# Articulatory characteristics of fricatives and affricates in Hindi: an electropalatographic study

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This study investigates articulatory characteristics of /s, z, ʃ, tʃ, dʒ/ in disyllabic nonsense words of the form [biCib], [buCub] and [baCab], where C represents the consonants listed above. The words were produced in a carrier sentence. Using the technique of electropalatography, quantitative and qualitative data were obtained from a speaker of Hindi. The results showed that the area of tongue-palate contact was significantly greater for the voiced fricative [z] than for the voiceless fricative [s]. In affricates, however, the contact area was significantly greater for the stop part of the voiceless affricate [tʃ] than for the stop part of the voiced affricate [dʒ]. On the other hand, the area of contact for the fricative part of [tʃ] and [dʒ] and the fricative [ʃ] was about the same. The area of contact for [s] and [z] was also significantly greater than for [ʃ] and the fricative part of [tʃ] and [dʒ]. The place of articulation for [ʃ] was significantly more posterior than for [s] and [z]. The place of articulation for the stop and fricative parts of [tʃ] and [dʒ] partly overlapped, but did not coincide. The width of the groove for [ʃ] and the fricative part of [tʃ] and [dʒ] was significantly greater than for [s] and [z]; however, the length of the groove for these segments was about the same. Numerical and electropalatographic data are presented and discussed in the light of the published numerical, palatographic and/or x-ray data on the fricatives and affricates. Coarticulatory effects of vocalic context on articulatory parameters of the investigated consonants are also discussed.

## 1 Introduction

This study investigates articulatory characteristics of sibilant fricatives (hereafter fricatives) /s/, /z/ and /ʃ/ and affricates /tʃ/ and /dʒ/ of Hindi. These sounds are both phonemic and phonetic. Both /z/ and /ʃ/ occur in words borrowed from Persian, Arabic, or English, while in words borrowed from Sanskrit only /ʃ/ occurs. This analysis extends work previously reported in Dixit (1990).

There are relatively few studies of Hindi providing reliable information on phonetic realization of Hindi phonemes (Ladefoged & Bhaskararao 1983; Dixit 1990, 1999; Ohala 2001). Previously, an extensive phonetic study on Hindustani (a colloquial, informal variety of Urdu, a sister language of Hindi) sounds was conducted by Qadri (1930). He obtained conventional

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**Table 1** Nonsense words used for electropalatographic recordings.

| | | | | | |
|---|---|---|---|---|---|
| bisib | busub | basab | bizib | buzub | bazab |
| biʃib | buʃub | baʃab | | | |
| bitʃib | butʃub | batʃab | bidʒib | budʒub | badʒab |

static palatograms on all of the vowels and consonants from a single speaker of Hindustani. Based on these palatograms, he described in his monograph all of the investigated sounds with considerable articulatory detail. Twenty-five years later, Švarný & Zvelebil (1955) published conventional static palatograms, linguograms, x-ray tracings and x-ray photographs of the consonants of Hindustani along with those of Tamil and Telugu. They obtained theses data from a single speaker of each language. Their data and descriptions provide much more phonetic information on articulatory characteristic of Hindustani sounds than those of Qadri. The words that were used in Qadri (1930) and Švarný & Zvelebil (1955) for generating experimental data were actual words that are commonly used by speakers of both Hindi and Urdu.

The experimental data on fricatives and affricates reported in Qadri (1930) and Švarný & Zvelebil (1955) are qualitative data. Quantitative data on various articulatory parameters of the fricative and affricate sounds are virtually non-existent in Hindi and Hindustani. Thus, the primary purpose of this study was to acquire quantitative data on the following articulatory parameters of the fricatives and affricates of Hindi: the area of tongue-palate contact for all of the investigated sounds, the anterior-posterior (A–P) location (place) and length, and the side-to-side (S–S) width of the groove for the fricatives and the fricative part of the affricates, and the A–P location (place) and length of the central constriction for the stop part of the affricates. A secondary purpose was to extend some more already existing qualitative data on these sounds.

# 2 Method

## 2.1 Subject and speech samples

The first author of this study served as the subject. He comes from Agra, situated in the western part of the Uttar Pradesh state in India. He was about 59 years old at the time of data collection for this study. He then was and now is free from oral/aural abnormalities. The data for this study were recorded and analyzed at the same time as those for Dixit (1990).

Disyllabic nonsense words shown in table 1 were used as speech samples. In these words, /s/, /z/, /ʃ/, /tʃ/ and /dʒ/ occur in a symmetrical vocalic context before a stressed vowel. The words were embedded in the carrier sentence /didi ___ lidʒɪje/ ‘Elder sister ___ (please) take’.

## 2.2 Equipment and procedures

A custom constructed electropalatograph (pseudopalate), which snugly fitted the subject’s hard palate, was used for tongue-palate contact data acquisition. The technique of constructing the pseudopalate and acquiring the contact data has been described in detail in Fletcher, McCutcheon & Wolf (1975) and McCutcheon, Smith, Kimble & Fletcher (1983). In short, the pseudopalate was made from a 0.3 mm thick acrylic sheet. Ninety-six gold-plated electrodes (sensors), less than 0.5 mm in diameter, were embedded in the oral surface of the pseudopalate in a $2 \times 2$ mm grid pattern in eleven rows from front to back as shown in figure 1 (see Dixit 1990). The unique placement of all 96 contact points in the anterior part of the pseudopalate makes it particularly suitable for the current investigation.

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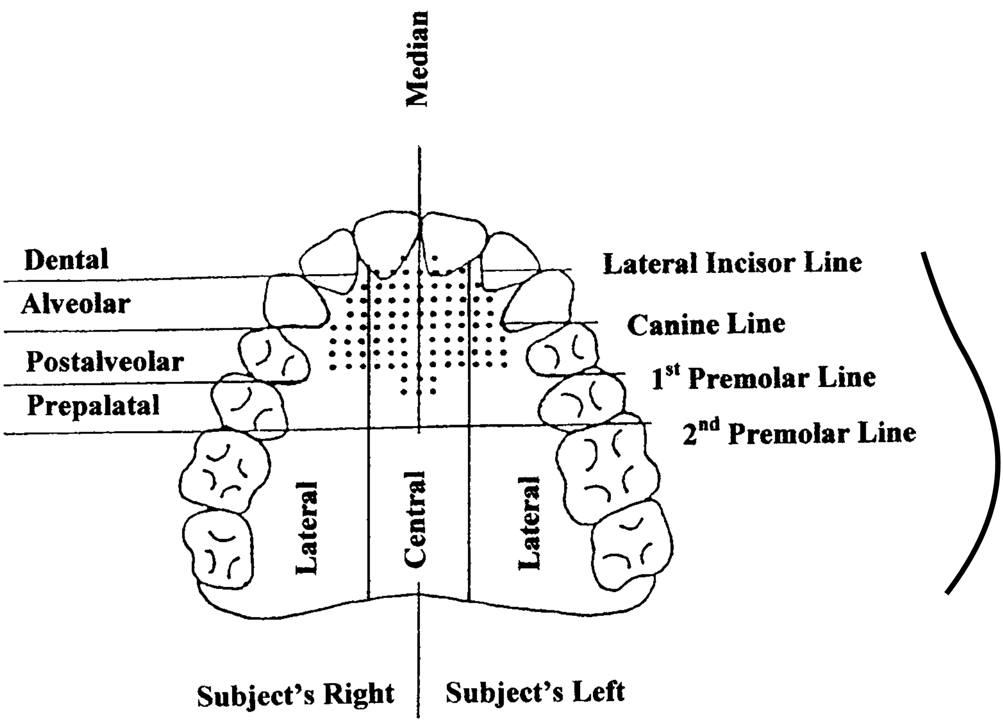


**Figure 1** Front-to-back location of 11 rows of 96 sensors on the oral surface of the pseudopalate in relation to the maxillary teeth of the subject. Reference lines and articulatory zones are based on the dentition plan suggested by Firth (1957: Plate 1, facing page 148) and zoning plan suggested by Ladefoged & Maddieson (1996: 13), respectively. A properly aligned line representing the trace made from back to front along the midline of the subject's hard palate is shown at the right of the figure. This line begins at the junction of the hard and soft palates and ends at the lateral incisor line. It represents the mid-sagittal view of the curvature of the hard palate vault. See text for further details.

