Morphological structure influences the initial landing position in words during reading Finnish

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Abstract

The preferred viewing location in words (Rayner, 1979) during reading is near the word center. Parafoveal word length information is utilized to guide the eyes toward it. A recent study of Yan et al. (2014) demonstrated that the word’s morphological structure may also be used in saccadic targeting. The study was conducted in a morphologically rich language, Uighur. The present study aimed at replicating their main findings in another morphologically rich language, Finnish. Similarly to Yan et al., it was found that the initial fixation landed closer to the word beginning for morphologically complex than monomorphemic words. Word frequency, saccade launch site, and word length were also found to influence the initial landing position. It is concluded that in addition to low-level factors (word length and saccade launch site) also higher-level factors related to the word’s morphological structure and frequency may be utilized in saccade programming during reading.

The seminal study of Rayner (1979) established the so-called preferred viewing location in words during reading: The initial fixation tends to land near the center of words (see also e.g., McConkie, Kerr, Reddix, & Zola, 1988; Vitu, O'Regan, & Mittau, 1990). This is an optimal viewing strategy, as by fixating around the word center all or most letters of the word fall on the foveal vision where the visual acuity is at its best. Studies have shown (e.g., Hyönä & Bertram, 2011; Nuthmann, Engbert & Kliegl, 2005; O'Regan, Lévy-Schoen, Pynte & Brugaillere, 1984; Vitu, McConkie, Kerr, & O'Regan, 2001; Vitu et al., 1990) that the further away the initial fixation is located from the word center, the longer readers stay fixating on the word before exiting it.

As the word center is the optimal viewing location for word recognition, it is not surprising that readers use word length information in guiding their eyes from one word to the next. There is a wealth of evidence demonstrating that word length is a significant determiner of saccade programming in reading. A saccade targeted to a long word is longer than a saccade launched to a short word; similarly, a saccade away from a long word is longer than from a short word (O'Regan, 1979, 1980; Rayner, 1979). As visual information concerning word length is course-grained (provided words are separated by spaces as is the case in most alphabetic scripts), it can be readily extracted from the parafovea to guide the eyes optimally toward the word center (e.g., Hyönä & Bertram, 2011; Juhasz, White, Liversedge, & Rayner, 2008; O'Regan, 1979; Rayner, 1979). Also the distance from which a saccade is launched to a word has a robust influence on initial landing position (ILP). With more distant launch sites, the saccade lands closer to the word beginning than with more near launch sites (Engbert & Krügel, 2010; McConkie et al., 1988; Nuthmann et al., 2005). Launch site effects are ascribed to oculomotor error and range error (McConkie et al., 1988).

In addition to word length and launch site effects, there is also evidence for orthographic effects on ILP. Hyönä (1995) demonstrated an orthographic irregularity effect on ILP. He found that when the word-initial trigram was highly infrequent in the language (Finnish), the initial fixation landed closer to the word beginning than was the case with frequent word-initial trigrams (see also Beauvillain, Doré, & Baudoin, 1996). An analogous effect was obtained by White and Liversedge (2004) for misspellings appearing in the word beginning.

The aforementioned evidence strongly suggests that saccade programming during reading is governed by oculomotor constraints (launch site effects), by course-grained visual information of word length and by orthographic irregularity. Attempts to find higher-order influences on ILP pertaining to lexical or morphological effects have so far largely failed. The rare exceptions are the studies of Hyönä, Niemi and Underwood (1989) and Underwood, Clews and Everatt (1990), who found ILP to shift rightward for words with an informative versus a redundant ending (e.g., a compound word head versus a derivation). However, Rayner and Morris (1992) were not able to replicate the result of Underwood et al. (1990) using the stimuli of Underwood et al. Beauvillain (1996) found little difference in ILP between French prefixed and suffixed words. Nor did Hyönä and Pollatsek (1998) find any differences in ILP between two-noun Finnish compounds, for which the length of the first constituent was varied while controlling the overall word length (see also Bertram & Hyönä, 2007). Deutsch and Rayner (1999) observed no effect of morphological structure on ILP between plural and singular words in Hebrew. Finally, Inhoff, Briihl and Schwartz (1996) found ILP to be more toward word center for compound words than for monomorphemic or derived words in English. Yet, they found the ILP to be similar for suffixed and monomorphemic words.

