論　文

Differences in Word Frequency and Length Effects on L2 and L1 Speakers' Eye Movements

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Abstract

This study analyzes whether word frequency and length effects differ between second language (L2) and first language (L1) speakers. The eye movements of Japanese learners and native speakers of English, specifically first fixation duration and gaze duration during silent reading of English sentences containing target words, were measured. The target words consisted of four categories: long high-frequency words, short high-frequency words, long low-frequency words, and short low-frequency words. The findings revealed that both native and non-native speaker groups demonstrated significantly longer fixations for infrequent words than frequent words in gaze duration. More importantly, the results showed stronger word frequency and length effects for non-native speakers with non-alphabetical L1 than for the native speakers. An additional analysis was conducted by including individual vocabulary sizes to verify the influence on the discrepancy. The analysis showed that the participant's vocabulary size did not eliminate this differential impact, demonstrating that an additional factor must be involved to explain the difference. The findings posit a significant discrepancy in L1 and L2 single-word processing and require further explanation beyond individual vocabulary sizes.

1. Introduction

It is widely accepted that word frequency and length are influential variables in first language (L1) and second language (L2) sentence processing. High-frequency words are generally recognized faster than low-frequency words (Forster & Chambers, 1973). Longer fixations have been found for low-frequency words in eye-tracking research (Inhoff & Rayner, 1986; Rayner, 1998, 2009; Rayner & Duffy, 1986). Non-native speakers (NNS) demonstrated a stronger word frequency effect than native speakers (NS) (Cop et al., 2015; Whitford & Titone, 2012 for the eye-tracking paradigm: Gollan et al., 2008 for picture-naming tasks; Duyck et al., 2008 for lexical decision tasks). Diependaele et al. (2013) proposed two hypotheses to explain the effect of different degrees of frequency: language competition and lexical entrenchment accounts. Language competition entails that L2 lexical processing is slower, owing to the existence of two languages in the mental lexicon. If words are orthographically similar between L1 and L2, the bilingual individual first needs to distinguish the words from their L1 and L2. According to the language competition account, Japanese speakers with non-alphabetical L1 would show a subtle difference or no frequency effect difference between L1 and L2, due to the absence of orthographical language competition. Japanese has a script that is different from English and does not contain orthographically similar words, so the expectation is that they do not generally need to distinguish English from their mother tongue to process L2 words in their mental lexicon.

The lexical entrenchment argument anticipates that the different effects in word frequency are because of language exposure to the target language. The hypothesis is based on the lexical representation of use-based theory involved in the amount of language exposure. NNS of English normally have a small L2 vocabulary and less exposure to English. NNS are less exposed to particularly infrequent words; therefore, it is time-consuming for them to process these words, owing to their reduced exposure and low proficiency (Brysbaert et al., 2017). Diependaele et al. (2013) found that the difference in magnitude disappeared by considering vocabulary size as a predictor. However, some studies have challenged the influence of vocabulary size, and reported that vocabulary size had a null impact on L2 speakers' greater frequency effect (e.g., Cop et al., 2015; Whitford & Titone, 2012). In summary, although a larger word frequency effect among NNS is confirmed, there have been conflicting results about the mechanism. In addition, there is little research on the different impacts of different-script NNS (see also Mor & Prior, 2021). Ishida (2022) revealed that word frequency effects were more prominent in NNS than NS. At this time, it is unclear what could explain the difference.

In terms of the word length effect, long words are processed more slowly and receive longer and multiple fixations (Kliegl et al., 2004: Barton et al., 2015 for review). Young children show a larger length effect than adults (Tiffin-Richards & Schroeder, 2015), with a larger length effect for L2 than L1 children (Schröter & Schroeder, 2018). Word length effects can be explained by the dual-route models of word recognition suggested by Coltheart et al. (2001). According to Tiffin-Richards and Schroeder (2015), the models suggest a sublexical route in which words are decoded letter-by-letter, and a lexical route whereby words are directly linked to representation in memory. Using the sublexical route takes more time to process and is sensitive to word length. However, no study has addressed the different magnitudes of word length effect for NNS with non-alphabetical L1 and the influence of vocabulary knowledge on the discrepancy.

The current study contributes to existing literature by examining word frequency and length effects in L1 and L2 eye movements. We employ an analysis of first fixation duration and gaze duration. The first fixation duration is the length of the first fixation in an interest area, and gaze duration is the sum of all the fixations made in the interest area until the eyes leave the interest region (Godfroid, 2020). This study uses these measures because they reflect the early measure of lexical access; other eye-movement measures (e.g., total reading time) are complicated, reflecting different processes.

