ARTICULATION OF SINGLE AND GEMINATE CONSONANTS AND ITS RELATION TO THE DURATION OF THE PRECEDING VOWEL IN JAPANESE

Masako Fujimoto[1], Seiya Funatsu[2] and Phil Hoole[3]

1 Advanced Research Center for Human Sciences, Waseda University, Japan
2 Science information center, Prefectural University of Hiroshima, Japan
3 Institute of Phonetics and Speech Processing, Ludwig Maximilians University, Germany
fujimoto1000@hotmail.com, funatsu@pu-hiroshima.ac.jp, hoole@phonetik.uni-muenchen.de

ABSTRACT

Japanese is a language that has contrasts between single and geminate consonants. This phonological contrast is claimed to affect the duration of the neighboring vowel so that the preceding vowel is phonetically longer before geminates. The present study examines the difference in articulatory manifestations between single and geminate consonants and their relation to the duration of the preceding vowel using an EMA system. The results showed that the tongue peak during CC occurs later than that during C for all speakers. However, the duration of the preceding vowel showed interpersonal variation. Thus, the later occurrence of peak timing per se does not directly affect the length of the preceding vowel. Other factors that may affect the duration of the preceding vowel are discussed.

Keywords: single and geminate consonants, articulation, timing of tongue rise, vowel duration, Japanese, Electromagnetic Articulography (EMA)

1. INTRODUCTION

Japanese has a phonological contrast between single and geminate consonants. The duration of geminates (CC) is 2.6 to 3.3 times longer than their single counterparts (C) [1-4]. This contrast is claimed to affect the duration of the preceding vowel, not phonologically but phonetically. Many studies reported that vowels are longer before geminates than before singletons in Japanese [5-8]. The durational pattern observed for Japanese is interesting because it is different from the common pattern observed across languages for there to be reciprocal relationship between vowel and following consonant [9]. We aim to investigate why and how the vowel lengthening occurs before geminates in Japanese.

Articulatory studies have shown that tongue contact or constriction is maintained longer for CC than C in Japanese [10-12]. If the timing of tongue rise is similar between CC and C, the duration of the preceding vowel would be similar, too. However, the tongue tends to move slower during CC than C [10,13,14]. This can presumably cause lengthening of the preceding vowel. Takada [10] and Fujimoto [14] found that the jaw or tongue tends to be more lowered during the vowel before CC than before C. Fujimoto [14] also notes that the tongue tends to stay at the position of the preceding vowel longer for CC than C. These findings suggest that the lengthening of the preceding vowel is due to the slower tongue movement during CC than C. In other words, the durational difference of the preceding vowel may be a side effect of articulatory manifestations between two consonant types. This paper examines the relationship between the timing of tongue movement during single and geminate consonants and the duration of the preceding vowel in Japanese, using an Electromagnetic Articulography system (EMA).

2. DATA

2.1. Data recordings

Data recordings were carried out at IPS, Munich, using Carstens AG500. We recorded the tongue movements at tongue tip (TT), middle of tongue (TM) and tongue back (TB). The speech signal was recorded simultaneously. See Hoole et al [15] for the detail of the EMA recording system.

Subjects were two Japanese male, JM1 and JM2, in their mid-twenties. Materials are the following 12 non-words with single or geminate stops, where ‘Q’ denotes the first half of geminate consonants. Note that /t/ is pronounced as [tʃ] before /i/ and [t] before /e/ in Japanese.

te-set: etete, eQte, eQtete
ti-set: etiti, eQti, eQtiti
ke-set ekeke, eQke, eQkeke
ki-set: ekiki, eQki, eQkiki

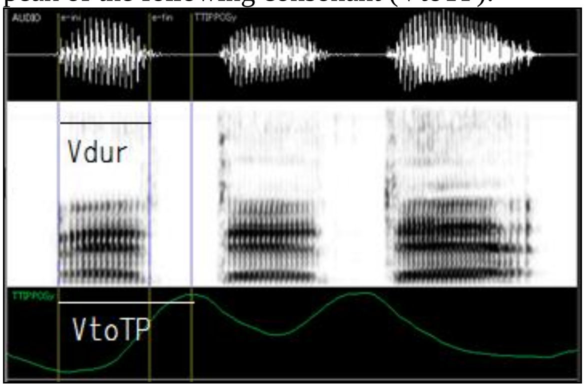
In each set, first and second words differ by the first consonant, single or geminate, but share three mora counts. The first and the third words differ by the first consonant, single or geminate, as well as the mora count; three in the first and four in the third.