However, a recent study of Yan et al. (2014) observed a morphological complexity effect on ILP during reading Uighur – an agglutinative alphabetic language with a rich suffixal system and an Arabic-derived alphabet. In Experiment 1, Yan et al. conducted a corpus-based analysis of ILPs for words with variable morphological structure. The sentence corpus consisted of words containing 1-6 morphemes. They observed the initial fixation to land closer to the word beginning as the number of morphological suffixes increased. In Experiment 2, they orthogonally manipulated the morphological complexity of target words for 6- to 9-letter words. The morphological complexity manipulation entailed two conditions: words containing a root morpheme with two suffixes and monomorphemic words with no suffixes. An effect of morphological complexity observed in Experiment 1 was replicated in Experiment 2. ILPs were located closer to the word beginning with suffixed words than with non-suffixed words. Moreover, Yan et al. found that with increased word frequency the initial fixation location shifted toward the word center. These are theoretically relevant findings, as they demonstrate higher-order influences on saccade targeting previously assumed to be governed in reading only by low-level visual information and oculomotor constraints.

The present study was designed to replicate the morphological and lexical effects on ILP in another agglutinative and morphologically rich language – Finnish. We reasoned that if the morphological and lexical effects observed by Yan et al. (2014) are genuine and not specific to Uighur, they should be observable in a different but morphologically rich language. Perhaps most importantly, Finnish differs from Uighur in that it is written in Roman script, whereas Uighur uses Arabic script. They also differ in the direction of writing; Finnish is written from left to right, whereas Uighur from right to left. In Finnish texts, the majority of content words are morphologically complex in that they contain more than one morpheme. Nouns in Finnish are marked for grammatical case (13 cases in active use) and number. They can also contain a possessive suffix and a clitic. Thus, it is common for Finnish nouns to have two suffixes attached to the word stem.

Yan et al. (2014) also found word frequency to affect ILP in reading Uighur. The incoming saccade went further into the word for high-frequency than low-frequency words. An analogous finding has been observed by Rayner, Reichle, Stroud, Williams, and Pollatsek

(2006) for 7-10-letter words in English. Hyönä and Pollatsek (1998) found a more rightward ILP for compound words with more frequent initial morphemes. In contrast, White (2008) failed to find a word frequency effect on ILP for 4-5-letter English words. In the present study, we examined whether an effect of word frequency can be observed on ILP. In order to do so, we did not orthogonally manipulate word frequency but used it as a continuous predictor (i.e., a covariate) in the linear mixed model (LMM) analysis.

In the present study, native Finnish readers read single sentences each containing a target word, either a monomorphemic noun or a length- (6-9 letters) and frequency-matched 3-morpheme noun (stem + two suffixes). Each monomorphemic word was paired with a 3-morpheme word, and a sentence frame was created for each pair that was identical up to the target word. Participants read the sentence silently for comprehension at their own pace. The results were analyzed by LMMs with morphological structure, word frequency, word length, saccade launch site and their interactions as the fixed effects. With this experimental design, we aimed at providing evidence for the notion that morphological structure can influence saccade target selection during the reading of Finnish sentences. Moreover, we were interested to see whether an effect of word frequency on ILP can be obtained in Finnish. If observed, these effects would provide evidence for high-level guidance of eye movements as a phenomenon generalizable across different writing systems and languages.

Method

Participants

A total of thirty-two university students (26 female and 6 male students; age range of 20-44 years, median 24.5 years) with normal or corrected-to-normal vision took part in the eye-tracking experiment. One participant had to be discarded due to her extreme blink rate. An independent group of 10 students participated in a norming study concerning the predictability of the target words. All participants were native speakers of Finnish from University of Turku and were naive about the purpose of the experiment. They received course credit for their participation.

Apparatus

Eye movements were recorded with an Eyelink1000 system (SR Research, Canada) in 1000 Hz. The sentences were presented on a 21-inch ViewSonic G220fB CRT monitor (1024×768 resolution; frame rate 100 Hz) controlled by an Intel Core 2 6400 computer running at 2.13 GHz under a Windows XP environment. Participants were seated 69 cm from the monitor with their head positioned on a chin rest.

Materials

The materials consisted of 50 pairs of sentences, where the target word was either monomorphemic or multimorphemic noun (stem and two inflectional suffixes). The multimorphemic words had a case ending and a possessive clitic (e.g., *eno-lle-en* 'uncle-for-his/her' -> 'for his uncle') or a plural suffix and a case ending (e.g., *auto-i-ssa* car-s-in ->'in (the) cars'. The target words were 6-9 letters long. Each multimorphemic target word was paired with a monomorphemic target word so that the pairs were matched for frequency (logarithmic (base 10) lemma frequency/million was on average 1.58 (SD = 0.72) for multimorphemic words and 1.58 (SD = 0.71) for monomorphemic words; t = .09, p = .926), for word length in characters 7.92 (SD = 0.92) for both (the length of each multimorphemic word was identical to its mached monomorphemic pair), and for initial trigram frequency, 76.3 (SD = 54.0) for multimorphemic words and 75.1 (SD = 56.0) for monomorphemic words; t = .12, p = .903). The number of target words of different length was as follows: six word pairs of six characters long, eight of seven characters long, 23 of eight characters long, and 14 of 9 characters long. The frequencies were computed on the basis of Turun Sanomat newspaper corpus comprising 22.7 million word tokens (Laine & Virtanen, 1999). The length of stems and suffixes both varied from 3 to 5 letters; in other words, across the target word set, the stems and suffixes were roughly equal in size. In order to minimize possible influences of sentence context, the sentence frame leading to the target was identical in the sentence pairs. The post-target word was either identical or at least the first three letters were identical within each pair; the sentence frames after the post-target word could vary to provide fluent sentence endings. The sentences were six to 14 words in length. The target words never appeared among the first two or the last two words. Each sentence frame was presented twice in two separate blocks, once with a monomorphemic target word and once with a suffixed target word.

