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VOWEL DURATION IN JAPANESE /tsu⌐ku/ AND /tsuku⌐/

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1. Introduction

In our previous studies[1,2] a minimal pair of Japanese words, /hu⌐ku/ and /huku⌐/, was examined in terms of both the occurrence of devoicing and the duration of vowels. The present study is an extension of those previous studies. A minimal pair of Japanese words, /tsu⌐ku/ and /tsuku⌐/, was examined in terms of both the occurrence of devoicing and the duration of vowels. The test words were placed in six different types of sentences.

2. Procedures and Method

The six pairs of sentences designed for comparison were as follows.

test words: /tsu⌐ku/ (arrive), /tsuku⌐/ (get at)

sentence 1: /tsu⌐ku/ "(He) arrives."
/tsuku⌐/ "(He) gets at..."

sentence 2: /tsu⌐kuka/ "(He) arrives or..."
/tsuku⌐ka/ "(He) gets at...or..."

sentence 3: /tsu⌐kuga/ "(He) arrives but..."
/tsuku⌐ga/ "(He) gets at... but...."

sentence 4: /Kyo:tsu⌐ku/ "(He) arrives today."

/kyowotsuku⌐/ "(He) catches (a person) off (his) guard."

sentence 5: /kyo:tsu⌐kuka#keʃʃingatsuka⌐naika/
"Whether (he) arrives today or can not decide."

/kyowotsuku⌐ka#kakushinwotsukanai⌐ka/
"Whether he catches (a person) off (his) guard or does not get at the kernel."

sentence 6: /kyo:tsu⌐kuga#keʃʃingatsuka⌐nai/
"(He) arrives today but can not decide."

/kyowotsuku⌐ga#kakushinwotsukanai⌐/
"(He) catches (a person) off (his) guard but does not get at the kernel."

Sentence 1 was a kind of one-word sentence and served as a reference for the other five test sentences. Sentences 2 and 3 were made by adding different words to the end of sentence 1. Sentence 4 was made by adding different word groups to the head of sentence 1. Sentences 5 and 6 were made by adding different word groups to both the head and the end of sentence 1.

Two subjects of Tokyo dialect, one male and the other female, read these sentences at their normal tempo more than ten times each.

The recording was performed in a anechoic recording studio, and the speech sounds were analyzed by means of an LPC analysis program [3]. The results were then calculated and examined with the SPSS program on the VAX-11/780 system.

In the present study, the duration of a vowel was defined as the time period when a periodic (or quasi-periodic) vibration for the vowel was observable on the speech wave. The measurement unit for duration was 0.1 msec. The relative duration of each segment in the test words was calculated in each case.

3. Results and Comments

3.1. Devoicing of vowels

The wave forms of 328 sentences for subject MS and 415 sentences for subject FK were examined for the minimal pair /tsuku/ in six types of sentences. The number of samples treated here is given in Table 1.

Table 2 shows the incidences of voiced or devoiced vowels for the two words produced by MS and FK. As for the results for subject MS, the vowel of the first mora, u1, was devoiced, and the vowel of the second mora, u2, was voiced in every case despite the difference in accent between the two words. Concerning /tsu$\urcorner$ku/ produced by subject FK, the vowel u1 was pronounced voiced in 80.0% (180 cases) of the total (225 cases). As for vowel u2 in these 180 cases, 127 cases (56.4% of 225 cases) were devoiced, but 53 cases (23.6% of 225 cases) were voiced. In relation to the rest of the cases which contained a devoiced u1 (45 cases, 20.0% of 225 cases) in /tsu$\bar{\urcorner}$ku/, 44 cases (19.6% of 225 cases) were voiced in the final vowel u2; only in one case (0.4% of 225 cases) u2 was devoiced. On the whole, the final vowel u2 was devoiced in 128 cases (56.8% of 225 cases) for /tsu$\bar{\urcorner}$ku/. As for /tsuku$\bar{\urcorner}$/ produced by subject FK, however, the vowel u1 was devoiced and the vowel u2 was voiced in every case, as in subject MS. Concerning /tsu$\bar{\urcorner}$ku/ by subject FK, the rate of voicing or devoicing of the first vowel (u1) and the second vowel (u2) was also examined for all the utterances of cases of each sentence (Table 2).

