Abstract

Articulatory properties of the sibilants [s, θ] and non-sibilant [ç] were studied for VCV syllables in Japanese, using the technique of electropalatography. We examined the relation between constriction width and location, and the nature of coarticulatory variability and directionality, specific to the two fricative categories. The results allow us to discuss the phonetic basis of the ‘precision’ in fricative articulations.

1. Introduction

This paper explores articulatory properties of the sibilants [s, θ] and non-sibilant [ç] in Japanese. The relationship between constriction location (CL) and (groove) width (CW) and the relative salience of anticipatory and carryover effects are examined using electropalatography (EPG).

Previous studies have identified the way in which the CW and CL are systematically organized for sibilant production but few attempts have been made for non-sibilant production nor the relation between the two categories. One controversial hypothesis is that the CWs and CLs correlate linearly: the CW becomes wider as the CL moves back. This hypothesis is supported by the analysis of American English [1]: the CW for [s] (6-8mm) at the alveolar ridge and that for [θ] (10-12mm) at around the corner of the alveolar ridge. However, the variation of the CWs in Swedish was observed for [s] (6-12mm) at the alveolar ridge [2]. Similar results come from the analysis of the Pekingese [s, θ, ç] [3]: the CW and CL of [ç] fluctuate between those of [s] and [θ]. These conflicting results do not necessarily negate the hypothesis above. Rather, they suggest that speakers of a language selectively control the two parameters in order to produce natural sounding sibilants.

In the current study we extend the hypothesis to a non-sibilant and assume that the two parameters vary linearly: |s|<|ç|<|ç|.

The precise control of the CW and CL attains a higher steadiness of the tongue shape [4]. This characteristic involves two issues. First, the degree of coarticulatory resistance and the directionality of coarticulatory effects are characteristic to fricative articulations. The tip/blade position for [s], for instance, is relatively invariant, while the dorsum is relatively free to coarticulate with the adjacent vowels [5]. When compared to [s], V-to-C carryover effects upon [θ] are more extensive than anticipatory effects [6]. Second, the overall tongue shape itself constitutes an important parameter of lingual fricatives [4]. It is claimed that the tongue shape and the dorsum position, as opposed to the CW and CL, are distinguishing parameters of [θ] from [ç] in Polish [7].

The general aim of this study is to further investigate the differential roles of the articulatory parameters for [s, θ, ç] in Japanese, with a view towards explaining the different degrees of ‘precision’ requirements for each fricative articulation.

2. Data Collection and Analysis

The speech items consisted of V1CV2 disyllabic words in which the consonants [s, θ, ç] and the vowels /i, a, u/ were in all possible combinations. All the target words were embedded in a frame sentence (‘moo [word] hkok’). Two native speakers of standard Japanese, one male (MN) and one female (TM), repeated the sentence six times at normal speed, with the default accent pattern on the target word (i.e. a low-high pattern). Five repetitions were used for the analysis. The EPG and acoustic recordings were done in the phonetics laboratory of the School of Oriental and African Studies, University of London.

The Reading EPG artificial palate has 62 electrodes arranged in eight rows and eight columns. The palatal morphology was studied from the impression of the hard palate and electrode locations were tape-measured. Three major zones were identified sagittally: front, central and back.

![Figure 1: EPG Prototypical Palatogram and Three Regions](image)

This zoning was applied to the analysis of the utterances produced by both speakers, because it was found that the corner of the alveolar ridge lies between row 4 and 5 on the EPG palate of the two informants.

The configurational characteristics were studied at the point of maximum linguopalatal narrowing (MAX). The MAX frame was determined as the EPG frame corresponding to the mid-point of the continuous noise energy, specified by acoustic recordings made simultaneously.

The width of the fricative channel was measured in millimeters. After identifying the MAX frame for each of the five repetitions, the minimum number of off-electrodes was inspected and the width of the fricative channel was estimated for each token by measuring the distance between the adjacent electrodes on the row. This inspection involves the specification of the position of the narrowing constriction in any one row. This is considered as the constriction location.

Coarticulatory directionality was analyzed for the three regions of each fricative articulation at the MAX contact. The effects of the three changing V1s and V2s were used for quantifying the relative salience of the carryover and anticipatory effects.
3. Results

3.1. Configurational Characteristics

Figure 2 above shows the EPG palatograms of [s, e, ç] in the symmetrical VCV sequences averaged over five repetitions.

3.1.1. [s]

The fricative [s] involves dental articulation in which the rim of the tongue touches the inner surface of the upper central incisors. A narrow constriction is formed in the dentalveolar and alveolar regions (rows 1-2) with accompanying side contact. This lateral seal sometimes becomes incomplete because the contact is made between the side of the tongue and the upper teeth. There are noticeable differences in the constriction formation between the speakers: apical (MN) and apicolaminal (TM) realization. They differ in the amount of lateral contact, as well as that of the narrowing constriction.

