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Cinefluorographic Study of Selected Allophones of English /l/

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Abstract. The purpose of this cinefluorographic study of a number of allophonic variations of English /l/ was to describe the articulatory characteristics of these variations and to assess factors which may be responsible for the variations. Three subjects produced a speech sample containing English words and phrases while the high speed cinefluorographic films were made. The observed variability centered around two allophone groups, the pre-vocalic and the post-vocalic, having different articulatory characteristics. The pre-vocalic productions showed a more anterior lingual position and faster speed of movement than was observed for the post-vocalic group. Consequently, the pre-vocalic allophones showed no undershoot of the anterior lingual contact, while the post-vocalics did show undershoot of this position. The syllabic /l/ productions displayed lingual configurations like the post-vocalic group and movement characteristics like those shown when /l/ is articulated in a pre-vocalic cluster. Variation within the three major allophone groups can be explained within current concepts of coarticulation and articulatory undershoot.

Introduction

Much has been learned in recent years about the articulatory characteristics of speech. Acoustic and articulatory studies of speech sound production suggest that the articulators move toward a target position appropriate for the production of a sound with characteristic speed and direction when the neuro-motor commands specific for that sound are issued [6, 11–13, 15, 17, 18, 21, 24]. Variation in articulatory position achieved can occur due to mechano-inertial factors or to the phenomenon of 'coarticulation' [5, 18, 20].

One English phoneme for which considerable allophonic variation has been suggested is /l/. Although a number of authors [1, 2, 9, 26, 28, 29] provide phonetic descriptions of the allophones of /l/ in articulatory terms, such descriptions appear to be based only on gross introspective observations. The only extensive empirical descriptions of /l/

come from the acoustic data of LEHISTE [16]. She found that three types of productions of /l/, initial and final in monosyllables, and syllabic productions, were acoustically different. In addition, acoustic characteristics for /l/ were found to vary as a function of morphemic boundaries; for example, the /l/ in the word 'freely' had formant frequency values like an initial /l/, and the /l/ in 'mealy' was like a final /l/. There are no extensive data on the articulatory correlates of the acoustic variations reported by LEHISTE [16].

The purposes of this study were to describe certain articulatory characteristics of selected allophones of /l/ in English and to assess the factors which lead to articulatory variability for this sound. The production of /l/ was examined in the following contexts and conditions: as a pre-vocalic and post-vocalic element in words, its articulation as a function of morphemic boundary, in consonant clusters, as a syllabic consonant, and in relation to durational factors such as increased rate of utterance.

Procedures

Subjects and Filming Procedures

Three normal adult speakers served as subjects. Each produced the entire speech sample while high-speed, lateral-view cinefluorographic records were taken. All of the subjects were natives of the midwestern United States and all were judged to possess a dialect typical of that region.

The cinefluorographic apparatus utilized was manufactured by the North American Philips and has been described previously by KENT and MOLL [11]. Films were taken at 150 frames per second, resulting in an interframe sampling interval of 6.7 msec. During the filming sessions, each of the subjects was seated upright in a dental chair and fitted with a head positioner, consisting of ear rods and a forehead clamp.

Radiopaque markers were used to mark flesh points on the surface of the tongue. These are small metal domes approximately 4 mm in diameter and similar to the lingual markers used by HOUDE [8] and KENT and MOLL [12, 13]. They will adhere to the tongue when pressed into the surface. Three radiopaque markers were placed on the dorsum of the tongue at the midline. The marker positions varied for each of the subjects (fig. 1); however, exactly identical positioning was not considered crucial since marker movements were not compared between subjects. A radiopaque paste (Rugar) was applied to the tongue tip and to the upper and lower lips at the midline to enhance visualization of those structures.

Speech Sample

The speech sample consisted of English words and phrases and is shown in table I. Sample set I.A was used to study the variability of pre- and post-vocalic productions of /l/ as a function of vowel context and changes in rate of utterance. For these words, the vowels following or preceding /l/ approximate the features 'high', 'low' and 'neutral' which characterize the position of the body of the tongue within the vocal tract. [3] The voiceless labial stops were chosen so that /l/ would be the only consonant element in the words articulated

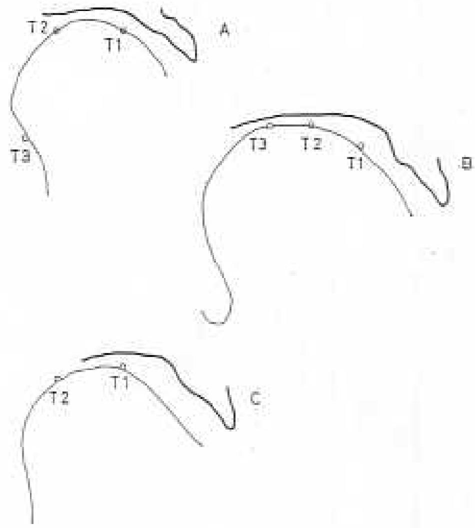

Fig. 1. Lingual marker positions for subjects A, B and C.

by the tongue. The words 'law', 'bell', and the nonsense syllable /lɛp/ were used because no words with these vowels and meeting other phonetic requirements could be found. The subjects were instructed to say the word once at what they judged to be an appropriate conversational or moderate rate and then three times at their fastest rate.

Sample set I.B, consisting of words and phrases, was used to investigate the production of /l/ as a function of syllable boundary placement. The subjects were instructed to produce each of the words and phrases, except the word 'really', with a syllable-final allophone of /l/ and then with a syllable-initial allophone. The subjects were instructed to produce the word 'really' first with both a final and initial allophone and then with only an initial allophone.

