean gaze duration was 511 ms during reading aloud and 381 ms during reading silently; first fixations that landed towards the center of words had longer durations than they landed at the edges of words; less frequent words, longer words, less predictable words, and words had more suffixes fixated longer, tended to receive multiple fixations, and first fixations closer to their left edges; as the distance of the previous fixation to the foveal word increased fixation durations increased and eyes tended to land closer to their edges (for reviews: Rayner, 1998, 2009a, 2009b; Rayner et al., 2012; Inhoff et al., 2011 for English; Kliegl et al., 2006; Kliegl, 2007; Laubrock & Kliegl, 2015 for German; Pollatsek et al., 2000; Hyönä & Pollatsek, 1998; Järvilehto et al., 2009 for Finnish; Yan et al., 2014 for Uighur; Deutsch & Rayner, 1999 for Hebrew; Paterson et al., 2015 for Arabic; Özkan et al., 2020 for Turkish). Influences of the neighboring words on eye movement measures in the current study were mixed. Increased fixation durations and the tendency of first landing locations towards the left edge of the words together with less predictable previous words during reading silently indicated a spillover of the processing a difficult previous word on the foveal word while the effect was not observed among oral reading instances. Length of the previous word influenced first fixation duration and relative first landing position during reading aloud, while among silent reading instances, the effect was observed only on relative first landing position. Frequency of the previous word, on the other hand, influenced relative first landing position only among oral reading instances. Successor effects of the predictability of the next word and length of the next word on the foveal word were observed in relative first landing position together with an influence of the frequency of the next word on first landing position dependent on the length of the foveal word. For successor effects on fixation durations, although only next word length influenced gaze duration during silent reading, there was an influence of predictability on gaze durations in both modalities if the next word was close to the last fixation on the foveal word.

The results of the LMMs indicated an influence of prelexical phonological processing on eye movements. In general, words fixated longer, and first fixations tended to land on the left edges of the words if trigram frequencies of them were low and if the next word was not respected vowel harmony. The influence of trigram frequency was stronger if the previous word was an infrequent word, and the influence of the vowel harmony of the next word was stronger if the foveal word was a frequent word. These results implied that parafoveal processing was decreased while fixating a difficult word. The interaction effects mentioned were indicators of foveal load hypothesis but on parafoveal processing of prelexical characteristics, rather than lexical characteristics (Kliegl et al., 2006, Kliegl, 2007). Although the effect of trigram frequency on fixation durations during oral reading was stronger among unfamiliar words, it was not lost among familiar words, which suggests prelexical phonological processing, even for familiar words. The familiarity of a word did not change the effect of trigram frequency while reading silently. The effects of prelexical characteristics of words on eye movement measures were accepted as signs of early influences of prelexical phonological processing on word identification times and saccade target selection.

The mean values of FSI were greater than 600 ms in the current study. That was greater than FSI found in English and German (486 ms in Inhoff et al., 2011 for English; 561 ms in Laubrock & Kliegl, 2015 for German) but close to that of Finnish (625 ms in Järvilehto et al., 2009). The mean values of EVS, on the other hand, were less than the findings reported in the literature (15-17 characters in Buswell, 1920; 16 characters, which was computed from first fixation onset in Laubrock & Kliegl, 2015). In Turkish, among short words, approximately one more word was viewed during FSI while the eyes tended to be on the same word at the beginning of its articulation for long words either by staying on the same word or returning to the word. Turkish has a shallow orthography. Therefore, the discrepancies observed in eye-voice span measures in Turkish sentence reading with the literature suggests that the distance between the eyes and the voice might be a function of phoneme count, rather than character count. The higher values of FSI in Turkish and Finnish, on the other hand, might be an indicator of increased need for prelexical phonological processing for languages with shallow orthographies (Frost, 1998, 2005; Coltheart, 2001).

The increase in FSI together with the increase in memory load (i.e., the effect of EVS), and decrease in predictability and frequency of words were accepted as an indicator of a delayed removal from the memory buffer (i.e., late articulation) due to increased difficulty in postlexical processing, according to P-GAG. Although the negative effect of word length on FSI was not significant, the results of the additional BCLM analysis indicated an indirect effect of word length through memory load. According to the results of BCLM, longer words tended to be fixated at the beginning of their articulation, either because eyes were not left the word yet at the beginning of articulation or because eyes returned to the word at the beginning of articulation. Shorter words, on the other hand, articulated while eyes were on the next word or further, which is an indicator of increased memory load with more than one word. Although the effect of word length on FSI was not significant, an increase in FSI, together with a decrease in word length, strengthens the interpretation of the influence of memory load. Among the prelexical characteristics of words, only trigram frequency of the next word influenced FSI, which was modulated by the length and frequency of the foveal word with stronger effects for short and infrequent words. Although unfamiliar words articulated later, familiarity did not change the effects of prelexical characteristics of words on FSI. Lastly, increased suffix count of the previous word showed a facilitating effect on postlexical processing with decreased FSI values. However, a more controlled study is required to understand the nature of the relationship between FSI and suffix counts due to the confounding effect of word length.

Lastly, as an indicator of postlexical processing difficulty FSI and as an indicator of memory load EVS influenced eye movement measures. Increased FSI values accompanied by increased fixation durations and first fixations closer to the left edge of words, implying that difficulty in postlexical processing result in a delay in word identification and probably refixations as suggested by P-GAG. On the other hand, for high EVS values, longer fixation durations and closer first fixations towards the center of words indicated that words that were easier to identify allowed memory buffer to hold more items.

In conclusion, in the current study, the P-GAG model of reading as a theoretical framework for an eye-movement control model that includes the role of sound coding was proposed. Most of the assumptions of P-GAG was supported by the statistical analyses. However, there were limitations regarding the experimental study. Firstly, it is not as evident as *prima facie* that the fixation durations selected in the current study reflect lexical access. Especially gaze duration as the sum of fixation durations in the first pass ignores the difference between processing times and corrective fixations. A follow-up study by investigating processing times fixation-by-fixation while taking intra-word forward and backward saccades into account would provide a clearer picture.[9] Similarly, it was highly probable that there were effects of processing related to prosodic features of the text on FSI. The follow-up studies that control prosodic

[9] We thank Prof. Dr. Reinhold Kliegl for mentioning the limitations of gaze duration as a measure for the processing time of a word (2019, personal communication).

features of words would provide a better understanding of the postlexical processes during FSI.[10] The other limitations regarding the empirical study were about the stimulus set. There was the confounding factor of word length on understanding the effects of inflectional suffix counts. As a second limitation related to the experimental study, the prelexical characteristics of words were not controlled for appearance in the stimulus set. In follow-up studies, the assumptions of P-GAG could be investigated with control on the stimuli specific to those assumptions. Turkish, with its agglutinative nature and shallow orthography, would provide a fruitful environment for the investigation of controversies in reading research regarding both distributed vs. serial processing and the influence of early prelexical phonological processing.

Last but not least, P-GAG, as a theoretical framework for a computational eye movement control model of reading, has theoretical limitations inherited from the eye-movement control modeling approach. Eye-movement control models of reading focus on a specific and narrow aspect of the complex cognitive processing underlying reading: the influence of word recognition processes on eye movements while reading a text. Even the explanations of lexical and postlexical processes are limited in these models – i.e., they are almost *black boxes*. They propose a coupled system of oculomotor processes and linguistic processes mediated by attentional mechanisms, with a limited explanation of inner processes of word recognition modules. Indeed, eye movement control models of reading could be deemed as explanations of the interface between cognitive processes that take place during reading and observable behavior, eye movements. Despite the fact that they provide a limited explanation of reading, in the past several decades, the eye-movement control modeling approach enhanced our understanding of reading as a cognitive process. Owing to the reading research guided by those models, we learned that linguistic processes do not strictly guide eye movements, but eyes do not move randomly over the text during reading, neither. We now know that eye-movements are influenced by the properties of the text. The assumption of a loosely coupled system of oculomotor processes and linguistic processes provided a foundation for testing theories of reading with physiological data. Although it was beyond the scope of the current study, eye movement control models of reading have the potential for an extension to include higher-level processes like syntactic processing or discourse comprehension. Despite their current limitations, we find them promising in the endeavor of understanding cognitive processes, at least during reading.

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APPENDICES

APPENDIX A: Stimuli and Comprehension Questions

Stimulus Texts

Short-Frequent Condition

Suffix	Word	Text
-	asit	Kapakçık ters çalışıyor ve midenin salgıladığı *asit* yemek borusunu tahriş ediyor, siz de sürekli öksürüp tıksırıyorsunuz.
-DA	asitte	Zaman kapsülünün içindeki eşyalar *asitte* yıkanmalarının ardından pirinç bir kutuya yerleştirilmişlerdi.
-DAki	asitteki	Tuz, kimyada, bir tepkime neticesinde oluşan maddedir ve bazdaki pozitif yüklü iyonla *asitteki* negatif yüklü iyondan meydana gelir.
-	depo	Teknenin taşıyabileceği tatlı su miktarı belirlenirken teknenin tasarımcısının planlarında hangi miktar *depo* hacimleri öngördüğü incelenmelidir.
-DA	depoda	Uzun yıllar boyunca *depoda* bekleyen geçmişim, bana dünyayla arasına duvarlar ören bir ülkeyi hatırlattı.
-DAki	depodaki	Kitle içindeki her birey *depodaki* farklı bir bilgiyi seçip ulaşabilir ve yayıncı kuruluşa gönderebilir.
-	doku	Üretim ortamları hazırlanarak alınan *doku* parçalarının bu ortamlara konulmasıyla köklendirme işlemleri gerçekleştirilmektedir.
-DA	dokuda	Hastanın hormon tedavisinden faydalanıp faydalanamayacağını görmek için alınan kanserli *dokuda* östrojen ve progesteron reseptörlerini tayin etmek gereklidir.
-DAki	dokudaki	Erişkin kök hücreler her yaştaki insanda bulunmakta ve ihtiyaç duyulduğunda bulundukları *dokudaki* değişik hücre türlerine dönüşebilmektedirler.
-	etüt	Haftada bir gün, cuma öğlenleri okulun *etüt* salonunda toplanıp, mısır - çıtır atardık birbirimize.
-DA	etütte	Heyecanlıydım çünkü bir gün önceki *etütte* kartlarını alamayan ve kartsız kalan çocuklar o gün öğle yemeğine çıkamayacaktı.
-DAki	etütteki	Öğrencilerin okuldaki durumlarından *etütteki* başarılarına kadar çeşitli konularda öğrencileri takip etmenizi sağlayan bir sistemdir.
-	fuar	Merkez bu yıl da çocukların sosyal ve toplumsal değerine katkıda bulunmak amacıyla *fuar* boyunca elde edeceği geliri çocuk yuvasına bağışlayacak.
-DA	fuarda	Şehir ekonomisine katkı sağlamak ve ticari hayatı hareketlendirmek amacıyla düzenlenen *fuarda* ziyaretçiler aradıkları tüm materyalleri bulabilecekler.
-DAki	fuardaki	Farklı ülkelerden gelen ziyaretçilerin *fuardaki* mevcut firmalarla markalarını buluşturmaları sağlanarak yeni iş fırsatları ortaya çıkmıştır.
-	gişe	Maddenin aslıyla muhatap olunup olunmadığı bilinemez. Açıkçası konu hakkında *gişe* rekorları kıran filmler bile çekilmişken bu teoriye kulak kabartmamak olmaz.

Suffix	Word	Text
-DA	gişede	Onda şeytan tüyü var: Çevirdiği filmler *gişede* başarılı oluyor, daha önemlisi, özel hayatını filmlerinin önüne geçirmiyor.
-DAki	gişedeki	Eski klişeye uygun olarak, bilet almak için sırada bekleyen müşterilere rağmen *gişedeki* bütün memurlar o anda moladaydı.
-	jüri	Rock müziğin önemli isimlerinden oluşan *jüri* tarafından yapılacak elemelerin ardından finale katılma hakkı kazanan gruplar, canlı performanslarıyla yarışacak.
-DA	jüride	Fotoğraf Sanatı Kurumu üyelerinin *jüride* bulunmaları tamamen iradeleri dışında gelişmiştir.
-DAki	jürideki	Hemen rezervasyon defterlerine bakıp *jürideki* isimleri arıyorlar ve 68 kişilik ekipten sadece 8 kişinin geldiğini öğreniyorlar.
-	kıta	Asya'nın en çok nüfus barındıran *kıta* olması özelliği korunmaktadır. Üstelik toplam nüfus içindeki payı da artmıştır.
-DA	kıtada	Güneşe tapmak, bir zamanlar egemen olduğu *kıtada* kutsallığını kaybetmiş olsa da etkisini yeni yöntemlerle sürdürüyor.
-DAki	kıtadaki	Avustralya onbinlerce yıldır *kıtadaki* yerliler tarafından yurt edinilmiş olmakla birlikte, yakın zamana kadar diğer ülkelerce bilinmiyordu.
-	kıyı	Kalenin denize hakim oluşu ve ticaret yollarının birleştiği noktada bulunuşu *kıyı* kontrolü amaçlı bir yapı olduğunu göstermektedir.
-DA	kıyıda	Merdivenlerden inin ve masmavi denizin *kıyıda* turkuaza dönüştüğü bu minik sahildeki dalgaların keyfini çıkarmadan sakın buradan ayrılmayın.
-DAki	kıyıdaki	Özellikle baskın avlarında *kıyıdaki* dalgaların hareketliliği dengemizi bozabileceği için ağırlık seçimini uygun ayarlamalıyız.
-	masa	Bu çare arayışında ben biliyorum anlayışı yok. Diyalog var. Burada en önemlisi *masa* etrafında sorunları tartışabilmek.
-DA	masada	Bu tozlu baraka senelerdir önemli bir bilgi akış noktası olmuştu. Dolayısıyla birazdan *masada* duran zarfın içinden çıkacaklar da önemli görünüyordu.
-DAki	masadaki	Kasabaya yakın olmanın avantajından *masadaki* çilek reçelini tadarak yararlanıyoruz.
-	ofis	Saatlerce oturarak çalışan bir kişinin *ofis* şartları ergonomik değilse bu kişi sağlık problemlerine gebedir.
-DA	ofiste	İki yılı bulan ekonomi muhabirliği görevinden sonra vaktinin büyük bir kısmını *ofiste* geçirmesinin nedeni olan editörlük süreci başlar.
-DAki	ofisteki	Çalışanlarla birlikte kendi sosyal komünlerini kuran kediler mekana yeni bir düzen getirirken *ofisteki* günlük hayatın tüm süreçlerine katıldılar.
-	öykü	Anlatının derin yapısı üstünde dururken bu tür sorulara yönelmek, tüm ilgiyi belli başlı *öykü* kişileri arasındaki ilişkiler üstünde topluyor.
-DA	öyküde	Etrafına çizilen daireden çıkamayan adamın azınlıkta kalan bireylerin simgesine dönüştüğü *öyküde* tarihsel bir arka plan varlığını duyuruyor.

Suffix	Word	Text
-DAki	öyküdeki	Sonunda adet olduğu üzere mutlu sona ulaşıldığında sarışın kız kardeş *öyküdeki* büyük ödüle kavuşurken esmer kız kardeşe düşen ölüp gitmektir.
-	saha	Eğer kaleci topu yumruklayıp *saha* dışına atarsa veya topu yakalayıp durdurursa şutu çeken kaleye geçiyor.
-DA	sahada	Sayı almak için vuruş yapılan topun *sahada* rakip oyuncu topa vuramadan iki kere sıçraması gerekir.
-DAki	sahadaki	Herhangi bir erteleme halinde, aksi kararlaştırılmaz ise, önceki skor ve oyuncuların *sahadaki* duruş yerleri muhafaza edilir.
-	uçak	İlk belirlemeye göre kayıp *uçak* bulunmadığı halde yetkililer ihbarın yine de araştırıldığını bildirdi.
-DA	uçakta	New York seferini yapan *uçakta* yaşananlar şu sıralarda sosyal medyada büyük bir çalkantıya sebep oldu.
-DAki	uçaktaki	Motor, havayı çektiği için, kullanılan motor gücünü düşürüyor. Sıcakta ve basınç altında *uçaktaki* titanyum borularla hava dışarı veriliyor.
-	uyku	Karnını doyurup kapıdan çıkınca, neredeyse tüm kasabanın gözüne o gece boyunca *uyku* girmediğini gördü: Millet sokağa dökülmüştü.
-DA	uykuda	Her günün en fazla altı saatini *uykuda* geçirdiği için, geri kalan on sekiz saat, haksız bir işkence haline geliyordu.
-DAki	uykudaki	Yakınında bulunan çocukları *uykudaki* küçük köylünün yanına getiriyor ve gene bir şeyler söylüyordu.
-	üzüm	Üreticiler, talep baskısı sayesinde fazladan *üzüm* satarak daha çok para kazanmak amacıyla olabildiğince fazla verim almaya çalışıyor.
-DA	üzümde	Dalıyla birlikte ezilen *üzümde* bulunan bir maddenin kanı sulandırıcı etkisi var, her yerde satılıyor.
-DAki	üzümdeki	Son zamanlarda yapılan çalışmalar *üzümdeki* aroma maddelerinin büyük kısmının kabukta toplandığını göstermektedir.

Long-Frequent Condition

Suffix	Word	Text
-	alternatif	Olası senaryolar, bunlar karşısında uygulanılacak eylem planları, birbirlerini destekleyecek *alternatif* uygulamalar ve tercih sıralamaları karar aşamasının ürünleri.
-DA	alternatifte	Bu kumsalda hafta sonu tatili geçirmek isteyenler için çeşitli *alternatifte* konaklama olanakları bulunmaktadır.
-DAki	alternatifteki	Geçen sezonda belli renklerde sunulan kalem etekler, bu yıl yüzlerce farklı *alternatifteki* renkleri ile satışa çıkarılıyor.

Suffix	Word	Text
-	bilgisayar	Çocukla, evle ilgili bir iş yapmak şartıyla *bilgisayar* kullanma süresi kazanması konusunda bir sözleşme yapılabilir.
-DA	bilgisayarda	Çalışmalarım, elektriksel işaretlerin *bilgisayarda* modellenmesine ve simülasyonuna dayanıyor.
-DAki	bilgisayardaki	Okuma ve yazma izni olduğunda *bilgisayardaki* dosyalara erişim sağlanarak değişiklik veya dosya silme yapılabilir.
-	cumhuriyet	Fransız ulusu, büyük bir endişeyi geride bıraktı ve bu seçim sonuçlarıyla *cumhuriyet* değerlerine güvenoyu verdi.
-DA	cumhuriyette	Her yurttaş istediği federe *cumhuriyette* yaşama hakkına sahiptir. Bu hakka hiçbir şekilde müdahale edilemez.
-DAki	cumhuriyetteki	Bağımsızlıktan önce azınlıklar *cumhuriyetteki* çoğunluğa karşı, çoğunluklar Sovyet sistemine karşı kültürel ve siyasal hak talep etmişlerdir.
-	eleştirmen	Bazı hesaplaşmalar belki *eleştirmen* cephesinde daha fazladır ama doğrusu modern sinema seyircisi de farklı davranmaz ve aşağı yukarı aynı güzergâhta ilerler.
-DA	eleştirmende	Belirtilenlerden anlaşılacağı üzere, nesnel bir çeviri eleştirisi yapabilmek *eleştirmende* birtakım birikimlerin bulunmasını gerektirmektedir.
-DAki	eleştirmendeki	Yazar, modern kültürü ve yüzyılların düşüncelerini yeniden kendilerine mal eden birçok *eleştirmendeki* bilindik yerel içgüdüleri, parodileştirme yoluyla ifade etmektedir.
-	enfeksiyon	Sağlığını kaybedenler hastanelerde *enfeksiyon* tehlikesiyle de karşı karşıya kalıyor.
-DA	enfeksiyonda	Ama ateşi her yükselen hastanın mutlaka antibiyotik kullanması gerekmez. Her gribal *enfeksiyonda* hastanın ateşi zaten yükselir.
-DAki	enfeksiyondaki	Kalp hastalığını tetikleyen *enfeksiyondaki* bakteriler diş etinde de kanama, ağrı ve kokuyla kendini gösteriyor.
-	ilköğretim	Eğitim fakülteleri *ilköğretim* okullarına öğretmen yetiştirmeyi temel görev olarak üstlenirlerse bu alandaki açık kolaylıkla kapanacaktır.
-DA	ilköğretimde	Okullar geleceği şekillendirecek yeni nesillerin yetiştirildiği yerlerdir. Bireyin eğitiminde *ilköğretimde* görevli öğretmenlerin işlevi çok önemlidir.
-DAki	ilköğretimdeki	Kurumların işbirliği sayesinde *ilköğretimdeki* trafik konulu derslere trafik birimlerinde görevli yüksek öğrenim görmüş personelin girmesi sağlanmıştır.
-	istatistik	Binlerce eğitimli anketör, onları her ay ziyaret edecek ve defterlerdeki sonuçları *istatistik* normlara göre analiz yapılması için toplayacaklardı.
-DA	istatistikte	Girdi katmanı dışarıdan gelen verilerin yapay sinir ağına alınmasını sağlar. Bu veriler *istatistikte* bağımsız değişkenlere karşılık gelmektedir.
-DAki	istatistikteki	Bu soruyu yanıtlamadıkça veya bir tercih yapmadıkça diğer planlar maalesef kendilerini *istatistikteki* negatif sonuçla yüzleşmekten koruyamayacaktır.