3.2. Duration

3.2.1 Duration of the second vowel (u2)

Table 3 gives the mean values of the duration of vowel u2 in subject MS. These data are also displayed in Fig. 1.1. In order to calculate the ratio of the duration of the vowels to the duration of the word, the residual duration which excluded the duration of closure for /t/ from that of /t͡suku/ in each sentence was measured because it was difficult to find the onset of the consonant /t/ in the speech wave forms for sentences 1, 2 and 3. However, the total duration of /t͡suku/ was measured for sentences 4, 5 and 6 because it was easy to find the the starting point of the consonant /t/ in the speech wave forms. Concerning /t͡su˩ku/ by subject FK, it was necessary to separate the voiced u2 group from the devoiced u2 group. The data were thus classified into two groups as follows for subject FK.

(1) The duration of the voiced u2 in the two words in all cases for comparison between /t͡su˩ku/ and /t͡suku˩/.
(2) Comparison of the duration of the voiced u2 plus the release of the consonant /k/ and that of the devoiced u2 plus the release of the consonant /k/ for /t͡su˩ku/.

Table 3 gives the mean values of the duration of the voiced u2 for subject FK. These data are also displayed in Fig. 1.2. Table 4 gives the mean values of the duration of the voiced u2 plus the release of consonant /k/ and the duration of the devoiced u2 plus the release of the consonant /k/. These data are displayed in Fig. 2.

3.2.2 Duration of the first vowel (u1)

Table 5 gives the mean values of the duration of the devoiced u1 plus the frication of the consonant /ts/ in /t͡su˩ku/ and /t͡suku˩/ by subject MS. The data are also displayed in Fig. 3.1.

Concerning /t͡su˩ku/ by subject FK, it was necessary to separate the voiced u1 group from the devoiced u2 group. The data were classified into two groups as follows for subject FK.

(1) The duration of the devoiced u1 plus the frication of the consonant /t͡s/ when u2 was voiced for /t͡su˩ku/ and /t͡suku˩/.
(2) Comparison of the duration of the voiced u1 plus the frication of the consonant /t͡s/ and the devoiced u1 plus the frication of the consonant /t͡s/, regardless of voicing or devoicing of u2 for /t͡su˩ku/.

Table 5 also gives the mean values of the duration of the devoiced u1 plus the frication of the consonant /t͡s/ when u2 was voiced for subject FK. These data are also displayed in Fig. 3.2. Table 6 gives the mean values of the duration of the

voiced ul plus the frication of the consonant /t͡s/ and the duration of the devoiced ul plus the frication of the consonant /t͡s/ in the word /t͡sɯ̥ ku/ for subject FK. These data are displayed in Fig. 4.

3.2.3 Duration of the words /t͡sɯ̥ ku/ and /t͡sukɯ̥ /

The duration of the sentences were measured to compare /t͡sɯ̥ ku/ with /t͡sukɯ̥ /. Table 7 gives the mean values of the duration of /t͡suku/ without /t/ closure and the duration of /t͡suku/ in two words by both subjects MS and FK, and the data is also displayed in Figs. 5.1 and 5.2. In subject FK, the duration for the words containing a voiced u2 was measured.

3.3 Comments

3.3.1. Devoicing of vowels

In subject MS, the first vowel (ie, the /u/ following /t͡s/) was always devoiced.

In subject FK, the first vowel (ie, the /u/ following /t͡s/) was devoiced for the word /t͡sukɯ̥ / completely. As far as the above results are concerned, they appear to be in agreement with the assumptions by M. S. Han that

> In sequences in which the voiceless consonants are stops and non-stops (that is to say, fricatives and africates) the vowels preceded by non-stops are more readily devoiced, while the vowels preceded by stops tend to remain voiced [4,5].

But this does not apply to the result for FK, where the voicing occurred far more frequently for the first vowel, the /u/ following /t͡s/ (80% of 225 cases), than for the second /u/ following /k/ (43.2% of 225 cases) in /t͡sɯ̥ ku/.

In subject FK, the rate of the occurrence of devoicing for the first /u/ was 20.0% for /t͡sɯ̥ ku/, while it was 100% for /t͡suku /. Also, the rate of occurrence of devoicing for the second /u/ was 56.8% for /t͡sɯ̥ ku/, while it was 0% for /t͡sukɯ̥ /. This result is in agreement with the assumption by M. S. Han that

> When /i/ or /u/ occurs in a 'virtual' accented syllable, devoicing is not common, though otherwise they are in the environment typical of the devoicing phenomenon [6,7].