In figure 1: Row one is located in the dental zone on the oral surface of the central maxillary incisors about 5 mm above their edges. Row two coincides with the lateral incisor line, which forms the boundary between the dental zone and the alveolar zone (the front part of the alveolar ridge). Row six coincides with the canine line, which forms the boundary between the alveolar zone and the postalveolar zone (the back part of the alveolar ridge). Row ten coincides with the first premolar (bicuspid) line, which forms the boundary between the postalveolar zone and the prepalatal zone (the forward part of the hard palate). It should be noted that 91 censors out of a total of 96 sensors are located in the alveolar and the postalveolar zones. Note also that row one has only two sensors and rows ten and eleven have only three sensors each, and that there are no midline sensors in rows seven and eight. Moreover, the lateral-most sensors in row five and rows seven to eleven are not located at the gingiva-teeth border (the gum line) of the subject's hard palate. This figure is a modified version of the figure in Dixit (1990). A properly aligned line representing the trace made from back to front along the midline of the subject's hard palate has been added to the right. This line begins at the junction of the hard and soft palates and ends at the lateral incisor line. It represents the mid-sagittal view of the curvature of the hard palate vault. The central and lateral zones of the hard palate have also been demarcated.

For data acquisition, the subject was seated in a dental chair situated in a sound-treated room. He was allowed about 15 minutes to adapt to the pseudopalate after it was positioned on the oral surface of his hard palate. During this time, the subject practiced the test sentences, which minimized the effect of the pseudopalate on his articulation. While the subject practiced the test sentences, all of the sensors were individually calibrated so that even the slightest tongue contact could be detected. During the recording session, the subject repeated the test sentences 10 times in a random order. A few sentences were re-recorded because of inadvertent misarticulations.

### 2.3 Analyses

Contact/no contact data from 96 sensors and acoustic data from a 32-channel filter bank were stored on a disc at a 100 Hz sampling rate. A 10 ms sampling interval, which showed the largest number of contacted sensors, was selected for analysis from each token of the fricatives and affricates. If there were several such sampling intervals, then the middle interval was selected.

The area of contact in terms of the number of contacted sensors was calculated by computer software. Since most of the sensors were located in the alveolar and the postalveolar zones, this measure does not represent the total area contacted during an articulation. It probably points to the differences in the total area of contact of various articulations that might have occurred if the sensors were located on the entire oral surface of the pseudopalate.

An unbroken string or loop of contacted lateral and central sensors was considered a complete constriction. If any row anterior to the unbroken string or loop of sensors had three or more medially located contacted sensors, then that row was considered to have been contacted. Row one was considered to have been contacted if both sensors in that row were contacted. The A–P location and length and the S–S width of the groove for the fricatives and the fricative part of the affricates, and the A–P location and length of the central constriction for the stop part of the affricates were determined by visual inspection of the tongue-palate contact patterns shown in figures 2–5 below.

The A–P length of the groove minima for the fricatives and the fricative part of the affricates was calculated by multiplying the sensor rows, which showed the same number of uncontacted sensors, by 2 mm, the inter-row distance. The S–S width of the groove was calculated by multiplying the number of uncontacted sensors by 2 mm, the distance between adjacent sensors in each row. The A–P length of the central constriction for the stop part of the affricates was obtained by multiplying the number of contacted sensor rows by 2 mm, the inter-row distance.

## 3 Results

Quantitative and qualitative (electropalatographic, hereafter palatographic) results on the articulatory characteristics of the fricatives and the affricates of Hindi are presented in tables 2–5 and figures 2–5. All of the results are based on the sensors that were contacted in between 80% and 100% of the tokens of the above-mentioned consonants. These sensors are shown by filled circles and those that were contacted less often or not at all are shown by dots in the electropalatograms (hereafter palatograms).

Analysis of variance was performed on the data reported in tables 2–5. The results of the ANOVAs are incorporated in the text of the paper in appropriate places.

### 3.1 Fricatives /s/ and /z/

Quantitative and palatographic results on the articulatory characteristics of the fricatives /s/ and /z/ are shown in table 2 and figure 2, respectively.

**Table 2** Area of tongue-palate contact (in number of contacted sensors), A–P location (place) and length, and S–S width of the groove for the fricatives [s] and [z] in the context of [i], [u] and [a].

| Vowel context | Area contacted | | A–P location (place) of groove | A–P length of groove | S–S width of groove |
|---|---|---|---|---|---|
| [s] | X | SD | | | |
| i_i | 38.20 | 1.24 | Sensor row 3 | 2 mm | 6 mm |
| u_u | 42.20 | 1.16 | Sensor rows 2 & 3 | 4 mm | 6 mm |
| a_a | 41.50 | 1.36 | Sensor rows 2 & 3 | 4 mm | 6 mm |
| Group | 41.70 | 3.57 | | 3.33 mm | 6 mm |
| [z] | X | SD | | | |
| i_i | 43.70 | 1.00 | Sensor rows 2 ,3 & 4 | 6 mm | 6 mm |
| u_u | 47.40 | 2.10 | Sensor row 2 | 2 mm | 4 mm |
| a_a | 49.90 | 1.81 | Sensor row 2 | 2 mm | 2 mm |
| Group | 47.00 | 3.06 | | 3.33 mm | 4 mm |

As shown in table 2 and figure 2, the area of tongue-palate contact was significantly greater during voiced fricative [z] than during voiceless fricative [s] ($F = 243.03$, dF 1, 54, $p < .0001$. On average, 47 sensors were contacted during [z], while 41.70 sensors were contacted during [s]. The average of tongue-palate contact also varied significantly as a function of the vowel context ($F = 50.889$, dF 2, 54, $p < .0001$). The average contact area for [z] was greater than for [s] for all vowel contexts. However, a significant interaction between consonant and vowel ($F = 6.242$, dF 2, 54, $p < .004$) indicates that the difference between [s] and [z] was greater in some vowel contexts than others. The average difference in the area between [s] and [z] was greatest in the [a] context (mean = 8.40) and less in the [i] (mean 5.50) and [u] (mean 5.20) contexts.

The groove minima for both [s] and [z] were usually found in sensor rows 2 and/or 3. Sensor row 2 forms the boundary between the dental and the alveolar zones and sensor row 3 falls in the anterior part of the alveolar zone. Thus, the groove minima for both [s] and [z] were located in the anterior part of the alveolar zone slightly encroaching upon the dental zone. The A–P length of the groove, on average, was exactly the same (3.33 mm) for both [s] and [z]. However, it should be noted that the groove length for [z] was three times greater in the context of [i] than in the context of [u] and [a]. The S–S width of the groove was greater for [s] than that for [z]. On average, it was 6 mm for [s] and 4 mm for [z]. As displayed in the palatograms, the airflow channel during both [s] and [z] was skewed to the right of the subject's mouth.

## 3.2 Fricative /ʃ/

Quantitative and palatographic results on the articulatory characteristics of the fricative /ʃ/ are presented in table 3 and figure 3, respectively. [ʒ], the voiced counterpart of /ʃ/, does not occur as a contrastive sound in Hindi, it only occurs as the fricative part of the voiced affricate /dʒ/.

