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Content

1	Introduction -----	P.3
2	Purpose of study -----	P.3
3	Methodology -----	P.4
	3.1 Subjects -----	P.4
	3.2 Test materials -----	P.4
	3.3 Recording -----	P.5
	3.4 Data analysis -----	P.5
4	Results -----	P.5
	4.1 Stop consonants [tt, t, kk, k] -----	P.6
	4.1.1 Voice onset time -----	P.6
	4.1.2 Durations of the closure and the preceding vowel -----	P.6
	4.1.3 Devoicing of the preceding vowel -----	P.7
	4.2 Affricates [čč] and [č] -----	P.10
	4.3 Fricatives [ss] and [s] -----	P.11
5	Conclusion -----	P.12
6	References -----	P.13
	Appendix 1 -----	P.14
	Appendix 2 -----	P.15
	Appendix 3 -----	P.17
	Appendix 4 -----	P.18

1 Introduction

Japanese is a mora-timed language, with respect to the prosody of the language. Mora is a timing unit in rhyme. In Japanese, a rhyme may contain one or two moraic units. According to Tamaoko, et al (2009), Japanese speakers use moraic units, rather than syllables, for auditory perception of speech segments. Kubozono (1989) also reported that the speech errors made by Japanese speakers can be analyzed in terms of mora, but they are very hard to be explained in terms of syllable. Due to the importance of mora in Japanese phonology, Japanese orthographic script *kana* represents one mora with one *kana* word. For instance, the English loan word *simple* is pronounced as /si.n.pu.ru/ in Japanese, taking up 4 moras and represented with 4 *kana* words.

The mora-timed prosodic characteristic leads to the occurrence of two sets of consonants, geminate consonants (or double consonants) and singleton consonants, in Japanese. There are two types of geminates in Japanese, stop and fricative. According to Vance (1987) and Esadakata, et al. (2014), the stop geminates, including plosives and affricates, are produced with an abrupt suspension of articulator movement or by sustaining an oral closure or constriction for a longer period than the singleton counterparts, and then represented with an additional stop symbol in the transcription such as /tt/ and /kk/. As for the fricative geminates, they are produced with sustained and longer frication than the singleton counterparts, and then represented with /ss/.

2 Purpose of study

The present study aims to investigate the temporal patterns of the geminate consonants in Japanese, through performing acoustic analysis of the speech samples from native Japanese speakers. The findings of the study are the useful information for teaching Japanese as a foreign language, especially when it comes across the timing patterns or the mora units and the pronunciation of geminates of Japanese.

In many Chinese written Japanese learning materials, geminates are often defined as a ‘pause’. This definition is not only too simple, but also not exactly the case, as Japanese geminates have different pronunciation rules in connection with the manner property of the geminates. These rules are not easily to be figured out without explicit education about the changes in the pronunciation of geminates when they appear in various positions. This study intends to find out the temporal patterns of geminates in Japanese, and thus to enhance the current pedagogy of teaching Japanese sounds to L2 learners.

3 Methodology

3.1 Subjects

Four exchange students from Japan studying at the City University of Hong Kong, aged between 19-22, were invited to provide speech samples for the study. All the four subjects are native speakers of Japanese, who were born and grew up in Japan and have no studying abroad experience before coming to Hong Kong. Two of the subjects are male Japanese from Tokyo, speaking the standard dialect, and the other two subjects are female from Osaka and Kyoto, speaking the western dialect, i.e., Kansai dialect. To my knowledge, no significant difference in the pronunciation of geminate consonants between the two dialects of Japanese has been reported in the literature.

3.2 Test materials

The test materials used for the investigation are presented in Table 1. As can be seen, two sets of polysyllabic words are selected. The test words in one set contain a medial geminate consonant and those in the other set contain a singleton consonant counterpart, making up of ten minimal pairs. All the test words are meaningful in Japanese and commonly used by Japanese speakers in daily communication.

Table 1. List of the test words used for the investigation.