An example target sentence pair is presented below. The target appears in bold in the example but not in the actual experiment.

Multimorphemic target word: *Onnettomuuden jälkeen **purjeissa** havaittiin paha repeämä*. (purje-i-ssa = ‘sail-plural-inessive’)

(After the accident a bad crack **in the sail** was noticed.)

Monomorphemic target word: *Onnettomuuden jälkeen **komisario** havainnoi ympäristöä systemaattisesti*.

After the accident **the inspector** systematically observed the environment.

In the sentence pairs, the sentence up to the target word was identical and the sentence pairs diverged after that. The word after the target word (Word N+1) was identical in 27 sentence pairs. In the remaining 23 pairs, a minimum of three initial letters were identical for Word N+1 and its length was either identical or differed for 1-2 letters. The sentences were presented in two blocks so that the two members of each sentence pair appeared in separate blocks. The order of the blocks was counterbalanced across the participants.

The sentence contexts were written to be equally non-predictive for the two types of target words. In the norming study, a group of participants were presented the sentence beginnings and they were asked to produce a suitable word in the target word position. The results showed that a target word was mentioned only once in the entire norming study. Thus, all target words were unpredictable from the sentence context.

The sentences occupied one line on the screen and were presented one at a time at the 1/3 vertical position from the top of the screen. Texts were displayed using 20 pt Courier New font; with a viewing distance of 69 cm, each letter subtended 0.50 degrees of visual angle.

Procedure

The eye-tracker was first calibrated using a nine-point grid. After the validation of the calibration accuracy, a fixation point appeared on the left side of the monitor. If the eye tracker identified a fixation on the fixation point, the fixation point disappeared and a sentence was presented so that the initial letter was located at the fixation point. The right eye was tracked, unless the participant reported a problem with it.

Participants were instructed to read the sentences for comprehension and to signal the completion of a trial by pressing the spacebar. Participants were occasionally asked to paraphrase the last read sentence, which was always done successfully. The detection of a fixation on the fixation point initiated the presentation of the next sentence or a drift correction.

Data Analysis

Using the same criteria as in Yan et al. (2014), we excluded from analyses (a) 147 (i.e., 4.9%) target words with first-fixation durations (FFDs; duration of the initial fixation on the word, irrespective of the number of fixations) shorter than 60 ms or longer than 600 ms or gaze durations (GDs; sum of fixation durations during the first pass reading of the word) longer than 800 ms and (b) 67 (i.e., 2.2%) words with fixations on the space before the word. These criteria were used for the consistency with the original study of Yan et al. (2014). The final data set contained 2688 observations.

Statistical inferences concerning the effects of word length, launch site, morphological complexity, and word frequency on ILP, FFD, and GD are based on LMMs. The analyses were carried out with the *lmer* program of the *lme4* package (version 1.1-8; Bates, 2010; Bates, Maechler, Bolker, & Walker, 2015) in the R environment for statistical computing and graphics (version 3.2.1; R Development Core Team, 2015). As in prior research, all continuous predictors were centered and logarithm transformed word frequency was used; for dependent variables logarithm transformation was applied to FFDs and GDs to meet the LMM assumptions (Kliegl, Masson, & Richter, 2010). Effects that are 1.96 times larger than their standard errors are interpreted as statistically significant; this is because given the large number of observations in total, the *t*-statistic [M/SE] effectively corresponds to the *z*-statistic.

In addition, we initially included model parameters of the variance components for participants and sentences (i.e., varying intercepts) as well as variance components and correlation parameters for participant-related experimental main effects. Such a full-model is likely to be over-parameterized and mask significant effects that would be apparent in a model with fewer parameters. Therefore, following the model-pruning procedures carried out by Yan et al. (2014), we reduced the ILP model by systematically removing non-significant (as reflected by the change in goodness of fit of the model in a likelihood ratio test) terms in three steps: eliminating non-significant (a) correlation parameters [$\chi^2(10) = 13.313$, $p = .207$], (b) variance components [$\chi^2(12) = 13.586$, $p = .328$], and (c) interactions terms [$\chi^2(11) = 7.789$, $p = .732$], respectively.