Suffix	Word	Text
-	istihbarat	Eksik, belgesiz, delilsiz denemez çünkü hepsinin delili var. Örneğin bankanın *istihbarat* raporlarında kredi verilemez nitelikte bulunan firmalara kredi verilmiş.
-DA	istihbaratta	Üç yıldır telefonlarının dinlendiği anlaşılan bir gazetecinin bütün kayıtları *istihbaratta* bulunuyor olsa da belli ki kafaları karıştırmamak için içlerinden özenle seçiliyor.
-DAki	istihbarattaki	Acaba onun defteri *istihbarattaki* karanlık çalışmaları gibi siyah mı, yoksa farklı renkte mi olacak onu ise biz bilemeyiz.
-	karşılaşma	Yoğun yağmur yağışı nedeniyle özellikle asansör ve yürüyen merdivende meydana gelen arızalar *karşılaşma* öncesi yapılan çalışmalarla giderildi.
-DA	karşılaşmada	Bu yönetimin görev almasından sonra oynanan *karşılaşmada* camianın beklentisi galibiyetti. Fakat takım, bir dağınıklık içinde maça başladı.
-DAki	karşılaşmadaki	Maçtan önce bir bahis bürosunda görüntülenmesinin ardından *karşılaşmadaki* şüpheli hareketleri de dikkat çekmişti.
-	koleksiyon	Mezuniyet gecelerine özel olarak *koleksiyon* hazırlayan ünlü giyim markası, özel fiyatlar ve taksit olanakları da sunuyor.
-DA	koleksiyonda	Yıllar boyunca topladığı *koleksiyonda* yılların yaşanmışlığı olan figürlerin dantel duygusu ile işlenmiş eserler olduğunu vurguluyor.
-DAki	koleksiyondaki	Şık elbiselerin yer aldığı *koleksiyondaki* parçalar bağcıklı ve boncuklarla örülmüş kemerlerle tamamlanıyor.
-	komutanlık	Çeşitli karargâhlarda ve alaylarda *komutanlık* görevi yaptı. Bu yarı akademisyen subayı görev aldığı birliklerde herkes seviyordu.
-DA	komutanlıkta	Bayram dolayısıyla sınırın sıfır noktasında bulunan *komutanlıkta* askeri tören düzenlendi.
-DAki	komutanlıktaki	Alınan Dersler Şube Müdürlüğü'nün yaptığı görevi duyunca çok şaşırdım. Çünkü bu görev *komutanlıktaki* önemli görevlerden biriydi bana göre.
-	kooperatif	Arabam, taksitlerini ödediğimiz *kooperatif* evimiz ve birlikte aldığımız gayri menkullerden payımızı almak için gerekli başvuruyu yaptık.
-DA	kooperatifte	Uygulamaya geçildi ama sorunun devam ettiği bölgeler var. İzmit ile Gölcük arası taşımacılık yapan *kooperatifte* yaşananlar buna bir örnek.
-DAki	kooperatifteki	Ortakların sorumlu olacakları miktar *kooperatifteki* paylarının tutarı ile orantılı olarak da gösterilebilir.
-	perspektif	Devlet Bakanı, uzun vadeli *perspektif* içinde siyasal güven, toplumsal güven ile ekonomik ve finansal güvenin birlikte olduğunu savundu.
-DA	perspektifte	Diğer disiplinlerle de bağlarını kurar; müzik sanatını eğitim, estetik, tarih gibi birçok *perspektifte* inceleyerek sonuçlara varır.
-DAki	perspektifteki	Tüm dünyadaki tarih yazımında çok önemli etkiler yapmışlar ve bunun karşılığında tarihsel *perspektifteki* değişimlere de katkıda bulunmuşlardır.

Suffix	Word	Text
-	psikiyatri	Psikolog, bu rahatsızlığı taşıyanların *psikiyatri* uzmanlarına başvurması gerektiğini söyledi.
-DA	psikiyatride	Diğer uzmanlık alanlarında daha ayrıntılı değerlendirmelere yer verilmişken *psikiyatride* ayrıntılı hekim değerlendirmeleri sınırlı kalmıştır.
-DAki	psikiyatrideki	Çoğu sosyal temsil araştırmasında *psikiyatrideki* klasik araştırma metotlarının kullanılıyor olması eleştirilere yol açmaktadır.
-	referandum	İki ülkenin başbakanları görüşlerini, niyetlerini, temennilerini söylediler. Bundan sonra tamamıyla *referandum* sonuçlarını karşılıklı olarak beklemek lazım.
-DA	referandumda	Bugüne kadarki süreç şunu gösteriyor: Pazar günü yapılacak *referandumda* partilerin kimi mensupları kararlarını verirken kendilerini baskı altında hissediyorlar.
-DAki	referandumdaki	Neredeyse tüm yazarlarımız *referandumdaki* oylarını açıkladılar ve şaşırtıcı bir biçimde hepsinin de oylarının rengi aynıydı.
-	yönetmelik	Bizim amacımız bu şirketlerin önündeki engelleri kaldırmaktır. Bununla ilgili *yönetmelik* çalışmamız var. Gelecek ay çıkartmayı düşünüyoruz.
-DA	yönetmelikte	Trafik kazalarında hayat kurtaran emniyet kemerinin arka koltuklarda da takılması zorunluluğu *yönetmelikte* olmasına karşın uygulanamıyor.
-DAki	yönetmelikteki	Orduya katılması için çağrının bildirilmesine rağmen buna uymayan kişilere *yönetmelikteki* ordudan kaçma hükümleri uygulanır.

Short-Infrequent Condition

Suffix	Word	Text
-	akaç	Kemerlerin üzerinde suyu taşıyan *akaç* delikleri bulunan kanalların izleri yıkıntılar arasındaki parçalarda görülmektedir.
-DA	akaçta	Binlerce çocuk, onların açtığı *akaçta* didiklemişlerdi dünyayı. Halkın yüreğine vurulan kara mührü kazımışlardı.
-DAki	akaçtaki	Vücut ısısı saat başı 1,5 derece düşürülür ve hedeflenen hipotermi düzeyine ulaşılana kadar *akaçtaki* soğuk su akımı devam eder.
-	çıma	Yüzme molası için durulabilecek yerlerdir fakat deniz derindir. İki koyun arasındaki kayalara *çıma* tutulup geçici olarak kalınabilmektedir.
-DA	çımada	Çoğu aday gibi uzun zaman *çımada* asılı kalan ve yardımla aşağıya indirilen adayın bacakları yaralanmıştı.
-DAki	çımadaki	Alanya'da balık ağlarını toplarken kopan *çımadaki* demir makaranın üstüne düşen balıkçı hayatını kaybetti.

Suffix	Word	Text
-	cura	Sempozyumun konusu isabetli olup, üzerine gidilerek sanatçılarla ve özellikle *cura* sanatçılarıyla ortak çalışmalar yapılmalıdır.
-DA	curada	Ustası, kalfanın çaldığı *curada* yerine getiremediği tavır ve eda ile ilgili olarak bir takım düzeltmeler yapar ve ona yol gösterir.
-DAki	curadaki	O dönemde yazının gramer kurallarının yapılmadığı bilinmektedir. Bundan dolayı *curadaki* yazının beşinci yüzyıla ait olduğunu düşünmekteyiz.
-	eviç	Yeden kullanmadan yapılan segâh çeşnili kararlar tam bir bitiş hissi vermediğinden *eviç* perdesindeki segâh çeşnili kararlarda yeden kullanılmalıdır.
-DA	eviçte	Hüzzam makamı seyri esnasında yukarıda zikredilen dizi ve çeşnilere ilave olarak zaman zaman *eviçte* segâh dörtlüsüne de yer verildiği görülmektedir.
-DAki	eviçteki	Irakta meydana gelen hicaz dörtlüye *eviçteki* hicaz dörtlüsünün simetriği de denilmektedir.
-	inak	Fransız yazarlarının özelliği, kutsallaştırılmış her türlü tabuya karşı çıkmaları; her türlü donmuş *inak* kalıplarının üstüne yürümeleridir.
-DA	inakta	Geçmiş çağlarda bilimciler dünyanın düz ve evrenin merkezi olduğunu söyleyen *inakta* yüzyıllar boyunca ısrar etmişlerdi.
-DAki	inaktaki	Tiyatro idolü felsefi *inaktaki* tarafgirlikten kaynaklanır. En tehlikelisi, insanın kavrayışına en büyük darbeyi vuranı budur.
-	irap	Çünkü şekilcilik var. "Merak ettim biraz oku bana." dedim. Adam okumaya başladı ama cümleyi okuyuşu *irap* hatalarıyla doluydu.
-DA	irapta	Burada diyaframatik solumanın *irapta* etkili şekilde kullanılması amacıyla alıştırmalar verilecektir.
-DAki	iraptaki	İlk görevi çocuğun düzgün beslenmesi olan süt dişlerinin sağlığı çocukların *iraptaki* gelişimini de büyük ölçüde etkilemektedir.
-	ışkı	Görüntülemekte olduğunuz resim *ışkı* kategorisinde yer almaktadır. Bu kategoride toplam 15 resim bulunmaktadır.
-DA	ışkıda	Sınırlı ölçülerde Orman Bakanlığımızdan satın alabildiğimiz geyik boynuzu özellikle *ışkıda* görselliğe önem veren kullanıcılar tarafından tercih edilmektedir.
-DAki	ışkıdaki	Olaya karışan iki kişi mahkemeye çıkarıldı. Tutuklanan iki kişinin üzerinde bulunan *ışkıdaki* izlerin sonuçlarının kriminalden gelmesi bekleniyor.
-	ivgi	Doğrama işlerini yaparken *ivgi* aşağı dönük olarak ürünün içine yerleştirilir. Dilimleme içinse tam tersi yapılmalıdır.
-DA	ivgide	Aynı boydaki yapay bileme taşının *ivgide* oluşturduğu yüzey ile kösüre taşının oluşturduğu yüzey kesinlikle aynı değildir.
-DAki	ivgideki	Ne yazık ki tüm şüpheler onun üzerinde toplanıyordu. Biricik umudu *ivgideki* parmak izleriyle onunkilerin uyuşmamasıydı.

Suffix	Word	Text
-	kete	En üstteki bezeyi de yağladıktan sonra *kete* yaparken olduğu gibi her tarafından katlayarak dikdörtgen yapın.
-DA	ketede	Bu yöntemi her türlü *ketede* kullanarak geliştirebilirsiniz. Fotoğraflardan da anlayacağınız üzere gerçekten işe yarıyor.
-DAki	ketedeki	Hazırlanan bu malzeme *ketedeki* kıyma yerine yufkanın içine konularak sac üstünde pişirilir.
-	loça	Ülkedeki iç savaştan kaçan dört genç, yurt dışına giden şilebe gizlice binerek *loça* deliğine saklanmış ve okyanusu geçmişti.
-DA	loçada	Salih denen bu adamın, yorgun bedenini serin suların kollarına bırakması uzun sürmemişti. Geminin motorları durdu ve boşalan zincir *loçada* dayanılmaz bir ses bıraktı.
-DAki	loçadaki	Az önce vira edilen çapanın *loçadaki* yerine oturmasıyla komutan emri verdi ve zincir denize bırakıldı.
-	maun	Kısa zamanda el yapımı *maun* mobilya alanında dünyanın önde gelen üreticilerinden birine dönüştüler.
-DA	maunda	Ağır bir ağaç olarak değerlendirilen *maunda* özgül ağırlık, türlerine göre değişiklik gösterir.
-DAki	maundaki	Dikimini izleyen üç yıl içinde şekil budaması uygulanır. Daha sonraki yıllarda *maundaki* çatal ve obur dallar ile çok zayıf sürgünler çıkarılıp atılır.
-	pişi	Hamur kızartması ya da diğer adıyla *pişi* bizde genellikle mayalı yapılırdı. Hatta ben çoğunlukla fırından aldığım ekmek hamurunu kızartmayı severdim.
-DA	pişide	Hamurun üçte birini *pişide* kullandıktan sonra çoğundan börek yaptık. Aynı hamurdan açma börek yapmak isterseniz diğer tarife bakabilirsiniz.
-DAki	pişideki	Sotelenmiş kırmızı biberle peynirin *pişideki* buluşması tadanlara mükemmel bir lezzet sunuyor.
-	şose	Asfaltlanma çalışmaları öncesinde *şose* olduğu için birçok kazaya neden olan yolun asfaltlanması köy sakinlerini sevindirmişti.
-DA	şosede	İleride, Ahı Dağı'nın yamaçlarından kıvrıla kıvrıla inerek uzanan *şosede* keskin bir ışık huzmesi belirip kayboldu.
-DAki	şosedeki	Evlerin açık kapısından sızan sarı huzmeler eğer az biraz aydınlık saçmasaydı köhne *şosedeki* deliklerde sendelemek işten bile değildi.
-	süje	Estetik olaylar da, tıpkı bilgi olaylarında olduğu gibi bizlere *süje* hakkında bilgi verir ve onun objeyle arasındaki ilişkiyi gösterir.
-DA	süjede	Ekminezi, psikolojik ayrışma içindeki *süjede* geçmiş yaşamlarında yer alan izlenimlerin tekrar canlanmasını sağlayan yöntemdir.
-DAki	süjedeki	Bu, sekreterin işini en çok kesen unsurdur. Bir önceki *süjedeki* unsura göre halledilmesi daha güçtür.

Suffix	Word	Text
-	tapa	Koyun ve kuzu yününden yapılan keçeleri avcılar *tapa* olarak veya çobanlar kepenek olarak kullanırlar.
-DA	tapada	Emniyet gözlüklerinizi takın; çekiç, çivi ve tahta yardımıyla plastik *tapada* dikkatlice bir delik açın.
-DAki	tapadaki	Top mermisi, fünyesi takılı olduğu halde yere düşse bile patlamaz ki! Patlaması için kovanın ateşlenip *tapadaki* mekanizmayı harekete geçirmesi lazım.
-	ulam	Oyun içinde pek çok farklı *ulam* altında incelenebilecek pek çok yetenek vardır.
-DA	ulamda	Yazarın yapıtında metinlerarası *ulamda* değerlendirilebilecek çok sayıda olgu bulmak olasıdır.
-DAki	ulamdaki	Yarışmaya katılan maketçilerin maketlerinden sadece en yüksek dereceyi aldığı *ulamdaki* maketi ödüllendirilecektir.

Long-Infrequent Condition

Suffix	Word	Text
-	anakronizm	Bugünün ihtiyaçlarının, sorunlarının ve yaklaşımlarının tarih yazımına yansıması *anakronizm* hatalarını kolaylaştırmaktadır.
-DA	anakronizmde	Prens Igor operasının bu bölümünün doğru çevrilmiş hali, Rusların yaptığı *anakronizmde* ısrar edilecek olunursa Peçenek danslarıdır.
-DAki	anakronizmdeki	Felsefesinden yola çıktığım *anakronizmdeki* biçimiyle farklı zaman dilimleri arasında zıplamalar yapmak bana heyecan veriyor.
-	endüksiyon	Motorlarda devir sayaçları *endüksiyon* bobinine bağlanıyor ve ateşleme sayısından yola çıkarak dakikadaki devir sayısını görüyoruz.
-DA	endüksiyonda	Bobinin hareketi sayesinde oluşan *endüksiyonda* şiddet sürekli değişir yani artar veya azalır.
-DAki	endüksiyondaki	Magnetik dedektörler metalik varlıklara karşı duyarlı olup, oluşan bir magnetik *endüksiyondaki* değişim bunların çalışma prensibini oluşturur.
-	hipnotizma	Hiç çalışmadan, hatta uyurken dersleri dijital *hipnotizma* metodu ile öğrenip sınıf birincisi olmak mümkün.
-DA	hipnotizmada	En basit olarak ağrı kesicinin bile çok yan etkisi vardır. Bugüne kadar *hipnotizmada* herhangi bir komplikasyon veya bu metoda bağımlılık görülmemiştir.
-DAki	hipnotizmadaki	Gevşeme halinin konforu nedeniyle *hipnotizmadaki* kişiler bu keyifli ortamdan çıkmama konusunda tercih kullanırlar.
-	jeodinamik	Raporda, bölgenin imarında *jeodinamik* karakterinin de dikkate alınması uyarısında bulunuldu.

Suffix	**Word**	**Text**
-DA	jeodinamikte	Atmosfer adı verilen hava küresi *jeodinamikte* önemli bir etken olarak bilinir.
-DAki	jeodinamikteki	Bu yenilemenin sebebi tarihsel *jeodinamikteki* bilgi birikiminin daha anlamlı ve güvenilir hale gelmesindendir.
-	kançılarya	O yıl ikametgahın bahçesinde yeni bir bina inşa edilene kadar ikametgah binası *kançılarya* olarak da kullanılmaya devam etmişti.
-DA	kançılaryada	Bünyesinde Askeri Ataşelik de bulunan Büyükelçiliğimiz, Temmuzda yeni taşınılan adresindeki *kançılaryada* hizmet vermektedir.
-DAki	kançılaryadaki	Temizlikçi bir annenin yetiştirdiği Alman Başbakanı, kent merkezinde bulunan *kançılaryadaki* küçük daireye taşınabilir.
-	mazhariyet	Çağdaş uygarlık düzeyine *mazhariyet* çabamızda bilim, teknoloji ve insan kaynağına yapılan yatırımlar büyük önem taşımaktadır.
-DA	mazhariyette	Varlık ve hayat şerefine *mazhariyette* aralarında gölge ile asıl arasındaki fark kadar fark var. Bunun bir misalini rüyada yaşamıyor muyuz?
-DAki	mazhariyetteki	Engelli kişilerin bilgiye *mazhariyetteki* sıkıntılarını azaltmayı amaçlayan proje, engelli vatandaşlar için büyük kolaylık sağlıyor.
-	müphemiyet	Irak ve IMF görüşmeleri, piyasaların gündemindeki iki önemli konu. Ve bu iki önemli konudaki *müphemiyet* devam ediyor.
-DA	müphemiyette	Küreselleşme süreciyle ilişkili yapısal değişiklikler, para politikasını kuşatan *müphemiyette* artışa ve kargaşanın genişlemesine neden olur.
-DAki	müphemiyetteki	Bundan dolayı siyasi belirsizlik arttı ve işin teorisinden bildiğimiz gibi siyasi *müphemiyetteki* artış faizlerde mutlaka karşılık bulur.
-	murakıplık	Kanun taslağı çalışmalarıyla gündeme gelen ve tartışmalara neden olan yeminli *murakıplık* sisteminin kaldırılmasının denetim sisteminde risk oluşturacağı belirtildi.
-DA	murakıplıkta	Mali müşavirlikten bağımsız sayılabilecek olan ve hatta yeni bir meslek olarak kabul edilen *murakıplıkta* avukatlar için de bir olanak yaratılabilirdi.
-DAki	murakıplıktaki	Denetçilerin çoğunluğunun *murakıplıktaki* kıdemlerinin fazla olması denetime daha çekingen yaklaşmalarına neden olabilir.
-	müsakkafat	Müdürlüğün uygulamaya itiraz nedeni *müsakkafat* olarak kabul edilen mülkün kendilerine devrini istemesidir.
-DA	müsakkafatta	Daha sonraları vakıfların elindeki *müsakkafatta* gayrimüslimlerin oturması dikkat çeker.
-DAki	müsakkafattaki	Yeni kazanç kanununun *müsakkafattaki* iradı gayrisafilerin esas tutulacağı dikkate alınarak tanzim edildiğine şüphe yoktur.
-	ornitorenk	Yeni Zelanda asıllı Amerikalı bir aktrist, sette yemek yediği sofrada mutlaka haşlanmış *ornitorenk* bulunmasını şart koşuyormuş.

Suffix	Word	Text
-DA	ornitorenkte	Yavrularda bulunan dişler ergin *ornitorenkte* yerini kemiksi çıkıntılara bırakır.
-DAki	ornitorenkteki	Yapılan bir araştırmaya göre, insan beyninde yaşlanmayı yavaşlattığı bilinen *ornitorenkteki* faydalı yağların kilo vermeye de yardımcı olduğu belirlendi.
-	sarfınazar	Avrupalı tarihçilere müracaat edildi ama bazıları makalelerini gönderdikleri halde *sarfınazar* ederek geri çektiler, tehdit aldıklarını söylediler.
-DA	sarfınazarda	Yasayla, tarafların arabulucuya başvurma, süreci devam ettirme, sonuçlandırma veya bu süreçten *sarfınazarda* serbest olması güvenceye alındı.
-DAki	sarfınazardaki	Sınırlayıcı faktör ancak bizim kendi inancımız ve kötü alışkanlıklarımızdan *sarfınazardaki* niyet ve azmimiz olacaktır.
-	senatörlük	Ülkenin önünde, başkanın icraatları nedeniyle yargılanmasına engel olan düzenleme ve kendisini dokunulmazlık zırhı ile saran, hayat boyu sürecek *senatörlük* engelleri bulunuyor.
-DA	senatörlükte	Efsane başkan, başında olduğu kurumu soyup soğana çeviren sonra da kurtuluşu *senatörlükte* arayıp dokunulmazlığa sığınan değildir.
-DAki	senatörlükteki	Üstelik, programa davet edildikten sonra hayli tedirgin olan kişinin *senatörlükteki* çalışma alanı uyum ve sivil toplum.
-	stronsiyum	Doğal deniz suyunda bulunan *stronsiyum* seviyelerini akvaryum içerisinde dengeye getiren araç, bu seviyeyi korumaktadır.
-DA	stronsiyumda	Piyasadan alacağınız hiçbir *stronsiyumda* ürünün yapısı gereği tam standardı tutturmak mümkün değildir.
-DAki	stronsiyumdaki	Modifiye olmadığı durumlarda gaz seviyesi önemli ölçüde değişmez. Sodyum ile modifiyede *stronsiyumdaki* kadar şiddetli olmasa da gaz absorbesini biraz yükselttiği gözlenmiştir.
-	tahtırevan	İstanbul'un dar sokaklarında hanımlar ancak sedan sandalyesi adı verilen bir çeşit *tahtırevan* aracılığıyla dolaşabilirlerdi.
-DA	tahtırevanda	Örneğin, elçinin kızını *tahtırevanda* betimleyen eserinde olduğu gibi yabancı elçiler ve elçilik çevrelerinden de siparişler almıştır.
-DAki	tahtırevandaki	Yanlarında bir de beyaz giysili kadın var. İyi giyimli dört atlı ise atlarından inerek *tahtırevandaki* kadını indirmeye gittiler.
-	taşeronluk	Teknik olarak ehil olmayan kişiler *taşeronluk* yaptığı için müşteri mağduriyeti yaşanıyor.
-DA	taşeronlukta	Bu kazanım hükümeti düzenleme yapmaya sevk etti. Dolayısıyla, şimdi gündemde *taşeronlukta* yapılacak yeni düzenlemeler var.
-DAki	taşeronluktaki	Teknik ekip, mevcut heyetin *taşeronluktaki* çalışması boyunca böyle bir sorumluluğu almak istemediğine dikkat çekiyor.

