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THE ARTICULATION OF JAPANESE INTERVOCALIC /d/ AND /r/: AN ELECTRO-PALATOGRAPHIC STUDY

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Introduction

Japanese /d/ is a stop consonant with the formation of closure at the back of the front teeth and/or the alveolar ridge, while it is generally said that Japanese /r/ in intervocalic position is realized as a tap or flap, with the tip of the tongue making one tap against the alveolar ridge. The stop-flap opposition implies that there is a difference in duration of palato-lingual contact between the two consonants. In addition to the durational difference, we are interested in whether some other characteristic differences can be observed during the articulation of /d/ and /r/. As to the articulation of /r/, the great influence of vowel environment has already been pointed out (Hattori, 1950; Fujimura, 1972). Further, Fujimura et al. (1973) touched upon the large inter-utterance variability for this flap. Thus, we decided to investigate the temporal patterns of the palato-lingual contact for /r/ and /d/ using electro-palatography, with special attention to the inter-utterance and contaxtual variability of these consonants.

Method

Three native Japanese speakers of the Tokyo dialect served as subjects. Subjects 1 and 2 were males (54 and 48 years of age, respectively); Subject 3 was a 26-year-old female. None of the subjects reported any speaking disabilities.

The linguistic materials used in this study consisted of intervocalic /d/ in all of the fifteen possible vowel environments in Japanese, and /r/ in the twenty-five possible environments of Japanese (d followed by /i/ and /u/ becomes an affricate). Meaningless sequences of the form /V_1 dV_2 V_1 dV_2/ (V_1 = i,e,a,o,u; V_2 = e,a,o) or /V_1 rV_2 V_1 rV_2/ (V_1, V_2 = i,e,a,o,u) were embedded in a carrier sentence of the form /Sorewa ____ desu/, or "It is ____ ."

The subjects were told to produce the sentences at a comfortable speaking rate, and the key words with a flat accent. They repeated the text of the word list ten times.

The data recording system was the same as in our previous study (Sudo et al., 1982). The artificial palates used in this study had sixty-three electrodes. The data was stored in a computer connected to a portable palatograph unit. The speech envelopes were sampled by the computer system at a rate of 64 frames/sec. In this study, only the results obtained in the utterances with symmetrical vowel environments, i.e., those where the preceding and following vowels were the same, will be reported.

Results

Fig. 1 shows the maximum contact patterns obtained during the articulation of /ada/, /ede/, /odo/, /ara/, /ere/ and /oro/ for three subjects, each being the superimposed pattern of twenty maximum patterns (the maximum contact pattern is defined as the pattern showing the largest number of on-electrodes during the articulation of /d/ or /r/). In these patterns, the blackened dots represent 100% on-contact electrodes, i.e., electrodes showing on-contact for all the twenty tokens. Circles with small dots or crosses show the frequency of the contact given by a subscribed number (the number 7, for example, represents a frequency of 70%). Each circle with a cross shows a more than 50% on-contact electrode, while each circle with a small dot represents a less than 50% on-contact electrode.