Results

Initial Landing Position

The initial landing position was measured in number of characters from the word beginning. The final model (Table 1) contained four fixed effects as well as participant-related variance components for intercept (*SD*=0.62), word length (0.11) and launch site (0.13) as well as the sentence-related variance component for intercept (0.25). Inspection of residual plots did not indicate any problems with the model fit. Figure 1 shows the four significant fixed effects. ILPs increased with word length (*b*=0.249, *SE*=.045, *t*=5.58) and decreased with launch site (*b*=-.262, *SE*=.026, *t*=-10.06). These results are canonical oculomotor effects on ILPs that have been consistently reported in previous research across different writing systems.

Insert Table 1 about here

More relevant to the theoretical importance of the present study, ILP decreased with morphological complexity (*b*=-.176, *SE*=.064, *t*=-2.74) and increased with word frequency (*b*=.130, *SE*=.052, *t*=2.50). Thus, replicating earlier findings in Uighur (Yan et al., 2014), these results demonstrate an effect of high-level cognitive processes on saccade-target selection during reading of Finnish.

Insert Figure 1 about here

Fixation Durations. The same model-building strategy used for ILPs was applied to the fixation duration analyses[1]. The analyses indicated that both FFD and GD (for the model, see Table 2) were significantly increased with morphological complexity (*b*=.053, *SE*=.016, *t*=3.41 and *b*=.139, *SE*=.022, *t*=6.27, respectively), validating our hypothesis that suffixes increase processing difficulty.

Insert Table 2 about here

First fixations were longer after short launch sites (*b*=-.008, *SE*=.003, *t*=-2.91). Such an effect appears counterintuitive, but it may indicate the difference in duration between first of multiple fixations and single fixations, because the refixation rate usually decreases for close launch site (e.g., Kliegl, Olson, & Davidson, 1983; Kliegl, Nuthmann, & Engbert, 2006). This is supported by the results on GDs that take possible refixations into consideration. GDs significantly increased with launch site (*b*=.026, *SE*=.005, *t*=5.10).

In addition, we also found the expected profile of positive slope of word length on GD (*b*=.083, *SE*=.013, *t*=6.33). Although the main effects of word frequency appeared only as numerical but not statistical trends (*b*=-.015, *SE*=.013, *t*=-1.21 and *b*=-.009, *SE*=.016, *t*=-0.58, for FFD and GD, respectively), there was an interaction with word length indicating a stronger word frequency effect in the expected direction for long words than for short words (*b*=-.008, *SE*=.003, *t*=-2.16; Figure 2A). Finally, the launch site effect on GD was more apparent for short words than for long words (*b*=-.048, *SE*=.015, *t*=-3.11; Figure 2B).

Insert Figure 2 about here

Finally, in Figure 3 FFD and probability of making a refixation on the word are plotted as a function of ILP. The FFD distribution demonstrates a well-established inverted optimal viewing position effect (IOVP; Vitu et al., 2001); FFD is longest at the word center. Interestingly, the effect is steeper for suffixed words, perhaps due to the reason that the word stem covers a smaller area in suffixed than monomorphemic words. The distribution of the refixation probability also replicates a well-known phenomenon (optimal viewing position effect = OVP) where the probability is smallest at the optimal viewing location at the word center and increases the further the initial fixation is located away from the center (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989). Interestingly, the probability of refixating the target word is much greater for suffixed than monomorphemic words when the initial fixation lands toward the word end, that is, away from the word stem. The replication of the canonical OVP and IOVP effects also indicates that the results of the present study are reliable.

Insert Figure 3 about here

Discussion

The present study was designed to replicate in Finnish the morphological effect obtained by Yan et al. (2014) on ILP during reading of Uighur. Their finding is theoretically relevant, as it provides evidence for higher-order control of saccade targeting during reading. Yan et al. found the first fixation on the word to be closer to the word beginning in morphologically complex, suffixed words than in monomorphemic words. This suggests that readers of Uighur are able to extract from the parafovea information of the word's morphological structure and use that information in guiding their eyes from one word to the next. Yan et al. noted that the generalization of their finding to other languages deserves further investigation. The present study was designed to respond to this call.

The present study was a close replication of Experiment 2 of Yan et al. (2014) except that it was conducted in another morphologically complex language, Finnish, and in another script, a Roman script instead of an Arabic-derived alphabetic script used to write Uighur. Despite the differences in language and script, we replicated the main finding of the Yan et al study. We found that also readers of Finnish are capable of using the word's morphological structure when launching a saccade to a word. This was evidenced by the ILP being about 0.2

character spaces closer to the word beginning for three-morpheme (stem + two suffixes) than monomorphemic words. The effect of morphological complexity on saccade programming agrees generally with recent findings in Chinese, a writing system without word spacing where word boundaries are defined only semantically. Yan and Kliegl (2016) reported that saccades executed during reading of Chinese can be influenced by word boundary ambiguity, supporting a view that parafoveal word boundary information is involved in saccade programming (Yan et al., 2010). These results jointly contribute to a growing body of evidence for the notion of high-level guidance of eye movements across different writing systems.