Suffix	Word	Text
-	tekdüzelik	Yaşamın halihazırda *tekdüzelik* kıskacında kıvrandığı ülkelerde futbol, ekranlarda keyifle hüküm sürmektedir.
-DA	tekdüzelikte	Her birimiz, her sabah aynı sıkıcı *tekdüzelikte* çalıştığımız bu büyük binalara geliyoruz.
-DAki	tekdüzelikteki	Medeni insanın genişleyen dünyasında estetik değerler, sanayi devriminin getirdiği *tekdüzelikteki* bunalımlı durumun da tedavisini sağlıyor.

Comprehension Questions

Forty-eight of the following comprehension questions were presented during one experiment. The questions were selected during the experiment by the software, depending on the text that was presented preceding the question. Questions appeared in a part, after 3, 4, 10, 13, 17, 21, 25, 26, 35, 36, 42, 45, 51, 52, 58, 61, 66, 71, 72, 78, 83, 84, 90, and 93 texts were presented. The presented questions were the questions of the texts that were presented just before the question.

Words	Questions	Answers
akaç	Az önce okuduğunuz metinde, yapının önceki halinden en ufak bir iz bile bulunmadığı söylenmişti.	Y
akaçta	Az önce okuduğunuz metinde, halkın karanlığa terk edildiği ima edilmişti.	Y
akaçtaki	Az önce okuduğunuz metinde, istenen durum oluşana kadar işlemin devam edeceği söylenmişti.	D
alternatif	Az önce okuduğunuz metinde, karar aşamasında yapılanlar anlatılmıştı.	D
alternatifte	Az önce okuduğunuz metinde, hafta sonu tatili için konaklama imkanı olmamasından yakınılmaktaydı.	Y
alternatifteki	Az önce okuduğunuz metinde, kalem eteklerdeki çeşitliliğin arttığı söylenmekteydi.	D
anakronizm	Az önce okuduğunuz metinde, bugünün ihtiyaçlarının gözardı edildiğinden yakınılmaktaydı.	Y
anakronizmde	Az önce okuduğunuz metinde, Prens Igor operasının çevirisiyle ilgili bir açıklama yapılmıştı.	D
anakronizmdeki	Az önce okuduğunuz metindeki kişi, farklı zaman dilimleri arasında geçiş yapmanın onu heyecanlandırdığını söylüyordu.	D
asit	Az önce okuduğunuz metinde, bir hastalık hakkında bilgi verilmekteydi.	D

Words	Questions	Answers
asitte	Az önce okuduğunuz metinde, zaman kapsülünün içindeki eşyaların kaybolduğu iddia edilmekteydi.	Y
asitteki	Az önce okuduğunuz metinde, tuzun kimyasal özelliklerinden bahsedilmekteydi.	D
bilgisayar	Az önce okuduğunuz metinde, çocukların bilgisayar kullanma süresinin düzenlenmesi için bir yöntem önerilmekteydi.	D
bilgisayarda	Az önce okuduğunuz metindeki kişi, elektriksel işaretlerin modellenemeyeceğini iddia etmekteydi.	Y
bilgisayardaki	Az önce okuduğunuz metinde, erişim sağlanan dosyalarda neler yapılabileceği anlatılmaktaydı.	D
çıma	Az önce okuduğunuz metinde, denizin derin olduğuna değinilmişti.	D
çımada	Az önce okuduğunuz metinde, asılı kalan tek adayın da yara almadan kurtulduğu iddia edilmekteydi.	Y
çımadaki	Az önce okuduğunuz metinde, balıkçının hayatını nasıl kaybettiği anlatılmaktaydı.	D
cumhuriyet	Az önce okuduğunuz metinde, Fransa'da yapılan seçimin sonuçları değerlendirilmekteydi.	D
cumhuriyette	Az önce okuduğunuz metinde, yurttaşların sadakat göstermesinin öneminden bahsedilmekteydi.	Y
cumhuriyetteki	Az önce okuduğunuz metinde, bağımsızlık öncesinde yaşananlar anlatılmaktaydı.	D
cura	Az önce okuduğunuz metindeki kişi, sempozyum için çok yanlış bir konu seçildiğinden yakınmaktaydı.	Y
curada	Az önce okuduğunuz metinde, ustaların kalfalarını rahat bırakmaları gerektiği iddia edilmekteydi.	Y
curadaki	Az önce okuduğunuz metindeki kişiler, curadaki yazının hangi döneme ait olduğunu tespit etmeye çalışmaktaydılar.	D
depo	Az önce okuduğunuz metinde, teknelerin taşıyabileceği su miktarının nasıl belirlenmesi gerektiği anlatılmaktaydı.	D
depoda	Az önce okuduğunuz metindeki kişi, geçmişi anlatmanın sakıncalarını açıklamaktaydı.	Y
depodaki	Az önce okuduğunuz metinde, depodaki bilgilere ulaşılmasının sakıncaları anlatılmaktaydı.	Y
doku	Az önce okuduğunuz metinde, köklendirme işlemi sırasında yapılan hatalar anlatılmaktaydı.	Y
dokuda	Az önce okuduğunuz metinde, hormon tedavisinin işe yaramayacağı iddia edilmekteydi.	Y

Words	Questions	Answers
dokudaki	Az önce okuduğunuz metinde, kök hücrelerin her insanda bulunduğu söylenmekteydi.	D
eleştirmen	Az önce okuduğunuz metinde, sinema seyircisinin de eleştirmenlerden farklı davranmadığı iddia edilmişti.	D
eleştirmende	Az önce okuduğunuz metinde, eleştirmenlerin çok bilgili olduğu söylenmekteydi.	Y
eleştirmendeki	Az önce okuduğunuz metinde, bir yazarın kullandığı anlatım biçimine değinilmişti.	D
endüksiyon	Az önce okuduğunuz metinde, devir sayısının nasıl hesaplandığı anlatılmaktaydı.	D
endüksiyonda	Az önce okuduğunuz metinde, bobin hareketinden ve bunun sonuçlarından bahsedilmekteydi.	D
endüksiyondaki	Az önce okuduğunuz metinde, magnetik dedektörlerin zararlarından bahsedilmekteydi.	Y
enfeksiyon	Az önce okuduğunuz metinde, hastaların karşılaştığı bir tehlikeden bahsedilmişti.	D
enfeksiyonda	Az önce okuduğunuz metinde, antibiyotik kullanmanın gerekli olmadığı bir durumdan bahsedilmekteydi.	D
enfeksiyondaki	Az önce okuduğunuz metinde, diş eti bozukluklarıyla kalp hastalıkları arasında herhangi bir ilişkinin bulunmadığı iddia edilmekteydi.	Y
etüt	Az önce okuduğunuz metindeki kişi, her cuma toplanıp ders çalıştıklarını söylemekteydi.	Y
etütte	Az önce okuduğunuz metindeki kişi, çocukların öğle yemeğine çıkıp çıkmadığını umursamadığını söylemekteydi.	Y
etütteki	Az önce okuduğunuz metinde, öğrencilerle ilgili bir sistemden alınabilecek bilgilerden bahsedilmekteydi.	D
eviç	Az önce okuduğunuz metinde, bir hatanın düzeltilme yöntemi anlatılmaktaydı.	D
eviçte	Az önce okuduğunuz metinde, bir makamın yanlış icrası tarif edilmekteydi.	Y
eviçteki	Az önce okuduğunuz metinde, bir terimin diğer adı verilmişti.	D
fuar	Az önce okuduğunuz metinde, merkezin, her yıl bağışta bulunduğu ima edilmekteydi.	D
fuarda	Az önce okuduğunuz metinde, ziyaretçilerin aradıkları hiçbir şeyi bulamadığından yakınılmaktaydı.	Y
fuardaki	Az önce okuduğunuz metinde, fuar sayesinde yeni iş fırsatları ortaya çıktığı ifade edilmekteydi.	D

Words	Questions	Answers
gişe	Az önce okuduğunuz metinde, popüler filmlerin aslında maddi nedenlerle çekildiği iddia edilmekteydi.	Y
gişede	Az önce okuduğunuz metinde, başarılı bir sanatçının nitelikleri anlatılmaktaydı.	D
gişedeki	Az önce okuduğunuz metinde, müşterilerin bazen klişe olanı tercih edebildiğinden bahsedilmekteydi.	Y
hipnotizma	Az önce okuduğunuz metinde, tembelliğin zararlarından bahsedilmekteydi.	Y
hipnotizmada	Az önce okuduğunuz metinde, ağrı kesicilerin yan etkileri olduğuna değinilmişti.	D
hipnotizmadaki	Az önce okuduğunuz metinde, gevşeme halinin her zaman keyifli olmayabileceği söylenmekteydi.	Y
ilköğretim	Az önce okuduğunuz metinde, ilköğretim okullarının açıldığı söylenmekteydi.	Y
ilköğretimde	Az önce okuduğunuz metinde, okulların ve öğretmenlerin öneminden bahsedilmekteydi.	D
ilköğretimdeki	Az önce okuduğunuz metinde, trafik konulu derslerin yeterli olmadığından bahsedilmekteydi.	Y
inak	Az önce okuduğunuz metinde, Fransız yazarların tabuları kırmakta yeterince cesur olmadığı iddia edilmekteydi.	Y
inakta	Az önce okuduğunuz metinde, bilimdeki eski bir yanlışlıktan bahsedilmekteydi.	D
inaktaki	Az önce okuduğunuz metinde, insanların idollere karşı önyargılı oldukları iddia edilmekteydi.	Y
irap	Az önce okuduğunuz metinde, bahsi geçen adamın okurken çok fazla hata yaptığı söylenmekteydi.	D
irapta	Az önce okuduğunuz metinde, diyaframatik solumanın kullanılabileceği bir durumdan bahsedilmekteydi.	D
iraptaki	Az önce okuduğunuz metinde, günümüzde çocukların dişlerinin sağlığına pek dikkat etmediği söylenmekteydi.	Y
ışkı	Az önce okuduğunuz metinde, bahsedilen kategoride kaç resim olduğu söylenmişti.	D
ışkıda	Az önce okuduğunuz metinde, geyik boyunuzunun, işlenmeye uygun olmadığı iddia edilmişti.	Y
ışkıdaki	Az önce okuduğunuz metinde, olaya iki kişinin karıştığı vurgulanmıştı.	D
istatistik	Az önce okuduğunuz metinde, eğitimli anketör bulmanın zorluklarından bahsedilmekteydi.	Y

Words	**Questions**	**Answers**
istatistikte	Az önce okuduğunuz metinde, girdi katmanının işlevinden bahsedilmişti.	D
istatistikteki	Az önce okuduğunuz metinde, bazen plansız hareket etmenin yararlı olabileceği iddia edilmişti.	Y
istihbarat	Az önce okuduğunuz metinde, kredi verilmemesi gereken firmalara kredi verildiği iddia edilmekteydi.	D
istihbaratta	Az önce okuduğunuz metinde, gazetecilerin telefonlarının neden dinlenmediği anlatılmıştı.	Y
istihbarattaki	Az önce okuduğunuz metinde, renkli defterler kullanan birinden bahsedilmekteydi.	Y
ivgi	Az önce okuduğunuz metinde, ince dilimler halinde doğramanın zorluklarından yakınılmaktaydı.	Y
ivgide	Az önce okuduğunuz metinde, yapay bileme taşı ile kösüre taşı karşılaştırılmıştı.	D
ivgideki	Az önce okuduğunuz metinde, bahsedilen kişinin tek umudunun çağırdığı şahit olduğu söylenmişti.	Y
jeodinamik	Az önce okuduğunuz metinde, bir raporda yer alan bir uyarıdan bahsedilmekteydi.	D
jeodinamikte	Az önce okuduğunuz metinde, atmosferin önemli olduğu bir alana değinilmişti.	D
jeodinamikteki	Az önce okuduğunuz metinde, tarihin güvenilir bir bilgi kaynağı olmadığından yakınılmaktaydı.	Y
jüri	Az önce okuduğunuz metinde, bir müzik yarışmasındaki süreçten bahsedilmekteydi.	D
jüride	Az önce okuduğunuz metinde, fotoğrafçılığın değerlendirilmesinin mümkün olmadığı iddia edilmekteydi.	Y
jürideki	Az önce okuduğunuz metinde, rezervasyon defterlerinde bilgilerin eksik olduğu söylenmekteydi.	Y
kançılarya	Az önce okuduğunuz metinde, bir binanın kullanım amacının değiştiği söylenmişti.	D
kançılaryada	Az önce okuduğunuz metinde, Büyükelçiliğin bünyesinde Askeri Ataşelik bulunduğu söylenmişti.	D
kançılaryadaki	Az önce okuduğunuz metinde, kent merkezlerinin çok sıkıcı olabileceğinden bahsedilmekteydi.	Y
karşılaşma	Az önce okuduğunuz metinde, yoğun bir yağışın ardından yaşananlar anlatılmaktaydı.	D
karşılaşmada	Az önce okuduğunuz metinde, takım dağınık olduğu için camianın yönetimden bir beklentisinin olmadığı iddia edilmekteydi.	Y

Words	Questions	Answers
karşılaşmadaki	Az önce okuduğunuz metinde, bahis oynamanın insanlarda alışkanlık yaptığı iddia edilmişti.	Y
kete	Az önce okuduğunuz metinde, bir hamurişi tarifi verilmişti.	D
ketede	Az önce okuduğunuz metinde, yemek tarifi verirken fotoğraf kullanımının yaygınlaştığı söylenmekteydi.	Y
ketedeki	Az önce okuduğunuz metinde, kıyma yerine kullanılabilecek bir malzemeden bahsedilmekteydi.	D
kıta	Az önce okuduğunuz metinde, Asya kıtasının nüfus özelliklerinden bahsedilmekteydi.	D
kıtada	Az önce okuduğunuz metinde, etkileri süren eski bir inançtan bahsedilmekteydi.	D
kıtadaki	Az önce okuduğunuz metinde, Avustralya'nın onbinlerce yıldır el değmemiş doğasını koruduğu söylenmekteydi.	Y
kıyı	Az önce okuduğunuz metinde, kalenin kıyıların kontrolünde kullanılmasının sakıncalarından bahsedilmekteydi.	Y
kıyıda	Az önce okuduğunuz metinde, bir sahilin güzelliklerinden bahsedilmişti.	D
kıyıdaki	Az önce okuduğunuz metinde, kıyıdaki dalgaların dengemizi bozabileceği iddia edilmişti.	D
koleksiyon	Az önce okuduğunuz metinde, ünlü bir giyim markasının düzenlediği bağış gecesinden bahsedilmekteydi.	Y
koleksiyonda	Az önce okuduğunuz metinde, artık kimsenin dantel örtü kullanmadığından yakınılmaktaydı.	Y
koleksiyondaki	Az önce okuduğunuz metinde, bir koleksiyonun tanıtımı yapılmaktaydı.	D
komutanlık	Az önce okuduğunuz metinde, sevilen bir subay hakkında bilgi verilmişti.	D
komutanlıkta	Az önce okuduğunuz metinde, düzenlenen törenin yeri belirtilmişti.	D
komutanlıktaki	Az önce okuduğunuz metindeki kişi, Alınan Dersler Şube Müdürlüğü'nde görev yapmak istemediğini söylemekteydi.	Y
kooperatif	Az önce okuduğunuz metindeki kişi, ne için başvuru yaptığını anlatmaktaydı.	D
kooperatifte	Az önce okuduğunuz metinde, bahsedilen uygulamada sorunların devam ettiği söylenmekteydi.	D
kooperatifteki	Az önce okuduğunuz metinde, ortakların sorumluluk almaktan kaçınmasından yakınılmaktaydı.	Y

Words	Questions	Answers
loça	Az önce okuduğunuz metinde, savaştan kaçan bir grup gencin öyküsü anlatılmaktaydı.	D
loçada	Az önce okuduğunuz metinde, Salih adında birinin neden dinlenmeye fırsat bulamadığı anlatılmaktaydı.	Y
loçadaki	Az önce okuduğunuz metinde, komutanın emirlerine uyulmaması sonucunda yaşananlar anlatılmıştı.	Y
masa	Az önce okuduğunuz metinde, sorunları çözmek için karşılıklı konuşma yolunun tercih edildiğinden bahsedilmekteydi.	D
masada	Az önce okuduğunuz metinde, zarfın içinde önemli bilgiler olabileceği söylenmekteydi.	D
masadaki	Az önce okuduğunuz metindeki kişiler, kasabaya yakın olmaktan hiç memnun olmadıklarını söylemekteydiler.	Y
maun	Az önce okuduğunuz metinde, bir mobilya üreticisinden bahsedilmekteydi.	D
maunda	Az önce okuduğunuz metinde, bir ağaç türü hakkında bilgi verilmişti.	D
maundaki	Az önce okuduğunuz metinde, ağacın dikiminde yapılan hatalar yüzünden zayıf sürgünler verdiği iddia edilmekteydi.	Y
mazhariyet	Az önce okuduğunuz metinde, günümüzde bilim ve teknolojiye yeteri kadar önem verilmediği söylenmekteydi.	Y
mazhariyette	Az önce okuduğunuz metinde, gölgede uyurken görülen rüyaların daha güzel olduğu iddia edilmekteydi.	Y
mazhariyetteki	Az önce okuduğunuz metinde, engelli vatandaşların sıkıntılarını çözmeye yönelik bir projeden bahsedilmekteydi.	D
müphemiyet	Az önce okuduğunuz metinde, Irak ve IMF görüşmelerinin piyasalar için önemli olduğu söylenmekteydi.	D
müphemiyette	Az önce okuduğunuz metinde, küreselleşmenin insan ilişkilerindeki samimiyeti zedelediği iddia edilmekteydi.	Y
müphemiyetteki	Az önce okuduğunuz metinde, faiz artışlarının siyasi bir başarı olduğu iddia edilmekteydi.	Y
murakıplık	Az önce okuduğunuz metinde, denetim sisteminde kanunsuzluğun hakim olduğu iddia edilmekteydi.	Y
murakıplıkta	Az önce okuduğunuz metinde, yeni olduğu kabul edilen bir meslekten bahsedilmekteydi.	D
murakıplıktaki	Az önce okuduğunuz metinde, bazı denetçilerin denetime daha çekingen yaklaşmalarının nedeninden bahsedilmekteydi.	D
müsakkafat	Az önce okuduğunuz metinde, Müdürlüğün bir mülk hakkındaki talebinden bahsedilmişti.	D

Words	Questions	Answers
müsakkafatta	Az önce okuduğunuz metinde, vakıf mallarının koruma altına alındığı söylenmekteydi.	Y
müsakkafattaki	Az önce okuduğunuz metinde, bir kanun hakkında yorum yapılmıştı.	D
ofis	Az önce okuduğunuz metinde, sürekli oturarak çalışmanın sakıncalı olduğu iddia edilmekteydi.	D
ofiste	Az önce okuduğunuz metinde, redaksiyon ve editörlük yapan birinin zamanının çoğunu ofiste geçirdiği söylenmişti.	D
ofisteki	Az önce okuduğunuz metinde, işyerinde kedi beslemenin uygun olmadığı iddia edilmekteydi.	Y
ornitorenk	Az önce okuduğunuz metinde, bir aktristin sette yemek yemeyerek formunu koruduğu iddia edilmişti.	Y
ornitorenkte	Az önce okuduğunuz metinde, bir hayvanın gelişiminden bahsedilmekteydi.	D
ornitorenkteki	Az önce okuduğunuz metinde, yağlı yemek yemenin kilo aldırdığı iddia edilmekteydi.	Y
öykü	Az önce okuduğunuz metinde, anlatının başlıca kişilerinin iyi işlenmesi gerektiğinden bahsedilmişti.	Y
öyküde	Az önce okuduğunuz metinde, öyküde tarihsel arka planın eksik olduğu söylenmekteydi.	Y
öyküdeki	Az önce okuduğunuz metinde, sarışın kız kardeşin büyük ödülü aldığı söylenmekteydi.	D
perspektif	Az önce okuduğunuz metinde, ekonomik güvenle siyasal güvenin birbirine karıştırılmaması gerektiği iddiası bulunmaktaydı.	Y
perspektifte	Az önce okuduğunuz metinde, bahsedilen kişinin birden fazla disiplinle ilgilendiği söylenmekteydi.	D
perspektifteki	Az önce okuduğunuz metinde, yazının bulunmasının tarihsel öneminden bahsedilmekteydi.	Y
pişi	Az önce okuduğunuz metindeki kişi, bir hamurişini nasıl yapmayı tercih ettiğini anlatmaktaydı.	D
pişide	Az önce okuduğunuz metindeki kişi, hamurun çoğunu kullanamadıklarından yakınmaktaydı.	Y
pişideki	Az önce okuduğunuz metinde, kırmızı biberle peynirin karıştırılmasının zararlarından bahsedilmekteydi.	Y
psikiyatri	Az önce okuduğunuz metinde, bahsi geçen rahatsızlığın pek yaygın olmadığı iddia edilmekteydi.	Y
psikiyatride	Az önce okuduğunuz metinde, ayrıntılı hekim değerlendirmelerine gerek olmadığından bahsedilmekteydi.	Y