Sample set II allowed the study of /l/ production in pre- and post-vocalic consonant clusters with vowel context held constant. The clusters studied were limited to those involving voiceless fricative and stop consonants preceding or following the /l/, except for one post-vocalic cluster involving the nasal consonant /m/. The subjects were instructed to produce each word at a conversational rate.

Sample set III was used to study the production of post-vocalic and syllabic allophones. Subjects were first instructed to produce the words at conversational rate without a syllabic /l/ by placing equal stress on both syllables. They then were instructed to produce the words with a syllabic /l/ by reducing stress on the final syllable. Words with syllabic /l/ were produced at both a conversational and a fast rate.

Film Analysis

The cinefluorographic films were hand-traced from the film projected to life size. Frame-by-frame tracings of structural contours and marker positions were made through the phonetic sequence under investigation. The movement of the principal articulator, the tongue, served as the basis for identifying portions of the films to be traced. Part of the steady-state[1]

[1] An articulatory steady-state is defined as an identified minimum in the absolute magnitude of the average rate of movement of the relevant articulator or articulators [22].

Table I. Speech sample

I. Pre- and post-vocalic /l/ productions			
A		B	
leap	peal	boiling	apple in
loop	pool	mealy	peel it
lap	pal	really	
law	Paul		
/lɛp/	belt		
II. /l/ productions in pre- and post-vocalic clusters			
pledge		help	
splendor		helps	
cleft		elk	
sklent		elks	
phlegm		self	
sled		health	
		elm	
		melt	
		belch	
III. Syllabic productions of /l/			
apple			
tunnel			
tackle			
bottle			
castle			

associated with the vowels immediately preceding the tongue gesture for /l/, the /l/ steady-state, the transition to the following vowel, and part of the steady-state of the following vowel were traced.

Tongue marker positions and measures of distance between articulatory structures were made directly from the tracings. The marker positions were specified on a Cartesian coordinate system established for each subject over the area of the vocal tract with the coordinates tangent to certain bony structures. The measures of distances between structures which were made are described in table II. All measurements were made to the nearest 0.5 mm, and the standard errors of measurement ranged from 0.22 to 0.77 mm.

It should be noted that no attempt was made to study the lateral components of the articulation of /l/ since the edges of the tongue could not be reliably distinguished from the tongue mass at the midline.

Results

Steady-State Configurations

The description of /l/ allophone articulation was made from measurements of articulator positions during steady-state and during arti-

Table II. Measures of structural positions made in this study

IL	(inter-labial distance): the minimal linear distance between the two lips
LPro	(lip protrusion): the anterior displacement of the lower lip from a reference line connecting the most superior and inferior points on the anterior mandible [5]
LD	(labial-dental distance): the minimal linear distance between the lower lip and the upper central incisors for /f/ in the particular sample
ID	(inter-dental distance): the minimal distance between the upper and lower incisors
LA	(lingua-alveolar distance): the minimal distance between the tongue tip and the point on the alveolus where the tongue tip made contact for /l/ in the particular sample
LP	(lingua-palatal distance): the minimal distance between the dorsum of the tongue and the palate, measured from the point of lingua-palatal contact (the point of contact was determined separately for each /k/ consonantal gesture) to the closest point on the tongue
VE	(velar elevation): velar position as measured from the physiological rest position of the velum along a line representing the approximate path of velum movement [21]
VP	(velopharyngeal aperture): the minimal distance between the velum and the pharyngeal wall

culator gestures to the steady-state positions. The steady-state configurations for each of the allophone productions were determined by choosing a sequence of tracings in which the positions of both the tongue apex and dorsum were invariant. One tracing from this sequence was chosen to represent the vocal-tract configuration for that allophone production. Each of the configurations was then described in terms of tongue marker positions and articulator distance measures.

Lingual shapes. To study variation in lingual shape between different /l/ allophones, tracings of lingual contours during each /l/ steady-state were overlaid and aligned so that maximum congruence of the lingual outlines was achieved. The composite outlines are shown in the left half of figure 2. It can be noted that for each of the subjects the tongue dorsum assumes approximately a constant shape for all of the /l/ productions, however, the lingual apex and root show variations in contour. These results suggest that there is a constraint on the shape assumed by the lingual dorsum during /l/ articulation similar to that reported previously for vowel production [10].

In order to assess the degree of similarity between dorsum contours for /l/ and vowels, one representative allophone contour was selected

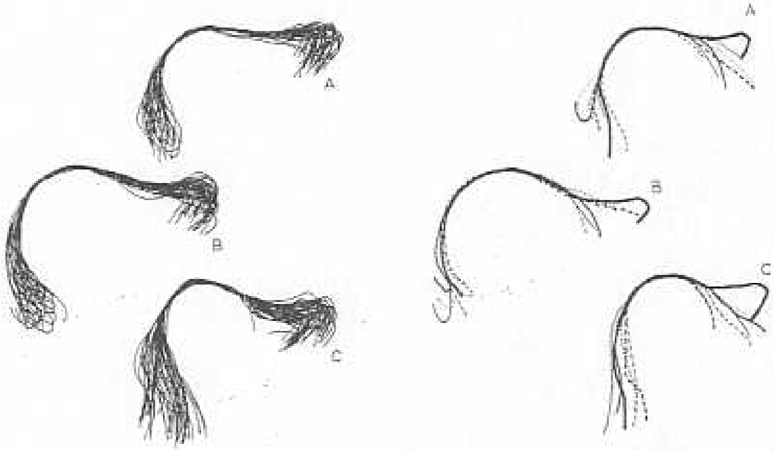

Fig. 2. Lingual shapes for subjects A, B and C. Left: a composite of lingual shape outlines for all /l/ allophones studied; Right: a comparison of lingual shapes for vowels and one representative /l/ allophone contour.

to be compared with contours selected from steady-state portions of the different vowel articulations. The comparison is shown in the right half of figure 2. The relatively close match between tongue contours suggests that the lingual dorsum shape assumed during production of /l/ allophones is essentially the same as that observed during production of the various vowels studied.