But this does not apply to the results for MS, where all of the first /u/s were devoiced and all of the second /u/s were voiced in both accent types. Concerning the u2 for /t͡sᵘ̥ku/ in subject FK, devoicing occurred in sentences 1,2,4 and 5, that is to say, in the cases where the vowel u2 was sentence final (sentence 1,4) or followed by the voiceless stop /k/ (sentences 2,5), but not in the cases where u2 was followed by the voiced stop /g/ (sentences 3,6).

3.3.2. Duration

3.3.2.1 Duration of u2

The duration of voiced u2 and its relative duration for /t͡sᵘ̥ku/ were constantly shorter than those for /t͡sukᵘ̥/ by both subject MS and subject FK (Table 3, Figs. 1.1 1.2), except for the case of sentences 2 by subject FK, where no voiced u2 was found for /t͡sᵘ̥ku/ (Table 3, Fig. 1.2). In /t͡sᵘ̥ku/ by subject FK, the duration of devoiced u2 plus the release of /k/ was shorter than the duration of voiced u2 plus the release of /k/, in the cases where the voiceless stop /k/ of /ka/ followed u2, but it was longer when it was sentence final (Table. 4, Fig. 2). The shorter duration of u2, for the sentences 2,3,5 and 6 compared with sentences 1 and 4 can be also explained by the difference in the context. It is clear that the duration of u2 in sentence final position was much longer, regardless of voicing or devoicing of u2, than in the other cases, where word groups followed u2.

3.3.2.2 Duration of u1

The duration of the devoiced u1 plus the frication of the consonant /t͡s/ was much longer for the ratio in sentences 1,4 in /t͡sᵘ̥ku/ than it was in /t͡sukᵘ̥/ by subject MS(Table 5, Fig. 3.1). On the other hand, the duration of the devoiced u1 plus the frication of the consonant /t͡s/ was longer in /t͡sᵘ̥ku/ than it was in /t͡sukᵘ̥/ except for the sentence 5 by subject FK (Table 5, Fig. 3.2).

The duration of the frication of the voiced u1 plus the consonant /t͡s/ was much longer than that of the devoiced u1 plus the frication of the consonant /t͡s/ in /t͡sᵘ̥ku/ by subject FK (Table 6 and Fig.4).

3.3.2.3 Duration of test words

The duration of the test words in the sentences was influenced by the difference in the context. It became much longer when the test words were sentence final, while it became shorter when both test words were followed by words or word groups.

As for the difference of duration between /t͡sᵘ̥ku/ and /t͡sukᵘ̥/, the duration of /t͡sukᵘ̥/ was longer in the sentences except for the sentence 2 by subject MS (Table. 7, Fig. 5.1). In

subject FK, it was longer in sentences 1 and 4 with the cases of voiced u2 (Table 7, Fig. 5.2).

4. Summary

Both the occurrence of devoicing and the duration of the vowels were examined for a pair of Japanese words consisting of the same sequence of phonemes, /t͡sū ku/ and /t͡sukū /.

1) The devoicing of vowels occurs in the case where the vowel follows a voiceless affricate.
2) The occurrence of devoicing is liable to be reduced in cases where the vowel which follows the voiceless affricate is accented.
3) The difference between the duration of the final vowel of /t͡sū ku/ and that of /t͡sukū / was significant, with the latter being longer.
4) The ratio of the duration of the devoiced ul plus the frication of the consonant /t͡s/ to the duration of /t͡sū ku/, except for /t/ closure, was greater than that in /t͡sukū /.
5) The duration of the voiced ul plus the frication of the consonant /t͡s/ was much longer than that of the devoiced ul plus the frication of the consonant /t͡s/, in /t͡sū ku/ by subject FK.
6) The duration of the word /t͡sū ku/ or /t͡sukū / is longer when the word is sentence final, while it becomes shorter when word groups follow.
7) It can be concluded that Japanese word accent is characterized not only by fundamental frequency, but also by the duration of vowels.

References

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Table 1. Number of samples for each subject.

Subject	Word	Sentence	N	Total
1) MS.	tsu̥ku	1	49	
		2	22	
		3	14	150
		4	23	
		5	20	
		6	22	
	tsuku̥	1	55	
		2	25	
		3	16	178
		4	32	
		5	26	
		6	24	
2) FK.	tsu̥ku	1	68	
		2	30	
		3	30	225
		4	30	
		5	32	
		6	35	
	tsuku̥	1	53	
		2	31	
		3	24	190
		4	29	
		5	24	
		6	29	

Table 2. The occurrence of devoicing or voicing in the first (u1) and the second vowel(u2).

