LIQUIDS IN TAMIL

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ABSTRACT

Tamil is unusual among the world's languages in that some of its dialects have five liquids. This paper focuses on the articulatory characterization of these sounds, with the ultimate goal of modeling their production dynamics and articulatory-acoustic mappings. Articulatory data were obtained using different techniques: palatography, magnetic resonance imaging (MRI), and magnetometer (EMMA). This study illustrates the use of multiple techniques for investigating both static and dynamic articulatory characteristics.

1. INTRODUCTION

Currently available articulatory information on speech sounds such as liquid consonants is far from adequate. Advanced technologies such as MRI and EMMA now enable detailed investigations of complex speech sounds.

Some dialects of Tamil have five voiced liquids. Two of these can be described as rhotics, one being dental (or at least pre-alveolar), [r], and the other being post-alveolar, [ɽ]. Another two are clearly laterals, one being dental, [l], and the other being retroflex [ɭ]. The fifth has been variously described, with the general notion being that it is some form of rhotacized-lateral approximant, [ɻ]. This paper focuses on the articulatory analysis of these sounds, using three techniques not previously jointly employed.

2. METHODOLOGY

Articulatory information was obtained using MRI, EMMA, and static palatography techniques from one native male speaker of the Brahmin dialect of Tamil (SN).

<u>MRI:</u> Information about the 'static' vocal-tract shapes came from MRI scans at contiguous 3 mm intervals in the sagittal and coronal anatomical planes, which allowed three dimensional views of the vocal tract to be constructed in a computer representation. Measurements of vocal tract length, area functions, and cavity volumes were also obtained. The subject, in a supine position in the scanner, produced each consonant preceded by '*pa*' (i.e., /*paC*/) and continued sustaining the final consonant for about 13 s enabling 4 contiguous image slices to be recorded (3.2 s/slice). The above procedure was repeated until the entire vocal tract region was covered. Details of image acquisition and analysis are similar to those given in [1].

<u>EMMA:</u> The EMMA magnetometer system provides articulator movement tracking using a set of transducers typically mounted on the lips, upper and lower teeth, tongue tip, and tongue body [2]. EMMA data provide valuable dynamic information but are restricted to the midsagittal plane of the vocal tract. The speech material comprised Tamil words that provided each of the five liquids in the following phonetic contexts: /*kaCi, paCi, vaC, aCai, paCam*/ where $C = \{$l, ɭ, ɻ, r, ɽ$\}$. Of the 25 words, three were nonsense words. Three parallel meaningful words were also included in the corpus yielding a total of 28 words. Ten repetitions of each word, embedded in the carrier phrase "*Andha vakyam* —— *perusu*" (The phrase —— is big), were recorded in a pseudo-random order. Simultaneous audio recordings were also made. Since the primary focus of this paper is to characterize vocal tract/tongue shapes, the EMMA data analysis is restricted to a qualitative discussion of the articulators' positions and movements.

<u>Palatography:</u> Static palatography is used to register graphically the contact of the tongue with the palate, alveolar ridge and inner margins of the teeth [3]. Carbon powder is coated on the tongue surface prior to speaking, and after articulation the resulting contact patterns on both the tongue and palate are captured with video imaging. A subset of the words used for the EMMA recording (without the carrier phrase) were used for palatography. The resulting (video) palatograms and linguograms provide data that are useful in inferring tongue shapes. This method records any and all palatal areas at which lingual contact occurred.

In summary, each of these techniques has its advantages and disadvantages. MRI scans require artificial prolongation of the sound but they provide information on the shape of the vocal tract not obtainable by other methods. Static palatography measures the aggregate articulatory contact throughout an utterance but does show fairly precisely what part of the tongue touched what part of the palate. EMMA recordings provide valuable dynamic information but are restricted to tracking a few points along the midsagittal plane. Nevertheless, together the articulatory data available from all three techniques enable us to obtain an increased understanding of vocal tract and tongue shape mechanisms.