Characteristics of pre- and post-vocalic allophones. Variation in the steady-state articulatory characteristics of pre- and post-vocalic /l/ allophones as a function of vowel context, rate of utterance and syllabic boundary placements were studied in speech sample sets I.A and I.B (table I). Figure 3 illustrates the lingual configurations for both pre- and post-vocalic allophones produced at conversational and fast rates of utterances in various vowel contexts. Since the results were consistent across subjects, only subject B is shown. The left hand portion of figure 3 illustrates that the tongue apex made contact with the maxilla in each of the pre-vocalic articulations. The anteroposterior position of tongue tip contact, measured as the shortest distance between the tip of the upper incisor and the point of lingual contact, was approximately the same for all samples for each of the subjects. This corresponded to a point on the alveolar ridge. It also can be noted that as the rate of utterance was increased, the position of the tongue dorsum for pre-

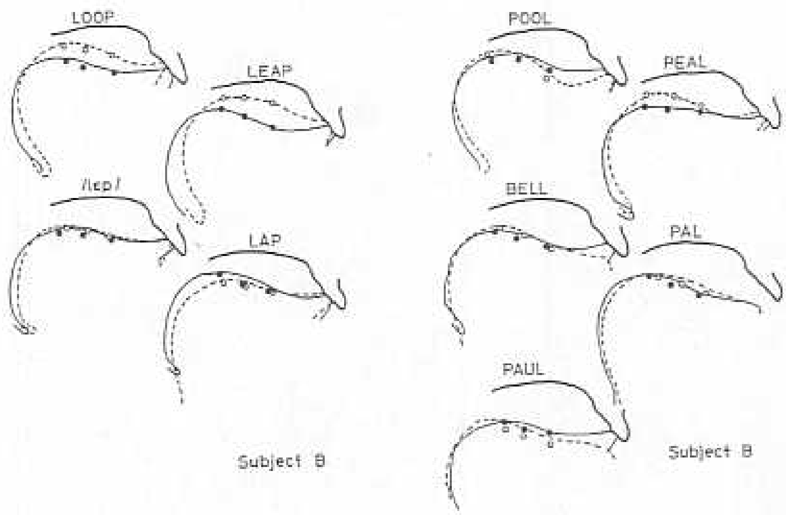

Fig. 3. Lingual configurations for pre- and post-vocalic /l/ allophones (subject B). Left: pre-vocalic productions; Right: post-vocalic productions. Productions at a conversational rate are shown in solid lines, those at fast rates in broken lines.

vocalic /l/ was shifted toward the position appropriate for the vowel following /l/.

The right hand portion of figure 3 illustrates post-vocalic allophone productions. It can be noted first that tongue apex contact with the maxilla was not always achieved. Generally, at conversational rates, tongue apex contact occurred for all of the subjects; however, with increased rate of utterance, contact was usually not achieved. In addition, the tongue dorsum positions appear to be shifted toward the positions of the preceding vowels in some articulations at the fast utterance rate. These results indicate that for the post-vocalic allophones, there can be undershoot of both tongue apex and tongue dorsum positions for /l/.

Variation in the position of the tongue dorsum as a function of allophone type and vowel context was evaluated for each subject from their conversational rate productions. It was shown in a preceding figure that the dorsum assumed a constant shape for each of the subjects for all allophones studied. Therefore, by plotting the position of one marker for each allophone steady-state, the variation of the position of the dorsum may be specified. Each subject had one lingual

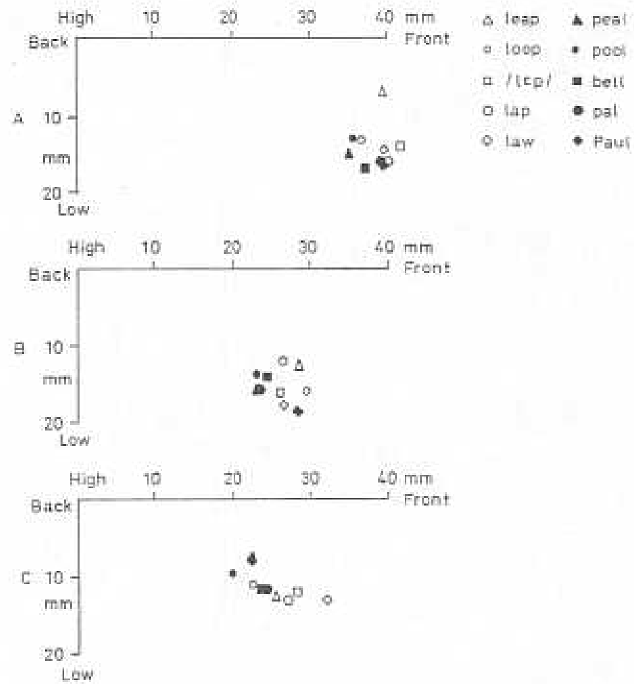

Fig. 4. Lingual dorsum positions for pre- and post-vocalic /l/ allophones of /l/ for subjects A, B and C. The pre-vocalic positions are shown with open geometric figures, the post-vocalic positions with closed geometric figures.

marker in approximately the same place on the lingual contour allowing for comparisons across subjects.