Test words with a medial geminate consonant			Test words with a medial singleton consonant		
IPA	Hiragana	Kanji / Katakana	IPA	Hiragana	Kanji / Katakana
[šokku]	しょつく	ショック	[šoku]	しょく	食
[kikku]	きつく	キック	[kiku]	きく	聞く
[rokkku]	ろつく	ロック	[roku]	ろく	六
[akka]	あつか	悪化	[aka]	あか	赤
[sakka]	さつか	作家	[saka]	さか	坂
[kitte]	きつて	切手	[kite]	きて	来て
[otto]	おつと	夫	[oto]	おと	音
[šuččo:]	しゅつちよう	出張	[šučo:]	しゅちよう	主張
[mačči]	まつち	マッチ	[mači]	まち	町
[assari]	あつさり	(N/A)	[asari]	あさり	浅瀬

In the table, the IPA transcriptions of the test words are adopted from Tsujimura (2013), where [č] is a postalveolar affricate allophone of /t/ and [š] a postalveolar fricative allophone of

/s/ when they are followed by the high front vowel /i/.

In the test words, the durations of the geminates and the singleton counterparts of the stops [t, k], affricate [č], and fricative [s] in the word-medial position were measured and compared.

3.3 Recording

The speakers took part in an individual recording of the test words in the sound-proof booth in the Phonetics Lab at the City University of Hong Kong. Before the recording, the speakers were told about the procedure of the audio recording. They were asked to read the word list and get familiar with the test words which were randomized on the list for the recording. They were instructed to utter the test words at normal speed and in the natural way that they are comfortable with. It should be noted that the speakers were not informed of the design of the experiment and the nature of the test words until the end of the recording, as the speakers might consciously lengthen the geminate consonants during recording.

Each speaker was asked to repeat the word list three times. The best two trials without hesitation and pause were selected for subsequent acoustic analysis.

3.4 Data analysis

The recorded speech samples from the speakers were analyzed and measured for the durations of the geminate and singleton consonants in the medial position of the test words, using the speech analysis software ‘Praat’. For the plosive consonants [tt, t, kk, k] and the affricates [čč, č], both their closure duration and voice onset time (VOT) were measured. For the fricatives [ss, s], the duration of frication noise was measured. According to Hardison, et al. (2009), the duration of the preceding vowel, in addition to the stop closure, has been reported to have an effect on the perception of the geminates in a number of studies. In this study, the length of the preceding vowel before the test word-medial geminate and singleton consonants were also examined.

4 Results

In this section, the results of the VOT, the closure duration, and the duration of preceding vowel of the test geminates [tt, kk, čč, ss] and singleton consonants [t, k, č, s] in the word-medial position are presented. The duration values are averaged across all the test tokens that contain the same geminate or singleton consonant for each of the four speakers and also averaged across all the four speakers. The raw data of the duration measurements for

the consonants in each individual token of the test words for the four speakers are presented in the appendixes. Appendix 1 presents the VOT durations of the stop consonants [tt, t, kk, k] and affricates [čč, č]. Appendixes 2, 3 and 4 present the closure duration and the duration of preceding vowel for the stops [tt, t, kk, k], affricates [čč, č], and fricatives [ss, s], respectively.

4.1 Stop consonants [tt, t, kk, k]

4.1.1 Voice onset time

Table 2 presents the VOT durations of the geminate and singleton stop consonants [tt, t, kk, k] in the word-medial position of all the test words for the four Japanese speakers. As shown in the table, there is no large difference in VOT between the geminate and singleton stop consonants in any place category, while the VOT tends to slightly longer for the velar [kk] (15-46 ms) and [k] (20-26 ms) than the alveolar [tt] (10-16 ms) and [t] (9-17 ms). Averaging across all the four speakers, the VOT is 12.5 ms for [tt], 13 ms for [t], 27 ms for [kk] and 22 ms for [k], showing a minimal difference in VOT between the geminate and singleton stops in each place category. Within speaker, the duration difference in VOT between the geminate and singleton of each type of stops is also small, not more than 5 ms. The data may suggest that VOT is not a distinctive acoustic feature for differentiation between the geminate and singleton stop consonants in Japanese.

Table 2. VOT durations (in ms) of the geminate [tt, kk] and singleton [t, k] stop consonants in Japanese for four speakers.

