Foot-Level and Boundary-Durational Effect Driven by Morphological Complexity in Japanese

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1 Introduction

The morphological structures of words are known to influence their phonological representations. In languages where pitch accent is distinctive, such as Japanese, compounds often have a different prosodic pattern than simple words, such as Japanese (Haraguchi 1999, Kubozono 2008, Vance 2008). The semantic or morpho-syntactic structures of a compound may also affect its supra-segmental or segmental realization. Some of these changes are observable in the writing system, such as sequential voicing in Japanese

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(henceforth, *rendaku*), but others, such as subtle changes in acoustic features, may not be easily perceived by listeners. For instance, the presence of a morphological boundary may subdivide a complex word into different morphophonological categories and cause different acoustic durations in languages. Previous studies have shown that the same segment in English may have different durations depending on the word structure in which it occurs (Bell et al. 2021, Hay 2003, Hedia and Plag 2017, Lee-Kim et al. 2013). Even the same segment appearing in the same prefix may have different durations depending on the word's degree of segmentability (Ben Hedia 2019, Hay 2007). In an experiment by Kunter and Plag (2016), it was observed that the duration of the third constituent (e.g., 'center' in 'day care center') was longer when the complex constituent (e.g., 'day care') had a higher frequency of occurrence. Additionally, the duration of the embedded constituent adjacent to the third constituent (e.g., 'care') was found to be acoustically shorter. This effect suggests that morphological structure is reflected in acoustic features such as duration.

Similarly, the realization of the English phoneme /l/ has been found to be contingent on the strength of the morphological boundary. Sproat and Fujimura (1993) and Lee-Kim et al (2013) conducted experiments that demonstrated a relationship between stronger morphological boundaries and longer durations of the /l/ sound. Bell et al. (2021) also provide a comprehensive review on this subject, highlighting that consonants positioned at morphological boundaries tend to exhibit longer durations.

While such experimental findings may not strongly support the segmentability hypothesis, they do suggest a relationship between the presence of morphological boundaries and the increased duration of consonants. These findings in terms of morphological structure pose a vital question in the language processing theory—namely, how the compound structure of a language is processed and whether compounds are decomposed or not. Some studies (e.g., Fernández-Domínguez 2010, Plag 2012) suggest that complex words are lexicalized and processed as a unit to some extent depending on the frequency or other factors, while others studies (e.g., Pinker and Ullman 2002) suggest that all compounds are decomposed into smaller units and then processed by human speakers.

If the difference in acoustic properties between complex and simple words also differ in Japanese, it may provide evidence that compounds are processed with their constituents in this language. Such a finding could confirm that the morphological inner structure of words affects phonetic realization. The focus of the present discussion revolves around the concept of duration, particularly in relation to the processing and acoustic realization of compounds.

2 Phonetic Realization of Japanese

Japanese is a mora-timed language with a relatively simple syllable structure (Warner and Arai 2001), where each mora has a similar duration. Duration of mora may differ depending on its phonological structure. Den (2015) shows that Japanese phrase-end is lengthening like many other languages, but less research has been done to compare the duration of mora of compound words and simple words. Regarding the length of mora potentially affected by foot, Ota et al. (2003) also conducted an experimental test on foot final lengthening and found Japanese to be a bimoraic foot language, while many languages in the rhythmic unit had lengthening at the end. However, they did not find statistically significant differences, and only found evidence of compensated lengthening.

Another important factor that may influence segmental duration is the morpho-syntactic boundary. Studies targeting English (e.g., Bell et al. 2021) often adopt the assumption that "compounds are more likely to be written spaced when their constituents are more frequent or orthographically longer" and utilize the spelling as an indirect measure of segmentability. Meanwhile, studies on the morphological structure of Japanese are still rare. Some studies found that boundary may influence duration. Preboundary lengthening refers to the lengthening of the segment immediately preceding a morpheme boundary. Seo et al. (2019) found that preboundary lengthening can extend beyond the immediate segment and exhibit a distance effect. Specifically, in words with multiple elements, such as four segments, the second and third segments, which are closer to the final segment, also demonstrate slightly longer durations. This lengthening effect spreads in a leftward direction.