The two research questions are:

1) Are stronger frequency and length effects observed for NNS with non-alphabetical L1?
2) If there is a different impact indicating NNS receive the greater effects of word frequency and length, how does the individual vocabulary size affect the difference?

2. Methods

2.1. Participants

The participants included 17 native speakers of English and 14 Japanese learners of English as a foreign language. Data from one native speaker and one Japanese learner were excluded owing to a procedural failure. The remaining 16 native speakers (6 males and 10 females) and 13 non-native speakers (4 males and 9 females) were either undergraduate or postgraduate students at a national university. All participants stayed in Japan at the time of the experiment. Most of the native English participants were exchange students who had been in Japan about a couple of months. The Japanese participants had studied English through formal education for more than 6 years. Table 1 shows the two groups' characteristics administrated in a questionnaire conducted before the experiment. All participants' English vocabulary size was measured with LexTALE (Lemhöfer & Broersma, 2012). The mean scores of LexTALE for NNS were 64.42%, which could be regarded as an intermediate level.

Table 1. Characteristics of participants (standard deviations in parentheses)

	Native speakers (N=16)	Non-native speakers (N=13)
Age	21.82 (2.43)	24.15 (8.54)
LexTALE (%)	93.60 (5.52)	64.42 (12.19)
Age started English learning		10.46 (4.31)
Self-reported proficiency		
Speaking		5.85 (1.95)
Listening		6.62 (2.10)
Reading		6.85 (1.63)
Writing		5.69 (1.38)

Note. Self-reported proficiency on a 10-point scale.

2.2. Materials

This study chose 96 target noun words within the most frequent 5000 words level (the standard university level in Japanese education) in the JACET list of *8000 Basic Words* (JACET Committee of Basic Words Revision, 2003), including short (3–5 letters), long (8–14 letters), high frequency (219.22 per million), and low frequency (18.85 per million) words in the British National Corpus (BNC Consortium, 2001). The target words consisted of four categories: 24 long (M = 10.33, SD = 1.43) high-frequency words (M = 2.31, SD = 2.11 log10 frequency), 24 short (M = 3.96, SD= 0.46) high-frequency words (M = 2.44, SD = 2.47 log10 frequency), 24 long (M = 9.71, SD = 1.37) low-frequency words (M = 1.22, SD = 0.62 log10 frequency), and 24 short (M= 4.41, SD= 0.76) low-frequency words (M = 1.23, SD = 0.47 log10 frequency). Sentences were 10–12 words (M = 11.32, SD = 0.75) and target words were positioned fifth in the experimental sentences. The frequency and length of words preceding target words did not differ in different conditions of length (p = 0.40) or frequency (p = 0.83). Examples of sentence stimuli with embedded target words are as follows.

Long high-frequency word (information)
He left all his information with the guard at the front desk.

Short high-frequency word (list)
I always make a list before going to the grocery store.

Long low-frequency word (management)
I relied on the management to help me solve the problem.

Short low-frequency word (inn)
We stopped at the inn after driving for 10 hours that day.

In addition to the main sentences, 24 filler sentences were constructed. A yes–no comprehension question followed every three sentences to keep participants focused.

2.3. Procedure

Participants took the test individually in a quiet room. They were asked to fill in a questionnaire about their language skills and educational background. Then, their eye movements were recorded using EyeLink 1000 (SR Research, Canada). The participants silently read the sentences on the computer screen using a chin rest. The participants pressed the space bar when they finished reading the whole sentence. The eye-tracker was calibrated by employing nine fixation points across the entire screen. Eye movements were recorded from only the right eye. To ensure that participants sustained attention while they read, yes–no comprehension questions per three experimental sentences appeared on the screen. The order of stimulus presentation was randomized. Ten practice trials were conducted given prior to the main experimental session. After the eye-tracking experiment, all the participants took the LexTALE to measure their vocabulary knowledge.

3. Results and discussion

Fixation durations of less than 100 ms in duration were removed for the analysis, resulting in the loss of 3.2% of NS data and 3.6% of NNS data. The comprehension questions were answered with an average accuracy of 91% for NS and 81% for NNS. Table 2 shows three dependent eye-tracking measures for all words used in the experiment. NNS fixated longer and more than NS in all measures ($p < 0.001$). In the current experiments, three separate analyses were conducted to investigate the effects of word frequency and length: (1) the first model verified the word frequency and length effects for each group; (2) the second model examined the different impacts of the effects between NS and NNS; and (3) the third model investigated the influence of vocabulary knowledge by adding individual vocabulary knowledge as a predictor to the second analysis.

