DISTINCTIONS BETWEEN [t] AND [tʃ] USING ELECTROPALATOGRAPHY DATA

Sheila J. Mair (1)
Celia Scully (2)
Christine H. Shadle (1)

(1) Department of Electronics and Computer Science, The University of Southampton, Southampton SO17 1BJ, U.K.

(2) previously at Speech Laboratory, Department of Psychology, The University of Leeds, Leeds LS2 9JT, U.K.

ABSTRACT

Electropalatography data are presented for the English alveolar plosive [t] and palato-alveolar affricate [tʃ] in VCV sequences produced by an adult female speaker. Selected composite contact patterns are presented for the closure frame, the frame of maximum contact, and the pre-release and release frames. The results are discussed with particular reference to (1) place of articulation, (2) constriction shape, (3) speed of release of the articulatory closure and (4) the effects of vowel context. The data suggest that [t] has a more anterior articulation than [tʃ], though the distinction is less apparent in the initial part of the closure phase. The release appears to be faster for [t] than [tʃ], and faster for both consonants in open vowel contexts than close vowel contexts.

1. INTRODUCTION

Traditionally, the phoneme /t/ is classified as an alveolar plosive and /tʃ/ as a palato-alveolar affricate [1], suggesting that the sounds contrast in terms of place of articulation and speed of the release. Based on published physiological data, in particular X-ray tracings, Keating [2] notes that palato-alveolars are only minimally different in place from alveolars "but with the whole tongue moved back and up just a little". Evidence from both aerodynamic and acoustic studies support the presumption that the stop closure in [t] is released more quickly than in [tʃ] [3].

Previous investigations with EPG for normally speaking young and older children have shown that the place of articulation of the stop component in [tʃ] is retracted in comparison with [t] and located at a place more similar to [ʃ] than [t]. In addition, there is more tongue-palate contact for the stop in [tʃ] than for [t] [4].

Prompted by a need for some preliminary data to model the contrasts between [t] and [tʃ] using an articulatory synthesizer, EPG recordings were used to obtain information about the changing pattern of linguo-palatal contact for these sounds when preceded and followed by various vowels.

2. DATA AND METHODS

The Reading EPG3 version 1.1 electropalatograph system was used for data-logging. The acrylic EPG palate contains 62 miniature silver electrodes, 6 in the most anterior row and 8 in each of the remaining 7 rows. Within each row, the electrodes are approximately equidistant and the spacing between the front four rows is half that between the back four rows. Two channels are recorded: (1) EPG channel sampled at 100 frames/second, and (2) acoustic channel sampled at 10kHz. A studio-recorded cue-tape was used to enable the speaker to match the style and tempo of the VCV sequences recorded in other data-logging sessions, which included aerodynamic and hi-fidelity acoustic recordings.

The subject, an adult female speaker of British English, repeated the sequences [pi:'Ci:], [pe:'Ce:], [pa:'Ca:] and [pu:'Cu:] (where C = [t] or [tʃ]) on a single expiratory breath, keeping subglottal pressure as constant as possible. The stress mark ' is used here to indicate that the second vowel is longer than the first but without any pitch contrast. Typically 8 repetitions were recorded. Repetitions 2-6 were used in the analysis.

For each [t, tʃ] token, the following EPG frames were identified: (i) the closure frame, C, defined as the first frame in which there is a complete line of contacts in a single row, (ii) the release frame, R, defined as the first frame following closure in which there is not a complete line of contacts in any of the rows, (iii) the pre-release frame, PR, which is the frame directly preceding frame R, and (iv) the maximum-contact frame, M, defined as the frame between the closure and release frames with the maximum number of contacts. If two or more frames between C and R have the same maximum number of contacts, the earliest of these frames is labelled M.

3. RESULTS

For each of the frames C, M, PR and R, the linguo-palatal contact patterns for 5 repetitions of [t] and [tʃ] in each vowel context are represented as composite patterns in Figure 1.