As shown in table 3 and figure 3, on average, 30.23 sensors were contacted during [ʃ]. The average area of contact varied significantly as a function of vowel context ($F = 25.119$, dF 2, 27, $p < .0001$). Contact area was greater in the [i] (mean 32.40) and [a] (mean 32.30) contexts and less in the [u] (mean 26) context.

The groove minimum for [ʃ] occurred in sensor rows 5 and/or 6. Sensor row 6 forms the boundary between the alveolar and the postalveolar zones and sensor row 5 falls in the

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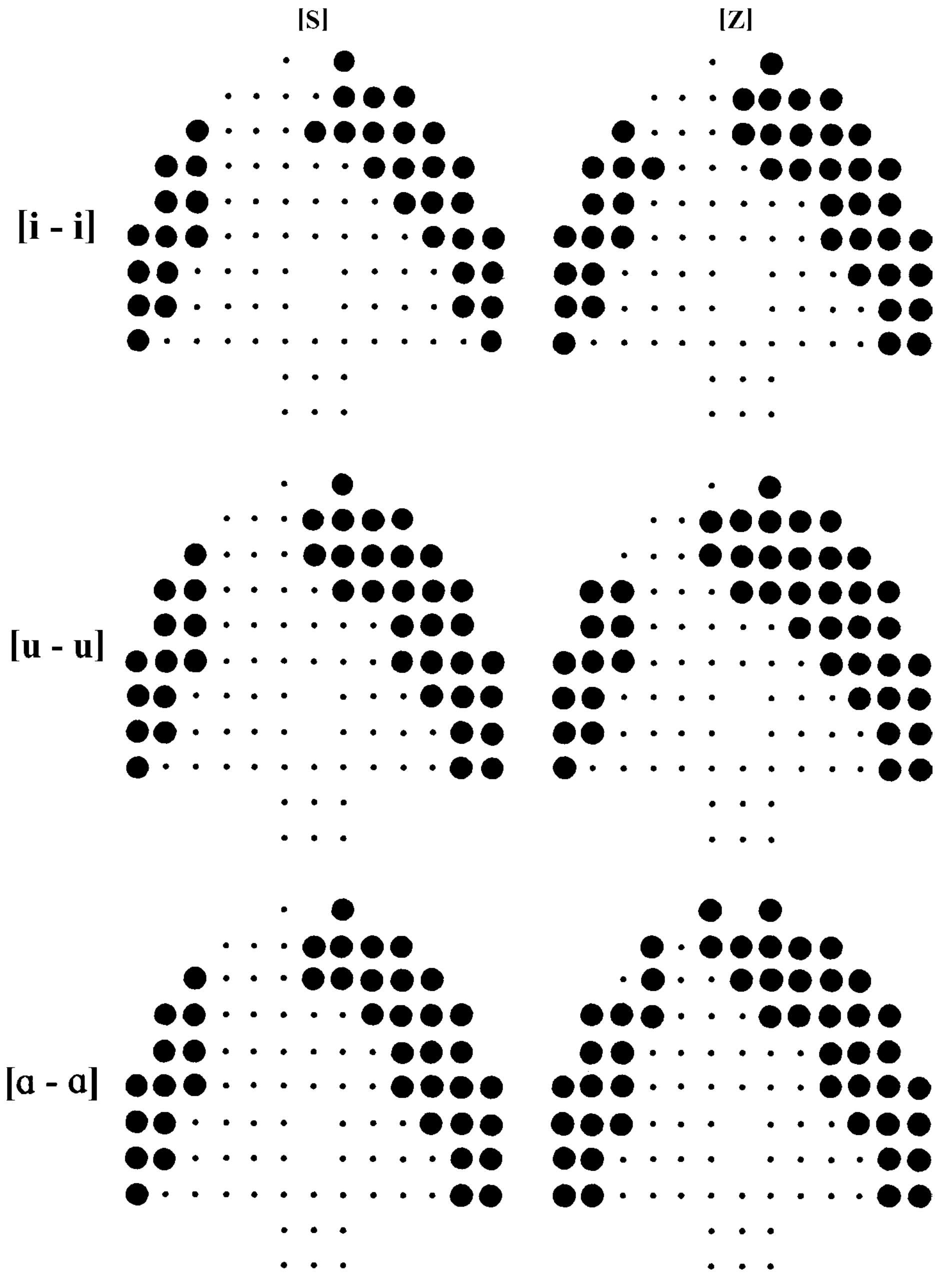


**Figure 2** Typical palatograms for the fricatives [s] (left column) and [z] (right column) in the context of [i], [u] and [ɑ].

posterior part of the alveolar zone. Thus, the A–P location of the groove for [ʃ] occurred in the posterior part of the alveolar zone slightly encroaching upon the postalveolar zone. On average, the A–P length of the groove [ʃ] was 3.33 mm and the S–S width of the groove was 11.33 mm. Skewing of the airflow channel was not apparent in [ʃ].

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**Table 3** Area of tongue-palate contact (in number of contacted sensors), A–P location (place) and length, and S–S width of the groove for the fricative [ʃ] in the context of [i], [u] and [a].

| Vowel context | Area contacted | | A–P location (place) of groove | A–P length of groove | S–S width of groove |
|---|---|---|---|---|---|
| [ʃ] | X | SD | | | |
| i_i | 32.40 | 2.72 | Sensor rows 5 & 6 | 4 mm | 12 mm |
| u_u | 26 | 1.84 | Sensor row 6 | 2 mm | 12 mm |
| a_a | 32.30 | 1.90 | Sensor rows 5 & 6 | 4 mm | 10 mm |
| Group | 30.23 | 3.71 | | 3.33 mm | 11.33 mm |

## 3.3 Affricates /tʃ/ and /dʒ/ (fricative part)

Quantitative and palatographic results on the articulatory characteristics of the fricative part of the affricates /tʃ/ and /dʒ/ are presented in table 4 and figure 4, respectively.

As shown in table 4 and figure 4, the area of tongue-palate contact for the fricative part of the affricates [tʃ] and [dʒ] was about the same ($F < 1.0$, dF 1, 54, $p < .948$). On average, 32.96 sensors were contacted during [tʃ] and 32.90 sensors were contacted during [dʒ]. The number of contacted sensors for both [tʃ] and [dʒ] was significantly greater ($F = 33.85$, dF 1, 54, $p < .0001$) in the context of the front vowel [i] (mean 38.30) than in the context of the back vowels [u] (mean 32.35) and [a] (mean 28.20).On the other hand, in the context of [u] the number of contacted sensors was greater for [dʒ] (mean 34.90) than for [tʃ] (mean 29.80), while in the context of [a] it was greater for [tʃ] (mean 31.30) than for [dʒ] (mean 25), as indicated by a significant interaction effect between consonant and vowel contexts ($F = 17.882$, dF 5, 54, $p < .0001$).

The groove minima for the fricative part of both [tʃ] and [dʒ] generally occurred in sensor rows 5 and/or 6, except in the context of [a], where the groove minimum for [tʃ] occurred in sensor rows 4, 5 and 6. Since sensor row 6 forms the boundary between the alveolar and the postalveolar zones and sensor row 5 falls in the posterior part of the alveolar zone, the groove minima for both [tʃ] and [dʒ] were, therefore, located in the posterior part of the alveolar zone, slightly encroaching upon the postalveolar zone.

On average, the A–P lengths of the grooves for [tʃ] and [dʒ] were exactly alike – 4 mm each. The S–S widths of the grooves for both [tʃ] and [dʒ] were quite similar. On average, they were 11.33 mm for [tʃ] and 12 mm for [dʒ].