3.1.2. [e]

The narrowing constriction is primarily made in the post-alveolar (rows 3-4) and pre-palatal (row 5) regions. This is accompanied by a larger amount of contact in the posterior regions. This suggests that both tongue blade and medio-dorsum are involved in the constriction formation, with the tongue tip always directed downwards. Realization of the constriction length is slightly different for each speaker. It is consistently realized at rows 3-5 for MN but varies within the range of rows 2-5 for TM. However, the shaping in the anterior regions is essentially the same for the two speakers.

3.1.3. [ç]

This consonant involves palatal articulation, in which the tongue medio- and post-dorsum is raised towards the medio- and post-palatal regions. The greatest narrowing is typically formed at rows 7-8, with the lateral contact extending up to row 2, across the vowel contexts. The overall tongue body is supposed to be convex to the hard palate and the tongue tip is always directed downwards.

3.2. Constriction Width and Constriction Location

Table 1 below summarizes the mean CWs in millimeters and Table 2 summarizes the mean CLs on the EPG palate.

To examine the differences between the fricatives, the contextual vowels, and the speakers, a four-way ANOVA was carried out: 3 fricatives × 3 V1s × 3 V2s × 2 speakers. For both CW and CL significant differences were found for 3 fricatives and 2 speakers: the CW of 3 fricatives [F(2,216)=779.76, p<0.01] and 2 speakers [F(1,216)=8.87, p<0.01]; and the CL of 3 fricatives [F(2,216)=7849.42, p<0.01] and 2 speakers [F(1,216)=17.20, p<0.01]. For CW significant interactions were found for 3 fricatives × V2s [F(4, 216)=8.87, p<0.01] and V2s × 2 speakers [F(2,216)=37.56, p<0.01]. For CL significant interactions were: 3 fricatives × V1s [F(4,216)=4.58, p<0.01]; V1s × V2s [F(4,216)=4.92, p<0.01]; and 3 fricatives × 2 speakers [F(2,216)=37.56, p<0.01].

A one-way ANOVA was performed separately for the two speakers. The CW differences between the three fricatives were significant: for MN, F(2,132)=190.94 (p<0.01); for TM,
3.3. Coarticulatory Directionality

Figure 3 below presents the mean percentage values of the MAX contact in the three regions for [s], [e], and [q] in the vowel symmetrical and asymmetrical contexts. The figure may help to identify a rough sagittal-view of the tongue shape.

By comparing the differences in the amount of contact as a function of the changing vowels, the relative salience of the anticipatory and carryover effects was examined for the three regions of each fricative articulation. A series of two-way ANOVAS were conducted separately for the two speakers: 3 V1s × 3 V2s. The Scheffe’s test was also made to compare the differences between the particular vowel pairs. The results are summarized in Table 3.

The pattern of the results in Table 3 reveals that the [s] articulation characteristically varies with the speakers; and that carryover effects are systematic and extensive in [e] and [q]. Also, considerable variations of the V-to-C coarticulatory effects are obtained for particular regions of a given consonant.

In the production of [s], as shown in Table 3, significant V-to-C coarticulatory effects occur in all the regions for MN but only in the central and back regions for TM. This reflects the realizational idiosyncrasies: apical realization is more variable than apicolinal realization. In the front region, the amount of contact decreases particularly in the /i/ context because the vowel makes the whole body of the tongue move forwards and the narrowing is effectively made between the tip and the back of the upper incisors. In the posterior two regions, the contact degree varies directly with the height of the preceding and/or following vowel: /u/ increases the contact in the central and back regions; /u/ in the back region.

For the alveolopalatal [q], carryover effects are favored in the posterior two regions, while anticipatory effects are also significant in the front region of TM. This is due to the fact that the CL was further forward (see Table 2): this allows more variation in the control of the tongue tip/blade.