Words	Questions	Answers
psikiyatrideki	Az önce okuduğunuz metinde, bir araştırma yöntemine ilişkin eleştirilerden söz edilmekteydi.	D
referandum	Az önce okuduğunuz metinde, iki ülkenin başbakanları arasındaki tartışmanın olumsuz sonuçları anlatılmaktaydı.	Y
referandumda	Az önce okuduğunuz metinde, bazı parti mensuplarının kendilerini baskı altında hissettiği iddia edilmekteydi.	D
referandumdaki	Az önce okuduğunuz metinde, bazı yazarların verecekleri oyları açıkladıkları söylenmekteydi.	D
saha	Az önce okuduğunuz metinde, anlatılan durumlarda şutu çekenin kaleye geçmesi gerektiği söylenmişti.	D
sahada	Az önce okuduğunuz metinde, sayı almak için ne yapılması gerektiği anlatılmıştı.	D
sahadaki	Az önce okuduğunuz metinde, erteleme halinde skorun sıfırlanacağı belirtilmişti.	Y
sarfınazar	Az önce okuduğunuz metinde, bazı tarihçilerin makalelerini neden geri çektikleri anlatılmaktaydı.	D
sarfınazarda	Az önce okuduğunuz metinde, bir yasanın açıklaması yapılmıştı.	D
sarfınazardaki	Az önce okuduğunuz metinde, inançlarımız sayesinde kötü alışkanlıklarımızdan kolayca kurtulabileceğimiz iddia edilmekteydi.	Y
senatörlük	Az önce okuduğunuz metinde, dokunulmazlık olmaması halinde icraatların engelleneceği iddia edilmekteydi.	Y
senatörlükte	Az önce okuduğunuz metinde, dokunulmazlık elde edebilen birinin efsane olacağı söylenmekteydi.	Y
senatörlükteki	Az önce okuduğunuz metinde, programa davet edilen kişinin görevinden bahsedilmişti.	D
şose	Az önce okuduğunuz metinde, bir köy yolunun asfaltlanmadan önceki durumuna değinilmişti.	D
şosede	Az önce okuduğunuz metinde, bir dağın yamaçlarında kaybolan birinden bahsedilmekteydi.	Y
şosedeki	Az önce okuduğunuz metinde, bahsi geçen mekanda delikler olduğuna değinilmişti.	D
stronsiyum	Az önce okuduğunuz metinde, akvaryumlara doğal deniz suyu koyulması gerektiği söylenmişti.	Y
stronsiyumda	Az önce okuduğunuz metinde, standardı yakalamakta ürünün yapısının mutlaka sorun çıkaracağı iddia edilmekteydi.	D
stronsiyumdaki	Az önce okuduğunuz metinde, gazların modifiye edilmesinin şiddetli patlamalara yol açabileceği iddia edilmekteydi.	Y

Words	**Questions**	**Answers**
süje	Az önce okuduğunuz metinde, estetik ile bilgi arasındaki bir benzerlikten bahsedilmişti.	D
süjede	Az önce okuduğunuz metinde, psikolojik ayrışmanın sorunlara yol açtığı iddia edilmekteydi.	Y
süjedeki	Az önce okuduğunuz metinde, sekreterlerin yaşamakta olduğu sorunlardan bahsedilmekteydi.	D
tahtırevan	Az önce okuduğunuz metinde, bir gezinti yönteminden bahsedilmekteydi.	D
tahtırevanda	Az önce okuduğunuz metinde, kimlerden sipariş alındığı belirtilmişti.	D
tahtırevandaki	Az önce okuduğunuz metinde, beyaz giysilerin kadınlara çok yakıştığından bahsedilmekteydi.	Y
tapa	Az önce okuduğunuz metinde, keçenin kullanım alanlarından bahsedilmekteydi.	D
tapada	Az önce okuduğunuz metinde, delik açmak için gerekli araçlardan bahsedilmekteydi.	D
tapadaki	Az önce okuduğunuz metinde, mermilerin kolayca patlayabilmesinin yarattığı endişeden bahsedilmişti.	Y
taşeronluk	Az önce okuduğunuz metinde, mağduriyet yaşayan müşterilerin haklarını aramaları gerektiği söylenmekteydi.	Y
taşeronlukta	Az önce okuduğunuz metinde, kazanımlara rağmen yeni düzenleme yapılmamasından yakınılmaktaydı.	Y
taşeronluktaki	Az önce okuduğunuz metinde, mevcut heyetin sorumluluk almak istemediği belirtilmişti.	D
tekdüzelik	Az önce okuduğunuz metinde, futbolun hangi tür toplumlarda daha popüler olduğundan bahsedilmekteydi.	D
tekdüzelikte	Az önce okuduğunuz metindeki kişi, her gün aynı şeyleri yaptığını söylemekteydi.	D
tekdüzelikteki	Az önce okuduğunuz metinde, medeni insanı ancak sanayi devriminin getirdiği güzelliklerin tatmin edebileceği iddia edilmekteydi.	Y
uçak	Az önce okuduğunuz metinde, yetkililerin ihbarı dikkate almadığı söylenmişti.	Y
uçakta	Az önce okuduğunuz metinde, uçakta yaşananların kimsenin umurunda olmadığı söylenmişti.	Y
uçaktaki	Az önce okuduğunuz metinde, titanyum boruların işlevi anlatılmıştı.	D
ulam	Az önce okuduğunuz metinde, oyuna yeni başlayanların yeteneksizliğinden bahsedilmekteydi.	Y

Words	**Questions**	**Answers**
ulamda	Az önce okuduğunuz metinde, yapıtın başarısız olduğu iddia edilmekteydi.	Y
ulamdaki	Az önce okuduğunuz metinde, bir maket yarışması hakkında bilgi verilmişti.	D
uyku	Az önce okuduğunuz metinde, kasabadaki herkesin uykusunun çok derin olduğundan bahsedilmekteydi.	Y
uykuda	Az önce okuduğunuz metinde, kişinin uyanık olduğu zamanların ona işkence gibi geldiği iddia edilmekteydi.	D
uykudaki	Az önce okuduğunuz metinde, yakınında çocuk bulunmadığı için şarkı söyleyemeyen birinden bahsedilmekteydi.	Y
üzüm	Az önce okuduğunuz metinde, talebin düşük olmasının kazançların düşmesine neden olduğu iddia edilmekteydi.	Y
üzümde	Az önce okuduğunuz metinde, kanı sulandırıcı bir maddenin nasıl elde edilebileceği anlatılmaktaydı.	D
üzümdeki	Az önce okuduğunuz metinde, yiyeceklere aroma vermesi için kullanılan maddelerin zararlarından bahsedilmekteydi.	Y
yönetmelik	Az önce okuduğunuz metindeki kişi, hazırladıkları yönetmeliğin amacını anlatmaktaydı.	D
yönetmelikte	Az önce okuduğunuz metinde, yasal düzenlemelerin trafik kurallarına uyulmasını sağlayamamasından yakınılıyordu.	D
yönetmelikteki	Az önce okuduğunuz metinde, ordudan kaçma hükümlerinin orduya çağırılan kişiler için geçerli olmadığı söylenmekteydi.	Y

APPENDIX B: Counterbalance Procedure

1) Each condition was divided into four word-groups. Within each word-group, there were four target words (see Table B 1).

Table B 1 Word grouping

Word groups	Target Words (roots)
Group-1	1 2 3 4
Group-2	5 6 7 8
Group-3	9 10 11 12
Group-4	13 14 15 16

2) Target words in each condition were organized such that root forms and suffixed forms were selected from different word groups. Accordingly, there were four combinations of words: A, B, C, D (see Table B 2).

Table B 2 Word combinations for a condition. There are 4*3 = 12 words in each combination

	A		B		C		D	
-	1	1 Word 2 Word 3 Word 4 Word	2	5 Word 6 Word 7 Word 8 Word	4	13 Word 14 Word 15 Word 16 Word	3	9 Word 10 Word 11 Word 12 Word
-DA	2	5 DA 6 DA 7 DA 8 DA	3	9 DA 10 DA 11 DA 12 DA	1	1 DA 2 DA 3 DA 4 DA	4	13 DA 14 DA 15 DA 16 DA
-DAki	3	9 DAki 10 DAki 11 DAki 12 DAki	4	13 DAki 14 DAki 15 DAki 16 DAki	2	5 DAki 6 DAki 7 DAki 8 DAki	1	1 DAki 2 DAki 3 DAki 4 DAki

3) One of the word combinations were chosen, and target words from all conditions presented according to that combination as target words in each block (4 words * 3 forms * 4 conditions = 48 texts) (see Table B 2, Table B 3, Table B 5, and Table B 6 – at the end of the Appendix).

Table B 3 Conditions in each block

part 1: 96	oral block: 48 SF: 4*3 = 12 SI: 4*3 = 12 LF: 4*3 = 12 LI: 4*3 = 12	silent block: 48 SF: 4*3 = 12 SI: 4*3 = 12 LF: 4*3 = 12 LI: 4*3 = 12
part 2: 96	silent block: 48 SF: 4*3 = 12 SI: 4*3 = 12 LF: 4*3 = 12 LI: 4*3 = 12	oral block: 48 SF: 4*3 = 12 SI: 4*3 = 12 LF: 4*3 = 12 LI: 4*3 = 12

SF: Short-Frequent condition, SI: Short-Infrequent condition, LF: Long-Frequent condition, LI: Long-Infrequent condition

4) Only one form of a target word (root, with the suffix -DA, or with suffixes -DA and -ki) appeared in one block (e.g., Short-Frequent condition (SF) in Table B 4).

Table B 4 Example word combinations for SF condition

	A			B			C			D		
-	1	1	asit	2	5	fuar	4	13	saha	3	9	kıyı
		2	depo		6	gişe		14	uçak		10	masa
		3	doku		7	jüri		15	uyku		11	ofis
		4	etüt		8	kıta		16	üzüm		12	öykü
-DA	2	5	fuarda	3	9	kıyıda	1	1	asitte	4	13	sahada
		6	gişede		10	masada		2	depoda		14	uçakta
		7	jüride		11	ofiste		3	dokuda		15	uykuda
		8	kıtada		12	öyküde		4	etütte		16	üzümde
-DAki	3	9	kıyıdaki	4	13	sahadaki	2	5	fuardaki	1	1	asitteki
		10	masadaki		14	uçaktaki		6	gişedeki		2	depodaki
		11	ofisteki		15	uykudaki		7	jürideki		3	dokudaki
		12	öyküdeki		16	üzümdeki		8	kıtadaki		4	etütteki

5) Each participant read a different combination of target words, conditions, and modality orders. Every participant read all words either aloud or silently (Table B 5 and Table B 6).

6) The texts that include target words that were selected according to the procedures 1-4 were randomized by the software within each block.

7) After conducting 48 experiments, each target word was read aloud 24 times, and read silently 24 times by different participants, in the following orders (see Table B 5 and Table B 6):

   a) The first 24 experiments:

   Part 1- Oral-silent: six times oral reading, six times silent reading

   Part 2- Silent-oral: six times silent reading, six times oral reading

b) The second 24 experiments:

Part 1- Silent oral: six times silent reading, six times oral reading

Part 2- Oral-silent: six times oral reading, six times silent reading

Table B 5 Word selections and orders for the first 24 experiments

	Participant Number		pn 1	pn 2	pn 3	pn 4	pn 5	pn 6	pn 7	pn 8	pn 9	pn 10	pn 11	pn 12
	Part order		AB-CD	AB-DC	AC-BD	AC-DB	AD-BC	AD-CB	BA-CD	BA-DC	BC-AD	BC-DA	BD-AC	BD-CA
	Mod. order		AB	AB	AC	AC	AD	AD	BA	BA	BC	BC	BD	BD
part 1	Oral	SF	A	A	A	A	A	A	B	B	B	B	B	B
		SI	A	A	A	A	A	A	B	B	B	B	B	B
		LF	A	A	A	A	A	A	B	B	B	B	B	B
		LI	A	A	A	A	A	A	B	B	B	B	B	B
	Silent	SF	B	B	C	C	D	D	A	A	C	C	D	D
		SI	B	B	C	C	D	D	A	A	C	C	D	D
		LF	B	B	C	C	D	D	A	A	C	C	D	D
		LI	B	B	C	C	D	D	A	A	C	C	D	D
	Participant Number		pn 1	pn 2	pn 3	pn 4	pn 5	pn 6	pn 7	pn 8	pn 9	pn 10	pn 11	pn 12
	Part order		AB-CD	AB-DC	AC-BD	AC-DB	AD-BC	AD-CB	BA-CD	BA-DC	BC-AD	BC-DA	BD-AC	BD-CA
	Mod. order		CD	DC	BD	DB	BC	CB	CD	DC	AD	DA	AC	CA
part 2	Silent	SF	C	D	B	D	B	C	C	D	A	D	A	C
		SI	C	D	B	D	B	C	C	D	A	D	A	C
		LF	C	D	B	D	B	C	C	D	A	D	A	C
		LI	C	D	B	D	B	C	C	D	A	D	A	C
	Oral	SF	D	C	D	B	C	B	D	C	D	A	C	A
		SI	D	C	D	B	C	B	D	C	D	A	C	A
		LF	D	C	D	B	C	B	D	C	D	A	C	A
		LI	D	C	D	B	C	B	D	C	D	A	C	A

	Participant Number		pn 13	pn 14	pn 15	pn 16	pn 17	pn 18	pn 19	pn 20	pn 21	pn 22	pn 23	pn 24
	Part order		CA-BD	CA-DB	CB-AD	CB-DA	CD-AB	CD-BA	DA-BC	DA-CB	DB-AC	DB-CA	DC-AB	DC-BA
	Mod. order		CA	CA	CB	CB	CD	CD	DA	DA	DB	DB	DC	DC
part 1	Oral	SF	C	C	C	C	C	C	D	D	D	D	D	D
		SI	C	C	C	C	C	C	D	D	D	D	D	D
		LF	C	C	C	C	C	C	D	D	D	D	D	D
		LI	C	C	C	C	C	C	D	D	D	D	D	D
	Silent	SF	A	A	B	B	D	D	A	A	B	B	C	C
		SI	A	A	B	B	D	D	A	A	B	B	C	C
		LF	A	A	B	B	D	D	A	A	B	B	C	C

		LI	A	A	B	B	D	D	A	A	B	B	C	C
	Participant Number		pn 13	pn 14	pn 15	pn 16	pn 17	pn 18	pn 19	pn 20	pn 21	pn 22	pn 23	pn 24
	Part order		CA-BD	CA-DB	CB-AD	CB-DA	CD-AB	CD-BA	DA-BC	DA-CB	DB-AC	DB-CA	DC-AB	DC-BA
	Mod. order		BD	DB	AD	DA	AB	BA	BC	CB	AC	CA	AB	BA
part 2	Silent	SF	B	D	A	D	A	B	B	C	A	C	A	B
		SI	B	D	A	D	A	B	B	C	A	C	A	B
		LF	B	D	A	D	A	B	B	C	A	C	A	B
		LI	B	D	A	D	A	B	B	C	A	C	A	B
	Oral	SF	D	B	D	A	B	A	C	B	C	A	B	A
		SI	D	B	D	A	B	A	C	B	C	A	B	A
		LF	D	B	D	A	B	A	C	B	C	A	B	A
		LI	D	B	D	A	B	A	C	B	C	A	B	A

SF: Short-Frequent condition, SI: Short-Infrequent condition, LF: Long-Frequent condition, LI: Long-Infrequent condition

Table B 6 Word selections and orders for the second 24 experiments

	Participant Number		pn 25	pn 26	pn 27	pn 28	pn 29	pn 30	pn 31	pn 32	pn 33	pn 34	pn 35	pn 36
	Part order		CD-AB	DC-AB	BD-AC	DB-AC	BC-AD	CB-AD	CD-BA	DC-BA	AD-BC	DA-BC	AC-BD	CA-BD
	Mod. Order		CD	DC	BD	DB	BC	CB	CD	DC	AD	DA	AC	CA
part 1	Silent	SF	C	D	B	D	B	C	C	D	A	D	A	C
		SI	C	D	B	D	B	C	C	D	A	D	A	C
		LF	C	D	B	D	B	C	C	D	A	D	A	C
		LI	C	D	B	D	B	C	C	D	A	D	A	C
	Oral	SF	D	C	D	B	C	B	D	C	D	A	C	A
		SI	D	C	D	B	C	B	D	C	D	A	C	A
		LF	D	C	D	B	C	B	D	C	D	A	C	A
		LI	D	C	D	B	C	B	D	C	D	A	C	A
	Participant Number		pn 25	pn 26	pn 27	pn 28	pn 29	pn 30	pn 31	pn 32	pn 33	pn 34	pn 35	pn 36
	Part order		CD-AB	DC-AB	BD-AC	DB-AC	BC-AD	CB-AD	CD-BA	DC-BA	AD-BC	DA-BC	AC-BD	CA-BD
	Mod. Order		AB	AB	AC	AC	AD	AD	BA	BA	BC	BC	BD	BD
part 2	Oral	SF	A	A	A	A	A	A	B	B	B	B	B	B
		SI	A	A	A	A	A	A	B	B	B	B	B	B
		LF	A	A	A	A	A	A	B	B	B	B	B	B
		LI	A	A	A	A	A	A	B	B	B	B	B	B
	Silent	SF	B	B	C	C	D	D	A	A	C	C	D	D
		SI	B	B	C	C	D	D	A	A	C	C	D	D
		LF	B	B	C	C	D	D	A	A	C	C	D	D
		LI	B	B	C	C	D	D	A	A	C	C	D	D

	Participant Number		pn 37	pn 38	pn 39	pn 40	pn 41	pn 42	pn 43	pn 44	pn 45	pn 46	pn 47	pn 48
	Part order		BD-CA	DB-CA	AD-CB	DA-CB	AB-CD	BA-CD	BC-DA	CB-DA	AC-DB	CA-DB	AB-DC	BA-DC
	Mod. Order		BD	DB	AD	DA	AB	BA	BC	CB	AC	CA	AB	BA
part 1	Silent	SF	B	D	A	D	A	B	B	C	A	C	A	B
		SI	B	D	A	D	A	B	B	C	A	C	A	B
		LF	B	D	A	D	A	B	B	C	A	C	A	B
		LI	B	D	A	D	A	B	B	C	A	C	A	B
	Oral	SF	D	B	D	A	B	A	C	B	C	A	B	A
		SI	D	B	D	A	B	A	C	B	C	A	B	A
		LF	D	B	D	A	B	A	C	B	C	A	B	A
		LI	D	B	D	A	B	A	C	B	C	A	B	A
	Participant Number		pn 37	pn 38	pn 39	pn 40	pn 41	pn 42	pn 43	pn 44	pn 45	pn 46	pn 47	pn 48
	Part order		BD-CA	DB-CA	AD-CB	DA-CB	AB-CD	BA-CD	BC-DA	CB-DA	AC-DB	CA-DB	AB-DC	BA-DC
	Mod. Order		CA	CA	CB	CB	CD	CD	DA	DA	DB	DB	DC	DC
part 2	Oral	SF	C	C	C	C	C	C	D	D	D	D	D	D
		SI	C	C	C	C	C	C	D	D	D	D	D	D
		LF	C	C	C	C	C	C	D	D	D	D	D	D
		LI	C	C	C	C	C	C	D	D	D	D	D	D
	Silent	SF	A	A	B	B	D	D	A	A	B	B	C	C
		SI	A	A	B	B	D	D	A	A	B	B	C	C
		LF	A	A	B	B	D	D	A	A	B	B	C	C
		LI	A	A	B	B	D	D	A	A	B	B	C	C

SF: Short-Frequent condition, SI: Short-Infrequent condition, LF: Long-Frequent condition, LI: Long-Infrequent condition

APPENDIX C: Stage-by-Stage Construction of Linear Mixed Models

In the current study, a total of seven *Linear Mixed Model*s (LMM) with the `lme4` package (version 1.1-15; Bates et al., 2015) in the R environment (version 3.4.2, 64-bit build; R Core Team, 2017) are provided: (i) oral reading LMMs (i.e., LMMs of FSI, FFD, GD, and RFLP), and (ii) silent reading LMMs (i.e., LMMs of FFD, GD, and RFLP). A similar strategy was applied to both LMMs such that the construction of LMMs began with a base model that included, followed by the selection of random slopes, and lastly, a test of nonlinear components indicated by visual inspection. The covariates included in LMMs were explained in Section 4.3.2 in detail. In the current Appendix, the focus is on the construction of the random structure of models, inclusion of additional nonlinear components, and final model tests.

Before including them to the models, all variables were transformed, as explained in Sections 4.2.4 and 4.2.5 (except categorical variables and suffix counts). The covariates were centered (except categorical variables) before their inclusion into the LMMs. RFLP and FSI as covariates in LMMs of FFD and GD, and EVS as a covariate in LMMs of FSI, FFD, GD, and RFLP were centered to their means. The characteristics of words were centered on their common means within the relevant modality. For example, predictabilities were centered on the common mean of predictabilities, as calculated in formulas 1-6.

$$\text{Oral Reading: } P0.c = P0 - \text{mean}(P0, P1, P2) = P0 - (-1.64) \quad (1)$$
$$\text{Oral Reading: } P1.c = P1 - \text{mean}(P0, P1, P2) = P1 - (-1.64) \quad (2)$$
$$\text{Oral Reading: } P2.c = P2 - \text{mean}(P0, P1, P2) = P2 - (-1.64) \quad (3)$$
$$\text{Silent Reading: } P0.c = P0 - \text{mean}(P0, P1, P2) = P0 - (-1.68) \quad (4)$$
$$\text{Silent Reading: } P1.c = P1 - \text{mean}(P0, P1, P2) = P1 - (-1.68) \quad (5)$$
$$\text{Silent Reading: } P2.c = P2 - \text{mean}(P0, P1, P2) = P2 - (-1.68) \quad (6)$$

The linear components of covariates are added to the models as random slopes one-by-one, in the following order. At each step, models are compared with `anova()` function for the contribution of the random slope to the model. A random slope was kept in the model only if the model converged, and the random slope contributed to the model significantly (i.e., if $p < 0.2$, Matuschek et al., 2017). Contribution of random slopes was tested for all LMMs in the following order:

For Participant as a random factor (with their abbreviations in the dataset, ".c" indicates that covariate was centered, ".f" indicates that the covariate was categorical)

Word n characteristics. `P0.c`, `WL0.c`, `SF0.c`

Word n-1 characteristics. `P1.c`, `WL1.c`, `SF1.c`

Word n+1 characteristics. `P2.c`, `WL2.c`, `SF2.c`

Suffix counts. `SC0.c`, `SC1.c`, `SC2.c`

Oral reading specific covariates. `EVS.c` (common), `FSI.c` (only for eye-movement models)

Eye-movement specific covariates. `LS0.c`, `LS2.c` (common), and `RFLP.c` (only for fixation duration models)

Prelexical characteristics. `TF0.c`, `TF2.c`, `VH0.f`, `VH2.f`

Familiarity. `FamCode.f`

For Word as a random factor (with their abbreviations in the dataset, ".c" indicates that covariate was centered, ".f" indicates that the covariate was categorical)

Oral reading specific covariates. `EVS.c` (common), `FSI.c` (only for eye-movement models)

Eye-movement specific covariates. `LS0.c`, `LS2.c` (common), and `RFLP.c` (only for fixation duration models)

In Table C 1, `anova()` results of random slopes that significantly contributed to the LMMs are presented.

