AN ARTICULATORY STUDY OF LIQUID APPROXIMANTS IN AMERICAN ENGLISH

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ABSTRACT

Articulatory patterns of the liquid approximants in American English are analyzed through MRI and EPG. MR images of the vocal tract during sustained productions of /l/ (both dark and light allophones) and /r/ (word-initial, syllabic, bunched, and retroflexed) by 4 subjects are used for quantitative and qualitative analyses of the 3D vocal tract geometry and tongue shapes. EPG contact profiles are used for studying inter- and intra-speaker variabilities in linguapalatal contact patterns.

INTRODUCTION

Articulatory patterns of the liquid sounds /l, r/ in American English are analyzed through magnetic resonance imaging (MRI) and electropalatography (EPG). MR images of the vocal tract during sustained productions of the lateral sound /l/ (both dark [ɫ] and light [l] allophones) and the rhotic approximant /r/ (in word-initial and syllabic positions, and the bunched and retroflexed allophones) are used for measuring vocal-tract lengths, area functions, cavity volumes, and for the analysis of the 3D vocal tract and tongue shapes. EPG contact profiles are primarily used as a source of converging evidence for the results of the MRI study and for studying inter- and intra-speaker variabilities in linguapalatal contact patterns.

TECHNIQUES

The sounds were produced in a neutral vowel context by 4 phonetically-trained subjects (2 males: MI, SC and 2 females: AK, PK). MR images were collected using a GE 1.5 Tesla SIGNA machine under a fast SPGR protocol with 3 mm image slice thickness and no interscan spacing in the coronal, axial, and sagittal planes. The subjects, in supine position, sustained each sound for about 13-16 s enabling four to five image slices to be recorded (about 3.2 s/image/plane). Analysis techniques are similar to those described in [1]. EPG data were collected using a Kay palatometer that employs an acrylic pseudopalate, custom-fit for each subject, with 96 sensing electrodes. The sweep rate of the system was 1.7 ms and the sampling period, 10 ms. Eight repetitions of each sound were recorded with the subjects in both supine and normal sitting positions.

RESULTS

Lateral approximants: MR images for both [l] (as in the word 'led') and [ɫ] (as in 'bell') indicate that the *mid-sagittal* tongue shapes can be different across subjects. Common characteristics, however, are revealed in cross-sectional and 3D tongue shapes, area functions, and linguapalatal contact profiles. These sounds are characterized by a lingual occlusion or, just a constriction as observed in the [ɫ] of one subject. The occlusion location is 1.0-1.5 cm away from the lip opening and the occlusion length, 0.5-1.0 cm in the alveolar region with relatively small openings (ranging in area between 0.1-0.8 cm^2) around both sides of the occlusion. The side '*lateral channels*' begin appearing from where the alveolar occlusion/constriction is seen and continue posteriorly until the lingua-velar contact is established (i.e. lingual contact with the roof of the oropharynx in the velar region which is about 5-6 cm from the lip opening). The right and left channels appear to be, in general, unequal and their areas start increasing behind the alveolar occlusion (due to inward lateral compression of the tongue body) and start decreas-

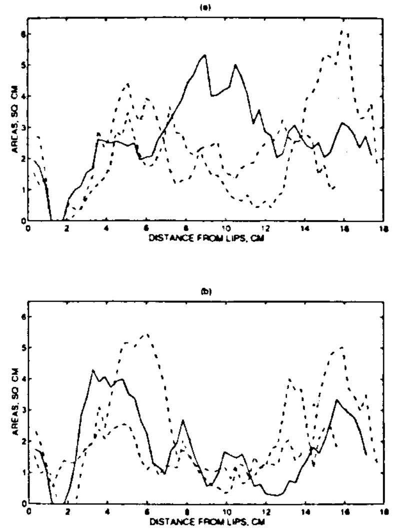

Figure 1: *Area functions, in cm^2, for different subjects: solid (AK), dashed (PK), dot-dashed (MI), dotted (SC). Top panel: [l], bottom panel: [ɫ]. The abscissa for the area functions are distances (in cm) from the lip opening.*

ing again as the lingua-velar contact is approached. Area functions calculated along the midline of the vocal tract are shown in Fig. 1. Note that the lateral areas in the region of medial occlusion are not shown in this figure.

The linguapalatal contact associated with the alveolar occlusion extends laterally into the palatal region, the degree of which varies between the light and dark variants with [l] exhibiting less lateral contacts. The articulations of subjects MI and SC were apical while those of subjects AK and PK were laminal. The extent of the lateral linguapalatal contact also appears to depend on the apical or laminal nature of the articulation, with the laminal articulations exhibiting a more extended contact than the apical ones.