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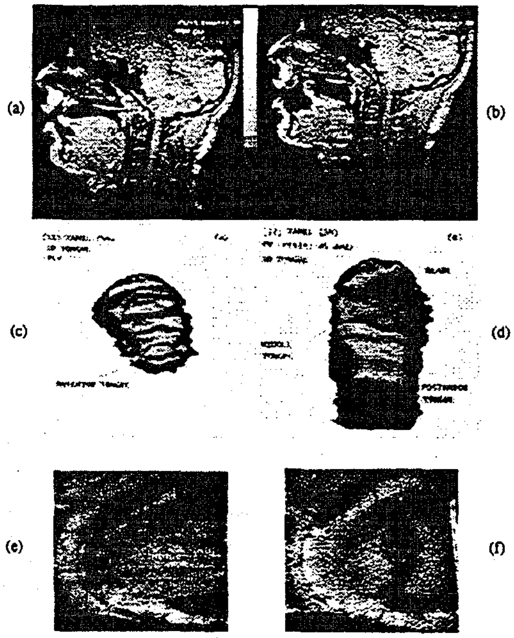

Figure 1: Midsagittal images: (a) l (b) ɭ. 3D tongue shapes: (c) l (anterior view, tongue tip toward lower right of the panel) (d) ɭ (posterior view with a forward tilt of 35°, tongue tip toward top of the panel). Linguopalatal contact (dark region, front of the mouth is toward the left): (e) l (f) ɭ.

3. DATA ANALYSIS

Traditionally, observations made along the midsagittal plane of the vocal tract have been used to deduce structural articulatory information. In particular, relative positions of the various articulators were studied and quantitative information on tongue shapes and area functions was derived fairly successfully, particularly for vowels. The analysis of sounds such as liquid consonants that are characterized by more complex vocal tract shapes require a fair amount of information from additional sources.

Midsagittal MRI scans for the five (artificially sustained) Tamil liquids are shown in Figs. 1-3. For the laterals, these figures show us that (1) [l̪] is characterized by tongue-tip contact in the dental region, a somewhat high posterior tongue body position, and retraction of the tongue root towards the posterior pharyngeal wall (Fig. 1a). (2) The anterior tongue body for [ɭ] (Fig. 1b) and [ɻ] (Fig. 2a) is drawn upwards and well inside the oral cavity, with the narrowest tongue constriction appearing in the palatal region. Although the place of constriction and the overall midsagittal tongue shapes for [ɭ] and [ɻ] appear very similar, the anterior-to-posterior tongue surface sloping is more gradual for [ɭ]. In the case of rhotics, (1) The overall midsagittal tongues shapes for [r] and [ṟ] are very similar (Figs. 3a-3b). (2) The region of tongue tip constriction in [r] is generally more anterior than in [ṟ]. (3) The posterior tongue body for [r] is somewhat higher than for [ṟ].

Studying tongue-palate interactions by means of palatography in conjunction with the midsagittal MR images provides important information. [l̪] is apical, characterized by medial tongue tip closure at, and behind, the central incisors and lateral contact in the postpalatal/velar region (starting near the first molar). Although these patterns suggest lateral airflow paths in the anterior region, prediction of actual cross-sectional tongue shapes and area functions is not straightforward. [ɭ], on the other hand, is sub-apical with contact made along the edge of the underside of the tongue in the palatal region. It should be noted that [ɭ] in syllable-initial cases occurs as a flap, and often may not involve complete (subapical) palatal *contact* (closure) in fluent speech. In cases where there is complete linguopalatal contact for [ɭ], such as in syllable final position, the anterior contact pattern is more extensive (laterally) when compared to [l̪]. This reflects basic differences in the tongue shaping involved in the creation of lateral airflow channels. Although [ɻ] appears similar to [ɭ] in the midsagittal plane, the linguopalatal contact profiles are quite distinct. [ɻ] shows subapical approximation but no medial contact. There is, however, lateral contact made with the tongue body middle in the palatal region (extending for about 1 cm). In the case of the rhotics, which are both apical, the available tongue-palate contact profiles are not very instructive although the presence of lateral linguopalatal bracing in the palatal region indicates a role in their tongue shaping (see Sec. 4). Example tongue-palate interactions for the Tamil liquids [l̪], [ɭ] and [ɻ] are given in Figs. 1e, 1f, and 2b, respectively.