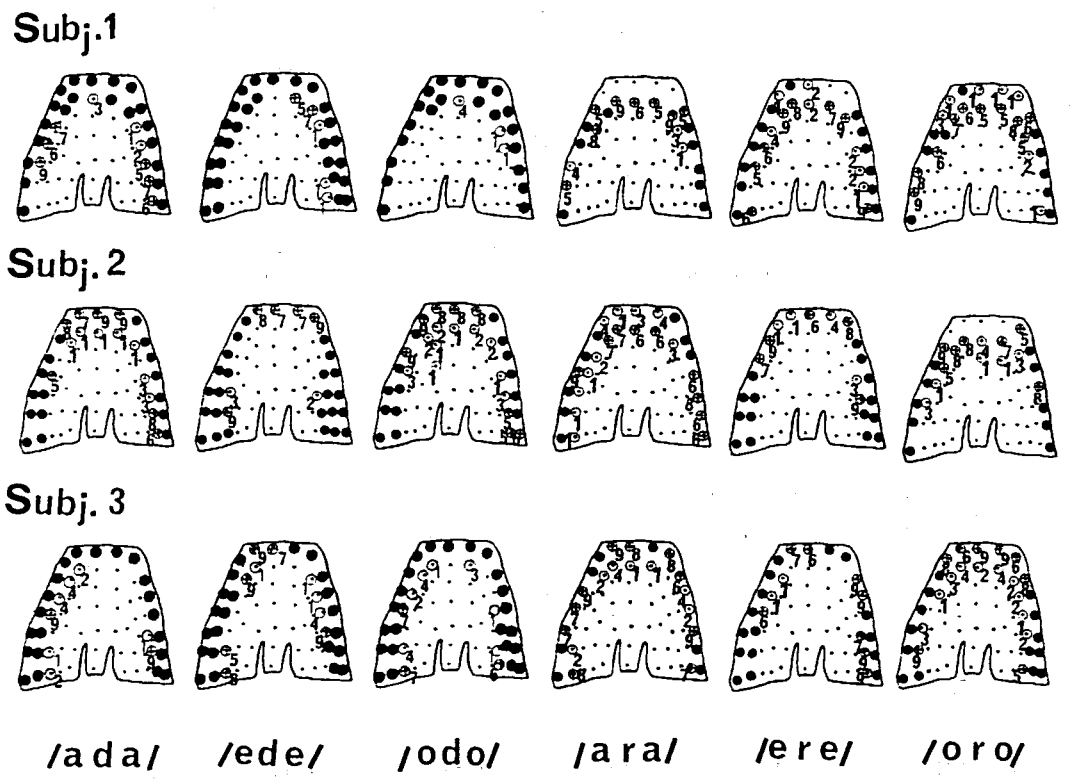

Fig. 1 *20 maximum patterns superimposed on each other*

The patterns for Subject 1 in Fig. 1 show that the palato-lingual contact was made in a more posterior place for /r/ than /d/. This difference in place of articulation can be clearly observed in the articulation of /ara/, whose place of articulation recedes most. Likewise, the contact for /ere/ and /oro/ withdraws to a posterior position. In addition to the place of articulation, there is a significant difference in contact area between the two consonants as shown by Table 1. In the utterances of Subject 1, the average number of on-electrodes for the maximum contact patterns of sixty /d/ and /r/ tokens was 25 and 18, respectively. Thus, /d/ takes a wider area than /r/.

Table 1 *The average number of on-electrodes in the maximum contact patterns of 20 tokens*

Subject \ Utterance	ada/ara	ede/ere	odo/oro	Average
Subj. 1	25	28	22	25
	16	20	17	18
Subj. 2	22	28	21	24
	17	20	16	18
Subj. 3	24	27	26	26
	17	22	22	20
Average	24	28	23	25
	17	21	18	19

The utterances of Subject 2 show similar characteristics regarding differences in the articulation of /d/ and /r/ to those observed in Subject 1. In the patterns of Fig. 1 for Subject 2, the lingual contact is made in a more posterior place in the case of /ara/ and /oro/ than /ada/ and /odo/, though the difference in the place of articulation is not clear in the /ede/-/ere/ pair. In addition, the contact area is wider in /d/ than in /r/, the average number of on-electrodes for /d/ and /r/ being 24 and 18, respectively.

We have observed for Subjects 1 and 2 the difference in the place of articulation between /d/ and /r/. In the utterances of Subject 3, however, /r/ is frequently articulated at the most anterior portion of the palate just like /d/. Therefore, the difference between the two consonants is not clear, as in the other subjects. Yet the contact area serves to distinguish between the two also in this subject. The average number of on-electrodes for /d/ is 26, for /r/ 20.

In addition to the place of articulation and the contact area, the frequency of the occurrence of complete closure in the pattern is significantly different between /d/ and /r/ as shown by Table 2. The presence of complete closure is defined as either when all the electrodes of any one line along the teeth ridge show contact or when the corresponding electrode of a neighboring line shows contact in spite of the presence of an off-contact electrode in a certain line. As shown in the table, for Subject 1, /d/ is always articulated with closure, while the average frequency of closure in /r/ is as low as 23%. It can also be observed that the duration of closure

Table 2 *The frequency of the occurrence of complete closure for 20 tokens*

Subject \ Utterance	ada/ara	ede/ere	odo/oro	Average
Subj. 1	20	20	20	20
	1	6	7	5
Subj. 2	13	13	13	13
	6	1	4	4
Subj. 3	19	14	20	18
	2	10	14	9
Average	17	16	18	17
	3	6	8	6

is much shorter in /r/ than the average duration for /d/, even when closure is attained. The frequency of the occurrence of closure for /d/ is lower in Subject 2, 65%, than in Subject 1, in whose utterances closure is always attained. Yet the average frequency for /r/ in Subject 2 is 18%, much lower than the frequency for /d/. Also, in the utterances of Subject 3, closure is attained 88% of the time in the case of /d/, while closure is observed 43% of the time in the articulation of /r/.