The palatal [q] exhibits height-dependent coarticulatory effects in TM’s production, but not in MN’s: the amount of contact in the posterior two regions substantially decreases in the /a/ contexts. As shown in Figure 2, the overall amount of contact is larger in MN than in TM. These results suggest that, while the raising gesture of the dorsum for the constrictive approximation is less constrained, the basic contact pattern was maintained across the vowel contexts.
Table 3: Two-way ANOVA Results for Coarticulatory Directionality in the Three Regions of [s], [ç], and [ç]†

<table>
<thead>
<tr>
<th></th>
<th>MN Front</th>
<th>Central</th>
<th>Back</th>
<th>TM Front</th>
<th>Central</th>
<th>Back</th>
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<tbody>
<tr>
<td><strong>Anticipatory</strong></td>
<td></td>
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<tr>
<td>F(2,36)</td>
<td>2.80 i=a</td>
<td>60.00** i&gt;a</td>
<td>39.90** i&gt;a</td>
<td>1.78 i=a</td>
<td>1.36 i&gt;a</td>
<td>6.22** i&gt;a</td>
</tr>
<tr>
<td>F(2,36)</td>
<td>12.40** a&gt;i</td>
<td>65.00** i&gt;a</td>
<td>23.70** i&gt;a</td>
<td>0.38 i=a</td>
<td>10.87** i&gt;a</td>
<td>27.55** i&gt;a</td>
</tr>
<tr>
<td>F(4,36)</td>
<td>10.69**</td>
<td>7.40**</td>
<td>4.20**</td>
<td>0.72</td>
<td>1.14</td>
<td>2.22</td>
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<td><strong>Carryover</strong></td>
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<tr>
<td>F(2,36)</td>
<td>1.23 i=a</td>
<td>2.11 i=a</td>
<td>0.53 i=a</td>
<td>4.92* i&gt;a</td>
<td>1.42 i=a</td>
<td>n.s.</td>
</tr>
<tr>
<td>F(2,36)</td>
<td>4.76* a&gt;i</td>
<td>11.86** i&gt;a</td>
<td>30.53** i&gt;a</td>
<td>8.59* i&gt;a</td>
<td>9.65** i&gt;a</td>
<td>n.s.</td>
</tr>
<tr>
<td>F(4,36)</td>
<td>1.76</td>
<td>0.40</td>
<td>1.33</td>
<td>2.13</td>
<td>3.65*</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
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<tr>
<td>F(4,36)</td>
<td>3.34*</td>
<td>1.36</td>
<td>2.00</td>
<td>2.10</td>
<td>3.83*</td>
<td>1.25</td>
</tr>
</tbody>
</table>

†=p<0.05; **=p<0.01; unmarked=non-significant. The relation between the particular vowel pairs was assessed by the Scheffé’s test (p<0.05): the symbol > indicates a significant difference but the symbol = indicates non-significant difference.

4. Discussion

The results obtained in the EPG experiments closely parallel earlier findings for sibilant production in various languages. Although the sibilants [s, ç] and the non-sibilant [ç] share common parameters, their controls appear to be different.

The hypothesis concerning the linear correlation between the CWs and CLs was generally supported for the Japanese [s, ç, ç]. However, although they have distinct CLs, [s, ç, ç] have an (almost) identical size of CW. Also, it appears that the size of the coronal sibilant inventory is less influential for creating the CW contrast. Thus, it is unlikely that the CW works as the primary distinguishing parameter for the sibilants in Japanese.

Coarticulatory behaviors of [s], although they are partly due to the realizational idiosyncrasies (apical and apicodental), revealed a stronger degree of coarticulatory resistance in the front region. In the posterior two regions the vowel-dependent effects were smaller (when compared to the corresponding stops [S]). This is a direct manifestation of the self-maintenance of a typical hollowing formed midsagittally.

Carryover effects were favored over anticipatory effects in [ç, ç]. This confirms the idea that an increase in dorsum involvement may cause a decrease in V-to-C anticipatory effects [9]. In contrast, the height-dependent carryover effects observed for [ç] can be explained by the functions of the jaw: building an obstacle and supporting the tongue to form a critical constriction. These functions are assessed for [s, ç] in [10]: while the sibilants require exact jaw positioning, in connection with the lower incisors (the second noise source), the stabilizing function is reduced in [ç]. The EPG data in our study suggests that further reduction occurs in stabilizing the tongue position for the non-sibilant [ç]; it allows speakers to have more degrees of freedom in the dorum raising gesture.

The fricative-specific controls of the parameters have implications for the relevant shape differences. The activity of the tip/blade with respect to the contrasting CLs contributes to generating different sizes of the front cavity for [s, ç, ç]. The positioning of the dorsum affords a primary or additional narrowing to the oral cavity, yielding a cross-sectional shape specific to a given fricative. Our results, although limited to one language, support the idea that the constriction shape is reduced to a small number of underlying parameters.

5. Conclusions

Articulatory properties of [s, ç, ç] in Japanese have been explored in terms of CW, CL, and coarticulatory directionality. The source of coarticulatory variability was discussed and speculated with reference to the two fricative categories, sibilant and non-sibilant. The findings suggest that differential precision for each fricative articulation is achieved through systematic changes of the parameters of relevant articulators.

6. References