Cross-sectional MRI scans were used to obtain a better understanding of the 3D vocal tract and tongue shapes. However, since MRI scans provide only 'static' information, EMMA data for liquids in natural speech were used for 'dynamic' information. Since the narrowest oral constriction for all these liquids was made with the tongue tip, a plot of the tongue tip position (height relative to the occlusal plane) provides a useful way of comparing the five liquids (Fig. 4). The tongue tip position data for each liquid suggest consistency in the articulatory configurations across different contexts. Furthermore, the data obtained from sustained utterances (MRI) and from naturally spoken words (EMMA) are found to be consistent. (Although not shown in these figures, spectrographic analysis indicated intra-token articulatory stability for the sustained utterances).

The place of articulation analysis across the five liquids (from Fig. 4) showed (1) Dental place of articulation for [l̪], pre-alveolar for [r], (post)alveolar for [ṟ], and palatal for [ɭ] and [ɻ]. (2) Tongue tip position for [ɭ] and [ɻ] are similar, although there is more variability across contexts in [ɻ]. (3) Tongue position for [ṟ] tends to be more posterior when compared to [r], although there is a region of overlap. (4) The tongue tip for [r] and [ṟ] does not achieve medial closure. (Note in Fig. 4 that the [r] and [ṟ] tongue tip positions are in the same vertical plane as that for [l̪]).

Analysis of the 3D shapes was made possible through computer reconstruction of the cross-sectional scans. 3D tongue shapes for the Tamil liquids are shown in Figs. 1-3.

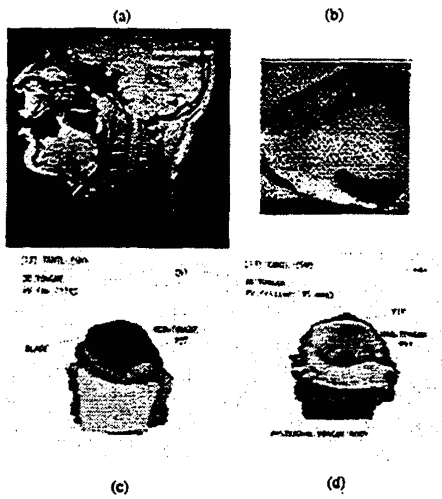

Figure 2: ɻ (a) Midsagittal image. (b) Linguopalatal contact profile (dark region, the front of mouth is toward the left). (c) 3D tongue shape (posterior view, tongue tip is toward the upper middle). (d) 3D tongue shape (posterior view, 45° front-to-back tilt of the tongue body).

For [l̪], the anterior tongue body surface is flat due to the dental contact, but the general tongue surface contour is convex (Fig. 1c). The curved sides of the posterior tongue body also suggest inward-lateral compression towards the midsagittal plane, a mechanism that facilitates airflow along the sides of the tongue. For [ɭ], the anterior tongue body is raised upwards and is at about 120 degrees to the posterior tongue body (Fig. 1d). The anterior tongue body surface is flat and slopes rather gradually towards the posterior side. The posterior tongue body surface is convex, and the lateral edges are curved to enable lateral airflow. The tongue body shape for [ɻ] is quite distinct from those of [l̪] and [ɭ]. The upward-raised and inward-pulled anterior tongue body creates a pit-like cavity in the middle tongue body (Fig. 2c-2d). The lateral bracing of the middle tongue with the palate facilitates maintaining this "cavity" in the middle tongue region. On the other hand, the posterior tongue body surface, with no lateral linguopalatal bracing, shows a somewhat flat, or at least less concave, surface. As a result, the areas posterior to the place of narrowest constriction are much greater in [ɻ] when compared to [ɭ]. When compared to [ɭ], the tongue shaping mechanisms for [ɻ] are more complex involving lateral bracing of the mid-tongue body against the palate. The tongue shapes for [r] and [r̠] are quite similar (Figs. 3c-3d). The overall tongue surface is slightly concave/flat and curves gradually towards the posterior pharyngeal wall. The anterior tongue body appears to extend more anteriorly in [r̠] when compared to [r]. The posterior tongue body has a somewhat higher position in [r] than in [r̠].