These words were randomized and presented on a monitor. The subjects read the test words in a sentence "Sage XX (Say XX)" in five different word lists. In total, 120 utterances were recorded. Note that German frame sentence was used because these recordings were done in Germany and included multiple sessions some of which used German test words. We clearly informed the subjects that the test words for this session are Japanese.

2.2. Data analysis

We analyzed the data using MATLAB-based custom software mview (Mark Tiede, Haskins Laboratories). In the present study, we measured 1) the duration of the first vowel (Vdur) and 2) the duration from the onset of the first vowel to the tongue peak of the following consonant (VtoTP). The timing of the tongue peak defined by the program is at the point when the velocity of the tongue reached zero (with an error rate of ± 0.2mm/sec.). We used the signal TT, TM or TB which best represents the tongue movements for the particular consonant, i.e., TT (tongue tip for te and ti syllables) and TB (tongue back for ke and ki syllables). Figure 1 shows a sample of the measurements.

Figure 1 Measurement of the first vowel (Vdur) and the beginning of the first vowel to the tongue peak of the following consonant (VtoTP).



3. RESULTS

One token of ekeke by JM1, eQke and eQtiti by JM2 were disfluent and removed from further analysis.

3.1. Timing of tongue peak

Fig.2 shows examples of tongue movement of etete and eQtete, respectively. As is seen in Fig 2, the tongue moves towards the palate slower in CC (eQtete) than in C (etete). The tongue reaches a peak during C at about the half of the closure duration for /t/ in etete. On the other hand, the tongue reaches a peak far later during CC, which is closer to the /Qt/ release in eQtete. This is a general tendency across words and subjects.

Table 1 shows the averaged VtoTP duration (ms) for each test word. The VtoTP duration is longer in CC than C, except for eQti by JM2 (marked by half-tone dot meshing). Hence, for both subjects, the tongue tends to reach the peak later in CC than in C.

Figure 2 Examples of tongue movement of etete (top) and eQtete (bottom) utterances.