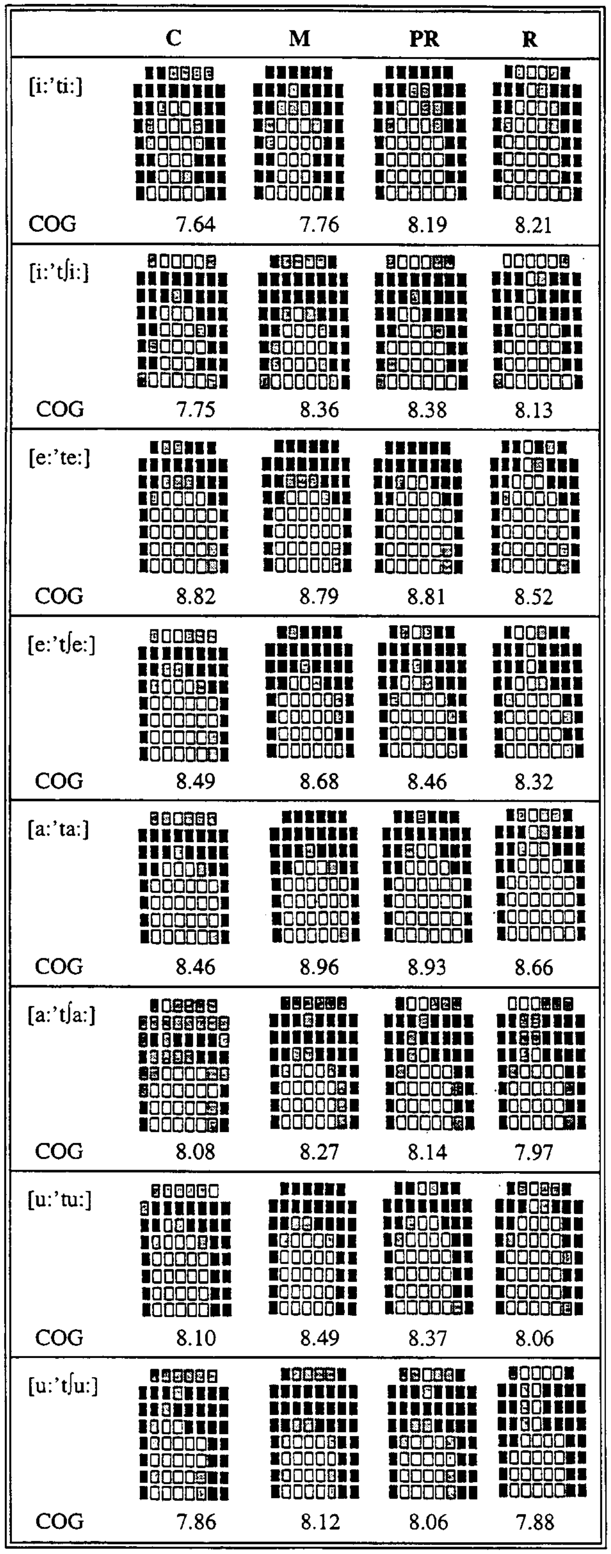

Figure 1: Composite frames C, M, PR and R respectively (see text for definitions) for [t] and [tʃ] in different vowel contexts. Mean COG values over the 5 repetitions are given below each frame.

Key

electrode contacted in all 5 repetitions

electrode contacted in 1-4 repetitions

electrode contacted in 0 repetitions

In order to quantify differences in place of articulation, "centre of gravity" (COG) values were calculated for frames C, M, PR and R, according to the following equation [5]:

$$COG = (R8x1)+(R7x3)+(R6x5)+(R5x7)+(R4x9)+(R3x10)+(R2x11)+(R1x12) / R8+R7+R6+R5+R4+R3+R2+R1$$

where R1 is the most anterior row, shown at the top of the EPG frames in Figure 1. Higher COG values indicate a more anterior tongue-palate position. Mean COG values, averaged over the 5 repetitions, are shown below each frame in Figure 1.

The rate of change in the number of activated electrodes will give some indication of the speed of movement of the tongue. Total number of contacts in rows 1-4 and in rows 5-8 for frames throughout the closure and release phases were plotted for the VCV sequences. Examples of three repetitions of [i:'ti:], [a:'ta:] and [a:'tʃa:] are shown in Figure 2. The change in contacts in rows 1-4 is likely to be most relevant for [t] and [tʃ], whose main articulation is in the alveolar/palato-alveolar region.

4. DISCUSSION

4.1. Place of Articulation

For each vowel context, the articulatory closure initially is at a similar location for both [t] and [tʃ], although a longer constriction for [tʃ] is suggested by the pattern of linguo-palatal contact. Mean centre of gravity values indicate a more posterior articulation for [tʃ] than [t], except in the [i:] context, where it is more anterior than [t] until the release frame. The posterior articulation of [tʃ] is further evidenced in the PR frames of Figure 1.