Figure 4 illustrates the positions of the dorsum for the pre- and post-vocalic allophones. Examination of the figure shows that the marker points tend to cluster in one particular area of the coordinate system with the variation within the cluster bearing a relation to the tongue position of the preceding or following vowel. Of more interest is the fact that the post-vocalic positions were generally farther back in the oral cavity than were those for pre-vocalic productions. Subjects A and B showed the post-vocalic dorsum positions to be farther back and lower than the pre-vocalic positions while subject C's dorsum positions were farther back and generally higher.

Data on differences between pre- and post-vocalic allophones also were obtained from sample set I.B (table I), in which subjects were

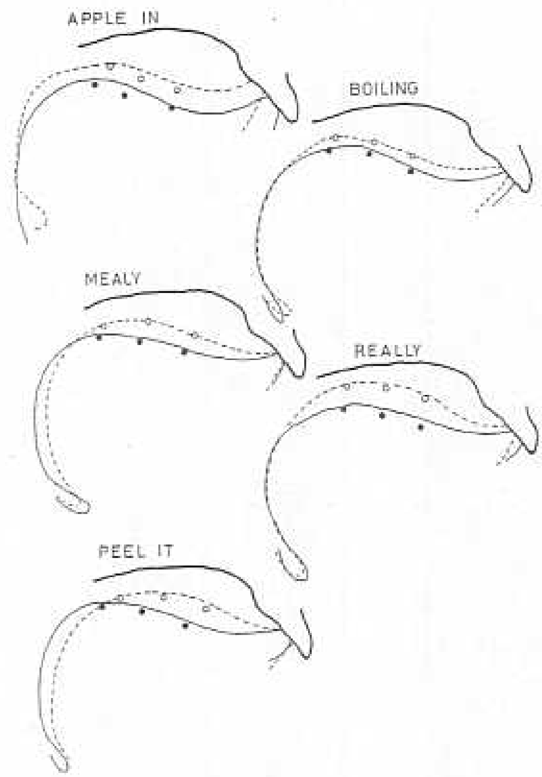

Fig. 5. Lingual configurations with changes in syllable boundary position (subject B). /l/ allophones preceding the boundary are shown in solid lines, those following the boundary in broken lines.

instructed first to produce words and phrases with a syllable boundary preceding the allophone (pre-vocalic production) and then with the boundary following the allophone (post-vocalic production). Figure 5 illustrates the differences between the lingual positions and again, only subject B is shown since the trends were similar for all subjects. The data reveal that the post-vocalic configurations tend to be shifted backward from those for the pre-vocalic allophones. This is the same trend shown for /l/ allophones in monosyllabic words.

Three additional characteristics of the steady-state configurations not directly involving lingual position were found for these allophones.

These were mandibular position or jaw opening, velar position, and lip protrusion or lip rounding. The descriptions are reflected in certain distance measurements and were made to assess whether or not articulator relationships other than lingual position were consistently related to /l/ allophone production. For instance, if a particular mandibular position was necessary for allophone articulation, we might expect jaw opening distances to fall within a narrow range for all allophones or perhaps two distinct distance ranges, one for the pre-vocalic allophones and the other for the post-vocalic /l/ allophones. The same sorts of relationships were sought for velar position and lip protrusion. Generally, none of these descriptions was found to be consistently related to /l/ articulation. Rather the structures were free to coarticulate in relation to the phonetic contexts surrounding the allophone.

For jaw position, the direction of variation in all subjects seemed to be related to the vertical position of the preceding or following vowel; i. e., the interdental distance was small when the vertical position of the vowel was high and large when the vowel position was low. As the rate of utterance increased, the variability of jaw opening increased.

Velar position for /l/ allophones in these contexts was not studied in detail since the velum was observed to be closed during the production of each of these allophones.

To study lip rounding for /l/, lip protrusion distances were found for the unrounded vowel /i/ and the rounded vowel /u/ and the distance means were compared to the lip protrusion distances measured for the /l/ allophones at steady-state. The data suggest that there was no lip rounding specifically associated with the articulation of the /l/ allophones since the distances varied with the phonetic context. All subjects showed lip protrusion distances similar to the mean for /u/ when the allophones were either preceded or followed by the rounded vowels /u/ or /ɔ/. When /l/ was articulated in other vowel contexts, the distance values were similar to the mean for the vowel /i/.

Allophones in consonant clusters. Lingual positions found for the allophones in consonant clusters (sample set II in table I) were similar to those observed for the single consonant element /l/ productions. In the pre-vocalic clusters, the tongue apex always made contact with the maxilla, although the point of contact varied slightly within each of the subjects. The dorsum positions were not greatly divergent from one another, and the variation was related to the phonetic composition of the cluster. Generally, for all subjects it appeared that when /l/