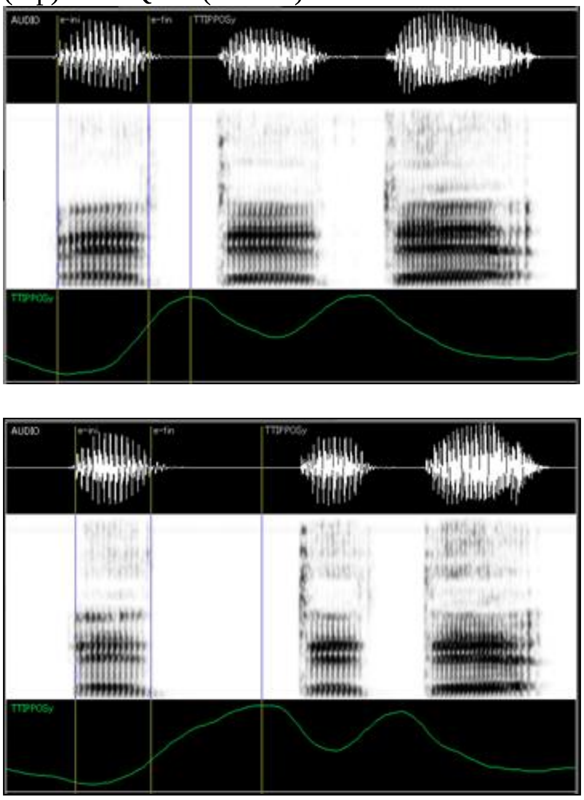


Table 1 The duration and the standard deviation (ms) of VtoTP

test words		subjects	
		JM1	JM2
te	etete	136.0 (20.4)	175.4 (7.4)
	eQte	194.4 (19.1)	251.0 (9.1)
	eQtete	228.3 (35.3)	258.4 (25.0)
ti	etiti	134.6 (14.0)	204.8 (18.9)
	eQti	161.1 (23.8)	192.0 (22.3)
	eQtiti	187.6 (26.8)	230.6 (23.2)
ke	ekeke	75.6 (30.8)	150.1 (3.9)
	eQke	91.9 (23.4)	191.2 (25.0)
	eQkeke	99.0 (16.3)	178.1 (15.2)
ki	ekiki	150.0 (16.3)	140.8 ((13.5)
	eQki	216.5 (26.2)	157.5 (18.0)
	eQkiki	190.1 (32.5)	197.7 (39.0)

3.2. Duration of the preceding vowel

Table 2 shows the average duration of the first vowel. The duration of the vowel is longer before CC than before C for JM1 regardless of the test words. This agrees with the results of previous studies. However, for JM2, the duration is often shorter before CC than before C (marked by half-tone dot meshing). Hence, interpersonal variation appears to be the tendency with regard to vowel length before CC.

Table 2 The duration and the standard deviation (ms) of the first vowel

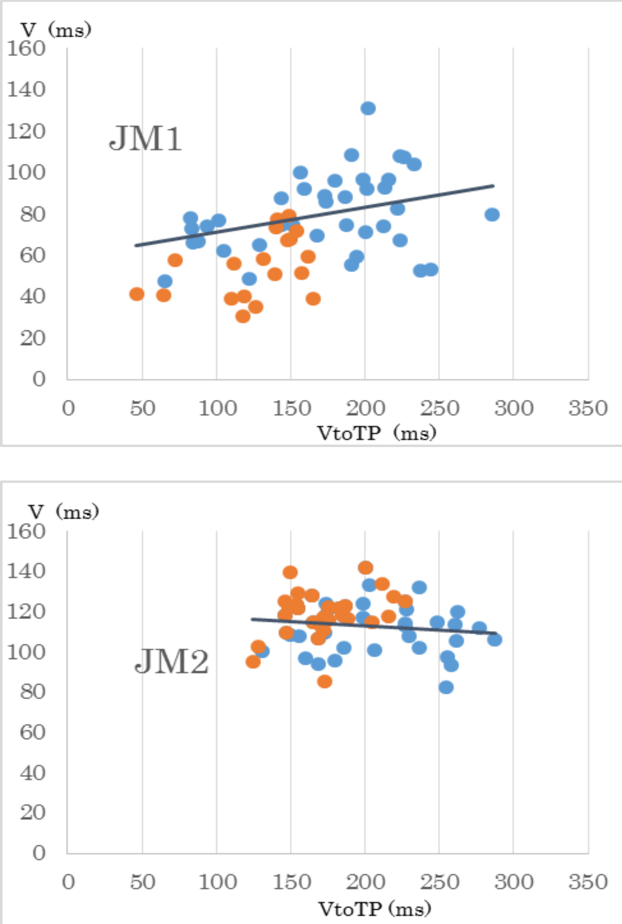
		JM1	JM2
te	etete	55.4 (19.0)	115.0 (2.6)
	eQte	86.7 (15.4)	108.3 (19.0)
	eQtete	92.0 (15.7)	106.9 (3.6)
ti	etiti	68.9 (10.9)	116.0 (18.8)
	eQti	92.6 (22.7)	106.1 (12.6)
	eQtiti	96.4 (8.0)	113.9 (9.2)
ke	ekeke	45.2 (8.6)	119.1 (5.8)
	eQke	65.3 (10.7)	119.2 (8.2)
	eQkeke	66.4 (11.9)	125.2 (10.5)
ki	ekiki	47.5 (10.1)	118.4 (18.8)
	eQki	63.9 (13.9)	106.9 (8.3)
	eQkiki	77.6 (15.4)	115.3 (15.2)

3.2. Relation between the timing of tongue peak during consonants and the duration of the preceding vowel

The above results showed that, when counted from the onset of the preceding vowel, tongue peak is generally later during CC than C for both subjects. However, the duration of the vowel is not always longer, at least for one subject. Thus, the delay of tongue peak is not a direct cause of the lengthening of the vowel before geminate consonants.