	VOT of [tt]	VOT of [t]	VOT of [kk]	VOT of [k]
Male 1	11	13	24	21
Male 2	13	9	15	19
Female 1	16	17	46	26
Female 2	10	13	23	20
All speakers	12.5	13	27	22

4.1.2 Durations of the closure and the preceding vowel

Table 3 and Table 4 present the data on the averaged values of the closure durations of [tt, t] and [kk, k] and the duration of the preceding vowel before the word-medial stop in all the test words for each and all of the four Japanese speakers.

Table 3. Closure durations (in ms) of the geminate [tt, kk] and singleton [t, k] stop consonants in Japanese for four speakers.

	Closure of [tt]	Closure of [t]	Closure of [kk]	Closure of [k]
Male 1	362	96	350	111
Male 2	176	103	170	89
Female 1	219	105	162	111
Female 2	255	94	222	101
All speakers	253	100	226	103

As shown in Table 3, the closure time is noticeably longer for the geminates [tt, kk] than the singleton [t, k] for each of the four speakers. Averaging across the four speakers, the closure duration is 253 ms for [tt] and 226 ms for [kk] which is more than the doubling of the closure duration of their singleton counterparts, [t] (100 ms) and [k] (103 ms). The between-speaker variation in the stop closure duration is large, in particular for the geminates [tt, kk], due to the difference in speaking tempo among the speakers. For instance, the closure durations of [tt, kk] for Male 1 are about two times longer than those for Male 2. Within speaker, the variation in the closure duration of the geminate stops [tt, kk] is also large, in the range of 162 ms to 362 ms, while the variation is less for the singletons [t, k], in the range of 89 ms to 111 ms. On average, the difference in closure duration between the geminate and singleton stop consonants is 138 ms, which is supposed to be long enough for listeners to perceive the length contrast between the two types of stops.

Table 4. Duration (in ms) of the preceding vowel before the geminate [tt, kk] and singleton [t, k] stop consonants in Japanese for four speakers.

	Vowel before [tt]	Vowel before [t]	Vowel before [kk]	Vowel before [k]
Male 1	112	105	117	97
Male 2	67	67	73	65
Female 1	76	49	83	69
Female 2	74	76	86	77
All speakers	82	74	90	77

Aside from the closure time, the length of preceding vowel before the geminate and singleton stops is also different. As presented in Table 4, for each of the four speakers the preceding vowel is longer before the geminate [kk] than before the singleton [k]. The

preceding vowel is also longer before the geminate [tt] than before the singleton [t] for Male 1 and Female 1, while it is not true for Male 2 and Female 2. This is considered in relation to the fast speaking tempo of Male 2 and Female 2, which leads to not much lengthening of the preceding vowel before a geminate stop. According to Port, et al. (1987), fast tempo will shorten the time of moras in the words with long duration more than in the words with short duration. Across all the four speakers, the preceding vowel is about 10-30 ms lengthened before the geminate stop consonants.

Based on the duration data on the geminate and singleton stop consonants presented before, the duration of a geminate stop is more than the doubling of the duration of the singleton counterpart as described in the traditional studies of the mora timing units in Japanese.

For illustration purposes, the waveforms of two minimal pairs, the test words [kite] and [kitte] and the test words [saka] and [sakka], containing the medial singletons [t, k] and geminates [tt, kk] from Female 1 are shown in Figure 1 and Figure 2, respectively. The figures show the differences in the VOT (period c), the closure time (period b), and the length of the preceding vowel (period a) of the geminate and singleton stop consonants in Japanese.

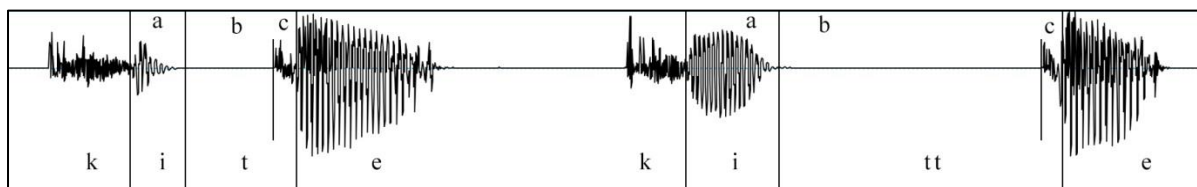


Figure 1. Waveforms of the test words [kite] and [kitte] from Female 1, denoting the length of the preceding vowel (period a), the closure duration (period b), and the VOT (period c) of the medial stops [t] and [tt].