Table C 1 LMM comparison results during the construction of the random structure

		Oral Reading		Silent Reading	
Random Factor	Random Slope	χ^2 (1)	*p*	χ^2 (1)	*p*
LMM of Fixation Speech Interval (FSI)					
Participant	Word length of word n (WL0)	3.32	0.07 < 0.2	-	-
Participant	Stem frequency of word n (SF0)	70.84	4.2E-16 < 0.2	-	-
LMM of First Fixation Duration (FFD)					
Participant	Predictability of word n (P0)	-	-	3.73	0.05 < 0.2
Participant	Word length of word n (WL0)	14.24	1.61E-04 < 0.2	34.47	4.32E-09 < 0.2
Participant	Stem frequency of word n (SF0)	7.32	6.82E-03 < 0.2	-	-
Participant	Stem frequency of word n+1 (SF2)	-	-	9.996	1.57E-03 < 0.2
Participant	Spatial eye voice span (EVS)	5.64	0.02 < 0.2	-	-
Participant	Launch site of word n (LS0)	-	-	10.33	1.31E-03 < 0.2
Word	Spatial eye voice span (EVS)	3.98	0.05 < 0.2	-	-
Word	Launch site of word n (LS0)	4.74	0.03 < 0.2	-	-

Word	Launch site of word n+1 (LS2)	-	-	3.1	0.08 < 0.2
LMM of Gaze Duration (GD)					
Participant	Predictability of word n (P0)	2.91	0.09 < 0.2	1.66	1.98E-01 < 0.2
Participant	Word length of word n (WL0)	158.14	< 2.2E-16 < 0.2	-	-
Participant	Stem frequency of word n (SF0)	-	-	39.33	3.58E-10 < 0.2
Participant	Predictability of word n-1 (P1)	-	-	5.27	0.02 < 0.2
Participant	Stem frequency of word n+1 (SF2)	3.68	0.06 < 0.2	-	-
Participant	Suffix count of word n (SC0)	-	-	6.48	0.01 < 0.2
Participant	Suffix count of word n+1 (SC2)	-	-	1.74	0.19 < 0.2
Participant	Fixation speech interval (FSI)	10.72	1.06E-03 < 0.2	-	-
Participant	Launch site of word n+1 (LS2)	9.62	1.92E-03 < 0.2	14.96	1.1E-04 < 0.2
Word	Fixation speech interval (FSI)	45.47	1.55E-11 < 0.2	-	-
Word	Launch site of word n (LS0)	5.64	0.02 < 0.2	-	-
LMM of Relative First Landing Position (RFLP)					
Participant	Predictability of word n (P0)	3.03	0.08 < 0.2	9.75	1.79E-03 < 0.2
Participant	Word length of word n-1 (WL1)	3.08	0.08 < 0.2	-	-
Participant	Predictability of word n+1 (P2)	-	-	5.85	0.02 < 0.2
Participant	Suffix count of word n-1 (SC1)	-	-	10.50	1.20E-03 < 0.2
Participant	Suffix count of word n+1 (SC2)	-	-	2.29	0.13 < 0.2
Participant	Fixation speech interval (FSI)	19.25	1.15E-05 < 0.2	-	-
Participant	Launch site of word n+1 (LS2)	-	-	44.71	2.28E-11 < 0.2
Participant	Trigram frequency of word n (TF0)	-	-	2.18	0.14 < 0.2
Word	Launch site of word n (LS0)	48.33	3.60E-12 < 0.2	-	-
The number of obs.		11081		12225	
Groups	Participant	196			
	Word	192			

Visual inspections on raw oral reading data indicated nonlinear relationships between (1) FSI and P0, (2) FSI and WL2, (3) FFD and WL0, (4) FFD and WL2, (5) GD and P0, (6) GD and FSI, and (7) RFLP and WL2. Among these nonlinear relationships, the only quadratic component contributed to the LMM of GD was quad. FSI (χ^2 (1) = 7.52, p < .2). Models that included the other nonlinear components failed to converge.

For silent reading instances, visual inspection on raw data indicated nonlinear relationships between (1) FFD and WL0, and (2) GD and P0. The LMM of FFD that included the quadratic component of WL0 was significantly better than the simpler model (χ^2 (1) = 46.22, p < .2) while the LMM of GD that included the quadratic component of P0 failed to converge.

Upon the construction of LMMs, the final models tested for the assumptions of LMM. The results are presented below.

LMM of FSI

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 2 PCA for the random structure of the LMM of FSI

Participant
Importance of components:

	[,1]	[,2]	[,3]
Standard deviation	0.9748	0.605	0.10268
Proportion of Variance	0.7162	0.2759	0.00795
Cumulative Proportion	0.7162	0.992	1

Word
Importance of components:

	[,1]
Standard deviation	0.3565
Proportion of Variance	1
Cumulative Proportion	1

Multicollinearity. There was not any component that had a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.51) (Field, 2009).

Table C 3 VIFs of the estimates of LMM of FSI

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.32	0.76
Stem frequency of word n (SF0)	2.68	0.37
Word length of word n (WL0)	5.6	0.18
Suffix count of word n (SC0)	1.74	0.57
Trigram frequency of word n (TF0)	2.71	0.37
Vowel harmony of word n (VH0)	1.79	0.56
Familiarity	3	0.33
Spatial eye voice span (EVS)	1.09	0.92
Predictability of word n-1 (P1)	1.25	0.8
Stem frequency of word n-1 (SF1)	4.56	0.22
Word length of word n-1 (WL1)	2.21	0.45
Suffix count of word n-1 (SC1)	1.86	0.54

Predictability of word n+1 (P2)	1.24	0.81
Stem frequency of word n+1 (SF2)	2.05	0.49
Word length of word n+1 (WL2)	2.78	0.36
Suffix count of word n+1 (SC2)	2.91	0.34
Trigram frequency of word n+1 (TF2)	3.05	0.33
Vowel harmony of word n+1 (VH2)	1.78	0.56
WL0 x SF0	1.98	0.51
WL0 x SF2	1.62	0.62
WL0 x TF2	2.8	0.36
WL0 x VH2	1.68	0.6
SF0 x SF2	1.93	0.52
SF0 x TF2	2.47	0.4
SF0 x VH2	2.02	0.49
SF1 x SF0	2.23	0.45
SF1 x TF0	1.97	0.51
SF1 x VH0	3.19	0.31
Familiarity x TF0	1.44	0.69
Familiarity x VH0	2.53	0.4
WL0 x EVS	1.09	0.92
Average Tolerance		0.51

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (5.60) and SF1 (4.56); (2) for 3 < *VIF* < 4 SF1 x VH0 (3.19), TF2 (3.10), and familiarity (3.00). Since all of the components had theoretical importance and according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2), there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.

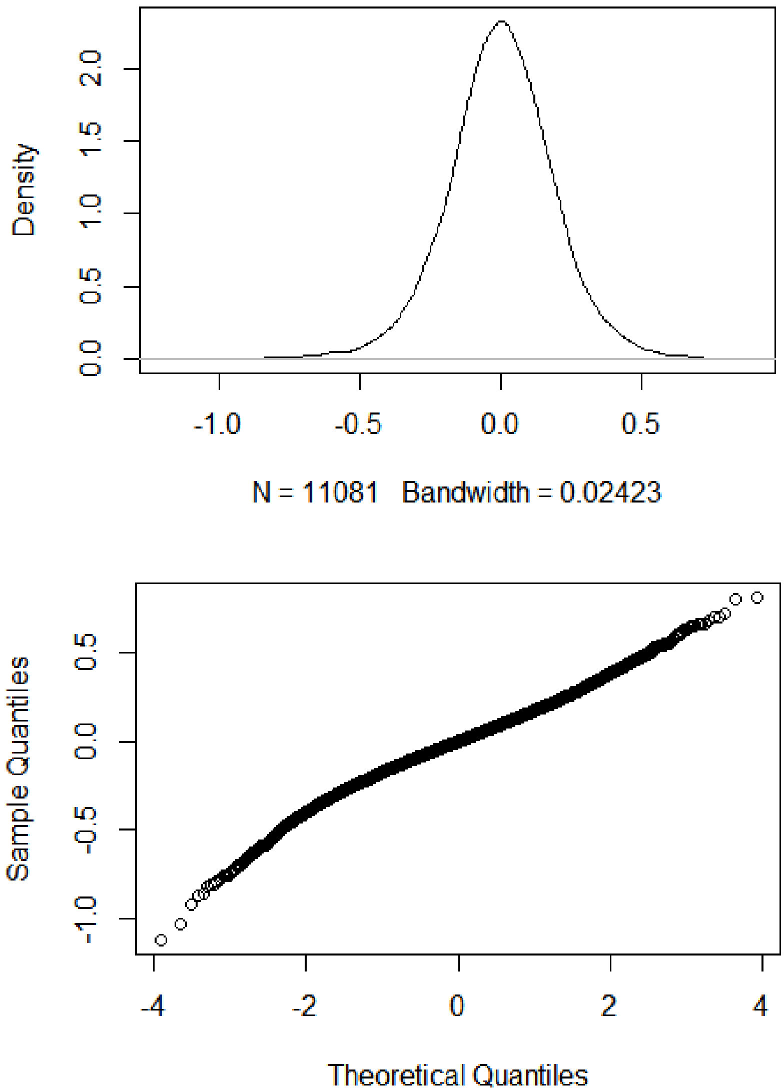


Figure C 1 Distribution of the residuals of LMM of FSI

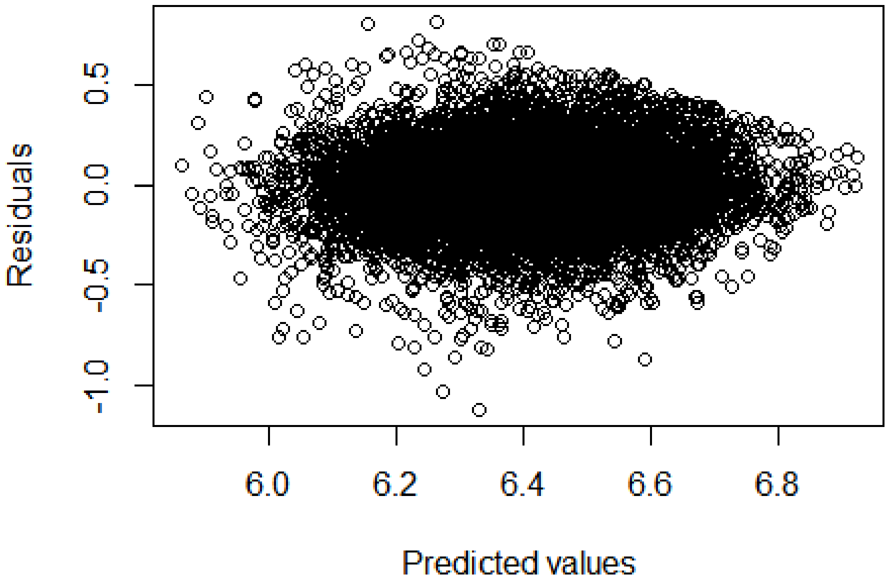


Figure C 2 Predicted values vs. Residuals of LMM of FSI

LMM of FFD (Oral Reading)

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 4 PCA for the random structure of the LMM of FFD (Oral Reading)

Participant
Importance of components:

	[,1]	[,2]	[,3]	[,4]
Standard deviation	1.4941	0.34326	0.11308	0.04751
Proportion of Variance	0.9438	0.04982	0.00541	0.00095
Cumulative Proportion	0.9438	0.99364	0.99905	1

Word
Importance of components:

	[,1]	[,2]	[,3]
Standard deviation	0.1552	0.1149	0.1056
Proportion of Variance	0.4971	0.2726	0.2303
Cumulative Proportion	0.4971	0.7697	1

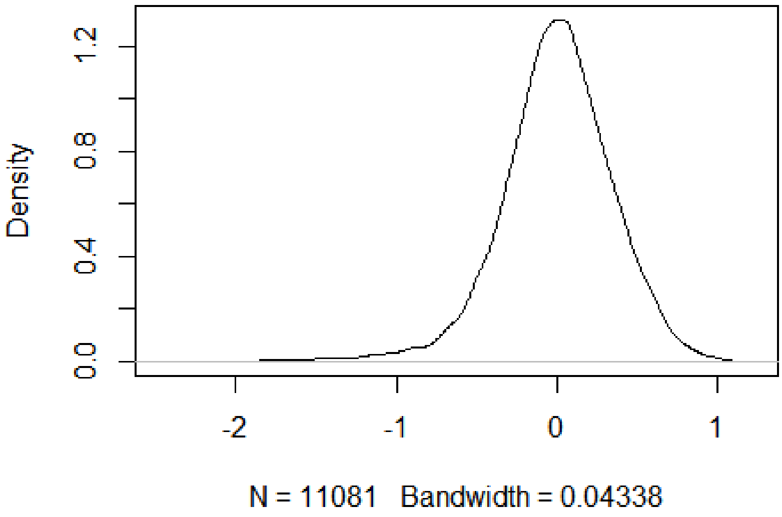
Multicollinearity. There was not any component that had a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.55) (Field, 2009).

Table C 5 VIFs of the estimates of LMM of FFD (Oral Reading)

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.35	0.74
Stem frequency of word n (SF0)	3.02	0.33
Word length of word n (WL0)	5.17	0.19
Suffix count of word n (SC0)	1.7	0.59
Trigram frequency of word n (TF0)	2.83	0.35
Vowel harmony of word n (VH0)	1.95	0.51
Familiarity	3.51	0.29
Spatial eye voice span (EVS)	1.08	0.93
Fixation speech interval (FSI)	1.11	0.9
Relative first landing position (RFLP)	1.3	0.77
RFLP quad.	1.09	0.92
Launch site of word n (LS0)	1.34	0.75
Predictability of word n-1 (P1)	1.25	0.8
Stem frequency of word n-1 (SF1)	4.47	0.22
Word length of word n-1 (WL1)	2.26	0.44
Suffix count of word n-1 (SC1)	1.85	0.54
Predictability of word n+1 (P2)	1.29	0.77
Stem frequency of word n+1 (SF2)	2.03	0.49
Word length of word n+1 (WL2)	2.75	0.36
Suffix count of word n+1 (SC2)	2.89	0.35
Trigram frequency of word n+1 (TF2)	2.99	0.33
Vowel harmony of word n+1 (VH2)	1.72	0.58
Launch site of word n+1 (LS2)	1.61	0.62
WL0 x SF0	2.06	0.49
WL0 x SF2	1.64	0.61
WL0 x TF2	2.72	0.37
WL0 x VH2	1.66	0.6
SF0 x SF2	1.86	0.54
SF0 x TF2	2.48	0.4
SF0 x VH2	1.99	0.5
SF1 x SF0	2.13	0.47
SF1 x TF0	1.97	0.51
SF1 x VH0	3.19	0.31
Familiarity x TF0	1.89	0.53
Familiarity x VH0	2.62	0.38
WL1 x LS0	1.21	0.83
LS2 x SF2	1.18	0.85
LS2 x P2	1.37	0.73
Average Tolerance		0.55

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (5.16) and SF1 (4.47); (2) for 3 < *VIF* < 4 familiarity (3.51), SF1 x VH0 (3.19), and SF0 (3.02). Since all of the components had theoretical importance and according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2), there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.



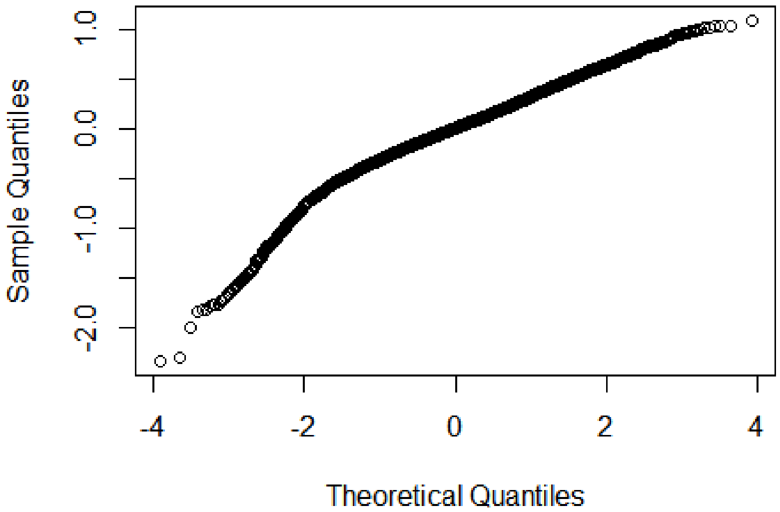


Figure C 3 Distribution of the residuals of LMM of FFD (oral reading)

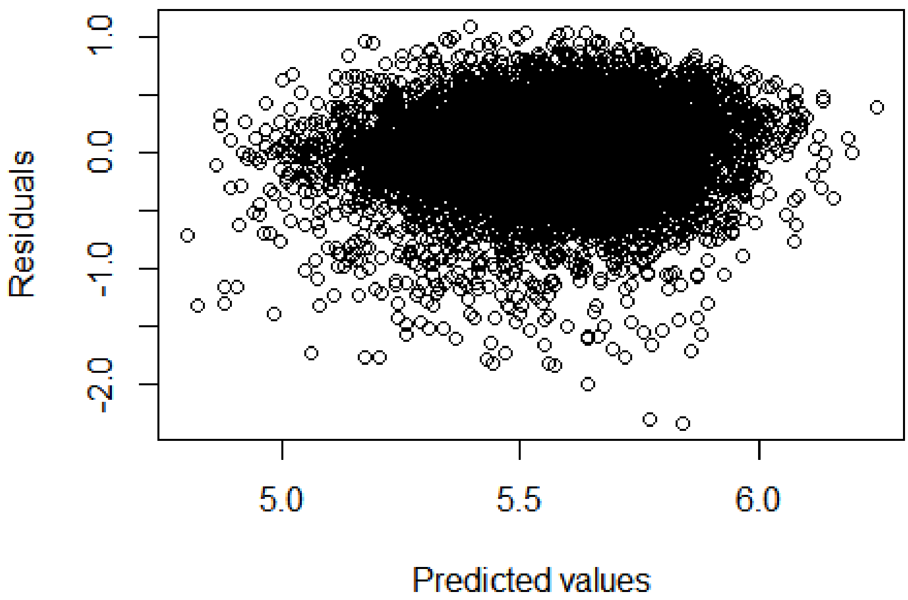


Figure C 4 Predicted values vs. Residuals of LMM of FFD (oral reading)

LMM of GD (Oral Reading)

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 6 PCA for the random structure of the LMM of GD (Oral Reading)

Participant
Importance of components:

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]
Standard deviation	3.1654	0.3601	0.328	0.20351	0.12767	0.0547
Proportion of Variance	0.9711	0.01257	0.01043	0.00401	0.00158	0.00029
Cumulative Proportion	0.9711	0.98369	0.99412	0.99813	0.99971	1

Word
Importance of components:

	[,1]	[,2]	[,3]
Standard deviation	0.5264	0.2845	0.11237
Proportion of Variance	0.7476	0.2184	0.03407
Cumulative Proportion	0.7476	0.9659	1

Multicollinearity. There was not any component that had a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.59) (Field, 2009).

Table C 7 VIFs of the estimates of LMM of GD (Oral Reading)

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.31	0.77
Stem frequency of word n (SF0)	2.98	0.34
Word length of word n (WL0)	4.52	0.22
Suffix count of word n (SC0)	1.63	0.61
Trigram frequency of word n (TF0)	2.55	0.39
Vowel harmony of word n (VH0)	1.77	0.56
Familiarity	3.23	0.31
Spatial eye voice span (EVS)	1.09	0.91
Fixation speech interval (FSI)	1.09	0.92
FSI quad.	1.09	0.91
Relative first landing position (RFLP)	1.23	0.81
RFLP quad.	1.05	0.95
Launch site of word n (LS0)	1.31	0.76
Predictability of word n-1 (P1)	1.25	0.8
Stem frequency of word n-1 (SF1)	4.52	0.22
Word length of word n-1 (WL1)	2.24	0.45
Suffix count of word n-1 (SC1)	1.86	0.54
Predictability of word n+1 (P2)	1.26	0.8
Stem frequency of word n+1 (SF2)	2.02	0.5
Word length of word n+1 (WL2)	2.75	0.36
Suffix count of word n+1 (SC2)	2.87	0.35
Trigram frequency of word n+1 (TF2)	3.02	0.33
Vowel harmony of word n+1 (VH2)	1.76	0.57
Launch site of word n+1 (LS2)	1.45	0.69
WL0 x SF0	1.89	0.53
WL0 x SF2	1.56	0.64
WL0 x TF2	2.45	0.41
WL0 x VH2	1.59	0.63
SF0 x SF2	1.9	0.53
SF0 x TF2	2.5	0.4
SF0 x VH2	2.05	0.49
SF1 x SF0	2.23	0.45
SF1 x TF0	1.94	0.52
SF1 x VH0	3.17	0.32
Familiarity x TF0	1.54	0.65
Familiarity x VH0	2.62	0.38
WL1 x LS0	1.18	0.85
LS2 x SF2	1.12	0.89
LS2 x P2	1.27	0.79
EVS x FSI	1.12	0.89
Average Tolerance		0.59

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (4.52) and SF1 (4.52); (2) for 3 < *VIF* < 4 familiarity (3.23), SF1 x VH0 (3.17), and TF2 (3.02). Since those components had theoretical importance and according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2), there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.