All data of first fixation durations and gaze durations for target words were analyzed with a linear mixed-effects model (LME) with cross random-effect factors using R version 4.1.1 (R Development Core Team, 2013) and R package *lme4* (Baayen et al., 2008). The models included predictors, random slopes of the predictors, and random intercepts associated with participants and items. All fixations were log-adjusted. The mixed-effect models included fixed effects for group (NS vs. NNS), logarithmic lengths and frequencies of target words (continuous), and logarithmic lengths and frequency of preceding target words (continuous). All continuous measures were centered. The best model was selected, including the interaction of group and logarithmic lengths and frequencies of target words by backward selection.

In the analysis of eye-tracking data, Table 3 illustrates the effect of frequency and length of the target words, including average durations for both groups. Main effects and interactions of word frequency and length are summarized in Table 4.

Table 2. Mean first fixation duration, gaze duration, and total reading time for all words in the stimulus sentences

	NS	NNS
First fixation duration (ms)	198.33 (104.01)	257.03 (136.75)
Gaze duration (ms)	223.15 (133.30)	385.33 (371.55)
Total reading time (ms)	287.71 (212.80)	574.33 (564.51)

Note. Standard deviations are in parentheses.

Table 3. Mean fixation durations on word frequency and length (standard deviations in parentheses)

	High frequency		Low frequency	
NS	Short	Long	Short	Long
First fixation duration (ms)	185.56	180.62	189.78	184.76
	(54.34)	(64.24)	(71.60)	(51.79)
Gaze duration (ms)	211.13	223.27	225.48	265.82
	(92.65)	(112.24)	(109.68)	(160.48)
NNS				
First fixation duration (ms)	287.13	265.52	299.67	262.09
	(139.57)	(124.09)	(176.41)	(130.70)
Gaze duration (ms)	486.76	734.34	682.54	1201.17
	(396.65)	(594.77)	(599.83)	(1068.83)

Table 4. Main effects and interactions of word frequency and length for NS and NNS in first fixation and gaze durations [1]

	First fixation duration		Gaze duration	
	t	*p*	*t*	*p*
Frequency	0.81	0.42	−2.51	0.01
Length	2.13	0.04	10.56.	< 0.001
Group	−6.59	< 0.001	−4.78	< 0.001
Pre-target length	−1.75	0.08	−0.48	0.63
Pre-target frequency	0.30	0.77	0.73	0.47
Frequency × Group	0.00	1.00	2.39	0.02
Length × Group	0.43	0.66	−10.37	< 0.001
Frequency × Length	2.90	< 0.01	1.06	0.29
Length × Frequency × Group	−0.32	0.75	-	-

3.1 Frequency effects

In the separate analysis for each group, NS demonstrated significantly longer fixations for infrequent words than for frequent words (β = 7.82, SE = 1.54, t = 5.06, p < 0.001) as did NNS (β = 0.37, SE = 0.05, t = 7.68, p < 0.001) in gaze duration. The word frequency affected eye-movements for both groups during sentence reading. In first fixation durations, there were no main effects for NS (β = 0.02, SE = 0.01, t = 1.73, p = 0.09) and for NNS (β = 0.01, SE = 0.02, t = 0.45, p = 0.65).

As shown in Table 4, in terms of the first fixation durations, no interaction of group and word frequency was obtained (β = 0.00, SE = 0.02, t = 0.00 p = 1.00). This result is similar to that in Tiffin-Richards and Schroeder's (2015) work. Importantly, the statistical analysis obtained a larger frequency effect for NNS than for NS (β = 0.31, SE = 0.13, t = 2.39, p = 0.02) in the gaze duration. The result is consistent with the prediction of the lexical entrenchment account, since even Japanese participants, with a different-script L1, displayed a greater frequency effect than NS did. It provides explicit evidence for the differential magnitude of word frequency effects.