Three empirical problems in the related research, however, should be addressed. First, although it has been pointed out that segments in the compound boundary may have a longer duration in words with a higher segmentability compared to those with lower segmentability, many studies have failed to replicate this durational effect, thus not supporting the segmentability hypothesis (Bell et al. 2021, Bürki et al. 2011). Second, many studies have focused on English and other European languages. Whether this durational effect is universal or language-specific remains unclear. For example, Hay (2007) observed that not all English and Dutch speakers lengthened the duration of the segment in the morphological boundary. The effect may also occur with large individual variance among the individual speakers of a language. Third, many studies have used corpora, in which the recorded speakers did not have a consistent sociolinguistic background, and in which the materials were limited by the nature of the corpus. Therefore, it would be challenging to conduct a precise analysis of specific words produced by the same group of speakers. To solve these problems, I conducted a production experiment to verify

whether the duration changes in acoustic properties because of the morphological structure of Japanese. In the experiment, the length of mora in four-mora compound words and simple words was compared to investigate whether morphological boundary and foot structure have any effect on duration. Through these two experiments, the question of whether the Japanese language can duplicate the boundary effect of compounding and the durational effect occurring at the foot-level is empirically authentic.

3 Production Experiment

To investigate the impact of morphological complexity and foot structure on duration realization in Japanese, a production experiment was conducted. The experiment involved two factors, each with two levels: morphological complexity (complex/simple) and foot position (foot-initial/foot-final). The first factor pertained to morphological complexity, encompassing four complex words comprising two morphological units, along with four simple words that cannot be separated into smaller units. The second factor focused on foot structure, whereby each four-mora word was divided into two feet. The two levels within this factor were distinguished as foot-initial and foot-final. Eight target words, each consisting of four morae, were selected. They are presented in Table 1.

The current study employed an online experiment conducted using jsPsych (De Leeuw 2015) on Cognition.run (https://cognition.run), an online platform for conducting web-based experiments. Seventeen participants participated in the experiment via CrowdWorks (https://crowdworks.jp) with their own device (restricted to Google Chrome to avoid potential technical problems). They were all from the Tokyo metropolitan area, where speakers share a highly similar dialect; the area encompasses Tokyo, Saitama, Chiba, and Kanagawa. This experiment was conducted together with another experiment that focused on investigating head-dependent structure in the Japanese language, and that consisted of two experimental blocks, with stimuli being randomly presented to participants.

Eight unaccented words were selected as the target items, since the syllables that are stressed or possess an accentual fall might cause a longer duration, as previous studies suggest—for English, the study of Rakerd et al. (1987), and for Japanese, the study by Hoequist (1983). Each item appeared twice in the experiment. Eight words that were four-mora long with other combinations of consonants and vowels were used as fillers.

Word Type	Items			
Complex	*yorukafe* 'night café'	*serubia* 'Serbia'	*komebitsu* 'rice bin'	*amerika* 'America'
Simple	*dorubako* 'money box'	*arukari* 'Alkali'	*harusame* 'vermicelli'	*berurin* 'Berlin'

Table 1. Items used in the experiment.

All items and fillers appeared with the same carrier sentence, with the structure 'これは_____です,'(*korewa____desu.*; 'this is _____') in Japanese. The subject of the sentence contained five variations—namely *kore* ('これ'), *sore* ('それ'), *are* ('あれ'), *koko* ('ここ'), and *soko* ('そこ'), since certain target words were place names. The variation *asoko* ('あそこ'; "there") was excluded because of its different mora count. Regarding the stimuli, each one comprised four morae, with the second mora serving as the target. The second mora in all stimuli consisted of a voiced consonant followed by a vowel. The vowel of the target syllable was either /e/ or /u/, and the consonant of the target syllable was either /r/ or /m/.

We formulated two hypotheses. First, we hypothesized that there would be a difference in mora duration between complex words and simple words. Specifically, we anticipated that complex words would exhibit longer mora durations compared to simple words. Second, we predicted that there would be a distinction between foot-initial morae and foot-final morae in terms of their characteristics. We expected that these two types of morae within the foot structure would not be equivalent in terms of their phonetic properties.