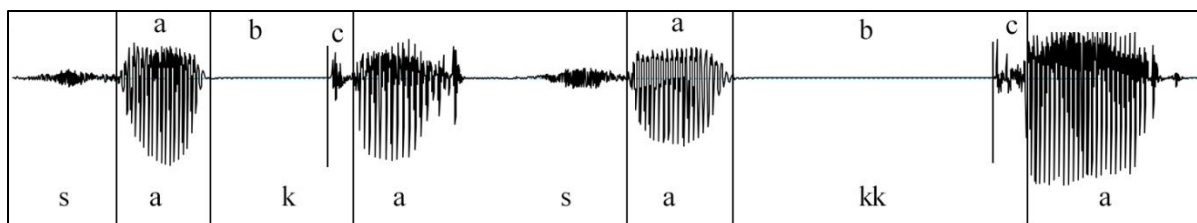


Figure 2. Waveforms of the test words [saka] and [sakka] from Female 1, denoting the length of the preceding vowel (period a), the closure duration (period b), and the VOT (period c) of the medial stops [k] and [kk].

4.1.3 Devoicing of the preceding vowel

Devoicing is a common phonetic phenomenon found in the Japanese standard dialect, where the high vowel /i/ or /u/ is devoiced between two voiceless consonants or at the end of a word following a voiceless consonant. For example, the word /hito/, which means ‘people’, is often pronounced as [hi̥to] in the standard dialect, and the word /gakusei/, which means ‘student’, is pronounced as [gakũsei].

In the present study, some of the test words are pronounced with a devoiced preceding vowel before a singleton stop consonant, such as the devoiced preceding [i̥] in [ki̥te] from Male 1 as shown in Figure 3, in comparison of the same word which is pronounced with a voiced [i] by the same speaker as shown in Figure 4.

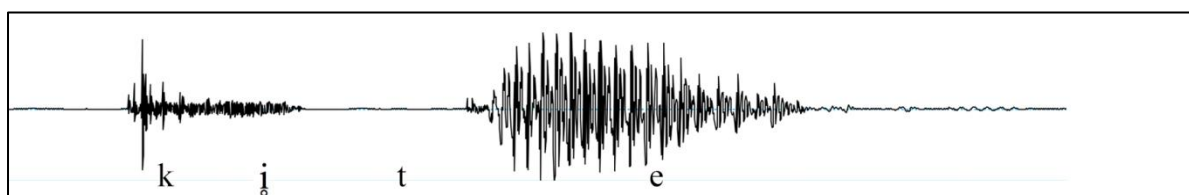


Figure 3. Waveform of the test word [ki̥te] pronounced with a devoiced preceding vowel [i̥] by Male 1.

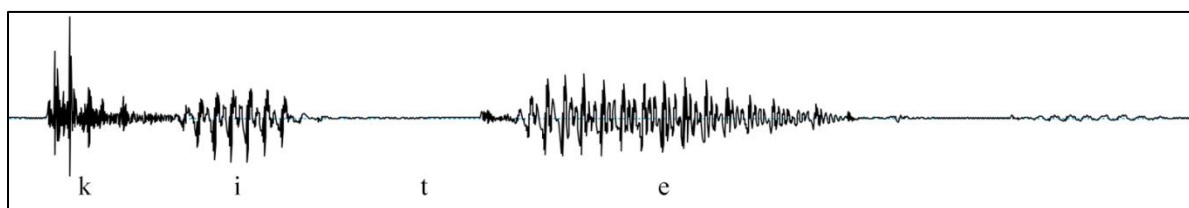


Figure 4. Waveform of the test word [kite] pronounced with a voiced preceding vowel [i] by Male 1.