3.2 Length effects

In gaze duration, there was a strong main effect for NNS (β = 0.62, SE = 0.08, t = 7.83, p < 0.001), but not for NS (β = 0.01, SE = 0.01, t = 1.54, p = 0.36). The absence of an explicit main length effect for NS

1　The model including a three-way interaction of length × frequency × group in gaze duration failed to converge.

might be attributed to high language proficiency and the target words selected from the JACET list used for Japanese learners. Schröter and Schroeder (2018) pointed out that the sensitivity to word length decreased as reading skill developed. It is noteworthy that the length effect for NNS was larger than for NS (β = –0.63, SE = 0.06, t = –10.37, $p < 0.001$). This significant interaction of Group × Length indicates that increasing word length has a stronger impact on NNS than NS. It can be argued that NNS tend to rely on a low sublexical route in which word recognition is primarily achieved through letter-by-letter decoding, while NS directly match word spelling with representation, effectively making use of a lexical route. Kurokawa et al. (2014) found that less skilled children utilizing letter-by-letter processing became more reliant on lexical processing as language competence increased. Long infrequent words are likely to be processed via a sublexical route, whereas short frequent words appear to successfully match spelling with representation. It is reasonable to assume that NNS could not employ the lexical route to process long infrequent words because of low proficiency and the lack of exposure to English.

As for first fixation durations, NS fixations were shorter for long target words than for short ones. There was a main effect of word length (β = 0.16, SE = 0.07, t = 2.48, p = 0.01) and an interaction of word Length × Frequency (β = 0.34, SE = 0.14, t = 2.50, p = 0.01). For NNS, no main effect was found in first fixation duration (β = 0.15, SE = 0.16, t = 0.95, p = 0.35). We also found no significant interaction for NNS (β = 0.46, SE = 0.32, t = 1.45, p = 0.16). People normally fixate more than once for longer words; therefore, the first fixations seem short (Tiffin-Richards & Schroeder, 2015).

3.3 Vocabulary size effect

To investigate whether vocabulary size affects the difference of frequency and length effects, additional analysis was conducted to submit individual vocabulary size to LME. Table 5 shows that the Length × Group and Frequency × Group persisted after controlling for vocabulary size. Vocabulary knowledge did not eliminate these interactions. The result is consistent with Whitford and Titone's (2012) findings, indicating that an additional factor must be involved. Brysbaert et al. (2017) stated that an adequate amount of exposure to the target language, and especially to infrequent words, would lead to decreased lexical access time. The present study employed LexTALE score as a measurement for amount of exposure to English. The findings in the present study indicate that the discrepancy of word frequency effects between L1 and L2 requires further explanation above and beyond individual vocabulary knowledge. Cop et al. (2015) discussed that subjective frequency for L2 participants is likely to differ from corpus-based objective frequency which is normally used in behavioral experiments. Inadequate exposure

Table 5. Main effects and interactions of word frequency and length for NS and NNS with vocabulary size in gaze durations

	Gaze duration	
	t	p
Frequency	–2.53	0.01
Length	5.45	< 0.001
Group	–2.05	0.04
Vocabulary	–4.52	< 0.001
Frequency × Group	2.51	0.01
Length × Group	–5.33	< 0.001
Vocabulary × Group	2.80	< 0.01
Frequency × Vocabulary	1.69	0.09
Length × Vocabulary	–2.43	0.01
Length × Vocabulary × Group	2.23	0.03

to specific L2 words would result in word frequency differences between NS and NNS. Using a subjective measurement, such as familiarity rate, would be beneficial for future research.

4. Conclusion

In this eye-tracking study, NNS showed larger frequency effects of word frequency and length over NS. Our findings revealed the stronger effects for participants with non-alphabetical L1, supporting the lexical entrenchment account. However, the results also suggested that vocabulary size did not provide a satisfactory explanation for this difference. The explanation of different magnitude might not be restricted to a single factor.

The current study did not directly address the issues of dual-route models, since multiple additional measures (e.g., fixation counts and landing positions) would be required for such an analysis. Future research should address these gaps to deepen our understanding of L2 processing.