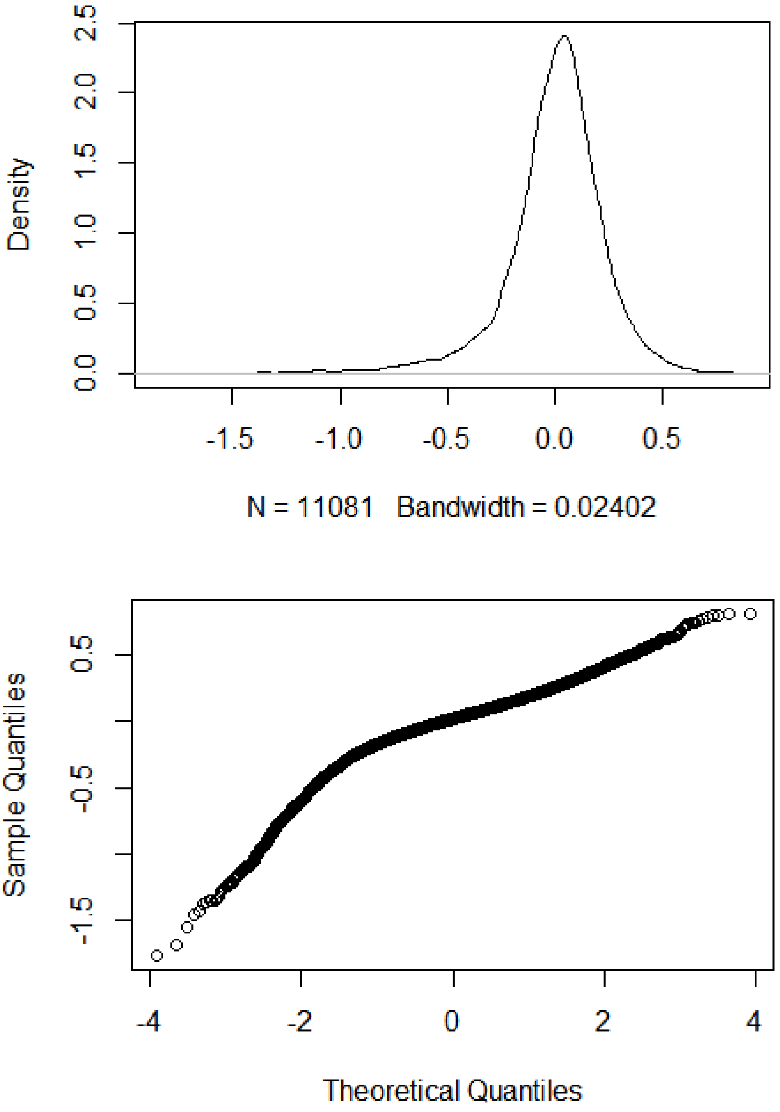


Figure C 5 Distribution of the residuals of LMM of GD (oral reading)

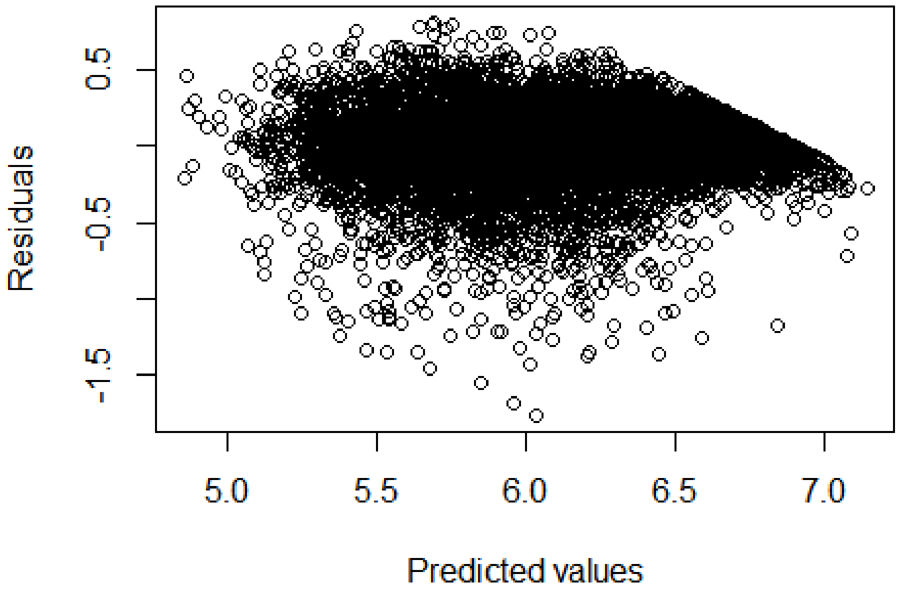


Figure C 6 Predicted values vs. Residuals of LMM of GD (oral reading)

LMM of RFLP (Oral Reading)

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 8 PCA for the random structure of the LMM of RFLP (Oral Reading)

Participant
Importance of components:

	[,1]	[,2]	[,3]	[,4]
Standard deviation	1.6587	0.45709	0.43806	0.17165
Proportion of Variance	0.8648	0.06567	0.06031	0.00926
Cumulative Proportion	0.8648	0.93042	0.99074	1

Word
Importance of components:

	[,1]	[,2]
Standard deviation	0.2005	0.1752
Proportion of Variance	0.5669	0.4331
Cumulative Proportion	0.5669	1

Multicollinearity. There was not any component that had a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.53) (Field, 2009).

Table C 9 VIFs of the estimates of LMM of RFLP (Oral Reading)

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.33	0.75
Stem frequency of word n (SF0)	3.19	0.31
Word length of word n (WL0)	5.81	0.17
Suffix count of word n (SC0)	1.76	0.57
Trigram frequency of word n (TF0)	2.96	0.34
Vowel harmony of word n (VH0)	1.98	0.5
Familiarity	3.55	0.28
Spatial eye voice span (EVS)	1.1	0.91
Fixation speech interval (FSI)	1.06	0.94
Launch site of word n (LS0)	1.22	0.82
Predictability of word n-1 (P1)	1.24	0.81
Stem frequency of word n-1 (SF1)	4.46	0.22
Word length of word n-1 (WL1)	2.18	0.46
Suffix count of word n-1 (SC1)	1.82	0.55
Predictability of word n+1 (P2)	1.29	0.78
Stem frequency of word n+1 (SF2)	2.05	0.49
Word length of word n+1 (WL2)	2.75	0.36
Suffix count of word n+1 (SC2)	2.9	0.34
Trigram frequency of word n+1 (TF2)	3.01	0.33
Vowel harmony of word n+1 (VH2)	1.74	0.57
Launch site of word n+1 (LS2)	1.5	0.67
WL0 x SF0	2.16	0.46
WL0 x SF2	1.68	0.6
WL0 x TF2	2.95	0.34
WL0 x VH2	1.71	0.59
SF0 x SF2	1.89	0.53
SF0 x TF2	2.51	0.4
SF0 x VH2	2.02	0.49
SF1 x SF0	2.18	0.46
SF1 x TF0	2	0.5
SF1 x VH0	3.18	0.31
Familiarity x TF0	1.85	0.54
Familiarity x VH0	2.65	0.38
WL1 x LS0	1.22	0.82
LS2 x SF2	1.17	0.85
LS2 x P2	1.36	0.73
Average Tolerance		0.53

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (5.81) and SF1 (4.46); (2) for 3 < *VIF* < 4 familiarity (3.55), SF0 (3.19), SF1 x VH0 (3.18), TF2 (3.01). Since all of the components had theoretical importance and according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2) there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.

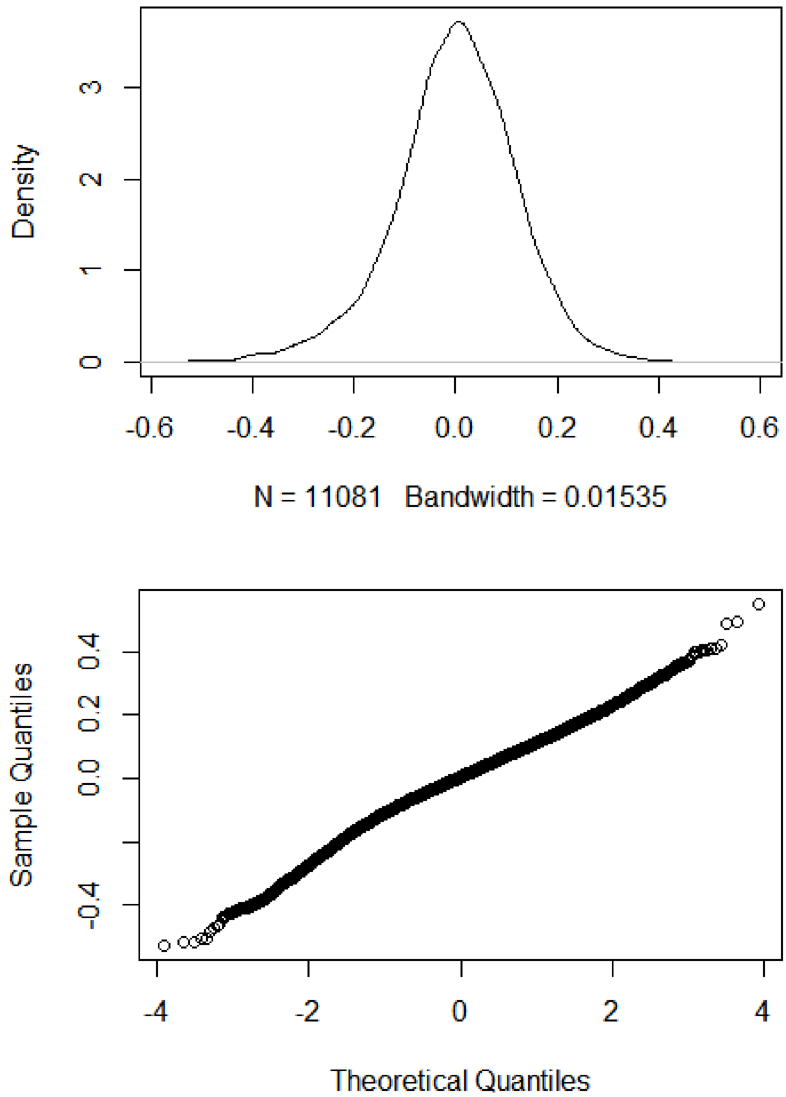


Figure C 7 Distribution of the residuals of LMM of RFLP (oral reading)

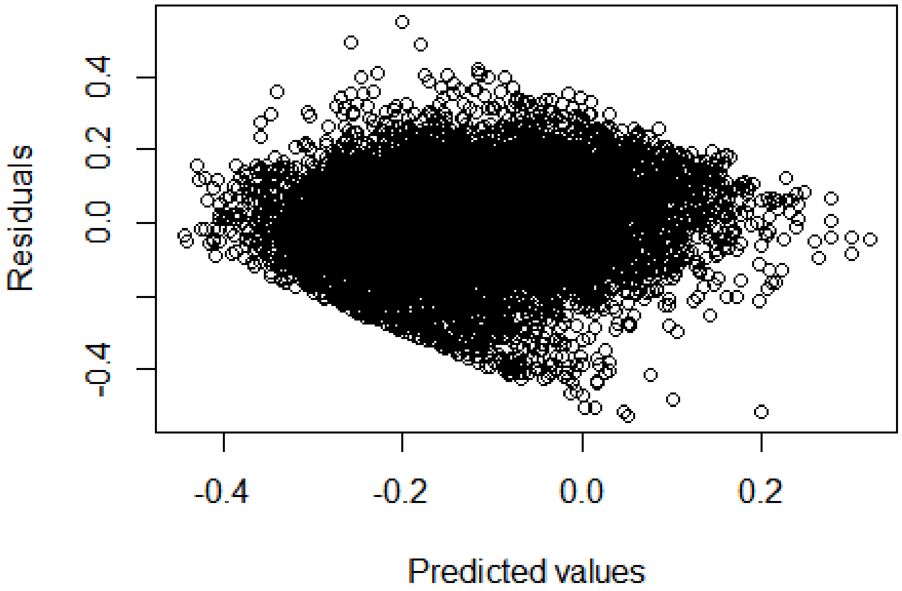


Figure C 8 Predicted values vs. Residuals of LMM of RFLP (oral reading)

LMM of FFD (Silent Reading)

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 10 PCA for the random structure of the LMM of FFD (Silent Reading)

Participant
Importance of components:

	[,1]	[,2]	[,3]	[,4]	[,5]
Standard deviation	1.9191	0.40257	0.17469	0.11921	0.06357
Proportion of Variance	0.9458	0.04162	0.00784	0.00365	0.00104
Cumulative Proportion	0.9458	0.98748	0.99531	0.99896	1

Word
Importance of components:

	[,1]	[,2]
Standard deviation	0.1116	0.07658
Proportion of Variance	0.6798	0.32024
Cumulative Proportion	0.6798	1

Multicollinearity. There was not any component that ha a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.52) (Field, 2009).

Table C 11 VIFs of the estimates of LMM of FFD (Silent Reading)

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.29	0.78
Stem frequency of word n (SF0)	3.48	0.29
Word length of word n (WL0)	5.03	0.2
WL0 quad.	3.67	0.27
Suffix count of word n (SC0)	1.56	0.64
Trigram frequency of word n (TF0)	2.9	0.35
Vowel harmony of word n (VH0)	2.06	0.49
Familiarity	3.93	0.25
Relative first landing position (RFLP)	1.3	0.77
RFLP quad.	1.09	0.91
Launch site of word n (LS0)	1.32	0.76
Predictability of word n-1 (P1)	1.24	0.81
Stem frequency of word n-1 (SF1)	4.5	0.22
Word length of word n-1 (WL1)	2.35	0.42
Suffix count of word n-1 (SC1)	1.86	0.54
Predictability of word n+1 (P2)	1.31	0.76
Stem frequency of word n+1 (SF2)	1.86	0.54
Word length of word n+1 (WL2)	2.69	0.37
Suffix count of word n+1 (SC2)	2.85	0.35
Trigram frequency of word n+1 (TF2)	3.07	0.33
Vowel harmony of word n+1 (VH2)	1.74	0.58
Launch site of word n+1 (LS2)	1.76	0.57
WL0 x SF0	1.97	0.51
WL0 x SF2	1.6	0.63
WL0 x TF2	2.41	0.42
WL0 x VH2	1.53	0.65
SF0 x SF2	1.81	0.55
SF0 x TF2	2.42	0.41
SF0 x VH2	2.08	0.48
SF1 x SF0	2.29	0.44
SF1 x TF0	1.98	0.5
SF1 x VH0	3.28	0.3
Familiarity x TF0	2.12	0.47
Familiarity x VH0	2.95	0.34
WL1 x LS0	1.24	0.81
LS2 x SF2	1.29	0.77
LS2 x P2	1.36	0.73
Average Tolerance		0.52

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (5.03) and SF1 (4.50); (2) for 3 < *VIF* < 4 familiarity (3.93), WL0 quad. (3.67), SF0 (3.48), SF1 x VH0 (3.28), TF2 (3.07). Since according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2), there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.

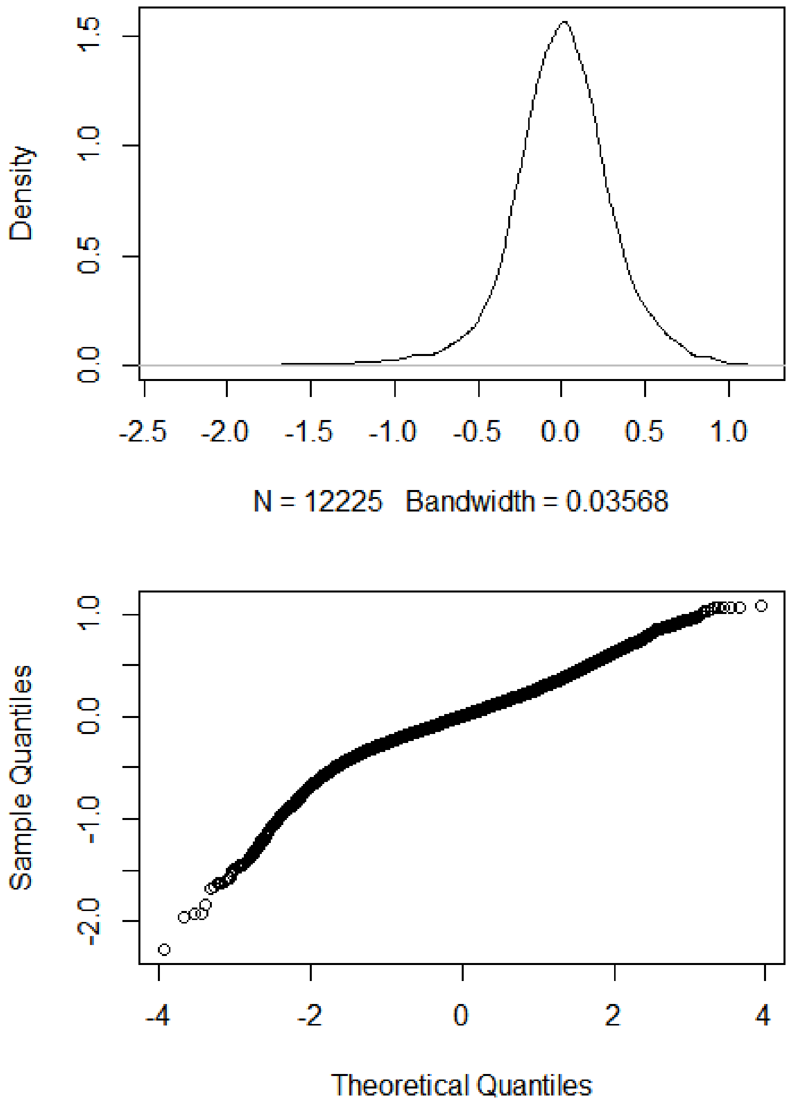


Figure C 9 Distribution of the residuals of LMM of FFD (Silent Reading)

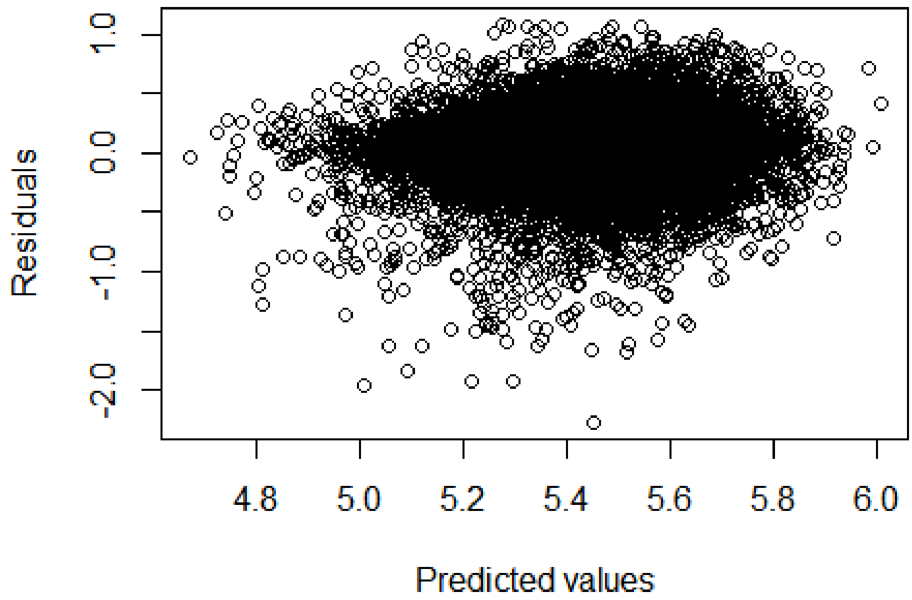


Figure C 10 Predicted values vs. Residuals of LMM of FFD (Silent Reading)

LMM of GD (Silent Reading)

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 12 PCA for the random structure of the LMM of GD (Silent Reading)

Participant
Importance of components:

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
Standard deviation	0.5318	0.13169	0.12062	0.09068	0.0803	0.07619	0.04651
Proportion of Variance	0.8384	0.05141	0.04313	0.02438	0.01911	0.01721	0.00641
Cumulative Proportion	0.8384	0.88976	0.93289	0.95727	0.97638	0.99359	1

Word
Importance of components:

	[,1]
Standard deviation	0.2853
Proportion of Variance	1
Cumulative Proportion	1

Multicollinearity. There was not any component that had a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.54) (Field, 2009).

Table C 13 VIFs of the estimates of LMM of GD (Silent Reading)

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.32	0.76
Stem frequency of word n (SF0)	2.84	0.35
Word length of word n (WL0)	5.59	0.18
Suffix count of word n (SC0)	1.69	0.59
Trigram frequency of word n (TF0)	2.78	0.36
Vowel harmony of word n (VH0)	1.9	0.53
Familiarity	3.18	0.31
Relative first landing position (RFLP)	1.3	0.77
RFLP quad.	1.07	0.93
Launch site of word n (LS0)	1.37	0.73
Predictability of word n-1 (P1)	1.23	0.81
Stem frequency of word n-1 (SF1)	4.56	0.22
Word length of word n-1 (WL1)	2.26	0.44
Suffix count of word n-1 (SC1)	1.86	0.54
Predictability of word n+1 (P2)	1.27	0.79
Stem frequency of word n+1 (SF2)	2.02	0.49
Word length of word n+1 (WL2)	2.73	0.37
Suffix count of word n+1 (SC2)	2.88	0.35
Trigram frequency of word n+1 (TF2)	2.98	0.34
Vowel harmony of word n+1 (VH2)	1.78	0.56
Launch site of word n+1 (LS2)	1.51	0.66
WL0 x SF0	1.94	0.51
WL0 x SF2	1.69	0.59
WL0 x TF2	2.68	0.37
WL0 x VH2	1.65	0.61
SF0 x SF2	1.92	0.52
SF0 x TF2	2.36	0.42
SF0 x VH2	2.06	0.48
SF1 x SF0	2.25	0.44
SF1 x TF0	2.04	0.49
SF1 x VH0	3.25	0.31
Familiarity x TF0	1.56	0.64
Familiarity x VH0	2.73	0.37
WL1 x LS0	1.22	0.82
LS2 x SF2	1.17	0.85
LS2 x P2	1.25	0.8
Average Tolerance		0.54

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (5.59) and SF1 (4.56); (2) for 3 < *VIF* < 4 SF1 x VH0 (3.25), and familiarity (3.18). Since all of the components had theoretical importance and according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2), there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.