4 Results

4.1 Data Analysis

The recording of the participants pronouncing the items was retrieved using Python and converted from base64 format to wav files. Following this, all segments were automatically annotated using Julius (Kawahara 2005), and the acoustic duration of each mora was computed automatically using Praat (Boersma and Weenink 2021). The duration values were later verified by the author. In cases where annotations were identified as targeting a different segment, potentially resulting from recording issues, human corrections were made. A total of six trials were manipulated by the author because of misprocessing caused by the auto-segmentation.

The statistical analysis was conducted using R and RStudio, using linear-mixed effects models (LMEs) with the *lme4* (Bates et al. 2014) and *lmerTest*

(Kuznetsova et al. 2015) packages. The fixed factors included in the analysis were foot structure, morphological complexity, age, and gender. These factors were investigated to examine their effects on the dependent variable, mora duration. Additionally, random factors included the intercepts of the vowel type of the target mora and of the final mora of the word, consonant type of the target mora and of the final mora of the word, item, and participants, to account for variability associated with these factors. To account for individual differences in speech rate, mora duration was evaluated and standardized for each participant. The optimal model was selected based on backward selection. Regarding the coding details, morphological complexity was coded as follows: complex words = 0; simple words = 1. The mora's position was coded as either foot initial (0) or foot final (1). Gender was also included as a factor (female = 0; male = 1).

4.2 Durational Differences

The result of the duration of the second mora from the left of each condition is shown in Figure 1.

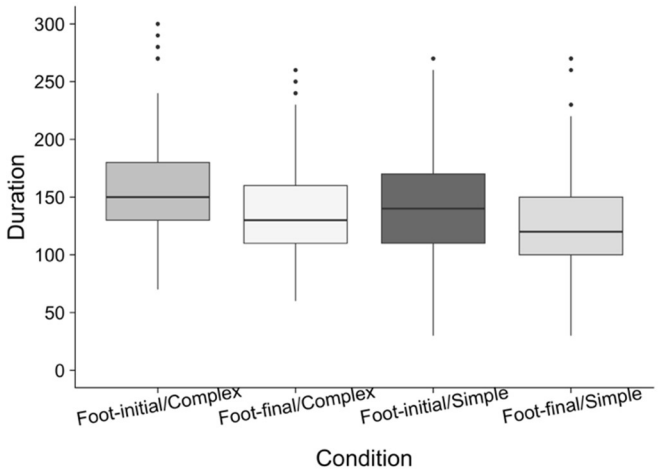

Figure 1. Duration(ms) of the target segment in each condition.

The statistical analysis revealed significant effects on the duration of morae in both factors and their interactions as shown in Table 2. The results indicated that foot-initial morae exhibited longer durations compared to foot-

final morae. This finding suggests that the position of morae within the foot structure influences the duration of those morae. A significant difference in duration between complex words and simple words was observed. Complex words exhibited longer durations compared to simple words, indicating that morphological complexity plays a role in the duration of morae. Furthermore, an interaction between the foot position and morphological complexity was observed, showing that the effects of these two factors are not simply additive.

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
(Intercept)	.462	.094	4.891	.005
Foot	-.644	.079	-8.184	< .001
Morph	-.412	.134	-3.080	.030
Foot:Morph	.256	.112	2.282	.023

Table 2. The LME results of the experiment evaluating the effects and the interaction of foot and morphological complexity.

An ad hoc analysis using *emmeans* showed a significant difference after Bonferroni correction in the duration of the target morae between the foot-initial position and the foot-final position in complex words, with an estimated difference of 0.591 ($\beta = 0.591$, $S.E = 0.102$, $t.ratio = 5.773$, $p < 0.001$). This difference implies a longer duration for the foot-initial position in complex words. The comparison between the foot-initial position in complex words and the same position in simple words, however, did not reach statistical significance ($\beta = 0.415$, $S.E = 0.141$, $t.ratio = 2.948$, $p = 0.181$). The comparison between the foot-final position in both word types showed no difference ($\beta = 0.150$, $S.E = 0.138$, $t.ratio = 1.084$, $p = 1.000$).