It should be noted that vowel devoicing is not observed in the speech of all the four speakers in the present study. For instance, Male 2 did not devoice the vowel [i] in [kite], but Male 1 did, although both Male 1 and Male 2 are speakers of the standard Japanese dialect. It may be due to the fact that vowel devoicing is not lexically significant with respect to the meaning of the words and it is optionally made in the speech by the speakers. It should be also added that in this study devoicing was not observed for the preceding high vowel before a geminate stop consonant, such as in [kitte]. This may be related to the fact that without a contrast in the length of the preceding vowel, the distinction between the geminate and singleton stops will rely only on the closure time of the stops, reducing the distinctiveness between the geminate and singleton stops.

4.2 Affricates [čč] and [č]

The word-medial affricates [čč] and [č] in Japanese, similar to the stops, produced with a closure period followed by a VOT period. It is expected that the geminate [čč] and singleton [č] affricates may also have an effect on the duration of the preceding vowel. Table 5 presents the averaged durations of the VOT, the closure time, and the length of the preceding vowel for the medial [čč] and [č] across all the test words for each and all of the four speakers.

Table 5. Durations (in ms) of the VOT, closure, and preceding vowel for the geminate [čč] and singleton [č] affricates in Japanese for four speakers.

	VOT of [čč]	VOT of [č]	Closure of [čč]	Closure of [č]	Vowel before [čč]	Vowel before [č]
Male 1	65	55	304	76	117	123
Male 2	50	40	132	67	76	80
Female 1	47	46	206	94	99	83
Female 2	50	48	189	75	96	84
All speakers	53	47	207	78	97	93

As shown in Table 5, for each speaker the difference in VOT between the geminate [čč] (47-65 ms) and the singleton [č] (40-55 ms) is not pronounced, while the VOT of [čč] tends to be slightly longer. The VOT duration averaged across all the four speakers is 53 ms for the geminate [čč] and 47 ms for the singleton [č]. As for the closure time, it is much longer for [čč] (207 ms) than [č] (78 ms). For each speaker, the closure duration of the geminate [čč] is around or more than the doubling of the closure duration of the singleton [č]. This results in a large increase in the duration of the entire word that contains a medial geminate affricate.

The difference in the length of preceding vowel between the geminate [čč] and singleton [č] is not pronounced. Based on the average value across the four speakers, the duration of preceding vowel is 97 ms before [čč] and 93 ms before [č]. There are also between-speaker variation and variation between the different types of preceding vowel, in relation to the fact that the high vowel [u] is devoiced in [šučo:] for the two male speakers but not the two female speakers, and there is no devoicing of the low vowel [a] in [mači] for all the four speakers. Since there are only two pairs of test words containing the mediate affricates [čč] and [č] used for the investigation, more data are needed for reaching a conclusion of the difference in the preceding vowel length between the geminate [čč] and singleton [č] affricates in Japanese.

Figure 5 shows the waveforms of the test words [mači] and [mačči] containing the medial affricates [čč] and [č] from Female 1, illustrating the differences in the VOT (period c), the closure time (period b), and the length of the preceding vowel (period a) between the geminate and singleton affricates in Japanese.



Figure 5. Waveforms of the test words [mači] and [mačči] from Female 1, denoting the length of the preceding vowel (period a), the closure duration (period b), and the VOT (period c) of the medial affricates [č] and [čč].

4.3 Fricatives [ss] and [s]

Different from the stop and affricate consonants, the geminate fricative [ss] does not have a closure period, but a lengthened duration of frication noise as compared with the singleton [s]. Table 6 presents the averaged durations of the frication noise and the preceding vowel for the medial geminate [ss] and singleton [s] across the test words for each and all of the four Japanese speakers. The averaged data for all the four speakers show that the frication noise is much longer for [ss] (194 ms) than [s] (94 ms). For each individual speaker, excluding Male 2, the frication duration of the geminate [ss] (163-255 ms) is around or above the doubling of the frication duration of the singleton [s] (83-97). For Male 2, the frication of [ss] (155 ms) is about a half longer than that of [s] (100 ms).

Table 6. Durations (in ms) of the frication noise and preceding vowel for the geminate [ss] and singleton [s] fricatives in Japanese for four speakers.

	Frication noise of [ss]	Frication noise of [s]	Vowel before [ss]	Vowel before [s]
Male 1	255	96	123	104
Male 2	155	100	82	64
Female 1	202	97	83	76
Female 2	163	83	91	80
All speakers	194	94	95	81

As for the preceding vowel, the duration tends to be longer before the geminate [ss] than before the singleton [s], and this is true for each of the four speakers. Averaging across the four speakers, the difference in the duration of the preceding vowel before the geminate [ss] (95 ms) and the singleton [s] (81 ms) is 14 ms.