As mentioned in the Introduction, two studies (Deutsch & Rayner, 1999; Inhoff et al., 1996) failed to find a difference in ILP between monomorphemic and suffixed words. The Inhoff et al. study was done with 9-letter English words; the suffixed words were derived words (e.g., *falsehood*) with a 3- or 4-letter suffix. Experiment 1 of Deutsch and Rayner was conducted with singular (non-suffixed) and plural (suffixed) 5-8-letter Hebrew nouns; the plural suffix comprised two letters. In the present study, the 6-9-letter suffixed nouns consisted of two inflections, a case ending and either a plural or a possessive suffix; the stems and the suffixes both comprised 3-5 letters. Thus, one possible reason for the effect emerging in the present study and not in the other two studies is that in the present study the suffixed part of the word contained two suffixes and was therefore quite long, roughly as long as the stem. The same is true for the materials used in Experiment 2 of Yan et al. (2014). In the other two studies, the target word only contained one suffix, which was shorter than the word stem. In other words, in the present study and that of Yan et al. the suffixation was a prominent feature of the word.

A plausible mechanism for morphological guidance may be based on the recognition of a suffix (suffixes) at the end of the to-be-fixated word. Once detected, the saccade program is modified so that the eyes would land closer to the word stem to facilitate word recognition. In fact, Farid and Grainger (1996) have found the optimal viewing location to shift toward the stem in isolated recognition of Arabic suffixed words. Parafoveal detection of a suffix at the word end is not implausible, as suffixes are highly frequent letter clusters in the language. This explanation may be examined in future studies by using the gaze-contingent display change paradigm (Rayner, 1975). If the suffix information is initially denied when the target word appears in the parafovea, the morphological ILP effect should disappear.

It should be noted that Yan et al. (2014) left open the issue of what cues Uighur readers may use to identify the morpheme boundaries. They offered as one possible mechanism the detection of morpheme boundaries on the basis of letter-transition frequencies at the morpheme boundary. In other words, the morphological effect does not necessarily depend on parafoveal recognition of suffixes. At present, we consider their explanation implausible for Finnish. This is because letter-transition frequencies at the stem-suffix boundary are typically high and thus non-salient. In other words, stem-suffix boundaries do not coincide with salient bigram troughs that may signal word’s morphological structure (Hay, 2003; Hay & Baayen, 2003; Seidenberg, 1987).

We also replicated in Finnish the word frequency effect on ILP observed earlier by Rayner et al. (2006), Hyönä and Pollatsek (1998) and Yan et al. (2014). . Analogously to these studies, we observed ILP to shift to the right with increased word frequency (see, however, White, 2008). The word frequency effect on ILP observed in the present study is unlikely a consequence of initial trigram frequency, as word frequency and initial trigram frequency correlated only minimally (r=.19). Thus, the effect may be taken as further evidence for higher-order control of saccade computation during reading. Yet, based on the present results it is not clear what mechanism may be behind the observed effect. One possibility is that the parafoveal processing of high-frequency words proceeds to a higher level than that for low-frequency words, leading the saccade to be launched a bit further into the word. For example, parafoveal preprocessing of higher-frequency words may result in an increased sense of familiarity, which in turn would indicate relative ease of processing leading to the reader programming a saccade a bit further into the word. Yet, the exact mechanism responsible for the effect is left for future studies to uncover.

It should be noted that we also observed the standard word length and launch site effects on ILP. The initial fixation landed further into the word for longer words. Moreover, with more distant launch sites the initial fixation was positioned closer to the word beginning than with nearer launch sites. It is also noteworthy that the word length and launch site effects were more robust than the higher-order effects related to morphological structure and word frequency.

The main aim of the present study was to study higher-order influences on saccade targeting during reading. Yet, we also examined fixation durations as a function of morphological structure, word frequency[2], word length and saccade launch site. We found morphological complexity to increase fixation time on words. An analogous result has been previously observed in isolated word recognition in Finnish (Laine, Vainio, & Hyönä, 1999). Also saccade launch site affected gaze durations on words (see e.g., Hand, Miellet, O'Donnell, & Sereno, 2010; Radach & Heller, 2000; Slattery, Staub, & Rayner, 2012). When a saccade was launched from a more distant location, a longer gaze duration ensued, in comparison with a near launch site. This is likely to reflect the degree of parafoveal preprocessing done for the target word prior to its fixation. Not surprisingly, longer words were read with longer gaze durations than shorter words (see also e.g., Calvo & Meseguer, 2002; Just & Carpenter, 1980; Kliegl, Grabner, Rolfs, & Engbert, 2004). Finally, an interaction between word frequency and length suggests that the frequency effect was apparent only for longer words.