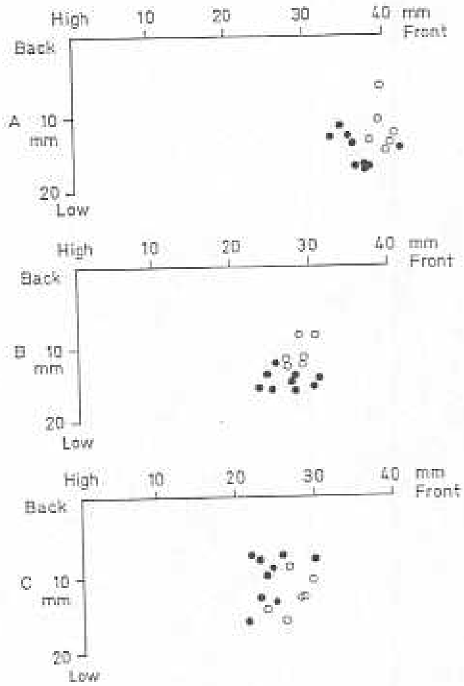

Fig. 6. Lingual dorsum positions for /l/ in pre- and post-vocalic consonant clusters for subjects A, B and C. The pre-vocalic productions are shown with open circles, post-vocalic productions with closed circles.

was preceded by /k/ and /s/, the dorsum position was raised and when preceded by /f/ the dorsum was relatively lower.

Tongue apex contact with the maxilla for /l/ was not achieved in some post-vocalic consonant clusters. When the allophone was followed by a phonetic element that was homorganic with /l/, contact with the maxilla was always achieved by all three subjects. When the following speech sounds were not homorganic, subject A failed to make contact in two contexts, subject B in five contexts, and subject C failed to make contact in all six contexts. Again, the dorsum positions were not greatly divergent from one another and the variation appears to relate to the phonetic composition of the cluster.

Finally, the dorsum positions for /l/ productions in pre-vocalic and post-vocalic clusters were compared (fig. 6). These data show that the post-vocalic marker positions were farther back in the oral cavity than were pre-vocalic positions. In addition, the post-vocalic positions were lower for subjects A and B but higher for subject C. A similar result was shown for /l/ productions as single consonant elements.

Jaw opening showed variation related to the phonetic elements of the consonant cluster. All subjects showed greater interdental distances when the consonant elements preceding or following were bilabial, labiodental or linguapalatal in their place of production. The interdental distances were smallest when the consonant elements were either linguadental or lingua-alveolar.

The pre- and post-vocalic consonant clusters present opportunities to study velar position for /l/ in relation to the velar adjustment associated with the surrounding consonant elements. The most consistent trend in the data suggests that the velar position for the /l/ allophone depends on the velar position characteristic of the phonetic element immediately following the /l/, since the velum was closed in the word 'elk' and open in the word 'elm' for all three subjects.

Each subject differed in the amount of lip protrusion shown for /l/ production in these consonant clusters. For subjects A and C, lip protrusion distance was greatest when there was a bilabial fricative or affricate consonant element preceding or following the allophone; larger distance values were similar to the mean distance for /u/. Subject B showed essentially no lip protrusion.

Syllabic allophones. For the articulation of syllabic /l/ allophones (sample set III), the tongue apex always made contact with the maxilla with the point of contact on the alveolar ridge varying only slightly within each of the subjects. When the allophones were produced at a fast rate of utterance, tongue dorsum shifts were similar over the three subjects. Each of the subjects showed considerable shifts in an anterior direction for the word 'tackle', and subjects A and B showed an anterior shift for the word 'tunnel'. There also was some change with increased rate of the other /l/ utterances but to a lesser degree.

The subjects were asked to produce the words in this section of the speech sample with a word-final /l/ allophone, considered for this study to be a post-vocalic production, as well as with a syllabic production. Figure 7 shows the lingual configurations for these conditions. Only subject B is shown since trends were the same across the subjects. The lingual configurations are essentially the same for the post-vocalic and syllabic productions.

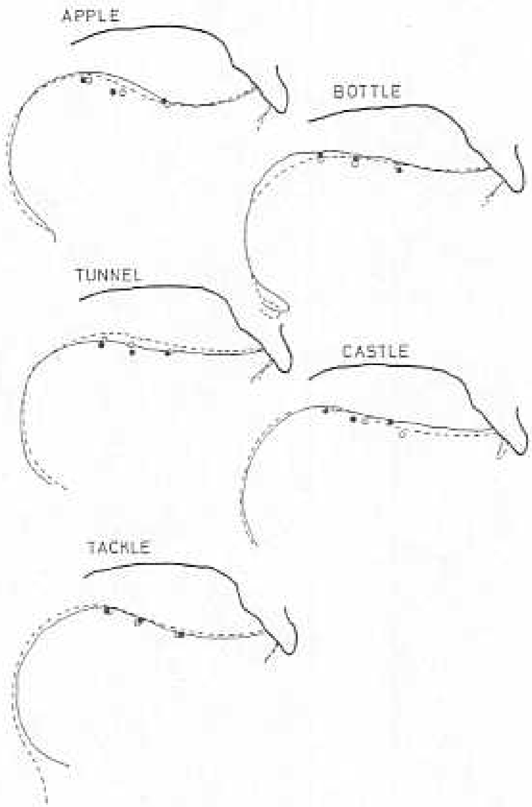

Fig. 7. Lingual configurations for word-final and syllabic /l/ allophone productions (subject B). Syllabic /l/ productions are shown in solid lines, word-final productions in broken lines.

No characteristic jaw opening, velar positions or lip protrusion activity was seen for the syllabic allophones; the measures appeared to vary with the phonetic context and rate of utterance.

Articulator Movement Characteristics

Movement velocity. The primary gesture for /l/ allophone production consisted of a tongue movement toward a position of apex contact with the maxilla. This movement was described by plotting the distance between the tongue apex and the point of eventual contact on the maxilla and by determining the velocity of this movement.