Vowel context effects are small, though consistent. The mean COG values indicate that the articulation of [t] and [tʃ] in [e:] and [a:] contexts is more fronted than in [i:] and [u:] contexts, although there is some overlap in the individual scores. This result may be partially explained by the greater number of contacts along the lateral edges of the back rows in the case of [i:] and [u:]; the tongue is more strongly anchored to the palate in readiness for articulating these close vowels.

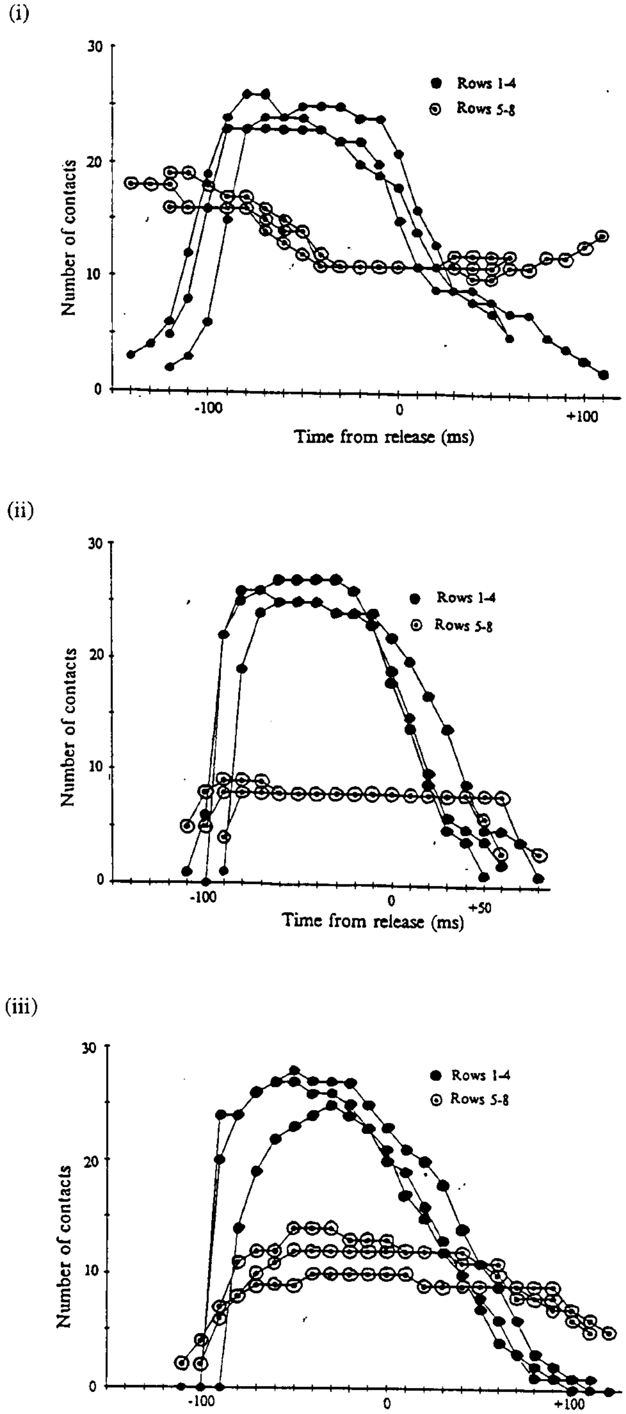

Figure 2: Number of front (rows 1-4) and back (rows 5-8) contacts for 3 repetitions of (i) [i:'ti:] (ii) [a:'ta:] and (iii) [a:'tʃa:], aligned at frame R (release = 0 ms).

4.2. Speed of Release

During the closure, the pattern of contact usually changes continuously, indicating that there is not a completely static tongue configuration for either consonant. This is consistent with X-ray data for stops in VCV contexts, which show that the movement of the tongue body continues even after the tongue tip has made a complete occlusion [6]. The number of front contacts for [t] tends to be maintained at a fairly steady maximum for about 50ms or so, while the contacts for [tʃ] begin to be released almost immediately after a maximum is reached (see Figure 2). It may be that the [tʃ] articulation needs to have a particular constriction shape at the time of release of the closure, so the tongue adjusts for the fricative segment during the stop segment. For [t], a fast release of the oral closure may be more crucial than the shape of the constriction at the release, so that once a complete closure has been made, the tongue configuration remains fairly stable until the release.