The cross-sectional tongue shapes immediately behind the medial linguoalveolar occlusion appeared either flat or slightly 'concave' (particularly until the disappearance of the lateral linguapalatal contacts). The concave shape was mainly due to a 'grooving'

Figure 2: *Lateral perspective of the 3D tongue shape: [ɫ] (subject SC).*

tendency along the mid-sagittal line. Analysis of the 3D tongue shapes, however, revealed that the general tongue body shape behind the occlusion tends to be convex. A sample 3D tongue shape is shown in Fig. 2 for [ɫ] of subject SC. The 3D tongue shapes indicate that the posterior tongue body shows a tendency towards an *inward lateral compression* which is directed towards the mid-sagittal plane. This enables the creation of lateral flow channels in the space between the curved sides of the tongue body and the teeth. The anterior medial grooving observed in the laterals, which is less prominent than that observed in alveolar sibilants such as /s/ [1], is attributed to the inward compression of the posterior tongue body. Unlike alveolar fricatives, the grooving does not continue through the posterior tongue region as a concave surface, suggesting that it is not a key component of a medial airflow channel. Hence, the modification of the tongue body contour, in terms of surface flattening and/or grooving, observed in some portions of the tongue surface for some subjects, is *not* a primary articulatory characteristic satisfying an aerodynamic constraint, but merely represent secondary effects of the linguapalatal bracing and the lateral contraction of the posterior tongue body.

The merging of the lateral channels with the central opening along the palatal region results in crescent-shaped cross-sections and relatively large area values (Fig. 1). The extent of the lateral flow component in the palatal region behind the linguoalveolar occlusion is limited by the extent of the linguapalatal contact behind the occlusion: [l] typically reveals more lateral contact than [ɫ], thus explaining the smaller area function values in the palatal region consistently observed in [l] when compared to [ɫ]. The back region areas for [l] show significant intersubject variability: the areas of the upper pharyngeal/uvular region are much smaller for subjects MI and SC due to a slightly raised and retracted posterior tongue body, perhaps a result of their apical articulation. In the case of [ɫ]s, on the other hand, all subjects reveal decreased areas in the upper pharyngeal/uvular regions due to a significant retraction of the tongue root and/or raising of the posterior tongue body. In addition, the effect of this upper pharyngeal 'constriction' is found to extend either as far as the velar/uvular region or through the entire lower pharyngeal region depending on the particular part of the tongue body actively involved in the constriction formation: either the upper-part of the tongue root (together the posterior/dorsal tongue body) or the entire tongue root. These results indicate that velarization, which is typically associated with /ɫ/, is not a consistent characteristic across speakers although decreased pharyngeal areas, when compared to those of /l/, is a consistent feature for all subjects.

The linguapalatal contact profiles from the EPG data were consistent with the observations of the MRI data. In addition, the differences between the articulations in the supine and upright positions, in general, were not significant. Left-right asymmetry in relative tongue positions and linguapalatal contacts were found only for subjects AK and PK; subject PK exhibited consistent asymmetry in the postpalatal/velar region with greater right-side linguapalatal contact while that of subject AK was not consistent.

Rhotic approximants: During the production of the American English /**r**/, the vocal tract appears to be characterized by three cavities due to the presence of two distinct supraglottal constrictions. The primary constriction occurs in the buccal cavity and the secondary constriction, in the pharyngeal cavity. A sample 3D vocal tract of /**r**/, by subject SC, and the 3D tongue shape associated with it are shown in Figs. 3 and 4 , respectively. The buccal constriction may arise anywhere in the palatal region: the more forward ones are typically due to a raised anterior tongue and the posterior ones, due to a raised dorsum. For our subjects, the buccal constriction begins 2.4-4.8 cm away from the lips and extends over 1.5-2 cm with minimum areas anywhere in the range of 0.25-0.7 cm^2. The secondary constriction occurs typically in the mid-pharyngeal region due to an advanced tongue root ('pharyngealization'). Analyses indicate that a more anterior buccal constriction is associated with a more superior pharyngeal constriction. A large volume anterior to the buccal constriction arises due a tongue body that is drawn inwards. The anterior tongue body is characterized by convex cross-sections.