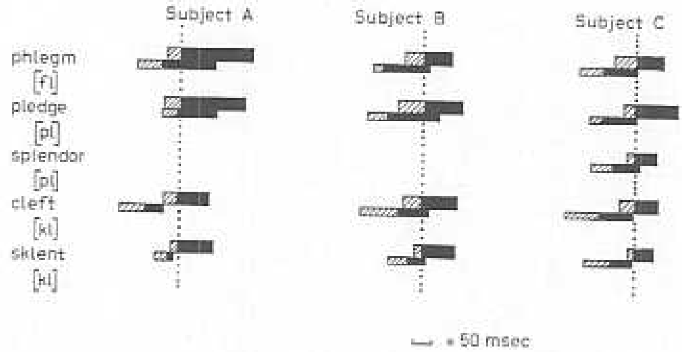

Fig. 8. Sequencing of articulator movement in pre-vocalic consonant clusters for subjects A, B and C. The upper large bar shows production of the /l/ allophone in the cluster, while the smaller lower bar shows the immediately preceding consonant production; striped bar sections indicate movement durations to contact, and the solid portions show the duration of articulator contact; the vertical dotted line indicates the beginning of tongue apex contact for the /l/ allophone productions.

The peak movement velocities were similar within each of the three allophone groups, pre-vocalic, post-vocalic and syllabic, for all of the subjects. Even with increases in the rate of utterance, the peak velocities were essentially the same within each of the groups. The mean peak velocity values in mm/sec for all subjects combined were 276.6 for pre-vocalic, 192.7 for post-vocalic, and 304.3 for syllabic allophones. The mean values for the syllabic and the pre-vocalic productions are similar, while that for the post-vocalic productions is considerably lower. To compare these mean peak velocity values,. an unweighted-means analysis of variance was carried out [14], and the F ratio was significant ($p < 0.001$). A comparison of allophone group means indicated that the syllabic peak velocity mean was significantly greater than either the pre- or the post-vocalic means ($p < 0.01$ and $p < 0.001$, respectively). Finally, the pre-vocalic peak velocity mean was significantly faster than the post-vocalic ($p < 0.001$).

Movement sequencing in clusters. The description of allophone articulation in consonant clusters allowed for study of the movement of other articulators for speech sounds in the cluster while the gesture for the /l/ allophone was underway. Figure 8 shows the sequencing of articulatory movements in pre-vocalic clusters. The beginning of articulatory activity was designated as the first change from a minimum in the average rate of movement to a maximum rate of movement for the articulatory gesture appropriate for the speech sound. The data indicate that activity for the phonetic element preceding the /l/ always began before that of /l/. When the element was articulated by the lips, the tongue apex movement began closer in time to the onset of lip closure movement than when the element was articulated by the dorsum of the tongue. All three subjects showed instances in which there was simultaneous occlusion of the vocal tract at two different points. This happened most often when /p/ preceded /l/ so that the vocal tract was occluded at the lips and at the alveolar ridge. No regular patterns related to the amount of time in which there was double occlusion were apparent.

There were differences among the subjects for the sequencing of activity in the word 'pledge'. For subject A, the activity for /l/ began at nearly the same point in time as the onset of activity for /p/, while for subjects B and C the activity for /l/ did not begin until after lip closure for /p/. These data suggest that there was no one particular pattern to the onset timing of gestures for speech sounds making up the consonant clusters. Each speaker may in fact have his own particular pattern of sequencing.

The articulatory activity in post-vocalic clusters was described in terms of time differences between the beginning of movement for the /l/ allophone and the beginning of movement for the following non-homorganic consonant. The time differences were much alike within and across the subjects, ranging from approximately 0 to 70 msec, but no absolute time differences between the onset of movements were apparent. In other words, the time of the onset of movement for the following consonant was relatively independent of that of the /l/ allophone in all subjects. In order to contrast times in which lingual contact with the maxilla was achieved and when it was not, mean time differences for both conditions were found. These mean values were 57.62 msec for contact conditions and 2.01 msec for no-contact conditions. These results indicate that if the movement for the following speech sound began at nearly the same point in time as movement for /l/, contact for the /l/ was not achieved.

The sequencing of movements for the production of syllabic allophones of /l/ in words like 'tackle' and 'apple' also demonstrated overlapping gestures. For instance, in the word 'apple' all subjects obtained lingual contact for the /l/ while labial contact for the /p/ was maintained. A similar sort of overlapping of gestures was seen for the lingual dorsum and apex in the word 'tackle'.

Time separations between the onsets of the articulatory gesture for /l/ and for the preceding consonant in the words 'tackle' and 'apple' produced under three conditions were determined. Mean time separations across subjects were 203.75 msec for the word-final condition, 45.0 msec for the syllabic production at a conversational rate, and 36.25 msec for syllabic production at a fast rate. These data suggest first that the timing of the onset of articulatory movement from /p/ or /k/ to /l/ varies depending on whether the subject is instructed to produce a word-final or a syllabic allophone. Secondly, the very small time separations in the syllabic conditions allow for considerable overlapping between the gestures for preceding consonant and the syllabic /l/.

Discussion

Pre- and Post-vocalic Allophones

In order to specify the lingual characteristics of /l/, both shape and position need to be described. The results indicate that the lingual dorsum shape is essentially constant for all of the /l/ allophones studied. In addition, the dorsum contours for these allophones were quite similar to those observed for the vowels investigated. Variability in the lingual contours was found only in the tongue root and apex, and the variations in the anterior-posterior shape of the root appear to be similar to those observed by other investigators, Houde [8] and Kent [10], for different vowels. These investigators found that changes in the shape of the tongue root were related to variation in dorsum position.