1)Subject:MS.

	u1			u2		
Word	V/DV	N	%	V/DV	N	%
tsu̥ku	DV	150	100	V	145	96.7
					(including fricative /k/ as follows) 5	3.3
tsuku̥	DV	178	100	V	178	100

2)Subject:FK.

	u1			u2		
Word	V/DV	N	%	V/DV	N	%
tsu̥ku	V	180	80	V	53	23.6
				DV	127	56.4
	DV	45	20	V	44	19.6
				DV	1	0.4
tsuku̥	DV	190	100	V	190	100

		u1	u2		
Sentence	N	V/DV	V/DV	N	%
1	68	V	DV	58	85.3
		V	V	10	14.7
2	30	V	DV	30	100.0
3	30	V	V	17	56.7
		DV	V	13	43.3
4	30	V	DV	14	46.7
		DV	V	14	46.7
		V	V	2	6.6
5	32	V	DV	25	78.1
		DV	V	6	18.8
		DV	DV	1	3.1
6	35	V	V	24	68.6
		DV	V	11	31.4

Table 3. Comparison of the duration of u2 between /tsu̥ku/ and /tsuku̥/ for six pairs of sentences(the voiced u2 only).

1) Subject: MS.

Sentence	Word	N	Duration (msec)	S.D.	Ratio of duration to "suku"	S.D.(%)	Ratio of duration to /tsuku/	S.D.(%)
1	tsu̥ku	49	153.4*	33.7	44.8	5.6		
1	tsuku̥	55	173.6	21.7	45.2	2.7		
2	tsu̥ku	21	101.2	11.0	35.2*	2.4		
2	tsuku̥	25	101.3	3.8	37.1	2.1		
3	tsu̥ku	14	90.7*	14.6	32.1*	3.7		
3	tsuku̥	16	103.7	9.4	35.5	2.2		
4	tsu̥ku	23	138.9*	12.7	42.8*	2.1	39.4*	2.5
4	tsuku̥	32	176.8	17.8	46.4	3.2	42.2	3.0
5	tsu̥ku	20	84.4*	8.6	34.0	2.7	31.6	2.5
5	tsuku̥	26	95.4	12.7	35.1	2.5	32.5	2.0
6	tsu̥ku	22	67.9*	13.3	27.8*	4.5	25.8	4.2
6	tsuku̥	24	79.1	16.2	30.6	4.1	28.0	3.7

2)Subject: FK.

Sentence	Word	N	Duration (msec)	S.D.	Ratio of duration to "suku"	S.D.(%)	Ratio of duration to /tsuku/	S.D.(%)
1	tsu̥ku	10	105.1*	11.5	30.5*	2.4		
1	tsuku̥	53	133.1	14.9	38.1	3.2		
2	tsuku̥	31	84.8	6.2	36.1	2.2		
3	tsu̥ku	30	92.0	18.2	34.2*	6.5		
3	tsuku̥	24	99.5	12.2	40.3	3.2		
4	tsu̥ku	16	86.4*	18.4	28.3*	4.7	23.4*	4.1
4	tsuku̥	29	116.8	13.3	36.2	3.5	29.5	2.6
5	tsu̥ku	6?	73.5	12.6	31.7	6.5	24.9	4.8
5	tsuku̥	24	78.4	11.3	33.5	4.0	26.7	3.2
6	tsu̥ku	35	82.6*	11.0	29.3*	5.0	23.8*	3.9
6	tsuku̥	29	92.8	10.1	36.5	3.3	30.2	3.0

Table 4. The duration of the voiced u2 plus the release of /k/ and the duration of the devoiced u2 plus the release of /k/ in /tsu̥ku/ for six sentences. Subject: FK.

Sentence	Word	N	u2	Duration (msec)	S.D.	Ratio of duration to "suku"	S.D.(%)	Ratio of duration to /tsuku/	S.D.(%)
1	tsu̥ku	10	V	124.6*	10.5	36.2*	2.2		
1	tsu̥ku	58	DV	191.4	35.1	44.8	5.1		
2	tsu̥ku	30	DV	89.6	12.7	31.6	4.8		
3	tsu̥ku	30	V	117.3	20.9	43.4	6.0		
4	tsu̥ku	16	V	107.4*	15.0	35.4*	3.2	29.2*	2.9
4	tsu̥ku	14	DV	162.1	31.1	42.4	5.9	35.5	5.3
5	tsu̥ku	6?	V	95.8	11.2	41.2*	6.0	32.4*	4.3
5	tsu̥ku	26	DV	86.3	12.7	31.7	4.8	24.7	3.7
6	tsu ku	35	V	107.9	10.4	38.3	5.2	31.0	4.2

* Significance level was $p<0.05$. (?) Inadequate for test+

"suku" is used for convenience instead of the residual duration which excludes the duration of the closure of /t/ from the duration of both word /tsu̥ku/ and /tsuku̥/.