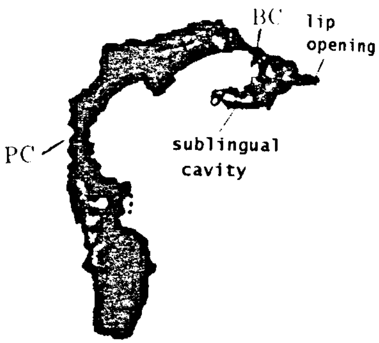

Figure 3: *Lateral perspective of the 3D vocal tract: 'word-initial' /***r***/ (subject SC). BC refers to the buccal constriction and PC refers to the pharyngeal constriction.*

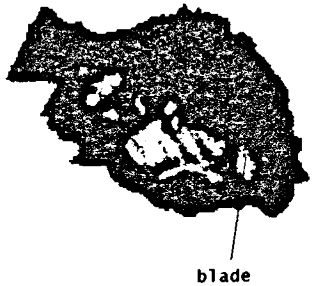

Figure 4: *Lateral perspective of the 3D tongue shape: 'word-initial' /***r***/ (subject SC).*

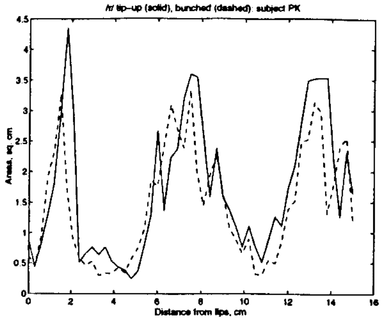

Figure 5: *Area functions for subject PK's /***r***/: 'retroflex' (solid), 'bunched' (dashed). The axes are similar to Fig. 1.*

Similarly, a large volume posterior to the buccal constriction (and superior to the pharyngeal constriction) is created by a significantly lowered posterior tongue body that exhibits a prominent concave shaping. The change in the cross-sections, from the convex anterior shapes to the more concave posterior shapes, appears to be more abrupt for the buccal constrictions that are at a more posterior location in the front region, resulting in more abrupt changes in the area functions. Variabilities in the details of the relative cavity sizes and their locations, which largely depend on the individual subject's articulation patterns and oral morphology, are expected to introduce variabilities in the corresponding acoustic patterns.

Subjects AK and MI produced /**r**/s as they would appear in 'word-initial' and 'syllabic' positions while subject PK produced deliberately /**r**/s with the tongue tip curled up ('retroflex' /**r**/) in one case and the dorsum bunched ('bunched' /**r**/) in the other (both varieties occur in PK's speech). Subject SC produced only the 'word-initial' version. Comparison of the bunched and retroflex /**r**/s produced by subject PK revealed that, in spite of the raised tongue tip in the latter case, the primary buccal constriction is attributed to a raised dorsum in both cases, and a three-cavity vocal tract description still holds. Area functions calculated along the midline for the bunched and retroflexed /**r**/ for subject PK are shown in Fig. 5. The minimum constriction is found at a more posterior location for the retroflex /**r**/ and the areas in the constriction region tend to be slightly larger than the bunched /**r**/ due to a relatively flatter tongue cross-sectional surface. The areas anterior to the buccal constriction tend to be larger for the retroflex /**r**/; the anterior cavity volume was 4.5 cm^3 for the bunched /**r**/ and 6.1 cm^3, for retroflexed /**r**/. The areas behind the buccal constriction were similar for both the bunched and retroflexed cases (Fig. 5). EPG contact profiles, which are restricted to the lateral postpalatal regions, were similar for both cases. Asymmetry was found in subject PK's palato-velar region with a more right-side favored linguapalatal contact observed in both the MRI and EPG data.

For the other subjects, the general tongue body shapes and area functions appeared very similar for the /**r**/s in both word-initial and syllabic positions although syllabic /**r**/s tend to show larger areas in the cavity between the buccal and pharyngeal constrictions. The buccal constriction in the /**r**/s of subjects AK and MI, in both word-initial and syllabic cases, were produced with a raised dorsum resulting in a tongue body shape resembling a canonical bunched /**r**/. The /**r**/ of subject SC, on the other hand, was produced with a raised anterior tongue body, rather than a raised tongue tip, resulting in a more anterior, and shorter, buccal constriction when compared to those seen in the other subjects.

As in the case of the lateral approximants, the EPG contact profiles revealed no systematic differences between the articulations in supine and upright positions.

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REFERENCES

[1] S. Narayanan, A. Alwan, and K. Haker. "An MRI study of Fricative Consonants," *ICSLP '94 Proc.* pp. 627-630. A full-version of this paper will appear in *JASA*, July, 1995.