Following the release, [t] very quickly becomes unconstricted, while for [tʃ], a constriction remains at rows 2, 3 and 4 for several frames. In the later part of the release, the [t] repetitions have a small number of contacts (less than 5) earlier than [tʃ]; for both [t] and [tʃ] this (arbitrary) threshold is reached earlier with the open vowels [e:] and [a:] than with the close vowels [i:] and [u:]. This is consistent with constriction area estimates made from aerodynamic data for 10 adult English speakers [3], which also indicated a faster articulatory release for [t] than [tʃ], and a faster release in open than close vowel contexts.

4.3. Constriction Shape

Representative [i:'ti:] and [i:'tʃi:] examples are chosen to illustrate some possible differences in the shape of the constriction for the plosive-affricate pair. Figure 3 represents a mid-sagittal view of the constriction at frame PR, just before the release of the closure. [t] has a complete closure at row 1. The contacts at rows 2, 3, and 4 show that the constriction widens quite rapidly for distances further back along the palate. For [tʃ], there is complete contact at rows 2 and 3; row 1 is relatively unconstricted, while row 4 is relatively constricted. The area behind the constriction opens out quite sharply for [t] but is more tapered for [tʃ]. The more domed tongue shape for [tʃ] compared to [t] is consistent with physiological evidence reviewed in the literature by Keating [2].

Since the tongue tip does not make much contact with row 1 for [tʃ], it will probably be lower than the tongue at row 2, so that as the constriction is released, the airflow is directed down towards the lower teeth. The linguo-palatal contact either side of the constriction for both [t] and [tʃ] ensures that the air cannot escape laterally. The closure at row 1 for [t] suggests a high tongue-tip position, indicating that the jet of air emerging from the constriction at the release is more likely to hit the upper teeth. This supports evidence in the literature that the direction of airflow is likely to vary for different consonants. For example, Shadle [7] concludes that for the fricative [ʃ] the obstacle appears to be the lower teeth, while for [s] the obstacle is possibly the upper rather than the lower teeth.

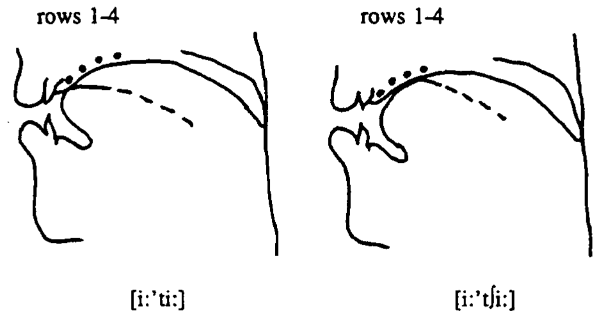

Figure 3. Midsagittal view of [i:'ti:] and [i:'tʃi:], based on evidence from EPG data just prior to the release of the closure.

5. CONCLUSIONS AND FUTURE WORK

Within each vowel context, the closure portion of [tʃ] is slightly posterior to [t], except in an [i:] context for which there is some overlap. This is consistent with other EPG data for English [4]. The constriction has a greater length and is released more slowly for [tʃ] than [t]. For both [t] and [tʃ] in open [e:] and [a:] vowel contexts, the constriction tends to be further forward than in the close [i:] and [u:] vowel contexts, and is released more quickly.

Stevens [8] models the articulation of [tʃ] with a two-part constriction; the anterior section forms the closure, and the posterior section forms the fricative constriction. Here, for [u:'tʃu:], contacts in rows 2, 3 and 4 form the main articulatory closure, and rows 2, 3 and 4 seem to form the constriction for the fricative following the release. A similar pattern is found with rows 2 and 3 for [i:'tʃi:]. The data here suggest that the affricate may be modelled as one long constriction, the whole of which is involved firstly in the initial closure and later in the constriction associated with the fricative segment.

Clearly, data for further speakers is needed. Variability in palate shapes and sizes will affect the strategies used to produce the [t]-[tʃ] contrast.

A severe limitation of the electropalatography method is the lack of information about the tongue shape. More direct estimates of articulatory dimensions, areas and shapes may be possible in the future using a combination of data from ultrasound imaging [9] and enhanced electropalatography [10].

Shockey and Gibbon [11] recorded simultaneous EPG and aerodynamic data for four English speakers and found that there was not always alignment between the closure as defined by EPG contacts and the closure defined by zero airflow. Simultaneous recordings of EPG, aerodynamic and high-fidelity acoustic data, though experimentally difficult, would be invaluable for determining the correspondence between the articulatory constriction shape, the aerodynamic conditions in and around the constriction, and the resulting acoustic output.

Acknowledgements

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