In conclusion, the present study established an effect of a word's morphological structure and word frequency on initial landing position in words during reading. The findings are newsworthy, as it has been widely assumed that saccade programming in reading is only governed by low-level factors, such as word length and saccade launch site.

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Footnotes

1. After eliminating non-significant correlation parameters [$\chi^2(10) = 14.544$, $p = .150$], variance components [$\chi^2(11) = 15.332$, $p = .168$], and interactions terms [$\chi^2(9) = 10.896$, $p = .283$], final LMM output for GD is shown in Table 2.

2. The failure of observing a main effect of word frequency on fixation durations is likely due to a restriction of word frequency range since it was controlled between the two types of words. The word frequency range in the current data set (from 3 to 1262 per million) covers only a small part in the Finnish word-frequency corpus (from 0.04 to about 50 000 per million).

Table 1. LMM estimates from the final model for ILP.

Fixed effects			
	Estimate	SE	t-value
Grand mean (GM)	3.351	0.118	28.41
Word length (WL)	0.249	0.045	5.58
Launch site (LS)	-0.262	0.026	-10.06
Suffix number (SN)	-0.176	0.064	-2.74
Word frequency (WF)	0.130	0.052	2.50
Random effects			
	Variance	SD	
Item – GM	0.061	0.246	
Subjects – GM	0.388	0.623	
Subjects – LS	0.017	0.130	
Subjects – WL	0.013	0.113	
Residual	1.134	1.065	

Table 2. LMM estimates from the final model for GD.

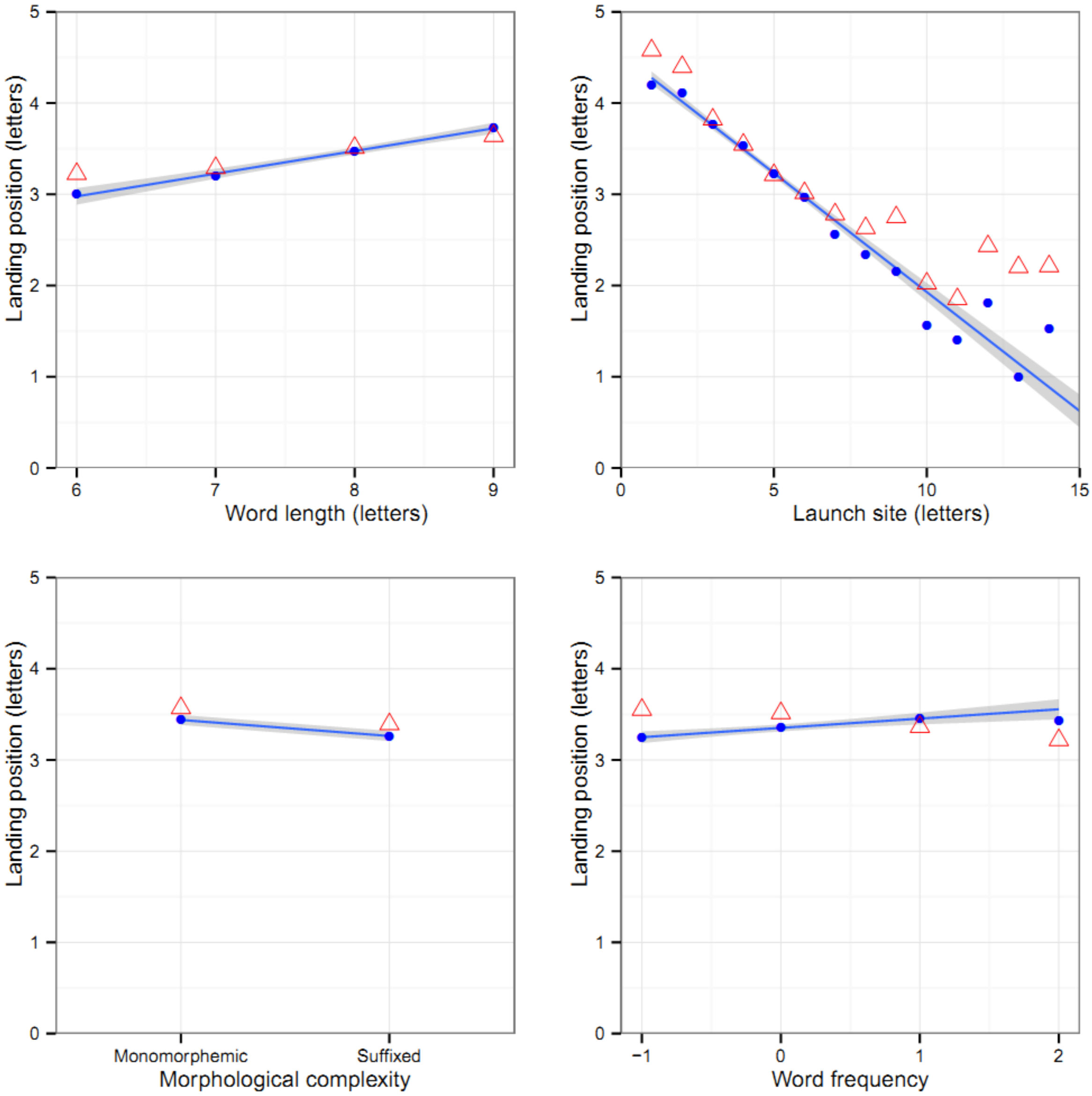
Fixed effects			
	Estimate	SE	t-value
Grand mean (GM)	5.727	0.046	123.18
Word length (WL)	0.083	0.013	6.33
Launch site (LS)	0.026	0.005	5.10
Suffix number (SN)	0.139	0.022	6.27
Word frequency (WF)	-0.009	0.016	-0.58
WL x LS	-0.008	0.003	-2.61
WL x WF	-0.047	0.015	-3.11
Random effects			
	Variance	SD	
Item – GM	0.004	0.061	
Subjects – SN	0.006	0.078	
Subjects – LS	0.000	0.020	
Subjects - WL	0.002	0.039	
Subjects - GM	0.063	0.251	
Residual	0.095	0.307	