Figure 6 shows the waveforms of the test words [asari] and [assari] containing the medial fricatives [s] and [ss] from Female 1, illustrating the differences in the frication duration (period b) and the length of the preceding vowel (period a) between the geminate [ss] and singleton [s] in Japanese.

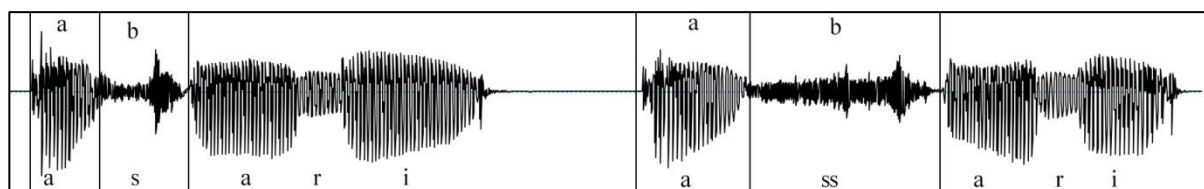


Figure 6. Waveforms of the test words [asari] and [assari] from Female 1, denoting the length of the preceding vowel (period a) and the duration of frication noise (period b) of the medial fricatives [s] and [ss].

5 Conclusion

To sum up, there are three types of geminate consonants in Japanese, including stops, fricatives, and affricates. Constriction time of the geminate consonants, i.e., the closure time of stops and affricates or the length of frication noise of fricatives, is the major acoustic feature for differentiation from the short counterparts. In this study, the lengthened constriction durations are 253 ms and 226 ms for the geminate stops [tt] and [kk], 207 ms for the geminate affricate [čč], and 194 ms for the geminate fricative [ss]. Comparing with the constriction durations of the singleton consonants [t] (100 ms), [k] (103 ms), [č] (78 ms), and [s] (94 ms), the geminate consonants are more than the doubling of their singleton counterparts.

The preceding vowel also tends to be slightly lengthened before a geminate consonant than its counterpart, which may be considered as a secondary acoustic feature for enhancing the distinction between the geminate and singleton consonants in Japanese. Furthermore, devoicing is observed for the preceding vowel before a singleton consonant, rather than a geminate one, which is also in connection with the duration difference between the geminate and singleton consonants in Japanese.

This study also reveals that the acoustic feature of the geminate fricative [ss] is the frication noise but not a long pause as in the production of the geminate plosives [tt, kk] and affricate [čč]. It follows that the geminate consonants in Japanese conventionally described to have a ‘long pause’ in the textbooks of Japanese language will give the learners a negative influence on acquisition of the correct pronunciation and their perception of the native speakers’ speech. It is hoped that the findings of the present study can serve as the information for L2 learners to have a correct understanding about the pronunciation of geminate consonants in Japanese.

6 References

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Appendix 1

The following tables present the data on the durations of voice onset time of the medial stop and affricate consonants, singleton [t, k, č] and geminate [tt, kk, čč], in each individual token of the test words produced by four Japanese speakers.

VOT durations (in ms) of [t] and [tt]

	[kite]	[kitte]	[oto]	[otto]
Male 1	17	11	12	8
	14	12	11	16
Male 2	11	15	10	13
	10	15	8	10
Female 1	19	20	16	16
	19	13	13	16
Female 2	12	13	14	12
	11	10	16	8

VOT durations (in ms) of [k] and [kk]

	[aka]	[akka]	[šoku]	[šokku]	[saka]	[sakka]	[roku]	[rokku]	[kiku]	[kikku]
Male 1	21	26	16	21	11	18	16	17	21	21
	20	27	21	20	19	25	22	30	39	33
Male 2	17	12	16	17	20	22	15	10	20	12
	19	18	22	13	20	18	17	15	19	15
Fem 1	18	21	28	29	25	19	32	42	32	34
	20	18	14	25	20	26	38	27	33	22
Fem 2	13	17	21	32	17	15	25	29	18	25
	16	19	22	28	16	15	32	20	23	26

VOT durations (in ms) of [č] and [čč]

	[šučo:]	[šuččo:]	[mači]	[mačči]
Male 1	41	50	57	71
	43	62	78	79
Male 2	32	40	40	50
	41	40	48	68
Female 1	46	34	49	54
	43	39	48	60
Female 2	44	33	65	65
	34	44	50	61

Appendix 2

The following tables present the data on the durations of the closure and the preceding vowel for the singleton [t, k] and geminate [tt, kk] stop consonants in each individual token of the test words produced by four Japanese speakers.