References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Barton, J. J. S., Hanif, H. M., Björnström, L. E., & Hills, C. (2014). The word-length effect in reading: A review. *Cognitive Neuropsychology, 31*(5–6), 378–412. https://doi.org/10.1080/02643294.2014.895314

BNC Consortium. (2001). The British national corpus (Version 2), Shogakukan corpus network [Distributor]. Retrieved from http://scnweb.jkn21.com/BNC2/

Brysbaert, M, Lagrou, E, & Stevens, M, (2017). Visual word recognition in a second language: A test of the lexical entrenchment hypothesis with lexical decision times. *Bilingualism: Language and Cognition, 20*(3), 530–548. https://doi.org/10.1017/S1366728916000353

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204–256. https://doi.org/10.1037/0033-295x.108.1.204

Cop, U., Keuleers, E., Drieghe, D., & Duyck, W. (2015). Frequency effects in monolingual and bilingual natural reading. *Psychonomic Bulletin & Review, 22*(5), 1216–1234. https://doi.org/10.3758/s13423-015-0819-2

Diependaele, K., Lemhöfer, K., & Brysbaert, M. (2013). The word frequency effect in first- and second-language word recognition: A lexical entrenchment account. *The Quarterly Journal of Experimental Psychology, 66*(5), 843–863. https://doi.org/10.1080/17470218.2012.720994

Duyck, W., Vanderelst, D., Desmet, T., & Hartsuiker, R. J. (2008). The frequency effect in second-language visual word recognition. *Psychonomic Bulletin & Review, 15*(4), 850–855. https://doi.org/10.3758/PBR.15.4.850

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning & Verbal Behavior, 12*(6), 627–635. https://doi.org/10.1016/S0022-5371(73)80042-8

Godfroid, A. (2020). *Eye tracking in second language acquisition and bilingualism: A research synthesis and methodological guide*. Routledge. https://doi.org/10.4324/9781315775616

Gollan, T. H., Montoya, R. I., Cera, C., & Sandoval, T. C. (2008). More use almost always means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis. *Journal of Memory and Language, 58*(3), 787–814. https://doi.org/10.1016/j.jml.2007.07.001

Inhoff, A. F., & Rayner, K. (1986). Parafoveal word processing during eye fixations in reading: Effects of word frequency. *Perception & Psychophysics, 40*, 431–439. https://doi.org/10.3758/bf03208203

Ishida, T. (2022). Comparison of word frequency effects between Japanese learners of English and native English speakers. Nihon Fukushi University Inter-departmental Education Center Bulletin, 10, 23-30.

JACET Committee of Basic Words Revision. (2003). *JACET list of 8000 basic words: JACET 8000.* JACET.

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of*

Cognitive Psychology, 16(1–2), 262–284. https://doi.org/10.1080/09541440340000213

Kurokawa, S., Sanbai, A., & Uno, A. (2014). Tenkei hattatu zi ni okeru kana mozi wo mochi i ta goi handan zi no mozi chou kouka to goi sei kouka [The effects of length and lexicality on lexical decision using Kana words in normal developmental children]. *The Japan Society of Logopedics and Phoniatrics, 55*, 326–332. https://doi.org/10.5112/jjlp.55.326

Lemhöfer, K., & Broersma, M. (2012). Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior Research Methods, 44*(2), 325–343. https://doi.org/10.3758/s13428-011-0146-0

Mor, B., & Prior, A. (2021). Frequency and predictability effects in first and second language of different script bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. https://doi.org/10.1037/xlm0000927

Perry, C, Ziegler, JC, & Zorzi, M, (2007). Nested incremental modeling in the development of computational theories: the CDP+ model of reading aloud. *Psychological Review*, 114, 273–315. https://doi.org/10.1037/0033-295X.114.2.273

R Development Core Team. (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Retrieved from http://www.R-project.org

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372–422. https://doi.org/10.1037/0033-2909.124.3.372

Rayner, K. (2009). The Thirty Fifth Sir Frederick Bartlett Lecture: Eye movements and attention during reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology, 62,* 1457–1506. https://doi.org/10.1080/17470210902816461

Rayner, K., & Duffy, S. (1986) Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition, 14,* 191–201. https://doi.org/10.3758/BF03197692

Schröter, P., & Schroeder, S. (2018). Differences in visual word recognition between L1 and L2 speakers: The impact of length, frequency, and orthographic neighborhood size in German children. *Studies in Second Language Acquisition, 40*(2), 319–339. https://doi.org/10.1017/s0272263117000201

Tiffin-Richards, S. P., & Schroeder, S. (2015). Word length and frequency effects on children's eye movements during silent reading. *Vision Research, 113*(A), 33–43. https://doi.org/10.1016/j.visres.2015.05.008

Whitford, V., & Titone, D. (2012). Second-language experience modulates first- and second-language word frequency effects: Evidence from eye movement measures of natural paragraph reading. *Psychonomic Bulletin & Review, 19*(1), 73–80. https://doi.org/10.3758/s13423-011-0179-5

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