When the tongue apex contact was achieved for /l/, it was at approximately the same position on the alveolar ridge for each of the subjects. Contact with the maxilla was not achieved in some post-vocalic contexts depending on the phonetic context and the rate of utterance. The tongue dorsum positions observed for all /l/ allophones studied fall into two groups: (1) pre-vocalic and (2) post-vocalic; the post-vocalic allophones exhibited more posterior positions than did the pre-vocalic allophones. Variation within the two allophone groups was similar and appeared to vary systematically as a function of the phonetic context and the rate of utterance. These lingual positions were shown to be shifted toward the position of the preceding or following consonants and/or vowels. Similar variations have been noted by investigators studying other allophonic variation and can be explained by applying current concepts of coarticulation and articulatory undershoot [18, 20].

Syllable boundary position, a linguistic factor, was varied to study the effect on /l/ production. If the subject was instructed to produce a /VlV/ sequence with the syllabic break before the /l/, the lingual configurations were like those of pre-vocalic allophones, and if instructed to articulate the syllable break after /l/, the result was a post-vocalic lingual configuration. Articulation of /l/ in consonant clusters also followed this predicted pattern: allophones in pre-vocalic clusters showed characteristics of pre-vocalic allophones, while /l/ in post-vocalic clusters showed post-vocalic characteristics.

Lateral opening features were not observed in this study. These characteristics probably do not vary independently of the positions of the apex and dorsum because of the physical adjacency constraints determined by the intrinsic musculature and other tissues of the tongue. Without knowing what these constraints are, speculation as to lateral opening is impossible. If these constraints can be determined in the future, it may be possible to predict these characteristics from observation of tongue apex and dorsum positions.

These data suggest certain similarities to the phonetic descriptions of light and dark /l/ articulation [9, 26, 28, 29]. The light allophone is said to be articulated with a lowering and flattening of the tongue, with the dorsum position fronted and somewhat raised; this description best fits the pre-vocalic /l/ productions. The post-vocalic allophones appear to be most like the dark /l/ since this type is described as having the dorsum shifted toward the velum and palate with lingual contact made either on the teeth or alveolar ridge. The dorsum position in the word 'pool' may correspond to the overdark /l/ described by Thomas [26] since the dorsum position in this context was nearest to the velum and palate of all the post-vocalic allophones produced.

Finally, the acoustic measures of Lehiste [16] which indicated that the first and second formants for /l/ in the syllable-initial position were farther apart in frequency than for /l/ in the final position, are consistent with these articulatory data. The frequency of the first formant is known [23] to be most closely related to the vertical position of the tongue within the oral cavity, and from these data we may assume that this first formant was approximately constant in the two allophone

Movement Sequencing in Clusters

Sequencing of consonant movements in clusters. Varying degrees of the overlapping of articulatory gestures were observed in all subjects during the articulation of consonant clusters; this same activity has been described by other investigators in the past [11, 27]. In the pre-vocalic clusters, when the preceding consonant was produced by the lips, movements for /l/ generally began before lip closure was achieved. When the tongue dorsum was involved in the articulation of /k/ before the /l/, linguapalatal contact for /k/ was always achieved prior to movement for /l/ contact. A partial explanation for this probably lies in the relative independence of the articulators, since the lip and tongue are more independent than the tongue apex and dorsum.

The onset of the articulation of the consonant elements appeared to be relatively independent of each other in the post-vocalic clusters as well. Moreover, it was observed that relative times of movement onset for the /l/ and the following non-homorganic consonants in post-vocalic clusters were related to the undershoot characteristics of /l/. As the forward coarticulatory activity between /l/ and the following consonants began closer in time, there was a greater chance of undershoot of the alveolar contact for /l/. The mechanisms relating to undershoot of lingual apex contact for /l/ produced as a single element and /l/ in a consonant cluster appear to be the same. Movements for post-vocalic allophones are relatively slow and when the time for their articulation is reduced, as happens with increases in the rate of utterance or changes in the timing of forward coarticulation, the tongue apex is not able to achieve contact.

Finally, KOZHEVNIKOV and CHISTOVICH [15] hypothesized that the timing of the articulatory onset for the second consonant in a /VCCV/ sequence was stimulated by the movements for the first consonant through a proprioceptive mechanism. They came to this conclusion upon observing that when two non-homorganic consonants were articulated in /VCCV/ sequence, the first consonant always achieved contact before the second. For this study in the pre-vocalic clusters, movements for the consonant preceding /l/ always came before those of the /l/, which may indicate some cueing effect by the movement of the first consonant. This was not the case for the post-vocalic consonant clusters; the consonant immediately following the /l/ was observed to begin in some instances at the same time that the movements for /l/ began. This contradiction may be explained by the fact that the /l/ in the post-vocalic consonant cluster is more similar to a vowel than to a consonant. More research is needed to understand the forward coarticulatory timing effects observed for these non-homorganic speech sounds and the role of feedback in the sequencing of articulatory gestures.

Characteristics of Syllabic /l/ Allophones

The syllabic characteristics were not distinctly different from those of the pre- and post-vocalic allophones for this allophone group. Tongue apex contact was always achieved for this group, with the dorsum positions similar to post-vocalic (word-final) productions. The speed of lingual movement was relatively fast and was similar to the velocity shown in pre-vocalic productions, with the steady-state being achieved while the articulation of the preceding consonant was still taking place. This coarticulatory activity was similar to that seen in the overlapping of movements in the pre-vocalic consonant clusters.