+ As the vowel u2 of /tsu̥ku/ was often devoiced in the case of sentences 1,2,4 and 5 by subject FK., the number of cases was not sufficient to compare the mean values of the duration in /tsu̥ku/ and /tsuku̥/.

Fig. 1.1

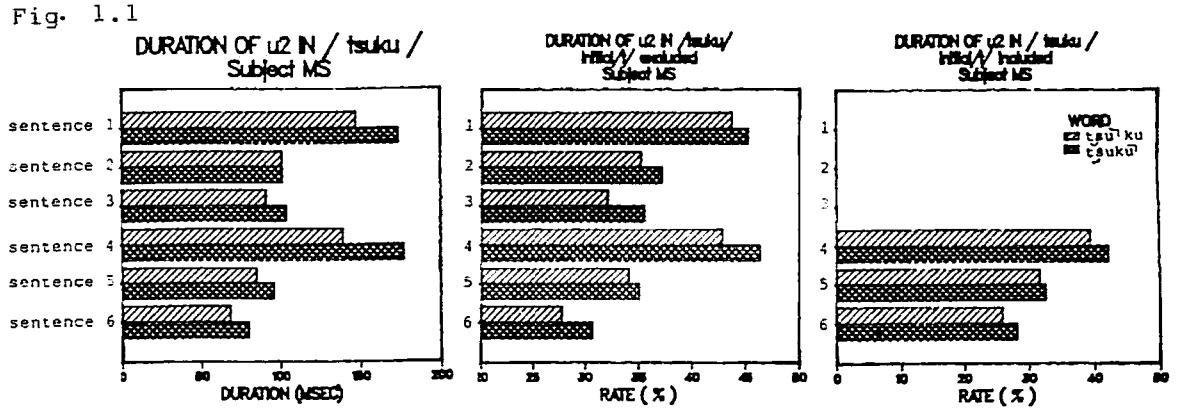

Fig. 1.2

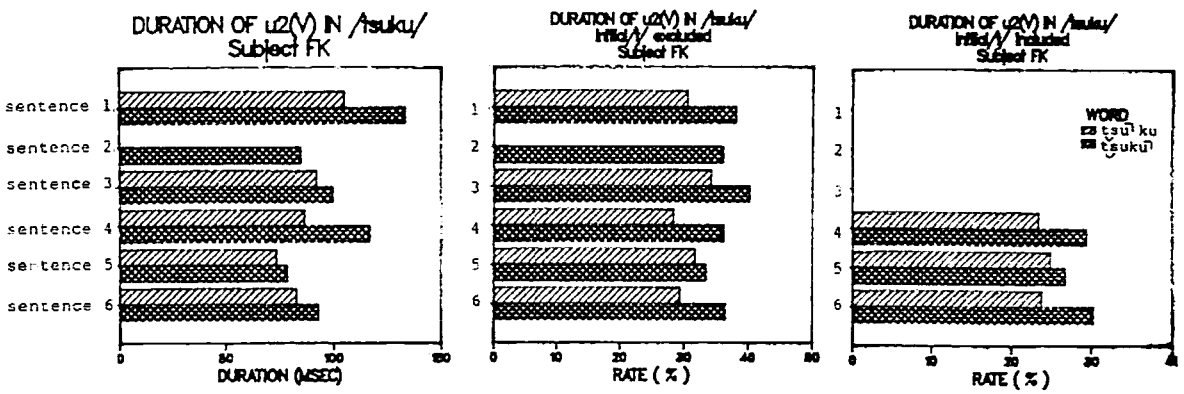

Fig. 2

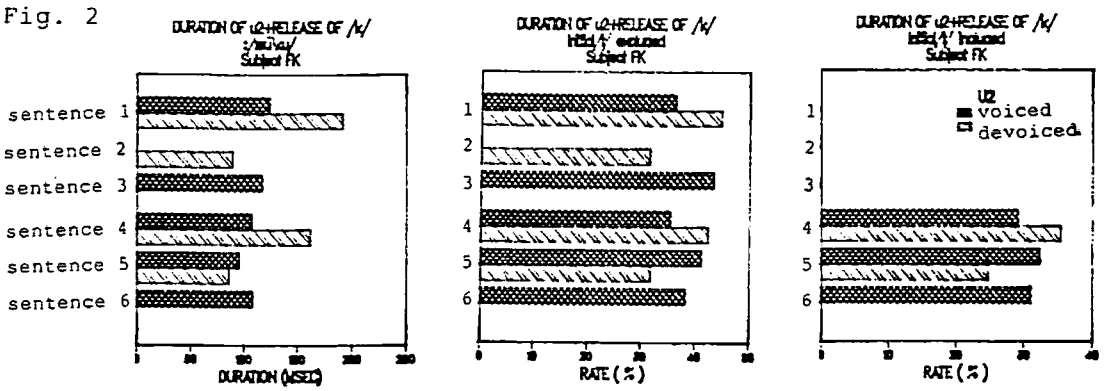

Table 5. Comparison of the duration of devoiced ul plus frication of /ʦ/ for /ʦ̯ū ku/ and /ʦ̯uku̥/ in six pairs of sentences (except for the devoiced u2).

1) Subject: MS.

Sentence	Word	N	Duration (msec)	S.D.	Relative duration to "suku"	S.D.(%)	to /ʦ̯uku/	S.D.(%)
1	ʦ̯ū ku	45	103.4	15.7	30.7*	4.5		
1	ʦ̯uku̥	55	108.1	15.0	28.2	2.6		
2	ʦ̯ū ku	21	105.2	16.9	36.6	4.5		
2	ʦ̯uku̥	25	100.9	9.5	36.9	2.8		
3	ʦ̯ū ku	14	101.6	12.6	36.1	4.4		
3	ʦ̯uku̥	16	105.5	7.3	36.1	1.7		
4	ʦ̯ū ku	23	101.5*	10.7	31.3*	2.9	28.9*	3.1
4	ʦ̯uku̥	32	107.6	8.3	28.3	1.9	25.7	1.9
5	ʦ̯ū ku	20	87.9	7.9	35.6	3.1	33.0	3.0
5	ʦ̯uku̥	26	102.2	14.7	37.6	4.1	34.9	3.9
6	ʦ̯ū ku	22	95.5*	9.9	39.2	3.6	36.5	3.5
6	ʦ̯uku̥	24	102.2	6.2	40.1	4.1	36.8	3.9

2) Subject: FK.

Sentence	Word	N	Duration (msec)	S.D.	Ratio of duration to "suku"	S.D.(%)	to /ʦ̯uku/	S.D.(%)