The A–P location (place) of the groove (in terms of the distance in mm from the edges of the central maxillary incisors to the most anterior row of sensors contacted), the A–P length of the groove, and the S–S width of the groove for the fricative part of the affricates [tʃ] and [dʒ] and the fricative [ʃ] were compared to those for the fricatives [s] and [z]. The location of the groove for [s] and [z] (mean 7.33, SD 0.82) was significantly more forward ($t = 10.44$, dF 13, $p < .0001$) than for [ʃ] and the fricative part of [tʃ] and [dʒ] (mean 13.22, SD 1.20). The length of the groove for [s] and [z] (mean 3.33, SD 1.63), [ʃ] and the fricative part of [tʃ] and [dʒ] (mean 3.78, SD 1.20) did not differ ($t = 0.61$, dF 13, $p < .729$). The width of the groove for [s] and [z] (mean 5.00, SD 1.67) was significantly smaller ($t = 8.44$, dF 13, $p < .0001$) than for [ʃ] and the fricative part of [tʃ] and [dʒ] (mean 11.56, SD 1.33).

## 3.4 Affricates /tʃ/ and /dʒ/ (stop part)

Quantitative and palatographic results for the articulatory characteristics of the stop part of the affricates /tʃ/ and /dʒ/ are presented in table 5 and figure 5, respectively.

As shown in table 5 and figure 5, the area of tongue-palate contact in all vowel contexts was invariably greater for the stop part of the voiceless affricate [tʃ] than for the stop part

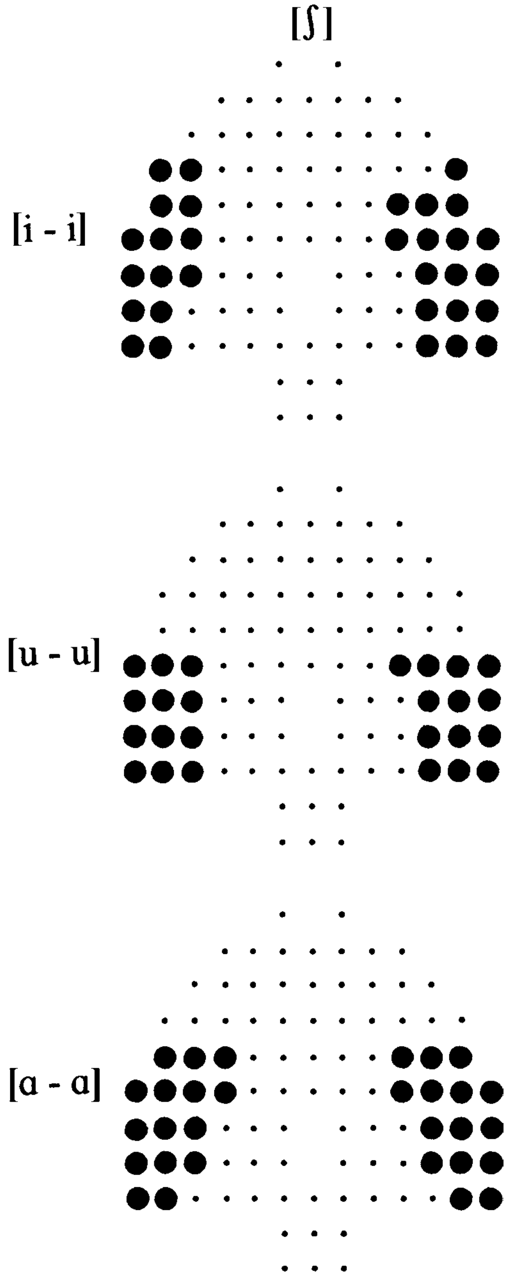


**Figure 3** Typical palatograms for the fricative [ʃ] in the context of [i], [u] and [a].

of the voiced affricate [dʒ]. On average, 70.76 sensors were contacted during [tʃ], while 66.06 sensors were contacted during [dʒ]. This difference in the contact area of [tʃ] and [dʒ] reached a significance level of ($F = 41.029$, dF 1, 54, $p < .0001$). The contact area during [tʃ] and [dʒ] was also significantly greater in the high-vowel context than in the low-vowel context ($F = 42.684$, dF 2, 54, $p < .0001$). Furthermore, the difference in the area between

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**Table 4** Area of tongue-palate contact (in number of contacted sensors), A–P location (place) and length, and S–S width of the groove for the fricative part of [tʃ] and [dʒ] in the context of [i], [u] and [a].

| Vowel context | Area contacted | | A–P location (place) of groove | A–P length of groove | S–S width of groove |
|---|---|---|---|---|---|
| [tʃ] | X | SD | | | |
| i_i | 37.80 | 3.81 | Sensor rows 5 & 6 | 4 mm | 10 mm |
| u_u | 29.80 | 3.91 | Sensor row 6 | 2 mm | 12 mm |
| a_a | 31.30 | 3.95 | Sensor rows 4,5 & 6 | 6 mm | 12 mm |
| Group | 32.96 | 5.21 | | 4 mm | 11.33 mm |
| [dʒ] | X | SD | | | |
| i_i | 38.80 | 3.73 | Sensor rows 5 & 6 | 4 mm | 10 mm |
| u_u | 34.90 | 4.15 | Sensor rows 5 & 6 | 4 mm | 12 mm |
| a_a | 25 | 2.48 | Sensor rows 5 & 6 | 4 mm | 14 mm |
| Group | 32.90 | 6.79 | | 4 mm | 12 mm |

[tʃ] and [dʒ] was greater in the [a] context (mean 8) than the [i] (mean 2.7) and [u] (mean 3.5) contexts.

A complete lateral-central constriction during the stop part of [tʃ] and [dʒ] was always formed in all vowel contexts, as shown in the palatograms in figure 5. During both [tʃ] and [dʒ], the contact for the central constriction usually extended from sensor row 2 to sensor row 5 with some differences in the context of [u] and [a]. Thus, the central constriction for both [tʃ] and [dʒ] occurred mainly in the alveolar zone with slight encroachment upon the dental zone. The A–P length of the central constriction during [tʃ] was somewhat greater than during [dʒ]. On average, it was 7.33 mm during [tʃ] and 6 mm during [dʒ].

## 4 Discussion

Contrary to what was observed in the voiced versus voiceless stops (Dixit 1990), the area of tongue-palate contact was significantly greater during the voiced fricative [z] than during the voiceless fricative [s] (see table 2 and figure 2 above). This result is in agreement with the results reported in Fletcher (1989) and Dagenais, Lorendo & McCutcheon (1994), where more sensors were contacted during American English fricative [z] than during [s]. The difference in the contact area between [s] and [z] appears to be a consequence of laryngeal action during these fricatives. Since, the glottis is open during [s] (Dixit 1975), it is relatively easy to generate adequate oral pressure for the turbulent airflow during [s]. On the other hand, during [z], the glottis is approximated and vibrating (Dixit 1975) making it rather difficult to generate required oral pressure for the turbulent airflow during [z]. The greater contact area during [z] reduces the size of the vocal tract space between the location of the groove for [z] and the glottis, thereby facilitating generation of required oral pressure for the turbulent airflow for [z]. Moreover, a somewhat narrower groove during [z], vis-à-vis [s], may have also assisted in this regard. A narrower groove for [z], as compared to [s], was also reported in Dagenais et al. (1994). However, in disagreement with the above, in Fletcher (1989), the size of the groove for [s] and [z] was the same. While the speculations made above are predicted by the inverse relationship between volume and fluid pressure, they should be considered tentative until experimental data on oral volume for [s] and [z] become