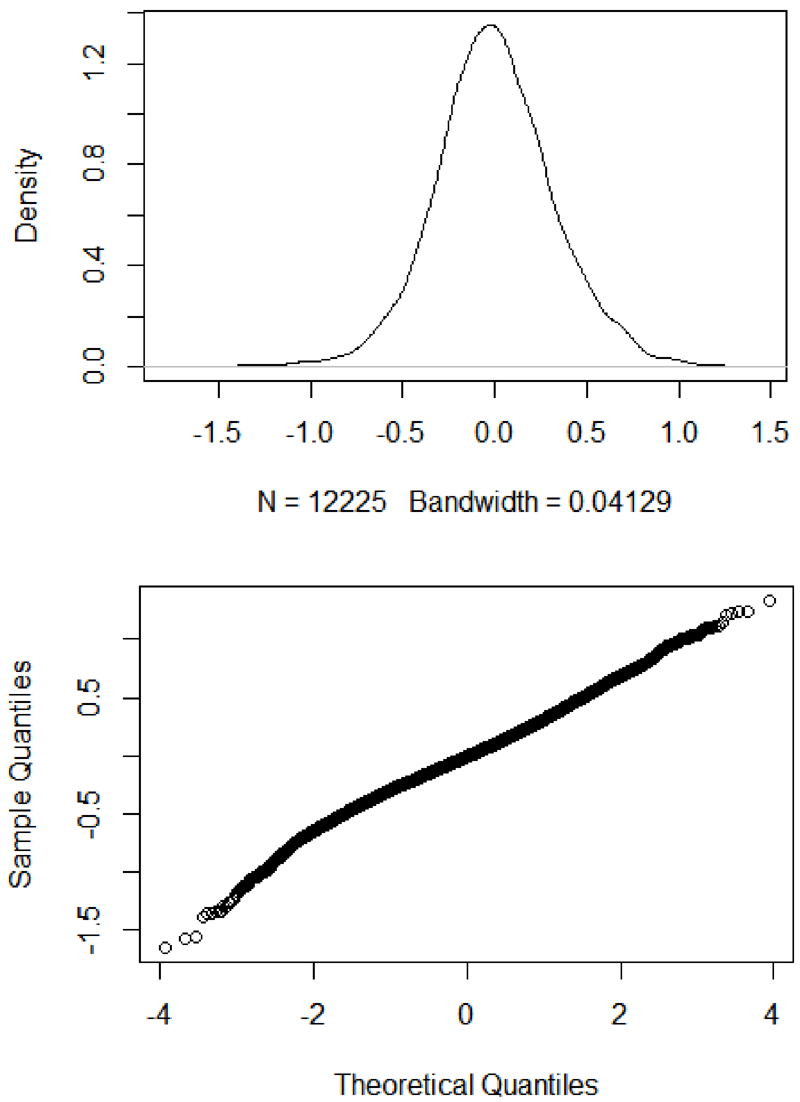


Figure C 11 Distribution of the residuals of LMM of GD (Silent Reading)

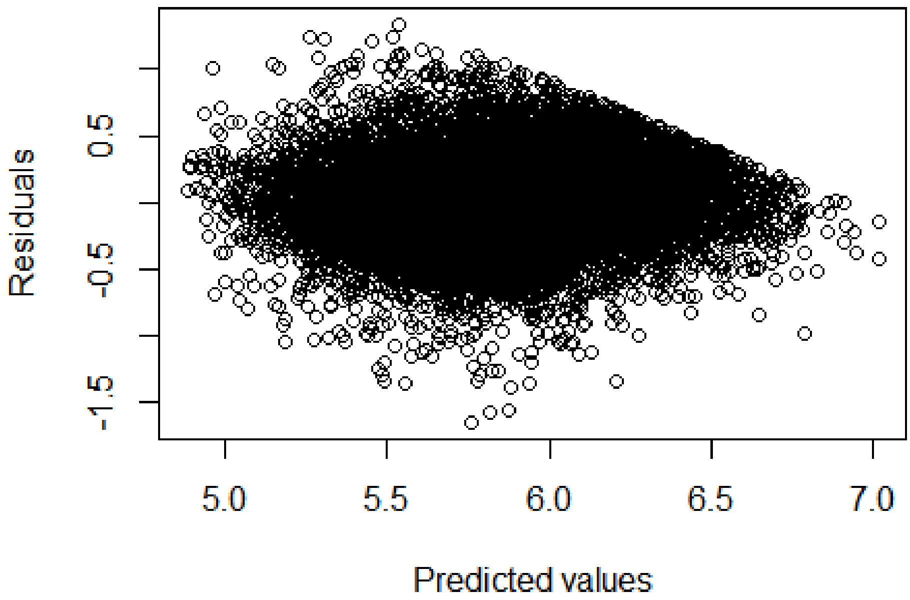


Figure C 12 Predicted values vs. Residuals of LMM of GD (Silent Reading)

LMM of RFLP (Silent Reading)

Random structure. None of the components in the random structure exceeded the principle component count that cumulatively accounts for 100% of the variance (Bates et al., 2015).

Table C 14 PCA for the random structure of the LMM of RFLP (Silent Reading)

Participant
Importance of components:

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]
Standard deviation	0.4674	0.2323	0.17016	0.15049	0.09748	0.08788	0.04949
Proportion of Variance	0.6356	0.157	0.08424	0.06588	0.02764	0.02247	0.00713
Cumulative Proportion	0.6356	0.7926	0.87688	0.94276	0.9704	0.99287	1

Word
Importance of components:

	[,1]
Standard deviation	0.2108
Proportion of Variance	1
Cumulative Proportion	1

Multicollinearity. There was not any component that had a variance inflation factor (*VIF*) value greater than ten, and the average tolerance value was greater than 0.2 (i.e., 0.52) (Field, 2009).

Table C 15 VIFs of the estimates of LMM of RFLP (Silent Reading)

Covariate	VIF	Tolerance (1/VIF)
Predictability of word n (P0)	1.29	0.77
Stem frequency of word n (SF0)	3.2	0.31
Word length of word n (WL0)	5.42	0.18
Suffix count of word n (SC0)	1.67	0.6
Trigram frequency of word n (TF0)	2.8	0.36
Vowel harmony of word n (VH0)	1.99	0.5
Familiarity	3.5	0.29
Launch site of word n (LS0)	1.22	0.82
Predictability of word n-1 (P1)	1.24	0.81
Stem frequency of word n-1 (SF1)	4.54	0.22
Word length of word n-1 (WL1)	2.22	0.45
Suffix count of word n-1 (SC1)	1.78	0.56
Predictability of word n+1 (P2)	1.27	0.79
Stem frequency of word n+1 (SF2)	2.02	0.49
Word length of word n+1 (WL2)	2.71	0.37
Suffix count of word n+1 (SC2)	2.85	0.35
Trigram frequency of word n+1 (TF2)	2.97	0.34
Vowel harmony of word n+1 (VH2)	1.77	0.56
Launch site of word n+1 (LS2)	1.33	0.75
WL0 x SF0	2.01	0.5
WL0 x SF2	1.69	0.59
WL0 x TF2	2.64	0.38
WL0 x VH2	1.63	0.61
SF0 x SF2	1.91	0.52
SF0 x TF2	2.38	0.42
SF0 x VH2	2.09	0.48
SF1 x SF0	2.28	0.44
SF1 x TF0	2.01	0.5
SF1 x VH0	3.24	0.31
Familiarity x TF0	1.78	0.56
Familiarity x VH0	2.85	0.35
WL1 x LS0	1.24	0.81
LS2 x SF2	1.16	0.86
LS2 x P2	1.24	0.81
Average Tolerance		0.52

According to more conservative thresholds (i.e., *VIF* < 4 and *VIF* < 3, Zuur et al., 2010) there were problematic components: (1) for *VIF* > 4, WL0 (5.42) and SF1 (4.54); (2) for 3 < *VIF* < 4 familiarity (3.50), SF1 x VH0 (3.24), and SF0 (3.20). Since all of the components had theoretical importance and according to less conservative criteria (e.g., *VIF* < 10, *VIF* < 8, average tolerance > 0.2), there was not any multicollinearity problem, all fixed effects of the model were kept.

Residual graphs.

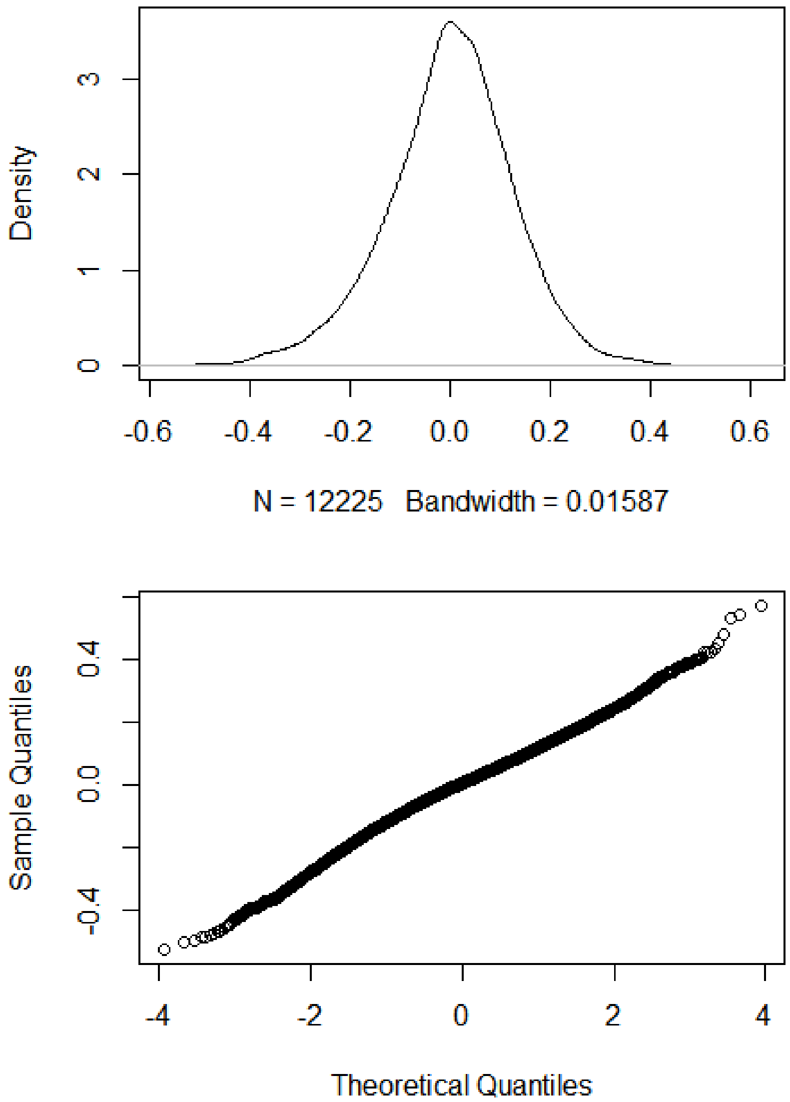


Figure C 13 Distribution of the residuals of LMM of RFLP (Silent Reading)

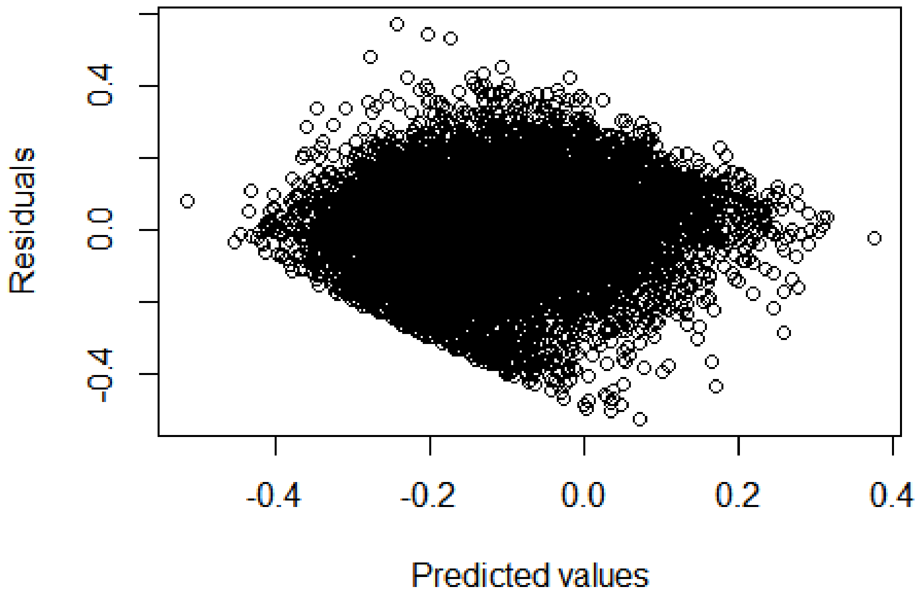


Figure C 14 Predicted values vs. Residuals of LMM of RFLP (Silent Reading).

APPENDIX D: A Baseline-Category Logit Model of Memory Buffer Load

The number of words held in the memory buffer component of P-GAG was modeled by a base-line category logit model (BCLM) using the `vglm()` function of the VGAM package (version 1.1-1; Yee, 2015; Yee & Wild, 1996). The distance in terms of word count between word n and the fixated word at the beginning of articulation of word n was assumed to represent the number of words hold in the buffer. Among levels of the variable `buffer`, *one word* represented the cases that word n was articulated before eyes left the word (i.e., one word in the buffer), *two words* represented the cases that word n was articulated while fixating word n+1 (i.e., two words in the buffer), *more than two words* represented the cases that word n was articulated while fixating any word on the right of word n+1 (i.e., more than two words in the buffer), and *regression* represented the cases that word n was articulated during a regressive fixation on word n (i.e., regressions). In Figure D 1, an example of *two words* condition is provided.

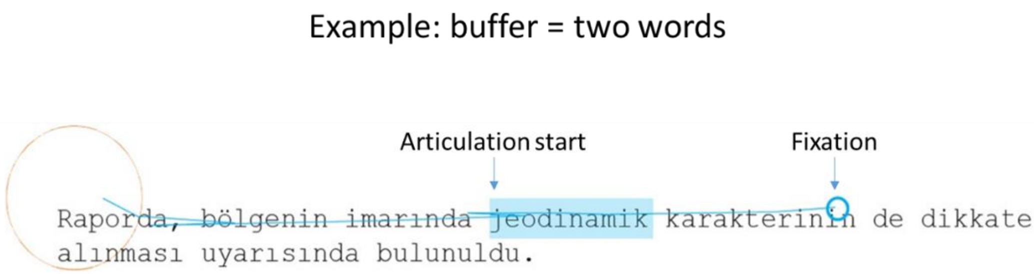


Figure D 1 Example memory buffer load

Covariates in the model were the results of a Corsi-Block test, a digit-span test, predictability of word n (P0), length of word n (WL0), and stem frequency of SF0 (see Sections 4.1.5 and 4.2.5.1). There was an additional elimination due to not recorded the Corsi-Block test of one participant and three outliers in Corsi-Block test scores (i.e., three participants who scored 2). The elimination was 2% of 196 participants (see Table 4.5 for other elimination criteria and their percents). The test scores were log-transformed (base 2) and centered on their means. The other covariates transformed and centered the same as in LMMs (see Section 4.3 and APPENDIX C).

In general, a BCLM is as follows:

$$log(\frac{\pi_{ij}}{\pi_{ij*}}) = x_i^T \beta_j,\ j \neq j*$$

where the log-odds of falling in the category j vs. the base category, $j*$ is modeled with a set of predictors, Xs (The intercept can be accepted as $X_1 = 1$). The categories in the current study as ordered alphabetically in `vglm()` were 1: *more than two words*, 2: *one word*, 3: *regression*, 4: *two words*. In the current study, the *one-word* category was accepted as the base category. Therefore, there were three equations that predict (a) log-odds of holding more than two words vs. one word (1 vs. 2), (b) log-odds of returning to the articulated word after leaving vs. holding one word (3 vs. 2), and (c) log-odds of holding two words vs. one word (4 vs. 2) as follows:

$$log(\frac{\pi_{i,1}}{\pi_{i,2}}) = \alpha_1 + \beta_{X1,1}X1_i + \beta_{X2,1}X2_i + ... + \beta_{X5,1}X5_i$$

$$log(\frac{\pi_{i,3}}{\pi_{i,2}}) = \alpha_3 + \beta_{X1,3}X1_i + \beta_{X2,3}X2_i + ... + \beta_{X5,3}X5_i$$

$$log(\frac{\pi_{i,4}}{\pi_{i,2}}) = \alpha_4 + \beta_{X1,4}X1_i + \beta_{X2,4}X2_i + ... + \beta_{X5,4}X5_i$$

where α indicating the intercepts and βs indicating the coefficients.

The estimated coefficients for digit-span test scores were significant for all categories vs *one word* (*more than two words* vs *one word*: b = 2.97, SE = 0.3, $\chi^2(1)$ = 100.52, p < .001; *regression* vs *one word*: b = 0.57, SE = 0.17, $\chi^2(1)$ = 10.89, p < .001; and *two words* vs *one word*: b = 1.2, SE = 0.12, $\chi^2(1)$ = 98.17, p < .001). The results indicated that an increase in digit-span score increased the probability of holding two words or more than two words in the buffer (i.e., moving to word n+1 or further during articulation of word n) relative to holding one word (i.e., staying on word n during articulation of it). Among the estimated coefficients for Corsi-Block test scores *more than two words* vs *one word* was significant (b = -1.43, SE = 0.39, $\chi^2(1)$ = 13.14, p < .001). In Figure D 2, the relationship between memory load probabilities and memory test scores are illustrated.

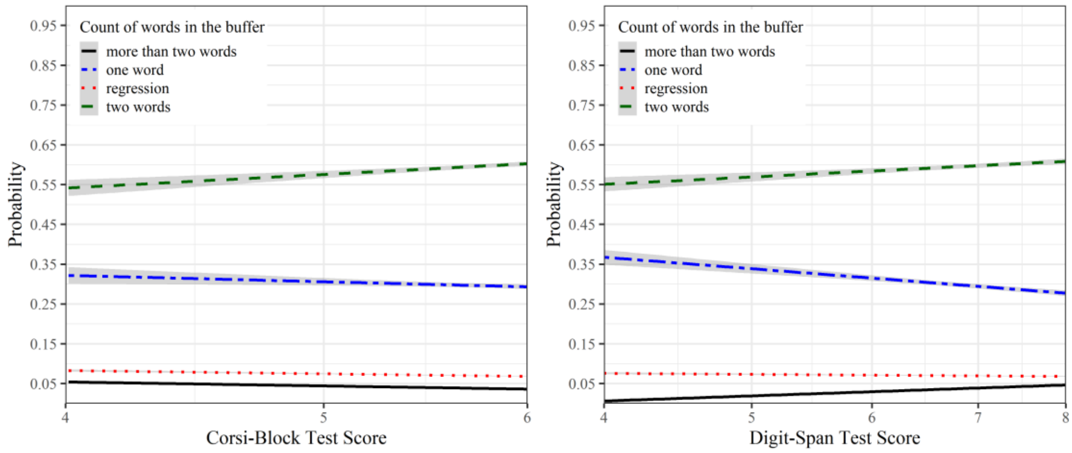


Figure D 2 Memory test scores and the memory buffer load.

The estimated coefficients for WL0 were significant for all categories vs *one word* (*more than two words* vs *one word*: b = 75.53, SE = 1.66, $\chi^2(1)$ = 2079, p < .001; *regression* vs *one word*: b = 36.71, SE = 1.6, $\chi^2(1)$ = 525.37, p < .001; and *two words* vs *one word*: b = 60.33, SE = 1.35, $\chi^2(1)$ = 1988.1, p < .001). The strongest effect on the memory load was the effect of WL0. Shorter words allowed buffer to hold more words. For longer words, the probability of staying on word n during articulation of it either because articulating word n before leaving it (i.e., *one-word* category), or by regressing to word n while articulating it was increased (see Figure D 3).

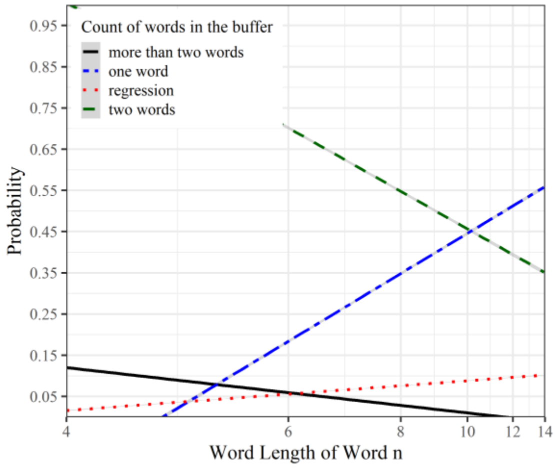


Figure D 3 The effect of WL0 on memory buffer load.

Although the effect of SF0 on memory buffer load was not as strong as WL0, the estimated coefficients for SF0 were significant for all categories vs *one word* (*more than two words* vs *one word*: $b = 1.02$, $SE = 0.05$, $\chi^2(1) = 412.74$, $p < .001$; *regression* vs *one word*: $b = 0.3$, $SE = 0.03$, $\chi^2(1) = 82.5$, $p < .001$; and *two words* vs *one word*: $b = 0.57$, $SE = 0.02$, $\chi^2(1) = 603.49$, $p < .001$). A pattern was observed for SF0 simlar to that of WL0 such that easier words (i.e., high-frequency words) allowed buffer to hold more items similar to the effect of short words. More difficult, low-frequency words tended to be articulated while eyes were on the same word (see Figure D 4).

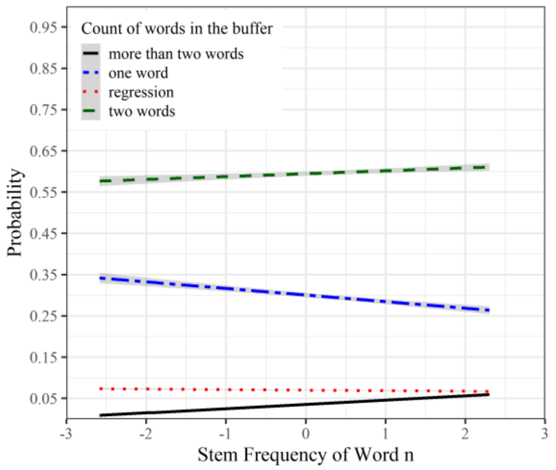


Figure D 4 The effect of SF0 on memory buffer load.

Lastly, the estimated coefficients for P0 were significant for *two words* vs *one word* ($b = -0.34$, $SE = 0.12$, $\chi^2(1) = 7.41$, $p < .01$). The pattern was similar to that of other characteristics of word n; however, only the increase in the probability of holding two words relative to staying on the same word together with an increase in P0 was significant (see Figure D 5).