1	ʦ̯uku̥	53	93.7	17.6	26.7	4.2		
2	ʦ̯uku̥	31	65.9	8.9	28.0	2.9		
3	ʦ̯ū ku	13	70.3*	15.8	26.9*	4.3		
3	ʦ̯uku̥	24	58.3	10.9	23.5	3.6		
4	ʦ̯ū ku	14	76.0	9.5	25.5*	3.4	21.0*	2.9
4	ʦ̯uku̥	29	71.3	7.2	22.1	2.2	18.1	2.1
5	ʦ̯ū ku	6?	62.0	10.1	26.5	3.2	20.8	2.8
5	ʦ̯uku̥	24	67.3	10.0	28.7	3.1	23.0	3.0
6	ʦ̯ū ku	11	82.1*	20.2	30.7*	3.6	25.2*	3.3
6	ʦ̯uku̥	29	68.5	11.3	26.9	4.3	22.4	4.1

* Significance level was $p<0.05$.

Table 6. The duration of the voiced ul plus the frication of /ʦ/ and the duration of the devoiced ul plus the frication of /ʦ/ for /ʦ̯ū ku/ in six sentences. Subject: FK.

Sentence	Word	N	ul	Duration (msec)	S.D.	Ratio of duration to "suku"	S.D.(%)	to /ʦ̯uku/	S.D.(%)
1	ʦ̯ū ku	68	V	146.4	15.5	35.8	4.0		
2	ʦ̯ū ku	30	V	143.6	11.3	50.5	3.0		
3	ʦ̯ū ku	17	V	120.8*	14.3	43.1*	3.2		
3	ʦ̯ū ku	13	DV	70.3	15.8	26.9	4.3		
4	ʦ̯ū ku	16	V	131.0*	18.4	35.7*	8.8	29.8*	6.8
4	ʦ̯ū ku	14	DV	76.0	9.5	25.5	3.4	21.0	2.9
5	ʦ̯ū ku	25	V	137.4*	14.4	50.2*	4.9	39.2*	4.5
5	ʦ̯ū ku	7?	DV	61.6	9.3	26.1	3.1	20.5	2.7
6	ʦ̯ū ku	24	V	124.9*	22.7	42.0*	4.4	34.0*	4.1
6	ʦ̯ū ku	11	DV	82.1	20.2	30.7	3.6	25.2	3.3

V: voiced, DV: devoiced, N: number of cases

* Significance level was $p<0.05$.