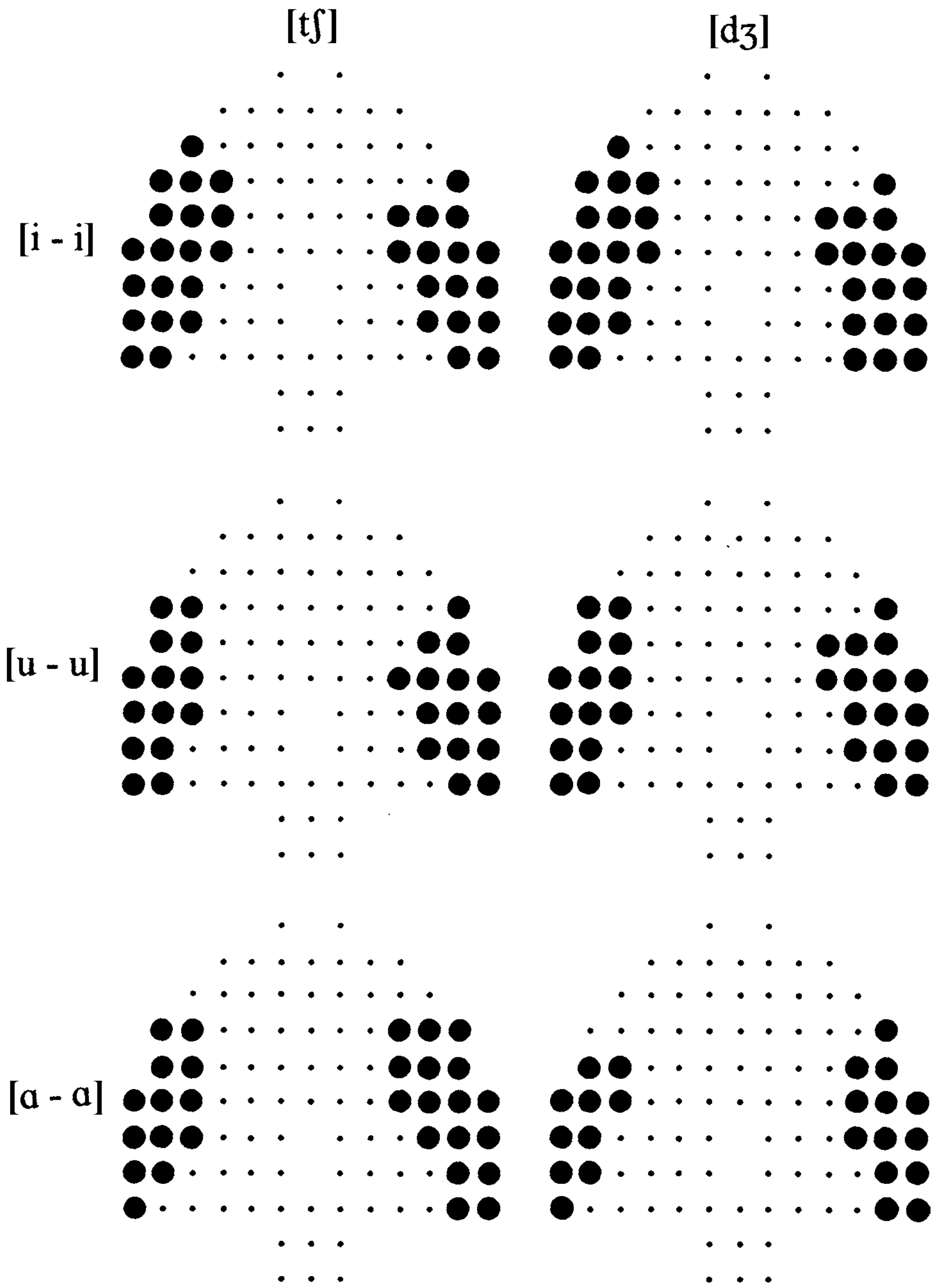


**Figure 4** Typical palatograms for the fricative part of the affricates [tʃ] (left column) and [dʒ] (right column) in the context of [i], [u] and [a].

available for quantitative evaluation of these speculations. As shown in figure 2, the area of contact for both [s] and [z] was skewed toward the right of the subject's mouth. According to Catford (1977: 144), articulatory asymmetry in the contact area 'is of little phonetic consequence'.

**Table 5** Area of tongue-palate contact (in number of contacted sensors), A–P location (place) and length of the central constriction for the stop part of the affricates [tʃ] and [dʒ] in the context of [i], [u] and [a].

| Vowel context | Area contacted | | A–P location (place) of groove | A–P length of groove |
|---|---|---|---|---|
| [tʃ] | X | SD | | |
| i_i | 73.80 | 2.13 | Sensor rows 2,3,4 & 5 | 8 mm |
| u_u | 70.30 | 2.19 | Sensor rows 2,3,4 & 5 | 8 mm |
| a_a | 68.20 | 2.13 | Sensor rows 2,3 & 4 | 6 mm |
| Group | 70.76 | 3.15 | | 7.33 mm |
| [dʒ] | X | SD | | |
| i_i | 71.20 | 1.66 | Sensor rows 2,3,4 & 5 | 8 mm |
| u_u | 66.80 | 3.99 | Sensor rows 3,4 & 5 | 6 mm |
| a_a | 60.20 | 3.31 | Sensor rows 3 & 4 | 4 mm |
| Group | 66.06 | 5.50 | | 6 mm |

As expected, the area of contact during [ʃ] was much smaller than during [s] and [z]. Since the overall width of the airflow channel during [ʃ] – as reflected in the reduced medial contact – was considerably greater than that during [s] and [z], a difference in the contact area for these sounds (see figures 2 and 3 above) was observed. Moreover, the S–S width of the groove during [ʃ] was generally twice as large as that during [s] and [z]. Also, the A–P location (place) of the groove for [ʃ] was about 4–6 mm posterior to that for [s] and [z] (see tables 2 and 3, and figures 2 and 3 above). The more posterior and wider the groove, the smaller the area of contact. The above results are consistent with those reported on Japanese in Shibata (1968) and for American English in Fletcher (1989), Fletcher & Newman (1991) and Dagenais et al. (1994). In standard phonetic texts, it is generally assumed that the A–P length of the groove during [ʃ] is longer than during [s] and [z] (see, for example, Pike 1958: 137). Contrary to this, in the present study, the A–P length of the groove (on average) was found to be about the same for [s] and [z] and for [ʃ]. Probably the length of the groove does not play a significant role in distinguishing these sounds.

The subject in the present study produced [s] and [z] in the anterior part of the alveolar zone with the tip of the tongue (see table 2 and figure 2 above, also figure 6). Thus, both [s] and [z] may be described as apical anterior alveolar fricatives. Qadri (1930) labels [s] and [z] as ‘prepalatal’, but provides no articulatory description of these sounds. However, palatograms in his monograph clearly show that [s] and [z] were produced as postalveolar by his subject. On the other hand, according to Švarný & Zvelebil (1955: 402), Hindustani [s] and [z] (which are labeled by them as ‘apical fricatives’) ‘show an articulation which is common with the Tamil s’. In their description, Tamil s ‘is articulated with the surface of the tip of the tongue . . . the narrowing of the air passage is formed not at the teeth but rather immediately behind the teeth at the alveolus’ (Zvelebil 1955: 393). It appears from the above that their Hindustani subject, like the Hindi subject of this study, articulated [s] and [z] with the tip of the tongue in the anterior part of the alveolar zone. The palatograms for [s] and [z], and a linguogram and an x-ray for [s] in Švarný & Zvelebil (1955) clearly show that their articulatory description of these sounds is accurate. Similar articulatory descriptions of [s] appear in Kelkar (1968) and Sharma (1972). Similarly, Ohala (1994) classifies [s] and [z] as alveolar. Following traditional classification of the fricatives [s], Dixit (1963) classifies [s] as dental. However, he cautions that his classification of [s] as dental is based on distributional rather than physiological grounds. The fricative [ʃ] was produced in the posterior part of the alveolar zone by the subject of this study (see table 3 and

