An Electromyographic Study of the American English Liquids*

David R. Leidner

With the advent of the sound spectrograph, phoneticians and linguists had before them a means of objectifying the acoustic qualities of speech sounds. In 1952 Jakobson, Fant, and Halle attempted to describe the minimal functional units of speech in acoustic terms. Phonologists found these acoustic terms quite useful in formulating phonological rules. As phonological research progressed, however, it was found that certain data could be accounted for only by a gymnastic use of the feature set because the articulatory aspects of the production of sounds were ignored in the formulation of phonological features. Recognizing this, Chomsky and Halle (1968) suggested a feature inventory based on articulatory configurations of the vocal tract. This had the mechanical advantage of capturing naturalness and of explicitly showing feature interaction. But Chomsky and Halle only occasionally discuss the acoustic and perceptual correlates of the features, not because the features are uninteresting or unimportant, but because, they say, "...such a discussion would make this section...much too long" (p. 299). One can reasonably infer from this that the acoustic qualities of sounds play little, if any role in their distinctiveness. A further conclusion would be that a fully satisfactory explanation of phonological phenomena--both synchronic and diachronic--can be made solely by reference to the way sounds are articulated. Finally, assigning a unique articulatory configuration to each phone assumes that there is a one-to-one mapping between the articulatory feature set assigned to the sound and the acoustic output.


+ The author is a student of Dr. Arthur S. Abramson, Haskins Laboratories and Department of Linguistics, University of Connecticut. The experiments discussed here were carried out at Haskins Laboratories, and partial support for the research was provided by a Dissertation-Year Fellowship from the University of Connecticut Research Foundation.

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The American English liquids are given the following feature set by Chomsky and Halle (1968):

<table>
<thead>
<tr>
<th></th>
<th>/r/</th>
<th>/l/</th>
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<tbody>
<tr>
<td>voc</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>cons</td>
<td>+</td>
<td>+</td>
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<tr>
<td>high</td>
<td>−</td>
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<td>back</td>
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<td>low</td>
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<tr>
<td>ant</td>
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<tr>
<td>cor</td>
<td>+</td>
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</tbody>
</table>

This is not meant to account for the allophonic variations in liquids: presumably, low-level variations would be taken care of by low-level phonetic output rules. The primary purpose of this study was to examine and explain the various allophones of the liquids by studying the activity of some of the muscles involved in their production. Specifically, we are interested in the activity of the lips and tongue in the production of American English /l/ and /r/ intervocally, word-finally, and preconsonantally. Bipolar wire electrodes were inserted into the lips and tongue muscles of two subjects who read lists of /l/ and /r/ in various contexts 19 times. The raw data were stored on FM tape, inspected visually for artifacts, and averaged by computer to get a general picture of the contribution of each muscle. Some selected aspects of the experiments will be discussed.

Figures 1 and 2 show orbicularis oris superior, styloglossus, and tongue tip activity for one subject producing the set ir-iri-irp-irb-irm (Figure 1) and il-ilp-ilb-ilm (Figure 2). The line drawn in the center of each curve represents the onset of phonation of the first vowel of the test utterance, with 400 msec to the left of the line and 600 msec to the right. Each utterance token was read in the frame "It's a h--" to provide for a neutral phonetic environment. Notice that for both /r/ and /l/ before the labials /p/, /b/, and /m/ the orbicularis oris superior shows two peaks after the line-up point. The second peak corresponds to the closing gesture for the labial consonant, an observation supported by high-speed cinematographic data taken during the experimental runs. The first peak cannot be associated with lip spreading for /l/, since it occurs considerably after the onset of phonation of the vowel—generally, this first peak occurs at least 100 msec after the onset of phonation, when the lips have already relaxed their spreading gesture.

Turning now to the activity of the styloglossus, we can see that for both /l/ and /r/, styloglossus activity is much less for the intervocalic member than for preconsonantal liquids: the styloglossus muscle, which can pull the tongue upward and back, is thus in part responsible for what is commonly called "velarization." Correlated with this in the articulation of /l/, though not of /r/, is a lessened tongue tip activity for the nonintervocalic set. Notice that
Figure 1
Figure 2

Orbicularis Oris Superior

Styloglossus

Tongue Tip

Time in milliseconds (1 sec.)

µv

/i1/

/i1i/

/i1p/

/i1b/

/i1m/
where there is less tongue tip activity there is a corresponding increase in styloglossus activity. We might speculate that tongue tip activity decreases either because the liquid is in word-final position—a phenomenon not uncommon for final consonants in languages generally—or because of a pressure to articulate the next consonant—in other words, a tendency toward consonant-cluster simplification. In any event, the significant observation is that the corresponding increase in styloglossus activity—i.e., velarization—cannot be explained on mechanical grounds: there is no articulatory factor which forces the styloglossus to act when tongue tip activity falls. Similarly, no mechanical explanation can be found for the extra orbicularis oris superior peak for preconsonantal liquids.

Data for the second subject, not provided here, yield similar results: the upper lip shows two peaks, both more closely associated temporally than in the first subject. For /l/, tongue tip activity is greatest when in intervocalic position, while for /r/, the anterior genioglossus, which can pull the tongue upward and forward, has greatest activity for the intervocalic position and least activity for /ir/ and for the prelabial set.