Fig. 3.1

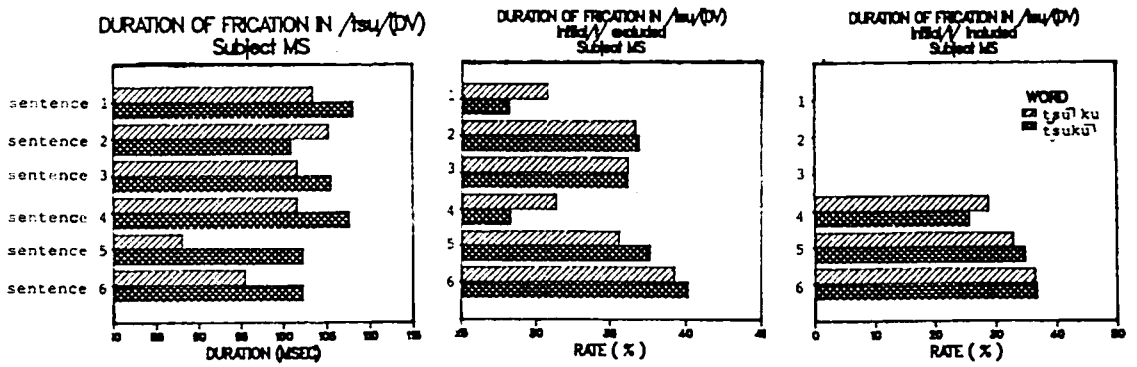

Fig. 3.2

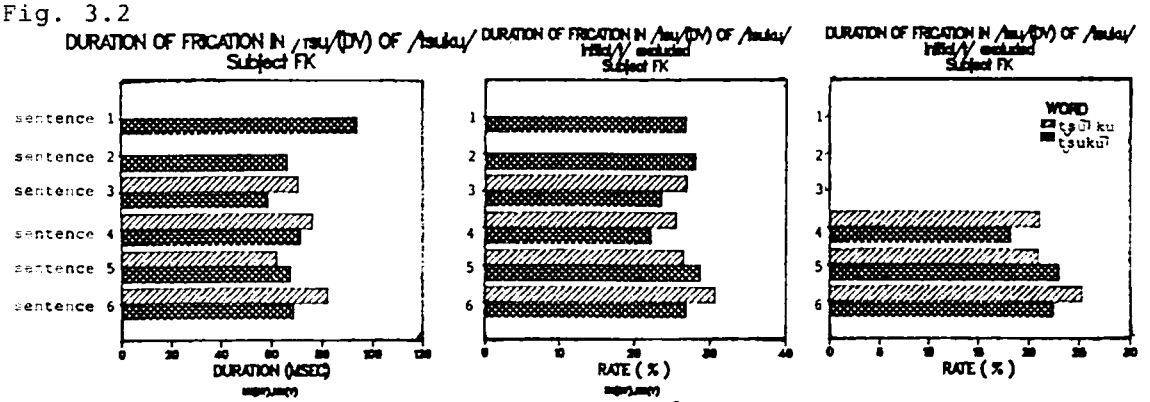

Fig. 4

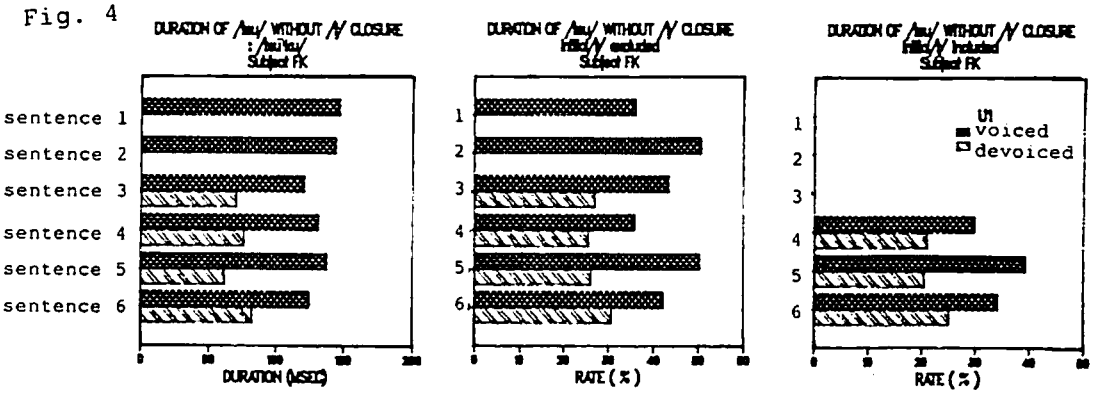

Table 7. Duration of sequence "suku" and /tsuku/ in /tsu˥ku/ and /tsuku˥/ for six pairs of sentences (voiced u2 only).

1) Subject: MS.

Sentence	Word	N	Duration S.D.(msec) for "suku"		for /tsuku/	
1	tsu˥ku	49	340.7*	38.8		
1	tsuku˥	55	384.0	39.9		
2	tsu˥ku	22	287.2*	19.6		
2	tsuku˥	25	292.1	13.5		
3	tsu˥ku	14	281.6	16.8		
3	tsuku˥	16	292.1	13.5		
4	tsu˥ku	23	323.9*	17.9	352.0*	15.9
4	tsuku˥	32	380.8	16.0	418.5	17.3
5	tsu˥ku	20	247.8*	15.7	266.9*	18.3