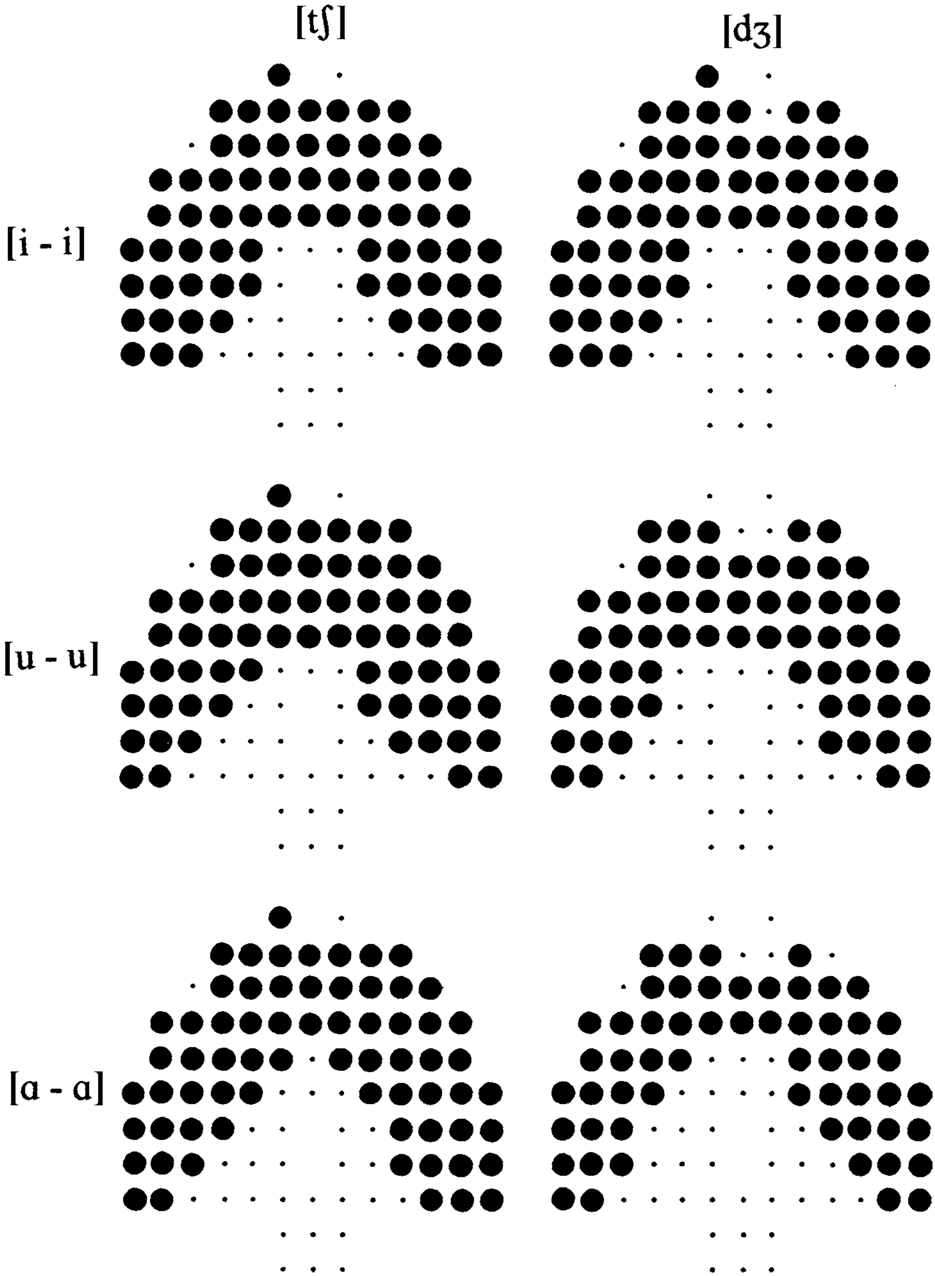


**Figure 5** Typical palatograms for the stop part of the affricates [tʃ] (left column) and [dʒ] (right column) in the context of [i], [u] and [a].

figure 3 above, also figure 7). Although the A–P length of the groove for [ʃ] and for [s] and [z] was the same (see tables 2 and 3 above), the groove for [ʃ] was formed not by the tip of the tongue but by the lamina of the tongue (see linguogram in figure 7). Thus, [ʃ] may be described as laminal posterior alveolar fricative. Although the grooves for [ʃ] and [s]–[z] occurred in the alveolar zone, the A–P location (place) of the groove for [ʃ]

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[asa]

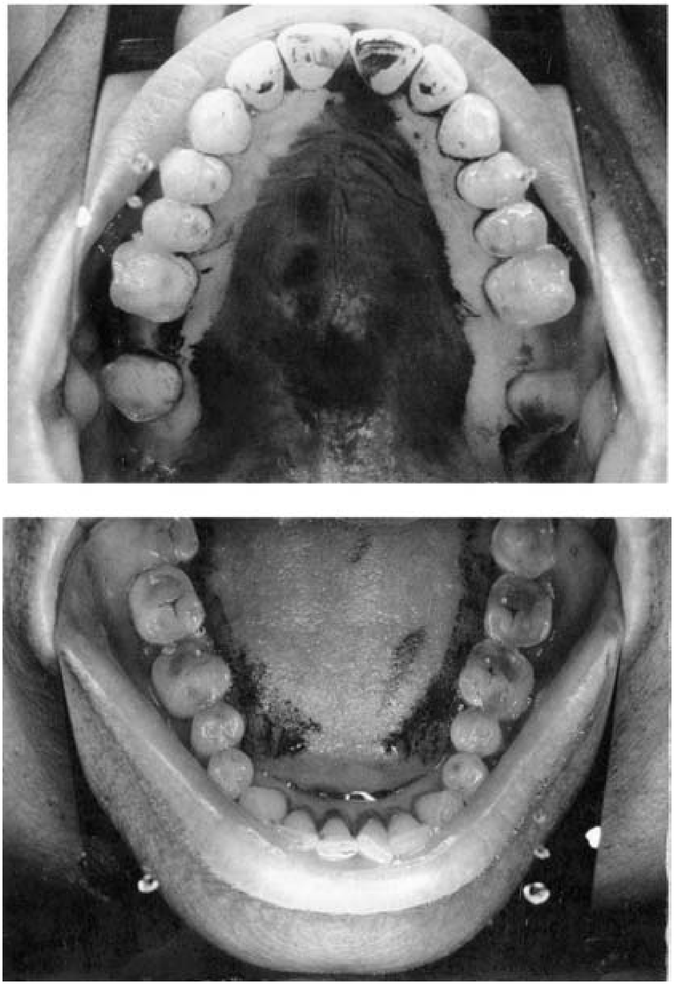

**Figure 6** Conventional direct palatogram (top) and linguogram (bottom) for [s]. Notice that the groove minimum was formed by the tip of the tongue just posterior to the lateral incision line in the anterior/alveolar zone.

did not overlap with the place of the groove for [s] and [z]. The place of the groove for [ʃ] was significantly behind that for [s] and [z]. Furthermore, the S–S width of the groove for [ʃ] was significantly greater as compared to that for [s] and [z] (see section 3 above). Hence, [ʃ] can be distinguished from [s] and [z]. They can also be separated on the basis of laminality versus apicality, since the groove for [ʃ] was formed by the lamina of the tongue whereas the groove for [s] and [z] was formed by the apex of the tongue. The laminality versus apicality of the tongue gesture has been shown previously to distinguish certain coronals in Malayalam (Dart & Nihalani 1999).