These syllabic articulatory characteristics, though not totally different from those associated with the other allophone groups, are capable of producing an allophonic variation of /l/ that is acoustically different from either of the other two allophone groups. The first acoustic implication is that this syllabic sound will resemble the post-vocalic productions in their acoustic steady-state characteristics. Secondly, the coarticulation of the /l/ with the preceding consonant in the syllabic condition will result in the complete reduction of the intervening vowel and the loss of the formant transitions to the /l/ steady-state. The acoustic result is a vowel-like /l/ steady-state following a consonant production with no formant transition to the steady-state. This sound will be acoustically quite different from either the pre- or post-vocalic allophones, a conclusion which is supported by the empirical data of Lehiste [16]. The perceptual similarity and differences of /l/ allophones as well as other allophonic variations based on the acoustic implications of current information on articulation need further investigation.

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Zusammenfassung

Röntgenographische Untersuchung ausgewählter Allophone von englischem /l/

Das Ziel dieser röntgenographischen Untersuchung einer Anzahl von allophonischen Varianten des englischen /l/ war es, die artikulatorischen Kennzeichen dieser Variationen zu beschreiben und die Faktoren abzuschätzen, die für die Variationen verantwortlich sein können. Drei Personen sprachen die englischen Beispielwörter und -sätze, wobei Röntgenfilme mit hoher Geschwindigkeit aufgenommen wurden. Die beobachteten Verschiedenheiten wurden um zwei Allophongruppen geschart: die vorvokalische und die nachvokalische, die verschiedene Kennzeichen haben. Die vorvokalischen Produktionen zeigten eine weiter vorn liegende Zunge und schnellere Bewegung, als dies bei der nachvokalischen Gruppe beobachtet wurde. Demzufolge zeigten die vorvokalischen Allophone kein Zukurzkommen des vorderen Zungenverschlusses, während die nachvokalischen eine solche Reduktion aufwiesen. Die silbischen /l/ zeigten Zungenstellungen wie die nachvokalische Gruppe, aber kennzeichnende Bewegungen, wie wenn /l/ in einer vorvokalischen Gruppe artikuliert wird. Die Variation in diesen drei Hauptallophongruppen kann erklärt werden im Rahmen von Koartikulation und artikulatorischer Reduktion.

Résumé

Etude cinéradiographique de certains allophones du /l/ anglais

Le but de la présente étude cinéradiographique est de décrire certaines variations allophoniques du /l/ anglais et de déterminer les facteurs qui pourraient provoquer ces variations. Trois sujets anglophones furent filmés par cinéradiographie ultra rapide tandis qu'ils prononçaient un texte fait de mots et d'expressions. L'observation se porta sur deux groupes allophoniques présentant des caractéristiques articulatoires propres, le groupe pré-vocalique et le groupe post-vocalique. Les allophones pré-vocaliques correspondent à une position linguale plus antérieure et à une vitesse articulatoire plus grande que les allophones post-vocaliques. En conséquence, les allophones pré-vocaliques présentent un contact lingual antérieur franc, ce qui n'est pas le cas des allophones post-vocaliques. Les /l/ syllabiques ont une configuration linguale qui correspond au group post-vocalique et des mouvements comme ceux du /l/ en position pré-vocalique. Les variations qui se produisent au sein de ces trois groupes allophoniques peuvent s'expliquer à partir des notions modernes de coarticulation et d'«undershoot» articulatoire.

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groups because the vertical position of the tongue was approximately the same in the two groups. It is also known [23] that the second formant is determined for the most part by the anteroposterior positioning of the tongue; as the tongue position moves forward in the vocal tract, the second formant increases in frequency. Therefore, the initial allophones with the more anterior position would show the greatest frequency difference between the first and second formants.

Pre- and post-vocalic allophones also differed in dynamic characteristics. The mean peak velocity of tongue apex movement for the pre-vocalic allophones was significantly faster than that for the post-vocalic allophones. In addition, there was essentially no change in the peak velocity of movement with increases in the rate of utterance. This result is consistent with data of other studies of consonant, diphthong and vowel articulatory movements [6, 8, 11–13, 17–19, 24].

The dynamic control of the tongue apex appears to be different in the two types of allophones. The post-vocalic type allophones may be regarded as vowel-like for they show relatively slow movement characteristics and undershoot of articulatory positions with increases in the utterance rate [17, 18, 24]. The same undershoot characteristics have not been noted for pre-vocalic allophones, and they seem to be similar to consonants because of their relatively high rate of articulatory movement. Although articulatory velocities for consonants also do not change with utterance rate, the relatively high rate of speed is enough to compensate for the reduction in the amount of time allowed for consonant articulation [11, 13].

In conclusion to this discussion of pre- and post-vocalic /l/ allophone differences, it appears that the two types should not be considered as the same element physiologically, but as separate elements with perhaps different learned motor patterns. The data suggest that the pre-vocalic /l/ functions as a consonant while the post-vocalic /l/ may be considered to be vocalic in nature, forming the second element of a diphthong. Studies of developing phonological systems support the notion that positional variants of phonemes are articulated differently. Curtis and Hardy [4] observed that types of /r/ could be differentiated by the patterns of misarticulation of /r/ in children. They showed that different error patterns were associated with vowel and consonant /r/ sounds. In addition, Templin [25] observed that initial and medial allophones of many phonemes were produced correctly at an earlier age than were final allophones.