Closure durations (in ms) of [t] and [tt]

	[oto]	[otto]	[kite]	[kitte]
Male 1	103	399	68	380
	134	338	80	332
Male 2	100	168	96	178
	120	194	98	164
Female 1	125	238	72	220
	140	206	86	215
Female 2	100	265	76	247
	105	241	95	265

Duration (in ms) of preceding vowel before [t] and [tt]

	[oto]	[otto]	[kite]	[kitte]
Male 1	102	145	devoiced	102
	108	121	devoiced	83
Male 2	76	73	40	57
	85	81	68	59
Female 1	70	89	30	61
	75	84	19	68
Female 2	100	82	56	51
	80	98	67	63

Closure durations (in ms) of [k] and [kk]

	[aka]	[akka]	[kiku]	[kikku]	[roku]	[rokku]	[šoku]	[šokku]	[saka]	[sakka]
Male 1	99	313	100	307	96	426	132	301	96	321
	75	493	189	321	105	387	120	331	105	304
Male 2	83	180	90	144	77	151	84	181	72	135
	105	216	86	179	107	171	96	164	89	179
Fem 1	107	267	123	190	108	196	112	220	100	244
	122	259	106	237	98	266	122	233	112	230
Fem 2	93	281	96	200	84	182	110	202	99	225
	107	283	105	202	106	187	116	225	95	240

Duration (in ms) of preceding vowel before [k] and [kk]

	[aka]	[akka]	[kiku]	[kikku]	[roku]	[rokku]	[šoku]	[šokku]	[saka]	[sakka]
Male 1	112	137	devoiced	94	78	108	101	132	108	118
	112	132	devoiced	100	68	106	106	113	88	129
Male 2	71	57	60	67	87	71	58	76	60	62
	67	68	73	75	60	98	70	88	62	66
Fem 1	75	99	42	68	61	64	81	82	76	98
	73	98	74	82	58	59	71	85	79	101
Fem 2	84	102	66	72	69	81	77	95	72	81
	79	106	74	66	88	85	82	86	87	82

Appendix 3

The following tables present the data on the durations of the closure and the preceding vowel for the singleton [č] and geminate [čč] affricates in each individual token of the test words produced by four Japanese speakers.

Closure durations (in ms) of [č] and [čč]

	[mači]	[mačči]	[šučo:]	[šuččo:]
Male 1	83	290	88	340
	67	244	66	343
Male 2	63	138	68	141
	55	182	82	65
Female 1	90	190	91	228
	117	185	79	221
Female 2	63	160	70	201
	95	201	73	194

Duration (in ms) of preceding vowel before [č] and [čč]

	[mači]	[mačči]	[šučo:]	[šuččo:]
Male 1	111	102	devoiced	112
	134	140	devoiced	113
Male 2	78	62	devoiced	67
	96	99	66	62
Female 1	96	109	73	78
	98	127	67	83
Female 2	114	102	62	90
	95	92	67	100

Appendix 4

The following tables present the data on the durations (in ms) of the frication noise and the preceding vowel for the singleton [s] and geminate [ss] fricatives in each individual token the test words produced by four Japanese speakers.

Closure durations of [s] and [ss]

	[asari]	[assari]
Male 1	100	250
	92	260
Male 2	95	150
	104	160
Female 1	101	195
	92	208
Female 2	80	162
	86	164

Duration (in ms) of preceding vowel before [s] and [ss]

	[asari]	[assari]
Male 1	113	145
	102	126
Male 2	55	66
	98	79
Female 1	75	115
	70	112
Female 2	66	111
	69	112