As to the place of articulation of [ʃ], the results of the present study do not find any confirmation in the studies by Qadri (1930) or by Švarný & Zvelebil (1955). Qadri (1930: 97) labeled [ʃ] as 'prepalatal' and described it as 'more forward than an English ʃ'. But the

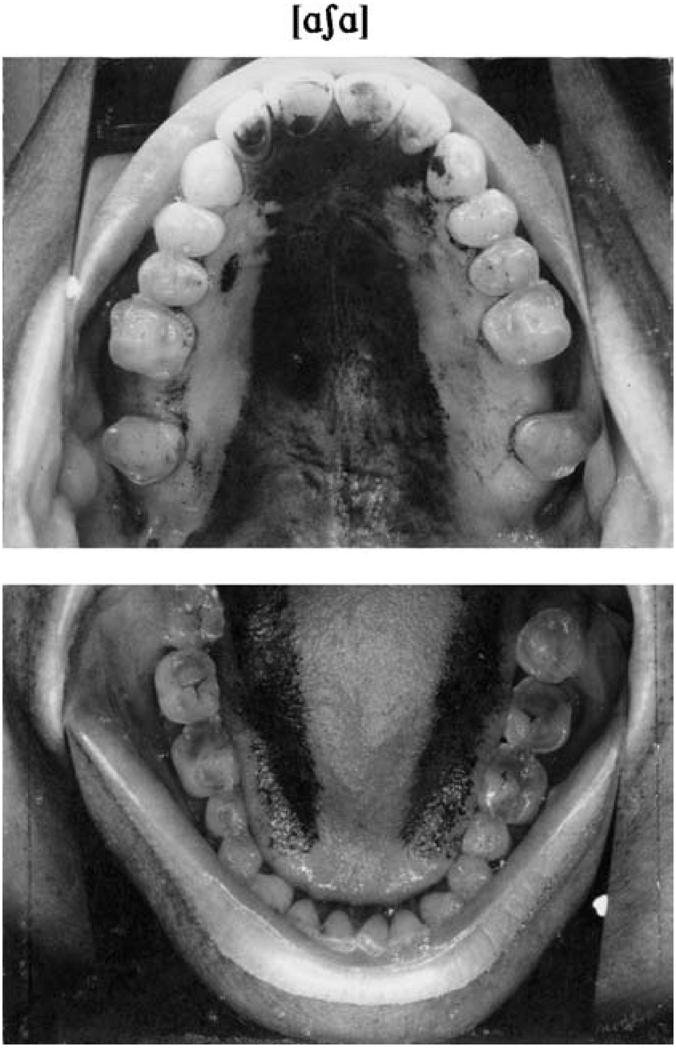


**Figure 7** Conventional direct palatogram (top) and linguogram (bottom) for [ʃ]. Notice that the groove minimum was formed by the blade of the tongue just anterior to the canine line in the posterior/alveolar zone.

palatograms in his study show that the groove for [ʃ] occurred generally in the postalveolar region. On the other hand, according to Švarný & Zvelebil, the palatogram and linguogram for [ʃ] in the word *çam* 'evening' are 'on the whole, identical with the palatograms and linguograms of the Tamil s', which is articulated 'approximately as far back as the first or second molar line'. Thus, Hindustani [ʃ] [(ç) for them] is postalveolar-prepalatal. They also labeled it as 'apical'. However, the x-ray tracing for [ʃ] (ç) presented in their study clearly shows the groove minimum for this fricative was formed by the tip of the tongue in the postalveolar zone. On the other hand, the palatogram and linguogram for [ʃ] (ç) show that this fricative was articulated by the tongue tip in the alveolar zone. The variance between the x-ray tracing and palatogram-linguogram of [ʃ] (ç) is rather perplexing. Like the experimental data discussed above, the classification and description of [ʃ] also differ considerably. It has been classified as alveopalatal in Dixit (1963) and as postalveolar in Ohala (1994); and it has been described as 'long-grooved lamino-dorso-alveolar-prepalatal' in Kelkar (1968: 23) and as 'pronounced with the tip of the tongue touching the palate' in Sharma (1972: 9). Kelkar's (1968) description of the release of [tʃ] and, thus, of [ʃ] as 'long-grooved lamino-dorso-alveolar-prepalatal' is entirely at odds with the results of this study, the phonetic classification of [ʃ] given in Ohala (1994), and the palatograms presented in Qadri (1930) and Švarný & Zvelebil (1955).

It has been observed in the studies cited below that stringent requirements imposed on grooving and place of articulation for fricative consonants make them resistant to coarticulatory effects of vocalic context (Bladon & Nolan 1977; Recasens 1985, 1999; Engstrand 1989; Stone 1990; Farnetani & Recasens 1993; Hoole, Nguyen-Trong & Hardcastle 1993; Fontdevila, Pallares & Recasens 1994; Fowler & Brancazio 2000). Others, however, have noted that the tongue dorsum contact for [s] and [ʃ] is greater in the context of the high vowel [i] than low vowels (Stone, Faber, Raphael & Shawker 1992), and that constriction (groove) width for [s] is narrower in the context of [i] than in the context of [u] or [a] (Engstrand 1989), thus demonstrating the coarticulatory effects of vocalic context on their area of contact and the width of the groove. In the present study, [s], [z] and [ʃ] showed little sensitivity to the coarticulatory effects of the vocalic context. Nevertheless, it should be noted that some small and unsystematic effects of vocalic context were found in the data presented in this study (see tables 2 and 3, and figures 2 and 3 above). For [s] and [z], the contact area was more extensive in the context of [u] and [a] than of [i]; the length of the groove for [s] was smaller in the context of [i] than of [u] or [a], while for [z], it was smaller in the context of [a] and [u] than of [i], and the width of the groove for [z] was smaller in the context of [a] than of [i]. On the other hand, for [ʃ], the contact area was more extensive and the length of the groove was greater in the context of [i] and [a] than of [u]. Such unsystematic effects of the vocalic context could hardly be called coarticulatory effects.

The area of tongue-palate contact during the fricative part of the affricates [tʃ] and [dʒ] was virtually identical, but it was somewhat greater than during the fricative [ʃ] (see tables 3 and 4, and figures 3 and 4 above). The above-mentioned difference in the contact area between the fricative part of [tʃ] and [dʒ] as against the fricative [ʃ] was probably caused by the stop part of the affricates, as discussed below. Unlike the fricatives [s] and [z], where the contact area was greater for the voiced fricative than for the voiceless fricative, the contact area of the fricative parts of the voiced versus voiceless affricates did not exhibit any effect of voicing. Clearly, the oral air pressure requirements for the generation of turbulence for the fricative part of the voiced affricate were already met during the stop part of the affricate.

The A–P location (place) and length of the groove were virtually identical during the fricative part of [tʃ] and [dʒ] and the fricative [ʃ] and the S–S width for them was about the same (see tables 3 and 4 above). Although a few vowel related differences in these parameters were observed, they were unsystematic. Like the present study, the location and the width of the groove were about the same for the fricative part of [tʃ] and [dʒ] and for the fricative [ʃ] reported in Fletcher (1989). Recall that the stop part of [tʃ] and [dʒ] had a broad central constriction which, generally, extended from sensor rows 2/3 to 4/5, whereas the groove for the fricative part of [tʃ] and [dʒ] occurred, generally, in sensor rows 5 and 6. This seems to suggest that as the seal of the tongue-palate contact during the release of [tʃ] and [dʒ] is broken, the opening gesture moves from front to back before a groove of appropriate size for the fricative part of these consonants is formed (see tables 4 and 5, and figures 4 and 5 above). Although, both occlusion and grooving for [tʃ] and [dʒ] occur, primarily, in the alveolar zone, their place of articulation is not entirely the same, and only a small part of the lamina forms the groove as reflected in the A–P length of the groove (table 4). In Fletcher (1989), however, the constriction for the stop part of [tʃ] was formed at a location that coincided with the location of the fricative part of [tʃ].