Figure 3 shows a scatter plot of V (ms) as a function of of VtoTP (ms) in order to examine the relation between the timing of tongue peak during consonants and the duration of the preceding vowel. For JM1, V is generally longer as VtoTP becomes longer. This shows that the preceding vowels are longer when the timing of tongue peak occurs later. On the contrary, V and VtoTP do not show any correlation for JM2. Thus, the present study revealed that marked interpersonal variations occur in timing of tongue peak of CC (geminate consonants) and the duration of the preceding vowels.

Figure 3 Scatter plot of V (ms) as a function of the duration of VtoTP (ms). Top panel shows JM1 and bottom, JM2. Blue dots show single consonants C, and orange, geminate consonants CC.



4. DISCUSSION

The present study confirmed for both subjects previous results which showed the tongue peak occurred later during CC than C. Comparison of voiceless and voiced consonants showed the timing of tongue peak is earlier during voiceless ones than voiced ones [16]. This faster movement for voiceless consonants is assumed to accomplish the voicelessness of the consonants during VCV sequence and to avoid the confusion between two consonant types [16]. However, it has been shown that such precise control is unnecessary in the case of voiceless geminate consonants. This may be because the voiceless period is long enough during voiceless geminates and they won't be mistaken with voiced consonants. This may also because geminates are limited to voiceless C in Japanese and voiced-voiceless contrasts need not be finely manifested for CC.

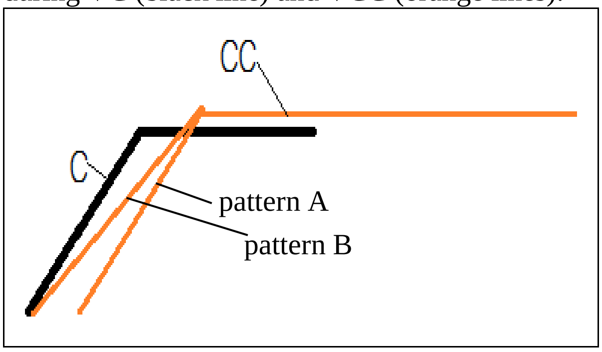
Although tongue peak occurred later during CC than C for both subjects, the duration of the vowel preceding the consonants was not necessarily longer. Rather it showed interpersonal variation. If the onset of tongue rise out of the vowel is also later for CC than C, the duration of the preceding vowel would be longer before CC than C. The present result suggests that it was not the case. Thus, the timing of tongue rise out of the preceding vowel may be in two patterns: similar timing between C and CC; and later rise for CC than for C.

The above results suggest that the tongue movement pattern during VCC can be twofold. For one, the timing of tongue rise out of V and that of tongue peak both delay (hereafter pattern A). In this case, the trajectory of tongue movement is similar for VC and VCC, and the preceding vowel tends to be lengthened. For the other, the timing of tongue rise out of V is similar to VC, but that of tongue peak delays (hereafter pattern B). In this case, the trajectory of tongue movement for VCC is gentler (more gradual) than VC, and the preceding vowel tends to show similar duration. Fig. 4 illustrates these patterns. As for the present subjects, pattern A exemplifies JM1 and pattern B, JM2.

We must note, however, the timing of tongue rise does not coincide with the end of the preceding vowel (see Fig. 2 and 3). It generally occurs in the middle of the vowel. Thus, the slope of the trajectory per se does not determine the duration of the vowel. Nevertheless, it is regarded as an important factor. Detailed investigation of the relationship between the timing of tongue rise and the duration of vowel and its duration is necessary.

Finally, it may be worthwhile to note that, although the sensor TB generally is the crucial articulator for /k/, TT shows pronounced movement for the ki-set by JM1 over TM and TB. Hence, TT is used for the measurement of ki-syllables for JM1. On the other hand, for JM2, sensor TB shows stronger movement than TT or TM for both the /ki/- and /ke/-set. Namely, /ki/ by JM1 is more palatalized. At this point, we are not certain if the degree of palatalization of the consonants correlates with the duration of the preceding vowel. But it possibly is a factor affecting the duration of the preceding vowel and deserves further examination.