Next, we conducted a statistical model comparing the duration of each moraic order (i.e., region). The results showed that complex words triggered longer durations in both the initial and final syllables compared to simple words (the first and the fourth mora were longer than the second and the third mora). This finding suggests that morphologically complex words tend to have a greater temporal duration in their syllabic structure, specifically in the first and final syllables. Figure 2 illustrates the duration of morae in four-mora words across various regions. The *x*-axis represents the order of morae, with a focus on morae numbered 4 to 7. The orange bars on the left show the duration of complex words, while the green bars represent the duration of simple words.

The statistical analysis in Table 3 revealed significant differences in duration between complex and simple words. Specifically, complex words

exhibited longer durations in the first and final syllables compared to simple words. Moreover, the durations of morae in Region 4 and Region 7 were significantly longer than those in Region 5 and Region 6.

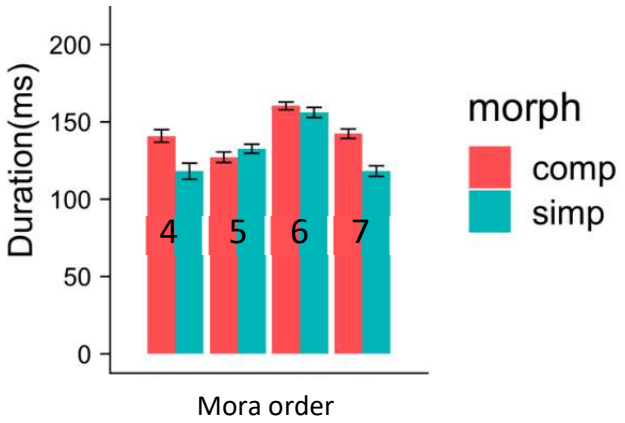

Figure 2. Duration depending on morphological complexity. Mora order indicates the order of mora in the target sentence (= region). Regions 4-7 are the target items.

	Estimate	*S.E.*	*t value*	*Pr(>|t|)*
(Intercept)	.311	.135	2.310	.060
Mora_order5	-.607	.272	-2.228	.092
Mora _order6	.253	.108	2.353	.019
Mora _order7	-.235	.273	-.861	.439
Morph	-.708	.448	-1.580	.195
Mora _order5:Morph	.952	.744	1.280	.270
Mora _order6:Morph	.485	.152	3.194	.001
Mora _order7:Morph	.089	.744	.120	.910

Table 3. The LME results of the regional comparison. The baseline of the order is the fourth region, which is the initial mora of the target words.

4.3 Other Predictors

We further investigated the potential effects of vowel type and consonant type on duration realization, considering their potential influence. The durational distribution is shown in Figure 3 and Figure 4. The results of additional statistical models indicated no significant effects of vowel type and consonant type on duration.

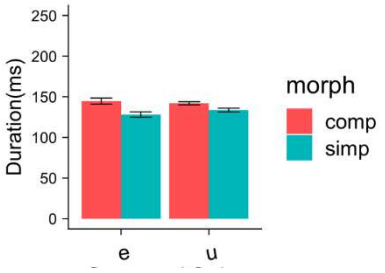

Figure 1. Durational differences regarding morphological complexity and the vowel of the target mora.

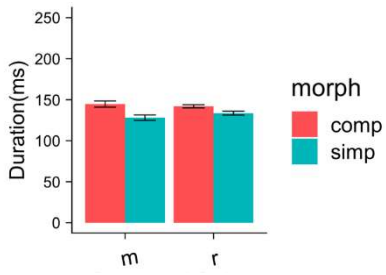

Figure 4. Durational differences regarding morphological complexity and the consonant of the target mora.

5 Discussions

5.1 Theoretical Implications

Our analysis did not find foot-final lengthening effects in either simple or complex words, which is consistent with the results in Ota et al. (2003). As mentioned in the results chapter, our post hoc analysis showed that foot-final morae exhibited shorter durations compared to foot-initial morae. This observation raises the question of why a 'shortening' phenomenon at the foot-level occurred in the second mora, which was also the boundary mora in the complex words. An intriguing possibility is rooted in the underlying rhythmic structure of Japanese, which follows a bimoraic and trochaic foot pattern (Inaba 1998, Itô and Mester 1992, Poser 1990). This rhythmic structure may account for the distinct findings in our investigation, where the duration patterns associated with foot position diverged from those reported in prior studies (Gordon 2011). The trochaic foot structure in Japanese, characterized by a strong-weak pattern, may lead to differences in realization of duration in different positions within the foot. The head of the trochaic foot, which is the first mora in each foot, is pronounced in a longer manner compared to the other mora.