5	tsuku˥	26	271.4	23.3	293.1	25.9
6	tsu˥ku	22	243.4*	11.9	261.8*	10.4
6	tsuku˥	24	256.4	21.9	279.9	24.1

2) Subject: FK.

Sentence	Word	N	Duration S.D.(msec) for "suku"		for /tsuku/	
1	tsu˥ku	10	343.4	11.7		
1	tsuku˥	53	349.2	23.0		
2	tsuku˥	31	235.0	12.2		
3	tsu˥ku	30	270.8*	28.1		
3	tsuku˥	24	246.6	16.0		
4	tsu˥ku	16	302.8*	20.7	367.0*	18.6
4	tsuku˥	29	322.6	13.4	395.7	15.0
5	tsu˥ku	67	233.3	11.0	296.9	11.7
5	tsuku˥	24	224.9	33.3	292.6	18.7
6	tsu˥ku	35	286.3*	40.5	352.5*	47.6
6	tsuku˥	29	252.2	16.6	307.1	16.3

* Significance level was $p<0.05$.

Fig. 5.1

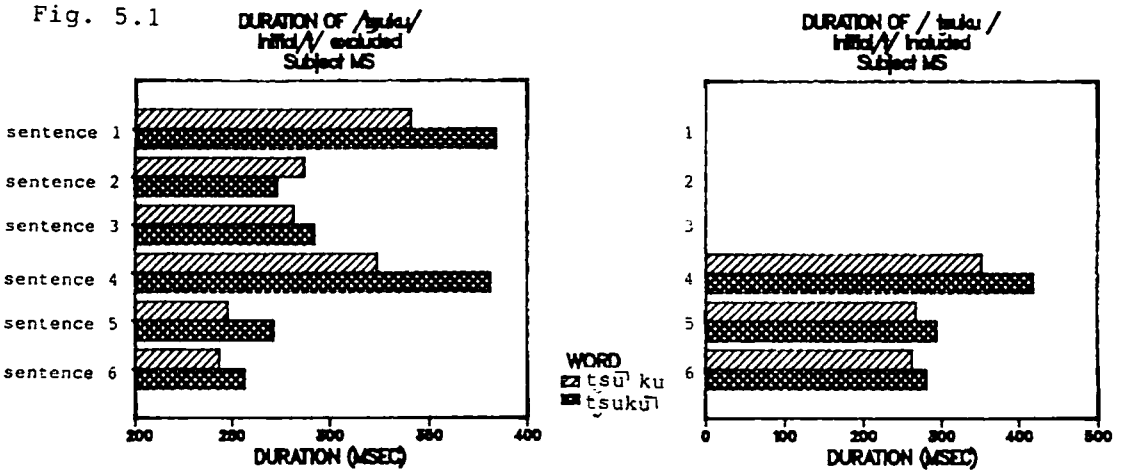

Fig. 5.2