Turning to the degree of inter-utterance variation of the two consonants, we calculated the following index as a measure of variability. First, each palato-lingual contact pattern was represented by the 63-dimensional vector with binary values in each component representing the on or off contact at each electrode: next, the average vector of the maximum contact patterns of the twenty utterances was calculated: then the standard deviation of the distance between the vector for each utterance and the average vector was estimated. The values of this index are given in Table 3. The indices for Subject 1 show that there is a larger degree of variation in /r/ than /d/. Likewise, for Subject 2 a larger variability is observed in /r/ than /d/ on the average. Only the /odo/-/oro/ pair shows a larger variability for /d/ than /r/ which results from its unstable lingual contact in the posterior portion of the palate. Also in the case of Subject 3, /r/ exhibits a larger inter-utterance variability than /d/.

Table 3 *Indices of inter-utterance variability*

Subject \ Utterance	ada/ara	ede/ere	odo/oro	Average
Subj. 1	1.3	0.9	0.7	1.0
	1.5	1.6	1.7	1.6
Subj. 2	1.4	1.1	1.7	1.4
	1.8	1.2	1.5	1.5
Subj. 3	1.1	1.2	1.3	1.2
	1.7	1.2	1.7	1.5
Average	1.3	1.1	1.2	1.2
	1.7	1.3	1.6	1.5

Turning to the variation due to the vowel contexts, we also calculated the mean of the average vectors obtained for the three vowel contexts. Then the standard deviation of the distance between this mean vector and the three average vectors was estimated. Table 4 shows these indices for the anterior portion, posterior portion and the entire palate, respectively. (The palate was divided into two parts as illustrated in Fig. 2 for calculating these indices.) The indices for the entire palate do not exhibit a clear difference between the two consonants. Judging from the manner of articulation of the two consonants, it may be the case that the characteristics of their articulation are observed more clearly in the movement of the tip and/or blade of the tongue, i.e., the contact pattern in the anterior portion of the palate. However, the results in Table 4 for the anterior portion show a larger contextual variability for /r/ than /d/ only in one subject, Subject 2. In the other two subjects, it can not be said that /r/ is more variable in the anterior portion than /d/.

Table 4 *Indices of contextual variability*

Palate / Subject		Anterior Portion	Posterior Portion	Entire Palate
Subj. 1	/d/	0.5	1.1	1.2
	/r/	0.7	0.7	1.0
Subj. 2	/d/	0.2	1.1	1.1
	/r/	0.8	1.0	1.3
Subj. 3	/d/	0.4	0.6	0.8
	/r/	0.5	0.9	1.1

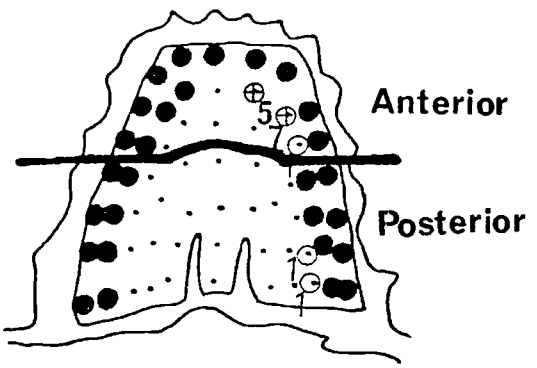

Fig. 2 *Portions of the palate discussed in the text*

Thus, the claim can not be supported that vowel environments exert a greater influence on the articulation of /r/ than /d/, at least as far as the environments tested in this study are concerned.

In the present study, the difference between /d/ and /r/ could be observed in terms of palato-lingual contact area and the frequency of the occurrence of closure. Also, for two of the subjects, the place of articulation also served to distinguish them. In addition, it was found that /r/ has a larger inter-utterance variability than /d/, though there is no clear difference in the contextual variability of the two consonants, at least for the contexts tested in this study. Further study is being conducted on other vowel contexts.

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