The findings in the present study support the dual-route model of morphological production in the Japanese language. The results provide compelling evidence indicating that complex words are pronounced with phonetic cues, leading to a longer duration than in simple words. This finding contributes to the growing body of evidence supporting the psychological reality of morphological boundaries in Japanese.

5.2 Potential Issues of Selected Items

The results reveal an intriguing aspect that the observed durational differences were not limited to simple compounds but rather extended to complex words undergoing additional morphological processes in Japanese, such as rendaku (e.g., *kome* + *hitsu* > *komebitsu*) and consonantal insertion (e.g., *haru* + *ame* > *harusame*). This finding suggests the psychological reality underlying the processing of morphological complexity in Japanese. The presence of durational distinctions in complex words undergoing various morphological processes indicates that speakers perceive and process the inner morphological structures of these words. These findings contribute to the understanding of the cognitive mechanisms involved in morphological processing and highlight the significance of morphological complexity in language production and comprehension.

The items used in the study had another potential problem that may affect the result: Two of the items were ended with a syllabized nasal (*serubia*) and a single syllable without a consonant (*berurin*). Despite previous studies showing that Japanese has approximately equal moraic length, it is possible that these two simple words have a shorter length and caused the length difference between the complex words and simple words. Thus, another model was conducted to test whether the result would change without those two words (Table 4). The results show that the group difference between complex words and simple words is still observed even if those two words are removed. The main effects and the interaction were observed, as the previous model showed.

	Estimate	*S.E.*	*t value*	*Pr(>|t|)*
(Intercept)	.458	.071	6.405	< .001
Foot	-.591	.100	-5.933	< .001
Morph	-.415	.109	-3.798	.002
Foot:Morph	.265	.127	2.081	.042

Table 4. The LME results evaluating foot and morphological complexity, in which *berurin* and *serubia* were excluded.

6 Remaining Issues

This study contributes to understanding the duration of morphological units in Japanese words and provides direction for further research. One crucial aspect that demands attention in future research is the effect of pitch accent on duration. This paper focused solely on unaccented words, leaving the influence of pitch accent patterns on duration largely unexplored. Investigating how pitch and accent interact with duration would provide a more comprehensive understanding of the phonetic realization of words in Japanese.

Furthermore, an investigation of different types of morphemes, such as bound and free morphemes, is necessary. This study primarily considered morphological complexity, but a deeper investigation into the specific contributions of different morpheme types would enhance the understanding of duration in relation to morphological structure. Additionally, investigating the interactions between morphemes, including phenomena like rendaku and other morphophonological processes, would further elucidate the factors influencing duration.

The influence of word frequency on mora duration is another important avenue for future research. Although not controlled for in the current study, word frequency has the potential to impact duration patterns. Exploring the relationship between word frequency and duration could provide valuable insights into the interplay of linguistic factors and frequency in language production.

7 Conclusion

This paper addressed two main questions regarding the phonetic realization of Japanese words. First, we examined the presence of morphological boundary lengthening and observed a nuanced pattern with compensatory effects. Specifically, compared to simple words, compounds exhibited longer

durations in the first and final morae. This finding suggests that morphological complexity influences the phonetic realization of Japanese words. Second, we explored foot-level durational effects and found that foot-initial morae triggered significantly longer durations. This phenomenon may be attributed to the trochaic structure of Japanese, where emphasis is placed on the initial mora of each foot. These results provide insights into the interaction between phonological structure and duration in Japanese. The overall findings of this paper highlight the significant impact of both morphological complexity and phonological structure on the phonetic realization of Japanese, implying that the morphological effect on acoustic duration is universal. This study also contributes to the broader understanding of language production and the intricate interplay between morphological and phonological factors.

Acknowledgments

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