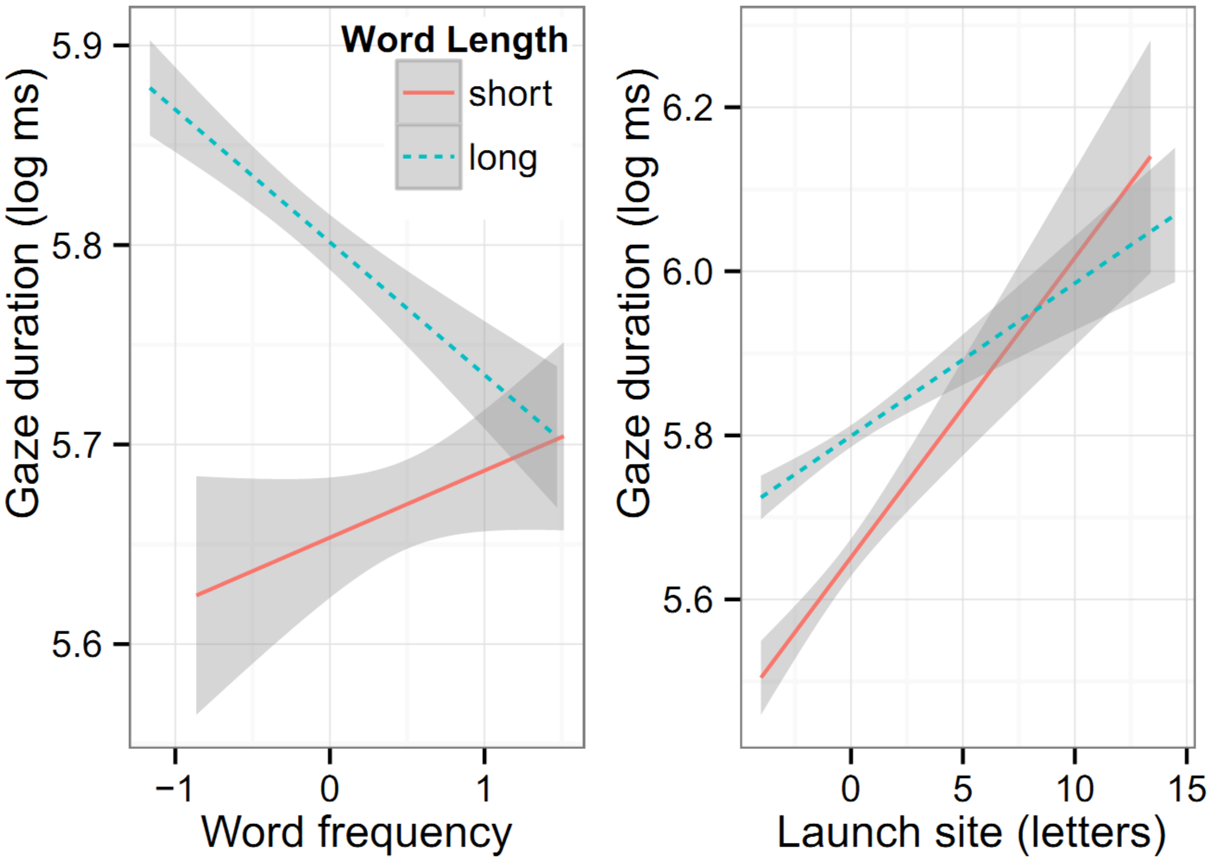
Figure captions

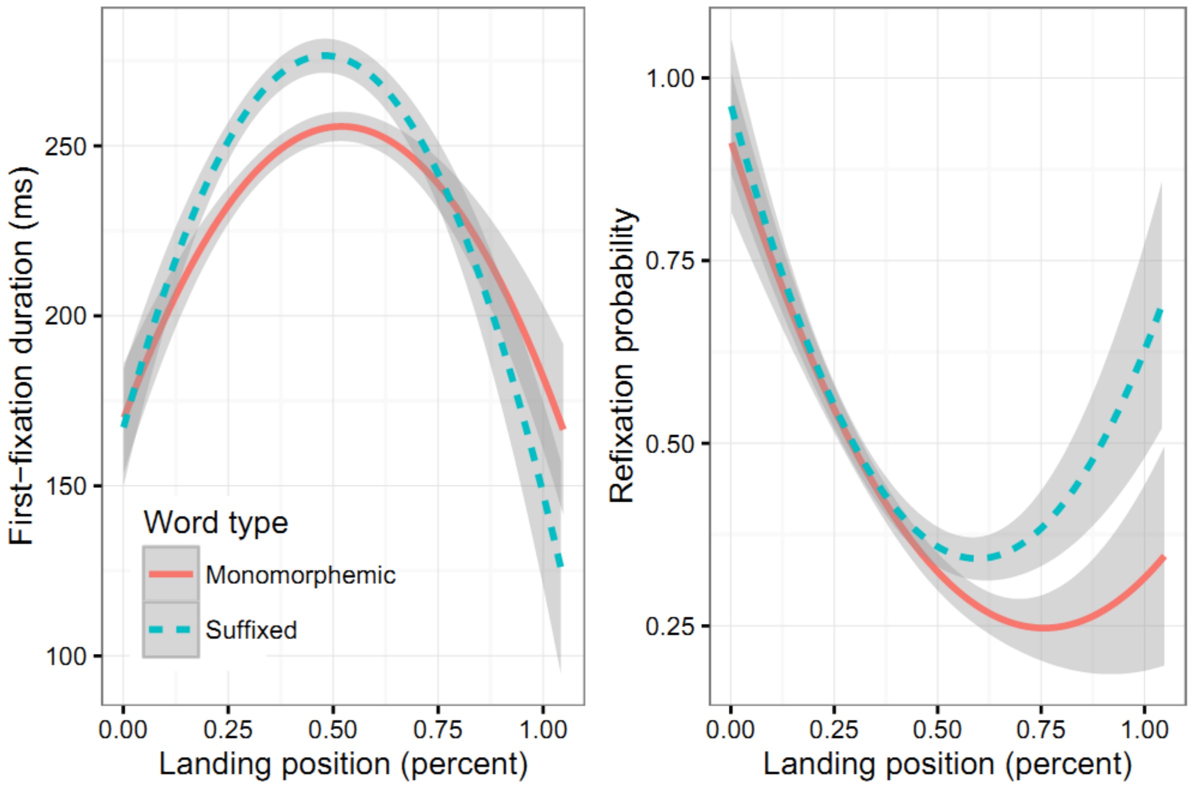
Figure 1. Four significant effects on ILP. Top row: standard effects of word length and launch site. Bottom row: effects of morphological complexity and word frequency. Lines, points, and grey 95% confidence intervals are partial effects (i.e., based on LMM estimates after statistical control of other variables in the model and removal of between-participant and between-sentence random effects), using the remef package (version 0.6.10; Hohenstein & Kliegl, 2013); triangles are observed means (rounded to the next integer on x-axis). Graphics were generated using the ggplot2 package (version 2.0.0; Wickham, 2009).

Figure 2. Two significant interactions (left: Word Length x Word Frequency; right: Word Length x Launch Site) in the analysis GD. Lines and grey 95% confidence intervals are partial effects. Short words are 6- and 7-letter words and long words are 8- and 9-letter words.

Figure 3. FFD and probability of refixation as a function of initial landing position in the target word, separately for monomorphemic and suffixed words.


Landing position (letters)
Word length (letters)
Launch site (letters)
Morphological complexity
Monomorphemic
Suffixed
Word frequency


Word Length
short
long
Gaze duration (log ms)
5.9
5.8
5.7
5.6
−1
0
1
Word frequency
Gaze duration (log ms)
6.2
6.0
5.8
5.6
0
5
10
15
Launch site (letters)


First−fixation duration (ms)
250
200
150
100
0.00
0.25
0.50
0.75
1.00
Landing position (percent)
Word type
Monomorphemic
Suffixed
Refixation probability
1.00
0.75
0.50
0.25
0.00
0.25
0.50
0.75
1.00
Landing position (percent)