Like the fricative [ʃ], the fricative part of the affricated [tʃ] and [dʒ] showed little sensitivity to the coarticulatory effects of the vocalic context. A few differences observed in the area of contact, in the A–P location and length of the groove, and in the S–S width of the groove, which could be related to the effects of the adjacent vowels, were unsystematic in both [tʃ] and [dʒ].

Like the voiceless versus voiced stops (Dixit 1990), the area of tongue-palate contact was invariably greater for the stop part of the voiceless affricate [tʃ] as compared to that for the stop part of the voiced affricate [dʒ] (see table 5 and figure 5 above). This difference in the contact area presumably reflects a relatively tighter closure during voiceless [tʃ] than during voiced [dʒ]. In contrast to the above result, the area of contact during the stop part of [tʃ] and [dʒ] in Fletcher (1989) and Dagenais et al. (1994) was about the same. However, in consonance with this study, they also found that the area of contact during the stop part of [tʃ] and [dʒ] was considerably greater than during the fricative part of [tʃ] and [dʒ]. This difference in the contact area is clearly a consequence of the complete lateral and central contact during the stop part vis-à-vis the complete lateral contact but incomplete central contact during the fricative part of [tʃ] and [dʒ] (see figures 4 and 5 above).

During the stop part of the affricates [tʃ] and [dʒ], the A–P location (place) of the central constriction generally extended from sensor rows 2/3 to 4/5, confining the central constriction, primarily, to the alveolar zone. Moreover, the A–P length of the central constriction was relatively large, but similar, for both [tʃ] and [dʒ] (see table 5 and figure 5). Clearly, the subject of this study articulated the stop part of [tʃ] and [dʒ] in the alveolar zone with the blade of the tongue. They may, therefore, be described as lamino-alveolar. Conventional direct palatograms for [tʃ] and [dʒ], shown in figure 8, seem to support the above description of [tʃ] and [dʒ]. (Unfortunately, linguograms for both [tʃ] and [dʒ] were spoiled.) It is interesting to note that there is a large difference between the A–P length of the central constriction and A–P length of the groove in [tʃ] and [dʒ]. This suggests that as the seal of the occlusion during [tʃ] and [dʒ] is broken, not only does their A–P location somewhat recede (as indicated earlier) but also their A–P length is reduced (see tables 4 and 5, and figures 4 and 5 above).

In contrast to the results of this study (discussed above), Qadri's (1930: 82) subject produced [tʃ] and [dʒ] by 'the spread-out blade of the tongue against the teeth-ridge', and Švarný & Zvelebil's (1955: 402, 403) subject articulated them as 'dorsal' and 'alveolar-prepalatal'. The stop part of [tʃ] and/or [dʒ] in Sindhi (Nihalani 1974), Malayalam (Dart 1991) and English (Fletcher 1989, Dagenais et al. 1994) was articulated in the alveolar/postalveolar zone by the lamina of the tongue. Thus, their results differ from those of this study and of Švarný & Zvelebil's (1955) study, but they are in agreement with the results of Qadri's (1930) study. Likewise, the description and the classification of the affricates [tʃ] and [dʒ] also differ considerably as indicated in the following. Kelkar (1968: 24) describes them as 'lamino-alveolar', whereas Sharma (1972: 7) describes them as 'sounded with the front of the tongue touching . . . the hard palate i.e. the part of the back of the teeth-ridge'. Similarly, [tʃ] and [dʒ] have also been classified as alveo-palatal (Dixit 1963), post-alveolar (Ohala 1994), palatal (Ladefoged & Maddieson 1996: 58), post-alveolar (Ladefoged 2001a: 130) and palatoalveolar (Ladefoged 2001b: 124).

Although the area of contact and the length of the central constriction for the stop part of [tʃ] and [dʒ] was greater in the high-vowel context as compared to that in the low-vowel context, suggesting a coarticulatory effect of the vocalic context, the location (place) of the central constriction remained confined mainly to the alveolar zone. It did not show systematic backward shift in the back vowel context (see table 5 and figure 5 above). It appears that their laminal articulation and the stringent articulatory requirement for their fricative part are restrictive to the coarticulatory effect of the vocalic context on their place of articulation. Laminal articulations are, generally, less sensitive to the coarticulatory effect of their phonetic context (Bladon & Nolan 1977).

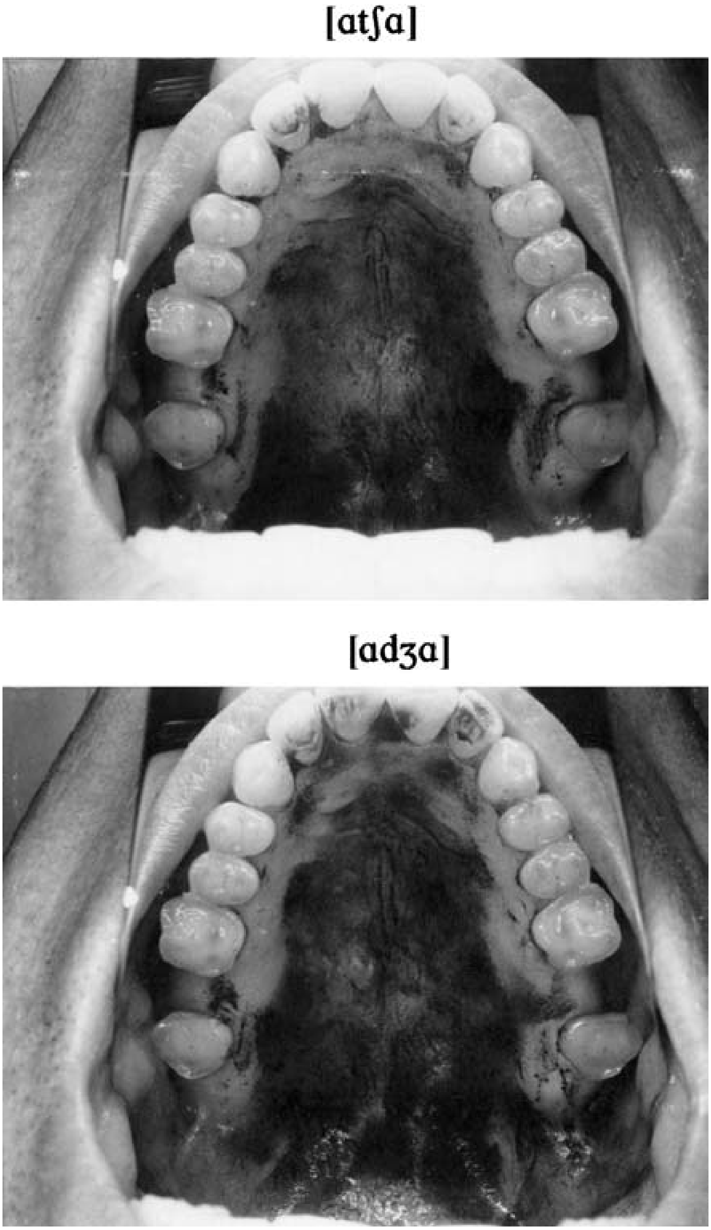


**Figure 8** Conventional direct palatogram for [tʃ] (top) and [dʒ] (bottom). Notice that the wipe off is cleaner and wider during voiceless affricate [tʃ] than during voiced affricate [dʒ].

## 5 Conclusion

It appears from the qualitative and quantitative results presented in this study and the classification tables given in Ohala (1994) and Ladefoged (2001a) that the place of articulation for the fricative [ʃ] and for the affricates [tʃ] and [dʒ], traditionally described as palatal, has

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moved forward, while for the fricatives [s] and [z], traditionally described as dental, the place of articulation has moved backward in the mouth. Several dynamic electropalatographic studies on various subgroups of Hindi consonants using three or more subjects are needed before any tangible generalizations with respect to various production parameters of Hindi consonants could be made or defensible conclusions could be derived from the experimental data.

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