Figure 4 Illustration of tongue movement pattern during VC (black line) and VCC (orange lines).



5. CONCLUSION

In the present study, we examined the articulatory manifestations of single and geminate consonants and their relation to the duration of the preceding vowel. Articulatory examination revealed that the tongue peak during CC occurs far later than that during C regardless of speaker. On the other hand, the duration of the preceding vowel showed interpersonal variation. Thus, the later occurrence of the peak timing does not necessarily affect the lengthening of the preceding vowel. Further articulatory studies involving more subjects are necessary to understand why the preceding vowel tends to be longer before CC than C. Additionally, the tongue movement during the vowel preceding the consonants, as well as its relation to the vowel duration, should be investigated.

Acknowledgment

This study is supported by a Grant-in-Aid for Scientific Research (No.26370470, 24520434) from the Japan Society for the Promotion of Science.

6. REFERENCES

[1] Han, M. S. 1962. The feature of duration in Japanese. *Study of Sounds* 10. Phonetic Society of Japan. 65-80.

[2] Homma, Y. 1981. Durational Relationship between Japanese Stops and Vowels, *J. of Phonetics* 9. 273-281.

[3] Beckman M. 1982. Segment Duration and the ‘Mora’ in Japanese, *Phonetica 39*. 113–135.

[4] Han M. S. 1992. The Timing Control of geminate and Single Stop Consonants in Japanese: A Challenge for Non-native Speakers, *Phonetica 49*. 102-127.

[5] Campbell, N. 1999. A study of Japanese speech timing from the syllable perspective. *J. Acoust. Soc. Japan* 3, 29‐39.

[6] Hirata Y. 2007. Durational variability and invariance in Japanese stop quantity distinction: Roles of adjacent vowels. *J. Acoust. Soc. Japan* 11, 9‐22.

[7] Idemaru, K., Guion, S. 2008. Acoustic covariants of length contrast in Japanese stops. *J. Int. Phon. Assoc.* 38, 167–186.

[8] Fujimoto, M., Maekawa K. 2014. Effects of sokuon on adjacent vowel duration: An analysis of The Corpus of Spontaneous Japanese. *J. Acoust. Soc. Japan* 18(2). 10-22.

[9] Maddieson, I. 1985. Phonetic cues to syllabification. V.A Fromkin (ed.). *Phonetic Linguistics*. Academy Press. 203-221.

[10] Takada M. 1985. Sokuon no chouon jyo-no tokuchou nit suite [Articulatory characteristics of sokuon]. National Institute for Japanese Language and Linguistics. Kenkyu Hokokusyo 06, 17-40.

[11] Löfqvist, A. 2007. Tongue movement kinematics in long and short Japanese consonants. *J. Acoust. Soc. Am.* 122-1, 512-518.

[12] Kochetov A., Kang Y. 2013. When long is tense and tense is long: An EPG study of Japanese and Korean stops. Paper presented at International Conference on Phonetics and Phonology 2013. Tachikawa, Japan.

[13] Ishii, T. 1999. A Study of the Movement of the Articulatory Organs in Japanese Geminate Production: An X-Ray Microbeam Analysis. *J. Oto-Rhino-Laryngol. Soc. Japan* 102, 622-634.

[14] Fujimoto, M. 2013. Timing differences in articulation between single and geminate voiceless stop consonants: An analysis of cine-MRI data. Paper presented at 3rd International Conference on Phonetics and Phonology. Tachikawa, Japan.

[15] Hoole P., Zierdt, A. 2010. Five-dimensional articulography. In: *Speech Motor Control: New developments in basic and applied research*, Ben Maassen, Pascal van Lieshout (eds.). Oxford University Press, 331-349.

[16] Fujimoto M., Kitamura T., Hatano H, Fujimoto I., 2013. Timing differences in articulation between voiced and voiceless stop consonants: An analysis of cine-MRI data. Proc. Interspeech 2013, Lyon, France. 26-30.