When the vowel is /a/ instead of /i/, slightly different data are obtained, as would be expected, but the effect is similar. Here, the posterior portion of the medial intrinsic tongue muscles, which upon contraction pull the tongue backward and possibly upward as well, show greater activity for preconsonantal /l/, while tongue tip activity is greatest in the intervocalic /ala/. For /r/ in the /a/ series, the styloglossus again shows least activity for the intervocalic member. We thus again find a tendency for velarization where tongue tip activity falls, while there are also two peaks in upper lip activity. Roughly similar results are obtained when the vowel is /u/, but the picture is much too complex to discuss here. Suffice it to say that here, too, a prelabial liquid calls for greater velarization than with the intervocalic liquids.

The interpretation of these data is enhanced when viewed in light of the behavior of liquids across languages. Consider, for example, the extra peak for the upper lip. If this is a rounding gesture, as I suggest, then we would expect coarticulatory effects to show up in the area of phonology. One example is a Viennese dialect of German, in which front vowels round before /l/ (Trubetzkoy, 1969:232). In certain nonstandard Czech dialects, a velarized /l/ can both round and back a preceding vowel (Entwistle and Morison, 1964:320). In Brazilian Portuguese, word-final alveolar /l/ often becomes /u/ (von Essen, 1964). In French, we find an /l/ ~ /o/ alternation in masculine nouns which end in /l/ in the singular, but in /o/ in the plural (Schane, 1968:51-52). Some Slavic languages show this change (Entwistle and Morison, 1964). In English, the Cockney dialect shows this quite clearly, as do certain midwestern and southern dialects of the United States, though not as pronounced. The phoneme written as /r/ varies widely in articulation, but it too is subject to velarization. For example, the earliest phase of breaking in Old Norse—the splitting of a vowel into a rising diphthong whose second member is a back vowel—occurred only when /e/ was followed by /r/ + consonant or /l/ + consonant (Flom, 1937). Similarly, /r/ or /l/ + consonant prevented /a/ > /e/—i.e., fronting—in Old Saxon and Old Frisian (Prokosch, 1939:116-117).

Putting all these observations together, we can clearly see that: (1) liquids tend to be "velarized" preconsonantly and, to an extent, word-finally; and (2) a
lip gesture often accompanies the loss of the liquid. The facts of language correspond quite closely with the observed EMG data described above. Let us consider, now, a hypothetical and much simplified case of both /l/ and /r/ becoming /w/. This would be handled under the framework presented by Chomsky and Halle (1968) as:

\[
\begin{array}{c}
{\text{+ voc}} \\
{\text{+ cons}}
\end{array} \rightarrow \begin{array}{c}
{\text{- cons}} \\
{\text{- voc}} \\
{\text{+ back}}
\end{array}
\]

Since we do not have to specify the precise articulation of the liquids, we can let the rule apply to the many variations of liquids found in languages. After applying the marking conventions for glides to the second term, we would get a fully specified matrix for /w/. What is bothersome about this approach is not only that a rule of this sort fails to explain the change in the fullest sense of the term, but also that the change seems to be an unnatural one. It would be simpler, for example, in a feature-counting sense, for the liquids to become either a true vowel or a true consonant: in other words, in a change in either [consonant] or [vocalic]. Looked at another way, we find phonemes—/l/ and /r/—whose allophonic variations—/u/ or /w/—are not related in the same sense as are, say, the advanced and retracted varieties of /k/, or a consonant with its palatalized counterpart, for example /k/ and /c/. In other words, we cannot account for the extra lip-protrusion gesture on these mechanical grounds.

The only way to explain the particular substitution is by reference to the acoustic properties of the liquids. Data provided in such studies as Lisker (1957), O'Connor, Gerstman, Liberman, Delattre, and Cooper (1957), and Lehiste (1964) show that the liquids are similar in formant structure to /w/ or /u/ in the first three formants: /r/, like /w/, has a low F2, while /l/, like /w/, has a relatively high F3 as well as a low F2. Furthermore, both liquids show an especially low second formant when in word-final position. One would expect this to happen in preconsonantal position. These similarities are brought into higher relief when /l/ is considered.

We can now begin to explain the observed velarization and the tendency toward lip protrusion. Under certain circumstances—namely, those conducive to lessened tongue-tip articulation—the speaker seeks to maintain the acoustic quality of the liquid phoneme by using compensatory maneuvers. In the case of the liquids, there are two ways to do this, both of whose aim is to increase the area in front of the major tongue constriction: one can hump the tongue posteriorily or one can lengthen the vocal tract by protruding the lips, or both. Either maneuver results in a lowered F2, which, among other factors, characterizes the liquids acoustically.

This explanation falls in line with Lieberman's (1970) Unified Phonetic Theory, which argues that not only are there preferred articulatory configurations for a sound, based on "acoustic stability" factors, but that different articulatory maneuvers can be used to achieve the same acoustic effect. This implies that in the case of certain phonemes—i.e., distinctive feature bundles—the acoustic consequences form a target with preferred articulatory configurations. Due to such factors as sluggishness of the articulators or a following semi-antagonistic gesture involving the same muscle, the speaker uses an entirely
different gesture to preserve the acoustic identification of a phoneme. And it is this acoustic goal which must be included in the distinctive feature matrix of certain phonemes in order to account for certain gestures found, at first, on the level of phonetic implementation.

We can also thus explain the observed pronunciation of /l/ and /r/ in the early speech of children. Since they cannot see how the tongue is positioned, they try to reproduce the acoustic output of the adult model. Hence, their rendering of "wabbit" for "rabbit" and "sweepy" for "sleepy." No doubt this principle operates not only with the liquids but with other sounds as well. Such a proposal has in fact been put forth by Menyuk and Anderson (1969). These observations have further consequences for what has been termed the "motor theory of speech perception." Rather than claiming that speech sounds are perceived in the way they are produced, we would amend this to say that speech sounds are perceived in the way or ways they could have been produced.

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