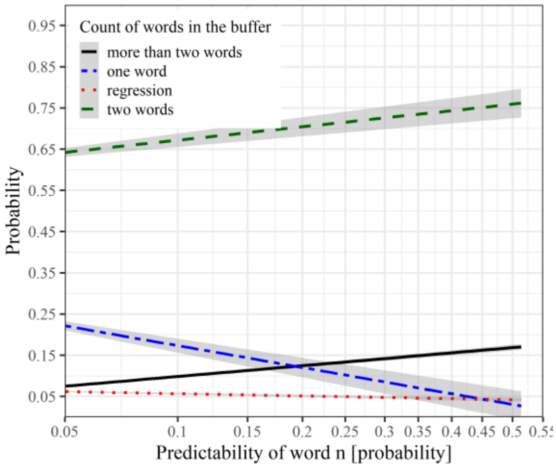


Figure D 5 The effect of P0 on memory buffer load.

In Table D 1, BCLM parameter estimates for memory buffer with odds ratio values (i.e., exponentiated values of the coefficients) are presented.

Table D 1 BCLM parameters estimates for memory buffer load

	More Than Two Words vs. One Word					Regression vs. One Word					Two Words vs. One Word				
Coefficient	Estimate	Std. Error	χ2 (1)	*p*	Odds Ratio	Estimate	Std. Error	χ2 (1)	*p*	Odds Ratio	Estimate	Std. Error	χ2 (1)	*p*	Odds Ratio
Intercept	**-2.02**	**0.12**	**282.44**	**< 2E-16**	**0.13**	**-0.5**	**0.09**	**31.35**	**0.00E+00**	**0.61**	**1.44**	**0.07**	**445.46**	**< 2E-16**	**4.22**
Predictability of word n (P0)	0.05	0.16	0.09	0.76	1.05	-0.05	0.17	0.08	0.78	0.95	**-0.34**	**0.12**	**7.41**	**0.01**	**0.71**
Word length of word n (WL0)	**75.53**	**1.66**	**2079**	**< 2E-16**	**6.3E+32**	**36.71**	**1.6**	**525.37**	**< 2E-16**	**8.8E+15**	**60.33**	**1.35**	**1988.09**	**< 2E-16**	**1.6E+26**
Stem frequency of word n (SF0)	**1.02**	**0.05**	**412.74**	**< 2E-16**	**2.77**	**0.3**	**0.03**	**82.5**	**< 2E-16**	**1.35**	**0.57**	**0.02**	**603.49**	**< 2E-16**	**1.77**
Corsi-Block test score	**-1.43**	**0.39**	**13.14**	**2.89E-04**	**0.24**	-0.39	0.28	1.89	0.17	0.68	-0.04	0.2	0.03	0.85	0.96
Digit-Span test score	**2.97**	**0.3**	**100.52**	**< 2E-16**	**19.49**	**0.57**	**0.17**	**10.89**	**9.67E-04**	**1.77**	**1.2**	**0.12**	**98.17**	**< 2E-16**	**3.32**

Residual deviance: 15080.76 on 32511 degrees of freedom

Log-likelihood: -7540.382 on 32511 degrees of freedom

Number of Fisher scoring iterations: 7

Note: Significant coefficients were set bold.

APPENDIX E: Descriptive Statistics of the Findings and Characteristics of Words

Variable	Both modalities, all conditions	Oral Reading					Silent Reading				
		All conditions	SF	SI	LF	LI	All conditions	SF	SI	LF	LI
Fixation count											
M	1.83	2.01	1.42	1.68	2.43	2.95	1.67	1.24	1.42	1.89	2.24
SD	0.93	0.98	0.63	0.85	0.85	0.91	0.84	0.51	0.7	0.78	0.98
First fixation duration (ms)											
M	264.32	283.4	281.16	316.84	256.73	279.83	247.02	239.45	266.26	228.55	256.16
SD	104.5	114.39	107.48	134.14	92.26	113.73	91.26	83.35	108.52	71.37	94.2
Gaze duration (ms)											
M	442.69	511.29	366.82	467.31	596.82	714.78	380.51	284.45	354.8	401.88	508.8
SD	213.06	216.55	155.08	200.32	185.31	165.84	189.5	124.25	179.55	172.1	211.97
Relative first landing position (0-1)											
M	0.38	0.37	0.41	0.4	0.33	0.33	0.39	0.44	0.43	0.34	0.33
SD	0.17	0.16	0.18	0.18	0.13	0.13	0.17	0.19	0.19	0.14	0.13
Fixation speech interval											
M		631.7	613.72	681.91	606.32	628.13					
SD		158.28	158.61	170.31	146.03	137.16					
Eye-voice span (letters)											
M		11.07	11.81	9.77	12.35	9.49					
SD		3.69	3.17	3.43	3.74	3.67					

Eye-voice span (words)											
M		0.67	1.02	0.83	0.41	0.19					
SD		0.55	0.43	0.45	0.49	0.39					
Amplitude (letters)											
Last saccade											
M	7.85	7.43	6.87	6.72	8.3	8.19	8.22	7.71	7.37	9.14	8.77
SD	1.99	1.82	1.56	1.47	1.88	1.8	2.06	1.93	1.73	2.1	1.93
Next saccade											
M	7.63	7.09	6.83	6.68	7.48	7.59	8.11	7.53	7.36	8.79	8.93
SD	2.22	1.95	1.77	1.92	1.95	2.13	2.33	1.9	2.06	2.41	2.51
Launch site (letters)											
Words n & n+1											
M	4.26	3.95	3.8	3.84	4.08	4.19	4.54	4.23	4.21	4.88	4.94
SD	1.8	1.63	1.56	1.53	1.72	1.7	1.91	1.79	1.74	2	1.98
Word n											
M	4.33	4.03	3.97	3.97	4.1	4.13	4.59	4.59	4.4	4.77	4.61
SD	1.75	1.59	1.56	1.52	1.69	1.59	1.84	1.88	1.73	1.92	1.81
Word n+1											
M	4.2	3.87	3.62	3.72	4.06	4.25	4.5	3.87	4.02	4.98	5.28
SD	1.85	1.66	1.55	1.53	1.75	1.79	1.97	1.61	1.73	2.08	2.08
Predictability (probability)											
Words n, n-1, & n+1											
M	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03
SD	0.11	0.11	0.11	0.14	0.08	0.11	0.11	0.11	0.13	0.07	0.11

Word n											
M	0.01	0.01	0.02	0.01	0	0	0.01	0.02	0.01	0	0
SD	0.06	0.06	0.08	0.08	0.03	0	0.06	0.08	0.07	0.03	0
Word n-1											
M	0.07	0.07	0.06	0.09	0.05	0.07	0.06	0.06	0.08	0.05	0.07
SD	0.16	0.16	0.12	0.22	0.11	0.17	0.15	0.12	0.21	0.11	0.17
Word n+1											
M	0.03	0.03	0.05	0.02	0.02	0.02	0.03	0.05	0.02	0.02	0.02
SD	0.08	0.09	0.13	0.04	0.06	0.05	0.08	0.13	0.04	0.06	0.05
Length (letters)											
Words n, n-1, & n+1											
M	8.29	8.25	7.38	7.18	9.69	9.14	8.32	7.38	7.24	9.7	9.12
SD	2.74	2.73	2.32	2.66	2.48	2.56	2.75	2.28	2.63	2.48	2.74
Word n											
M	8.68	8.54	6.14	5.98	11.81	11.6	8.81	6.19	6.11	11.84	11.68
SD	3.24	3.24	1.59	1.61	1.62	1.61	3.23	1.58	1.59	1.62	1.61
Word n-1											
M	7.83	7.85	7.89	7.24	8.58	7.47	7.81	7.86	7.22	8.56	7.53
SD	2.22	2.23	2.35	2.11	2.29	1.62	2.2	2.26	2.05	2.26	1.93
Word n+1											
M	8.35	8.36	8.1	8.31	8.69	8.36	8.34	8.09	8.4	8.69	8.17
SD	2.6	2.58	2.4	3.39	1.94	2.23	2.63	2.41	3.37	1.97	2.52
Stem frequency (log-Laplace smoothing)											
Words n, n-1, & n+1											
M	0.998	1.02	1.4	0.36	1.49	0.56	0.97	1.4	0.35	1.48	0.58

SD	1.43	1.41	0.99	1.76	0.99	1.5	1.44	1	1.75	0.99	1.56
Word n											
M	0.19	0.27	1.32	-1.49	1.38	-0.88	0.12	1.33	-1.49	1.36	-1.03
SD	1.41	1.4	0.29	0.65	0.57	0.46	1.42	0.29	0.64	0.56	0.52
Word n-1											
M	1.44	1.44	1.49	1.56	1.45	1.11	1.45	1.55	1.55	1.46	1.18
SD	1.3	1.3	1.17	1.44	1.2	1.42	1.3	1.15	1.43	1.19	1.4
Word n+1											
M	1.36	1.37	1.38	1.02	1.63	1.46	1.36	1.31	0.98	1.61	1.58
SD	1.2	1.19	1.21	1.25	1.05	1.15	1.2	1.26	1.24	1.08	1.09
Word frequency (log-Laplace smoothing)											
Words n, n-1, & n+1											
M	0.576	0.6	0.94	0.04	0.93	0.28	0.55	0.93	0	0.92	0.29
SD	1.64	1.61	1.27	1.94	1.26	1.81	1.66	1.29	1.95	1.27	1.88
Word n											
M	-0.79	-0.7	0.3	-2.17	0.15	-1.76	-0.87	0.27	-2.22	0.11	-1.88
SD	1.5	1.5	1.04	0.63	1.29	0.83	1.5	1.03	0.6	1.3	0.8
Word n-1											
M	1.34	1.33	1.33	1.34	1.36	1.23	1.35	1.37	1.34	1.36	1.31
SD	1.22	1.23	1.13	1.37	1.23	1.15	1.21	1.12	1.36	1.2	1.14
Word n+1											
M	1.18	1.18	1.2	0.94	1.29	1.38	1.17	1.13	0.88	1.28	1.44
SD	1.22	1.19	1.35	1.29	0.82	1.22	1.24	1.41	1.31	0.85	1.26
Suffix count											
Words n, n-1, & n+1											

M	1.12	1.12	1.15	1.08	1.17	1.03	1.12	1.15	1.1	1.17	1.04
SD	0.92	0.92	0.95	0.89	0.95	0.85	0.92	0.94	0.88	0.95	0.88
Word n											
M	0.97	0.96	1.07	0.99	0.91	0.8	0.99	1.1	1.06	0.92	0.84
SD	0.81	0.81	0.79	0.81	0.81	0.8	0.8	0.79	0.79	0.81	0.8
Word n-1											
M	1.18	1.18	1.23	1.05	1.35	1.02	1.17	1.21	1.06	1.33	1.08
SD	0.89	0.89	0.92	0.86	0.92	0.73	0.89	0.91	0.88	0.92	0.8
Word n+1											
M	1.21	1.21	1.16	1.19	1.26	1.25	1.2	1.14	1.19	1.27	1.21
SD	1.03	1.03	1.11	0.97	1.04	0.94	1.03	1.11	0.96	1.05	0.98
Trigram requency (log-transformed)											
Words n, n-1, & n+1											
M	3.114	3.11	3.09	2.99	3.26	3.12	3.11	3.08	2.99	3.26	3.12
SD	0.52	0.53	0.53	0.69	0.35	0.42	0.52	0.52	0.67	0.35	0.41
Word n											
M	2.78	2.77	2.67	2.59	3.02	2.81	2.78	2.68	2.62	3.02	2.81
SD	0.55	0.57	0.52	0.83	0.24	0.33	0.54	0.51	0.79	0.24	0.32
Word n-1											
M	3.3	3.31	3.35	3.22	3.38	3.23	3.3	3.35	3.21	3.39	3.24
SD	0.38	0.37	0.31	0.45	0.33	0.36	0.38	0.3	0.48	0.33	0.34
Word n+1											
M	3.26	3.27	3.23	3.16	3.38	3.31	3.26	3.21	3.15	3.38	3.3
SD	0.45	0.45	0.45	0.54	0.33	0.37	0.45	0.47	0.54	0.34	0.39
Vowel harmony (word count)											
Words											

n, n-1, & n+1											
Rule respected	46245	22060	6852	6624	5733	2851	24185	6693	7194	5822	4476
Broken rule	23673	11183	3198	2094	3678	2213	12490	3189	2277	3805	3219
Word n											
Rule respected	9294	4425	1708	1782	771	164	4869	1659	1905	874	431
Broken rule	14012	6656	1642	1124	2366	1524	7356	1635	1252	2335	2134
Word n-1											
Rule respected	18879	9057	2692	2560	2503	1302	9822	2628	2790	2458	1946
Broken rule	4427	2024	658	346	634	386	2403	666	367	751	619
Word n+1											
Rule respected	18072	8578	2452	2282	2459	1385	9494	2406	2499	2490	2099
Broken rule	5234	2503	898	624	678	303	2731	888	658	719	466
Familiarity (word n count)											
Familiar	17047	8412	3330	735	3124	1223	8635	3277	762	3192	1404
Unfamiliar	6259	2669	20	2171	13	465	3590	17	2395	17	1161

Note: Descriptive statistics were calculated over valid data included in LMMs. Conditions were determined according to the length and frequency of target words (i.e., word n) such that short-frequent (SF), short-infrequent (SI), long-frequent (LF), long-infrequent (LI). Eye-voice span and eye movement measures belong to the target words unless it was indicated otherwise explicitly.

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Özkan, Ayşegül
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EDUCATION

9/2011-9/2020	Ph.D. in Cognitive Science, Graduate School of Informatics, Middle East Technical University, METU, Ankara, Turkey. Cumulative Grade Point Average: 3.95/4. Thesis: "Phonological Mediation in Reading: A Theoretical Framework" (In English) Advisor: Dr. Cengiz Acartürk, METU Cognitive Science Dept. Co-Advisor: Dr. Bilal Kırkıcı, METU Foreign Language Education Dept.
10/2006-12/2010	M.A. in Philosophy, Graduate School of Social Sciences, METU, Ankara, Turkey Cumulative Grade Point Average: 3.50/4. Thesis: "Structure and Process: Prospects for Theories of Cognitive Science" (In English) Advisors: Dr. John Bolender, Dr. Erdinç Sayan, METU Philosophy Dept.
8/1998-6/2003	Undergraduate in Economics, Faculty of Economics & Administrative Sciences, Hacettepe University, Ankara, Turkey. Cumulative Grade Point Average: 2.87/4.
9/1995-6/1998	High school diploma in information technologies, Meram Anatolian Commercial High School, Konya, Turkey. Cumulative Grade Point Average: 4.85/5.

PUBLICATIONS

Journal Paper

Özkan, A., Beken Fikri, F., Kırkıcı, B., Kliegl, R., & Acartürk, C. (2020). Eye movement control in Turkish sentence reading. *Quarterly Journal of Experimental Psychology*. doi:10.1177/1747021820963310

Conference Papers

Acartürk, C., Can Buğlalılar, B., Kılıç, Ö., Kırkıcı, B., & Özkan, A. (2017). Eye movements in Turkish pseudoword reading. *18th International Conference on Turkish Linguistics (ICTL)* [talk abstract], Adana, Turkey

Acartürk, C., Özkan, A., & Bozkurt, T. N. (2016). Reading in agglutinative languages: silent reading and oral reading in Turkish. *SWAET 2016 (ScandinavianWorkshop on Applied Eye Tracking)* [talk abstract], Turku, Finland

Özkan, A. (2017). Oral reading in Turkish: An investigation of the eye-voice span. *18th International Conference on Turkish Linguistics (ICTL)* [talk abstract], Adana, Turkey

Özkan, A. (2017). Türkçede sesli okuma: Göz-ses aralığı araştırması [Oral reading in Turkish: An investigation on the eye-voice span]. *The Symposium on Eye Tracking Research and Applications (EyeTR 2017)* [talk abstract], Ankara, Turkey

Özkan, A. (2019). Eye movement control in Turkish reading. *The Symposium on Eye Tracking Research and Applications (EyeTR 2019)* [talk abstract], Ankara, Turkey

Poster Presentations

Acartürk, C., Kılıç, Ö., Kırkıcı, B., Can, B., & Özkan, A. (2017). The role of letter frequency on eye movements in sentential pseudoword reading. In G. Gunzelmann, A. Howes, T. Tenbrink, & E. Davelaar (Ed.), *Proceedings of the 39th Annual Conference of the Cognitive Science Society* (pp. 1495-1500). London: Cognitive Science Society.

Acartürk, C., Kırkıcı, B., Kılıç, Ö., Özkan, A., Bozkurt, T. N., Ormanoğlu, Z., Göl, A. Y. (2017). The investigation of cognitive processes in reading: Development of a corpus of Turkish reading patterns for eye movement control modeling. *International Symposium on Brain and Cognitive Science (ISBCS)*

Kılıç, Ö., Acartürk, C., Kırkıcı, B., Can, B., & Özkan, A. (2017). The role of letter frequency on eye movements in Turkish pseudowords. *International Symposium on Brain and Cognitive Science (ISBCS)*

Ormanoğlu, Z., Acartürk, C., Özkan, A., Kılıç, Ö., & Bozkurt, T. N. (2018). Perceptual span in Turkish reading: A study on parafoveal information intake. *International Symposium on Brain and Cognitive Science (ISBCS)*

Özkan, A., Acartürk, C., & Bozkurt, T. N. (2016). Reading in agglutinative languages: Silent reading and oral reading in Turkish. *International Symposium on Brain and Cognitive Science (ISBCS)*

Unpublished Project Deliverable

Acartürk, C., Kırkıcı, B., Kılıç, Ö., Zeyrek Bozşahin, D., Bozşahin, C., Özkan, A., Bozkurt, T. N., Ormanoğlu, Z., Beken Fikri, F., Yalçın, Ö. N., Coşkun, M., Fal, M., Göl, A. Y., İpekoğlu, U., Hülagü, A. (2017). *The investigation of cognitive processes in reading: Development of a corpus of Turkish reading*

patterns for eye movement control modeling. Unpublished project deliverable (TÜBİTAK SOBAG Project, project no: 113K723).

Unofficial Workshops

Özkan, A. (2017). *Experiment Builder & Data Viewer*. Workshop. METU, Ankara, Turkey

Özkan, A. (2018). *Data Viewer & Eye-Movement Data*. Workshop. ISPA, Lisbon, Portugal

IT & PROGRAMMING SKILLS

- EyeLink 1000 & EyeLink 1000 Plus eye-tracking devices (Excellent)
- Data Viewer & Experiment Builder (Excellent)
- Oracle Human Resources Management System (Excellent)
- SPSS (Good)
- R (Good)
- Prolog (Beginner)
- ACT-R (Beginner)
- Adobe InDesign (Good)
- Adobe Photoshop (Beginner)
- MS Office (Excellent)

LANGUAGE SKILLS

- English (Advanced)
- Turkish (Native)

GRANTS

February 15 – April 15, 2017	TUBITAK Scholarship for Employed Students
1999-2002	The Republic of Turkey Prime Ministry Higher Education Scholarship
1991-1998	The Republic of Turkey Ministry of National Education Scholarship.

NON-ACADEMIC ACTIVITIES

Professional Experience

9/2005-Present	Computer Executive (full-time), Academic Personnel Affairs Department, Personnel Affairs Directorate, METU, Ankara, Turkey.
8/2004-8/2005	Call Center Operator (part-time), Siemens Business Center, Ankara, Turkey.

Erasmus

May 3 – May 9, 2009	Erasmus Grant of € 1463 Staff Training Program, University of Kassel, Kassel, Germany. The aim of the training was to observe the experiences of the performance evaluation system of administrative personnel and administrative personnel training systems of the University of Kassel.

Amateur Work

2011-2014	Member of Editorial Board & Member of Page Layout Designer and Typographer Team, *Kalem Literature and Art Magazine*, Ankara, Turkey.
2011-2012, 2005-2007	Fictional Short Story Writer, *Kalem Literature and Art Magazine*, Ankara, Turkey.
2006	Member of Editorial Board, *Kalem Literature and Art Magazine*, Ankara, Turkey.

Fictional Short Stories

Şenol Atalet'in Sağlığı (The Health of Şenol Atalet), *Kalem Literature and Art Magazine, Theme: Neşe (Cheer)*, (2012). pp. 28-31

Duvardaki Çatlak (The Crack in the Wall), *Kalem Literature and Art Magazine, Theme: Özgürlük (Freedom)*, (2012). pp. 42-46

Gidelim mi? (Shall We Go?), *Kalem Literature and Art Magazine, Theme: Korku (Horror)*, (2012). pp. 3-5

Çiçekler (The Flowers), *Kalem Literature and Art Magazine, Theme: Pişmanlık (Regret), 5*, (2011). pp. 15-18

Kabus (Nightmare), *Kalem Literature and Art Magazine, Theme: Düş (Dream), 4*, (2011). pp. 24-26

Fotoğraftaki Kadın (The Woman in the Photograph), *Kalem Literature and Art Magazine, Theme: Tutku (Passion), 3*, (2011). pp. 13-17

Yaş Farkı (Age Gap), *Kalem Literature and Art Magazine, Theme: Zaman (Time), 2*, (2011). pp. 44-46

Yani Haklısınız Ama… (I Mean, You Are Right But...), *Kalem Literature and Art Magazine, Theme: Mutluluk (Happiness), 1*, (2011). pp. 26-28

Uyku (The Sleep), *Kalem Literature and Art Magazine, Theme: Yalnızlık (Solitude), 6*, (2007). pp. 29-30

Market (The Supermarket), *Kalem Literature and Art Magazine, Theme: Öfke (Anger), 5*, (2006). pp. 8-9

Çivi (The Nail), *Kalem Literature and Art Magazine, Theme: Hope, 4*, (2006). pp. 14-16

Doğum Günü (Birthday), *Kalem Literature and Art Magazine*, *Theme: Hüzün (Melancholy), 3*, (2005). pp. 28-31

Ceset (The Corpse), *Kalem Literature and Art Magazine, Theme: Arayış (Quest), 2*, (2005). p. 10