Observations from of the articulator (EMMA transducer) movements provided further contrasting characteristics among the liquids. Both [ɭ] and [ɻ] showed a more rapid movement towards closure position, with the tongue tip making the greatest displacement in and out of the closure. Furthermore, [ɭ] shows greater, and faster, back-front displacement, after the closure, in prevocalic positions (flapping). In postvocalic position, [ɭ] and [ɻ] show the least narrow constrictions (Fig. 4). The narrowest constriction location is generally more anterior in [ɻ] when compared to [ɭ], and also shows greater variability across contexts. This suggests that the critical articulatory property of [ɻ] is that of tongue shape rather than constriction location. In the articulation of [ɻ] we observe relatively inconsistent constriction locations, however, the tongue shape invariably involves lateral linguopalatal bracing at the mid tongue. The (clockwise) movement pattern of the tongue tip in and out of the closure in [ɭ] and [ɻ] indicates that the displacement in the x-direction (location) attains its maximum value before the displacement in the y-direction (height). The movement patterns for [l̪] were less circuitous when compared to [ɭ] and [ɻ]. Among the laterals, the greatest coarticulatory effects are noticeable in [l̪] (particularly, in /a_i/ context greater velarization was observed). Both [r] and [r̠] exhibited simple, and similar, (counter-clockwise) movement patterns in and out of the closure position.

4. DISCUSSION AND SUMMARY

These data demonstrate that tongue shaping is the primary difference among these five liquids. The vocal tract shapes for the Tamil liquids are primarily influenced by the tongue shaping. A comparison of [l̪], [ɭ], and [ɻ] shows increasing order of complexity in their tongue shapes. The convex tongue body shape, lateral linguopalatal contact, and tendency for inward-lateral compression of the tongue body of Tamil [l̪] are very similar to that observed for /l/ of some American English (AE) talkers [4]. In addition, the high position of the posterior tongue body and retracted tongue root are similar to the dark [l] of some AE talkers. The posterior tongue body behavior results in a lowering of the F2 (back cavity resonance) value. The mechanisms of [ɭ] production are very similar to those of [l̪]: an oral constriction along the midsagittal line, lateral channels along the sides of the tongue, and convex posterior tongue body surface facilitating lateral airflow. However, the medial oral constriction occurs in the palatal region, creating a large front-cavity volume that results in lowering the front-cavity resonance. The anterior tongue is forced to curl backwards to create a (subapical) constriction at a rather posterior location in the oral cavity. The raising of the anterior tongue also results in a concomitant lowering of the posterior tongue body. It is interesting to note that [ɭ] may be produced without a complete oral lingual closure, similar to productions of dark [l] in some AE talkers [4]. The absence of complete closure may be interpreted as an instance of articulatory undershoot [5] wherein the articulator does not attain the final 'target' value.

The production of [ɻ] shares some common features with [ɭ] in that they are both subapical with the oral constriction appearing in the same general palatal region, and that the raised anterior tongue is accompanied by a lowered posterior tongue. The main difference in the tongue shaping, however, is in the creation of a pit-like cavity in the middle tongue region for [ɻ]. This is fundamentally due to the differences in the linguopalatal bracing: in [ɻ], the sides of the middle tongue are braced against the palate creating the middle-tongue cavity, while the lateral contact found in [ɭ] is due to the lateral edges of the underside of the curled anterior tongue touching the palate. The bilateral linguopalatal bracing however impedes or prevents rapid (forward) movement (unfurling) of the anterior tongue when released out of the retroflex position and hence is not prone to flapping as seen in (syllable-initial) [ɭ]. Furthermore, unlike [ɭ], there is no medial oral closure in [ɻ] and there is central airflow. As a result, the back-cavity volume in [ɻ] is greater than in [ɭ] yielding a relatively lower value of F1 (Helmholtz resonance). In these respects, [ɻ] is similar to /r/ produced by some AE talkers. Specifically, AE /r/s that are produced with more posterior oral constrictions are associated with a relatively large back cavity volume created by greater concavity in the shaping of the posterior tongue body.

The tongue shapes of [r] and [r̠], on the other hand, are relatively simple: raised tongue-tip (apical) constriction, gradually lowered tongue body in the antero-posterior direction, and slight concavity of the surface. There is also a notable sublingual contribution to the front cavity volume. The main structural differences between [r] and [r̠] are that the tongue tip is further back in [r̠] when compared to [r], with a relatively lower posterior tongue body height (Fig. 3). As a result, acoustically, the front cavity resonance can be expected to be lower for [r̠] when compared to [r]. The concomitant posterior tongue body lowering tendency in [r̠], on the other hand, would result in a relatively higher F2 value. A comparison with the /r/s in English shows that the tongue shapes of Tamil rhotics can be characterized as members of the same continuum of possible tongue shapes suggesting generality in /r/ production mechanisms [4].

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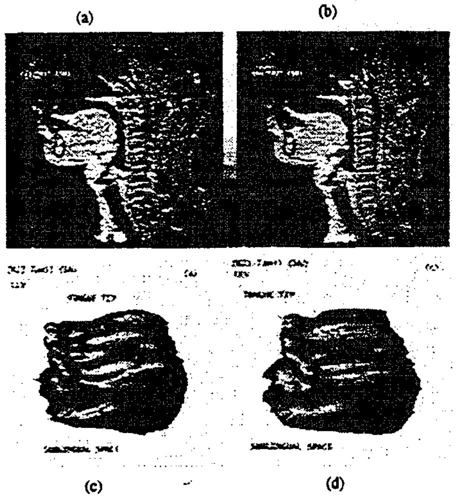

Figure 3: Midsagittal images: (a) r̠ (b) r. 3D tongue shapes (tongue tip toward the left of the panels): (c) r̠ (d) r.

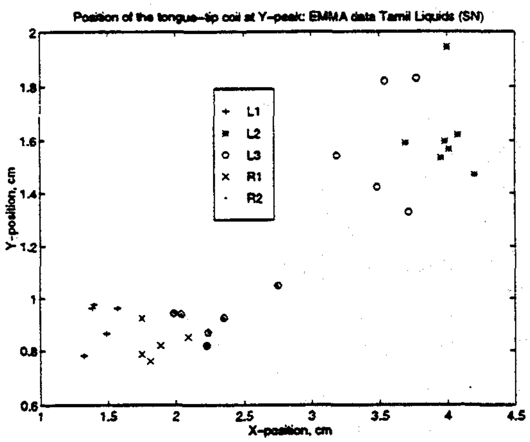

Figure 4: Tongue tip position with respect to the occlusal plane at the point of narrowest constriction (EMMA data). Legend symbols: L1 - l, L2 - ɭ, L3 - ɻ, R1 - r, R2 - r̠.

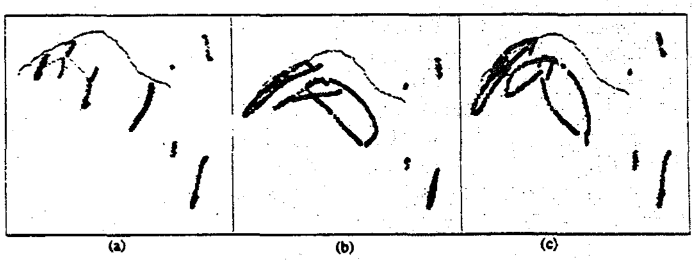

Figure 5: Position trajectories for the articulator transducers: (a) l (b) ɭ (c) ɻ. The segment displayed is for the duration between the points of minimum tongue tip height preceding, and following, the point of maximum tongue tip height (i.e., narrowest constriction). The rightmost transducers in each panel correspond to the upper and lower lip while the leftmost transducers correspond to the tongue dorsum. An approximate palatal trace is superimposed for reference purposes.