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Long-range liquid coarticulation in American English: a preliminary study

Brianna A. Maloney, Louise Barbosa
Linguistics
California State University, Long Beach
1250 Bellflower Blvd.
Long Beach, CA, 90803 USA

Faculty Advisor: Dr. Nancy Hall

Abstract

The sounds [r] and [l] are unique in the sense that in a word containing that sound, vowels for several syllables before and after the [r]/ [l] will be slightly [r]- or [l]-like themselves. The effect of different sounds on vowels can be measured by analyzing the specific formants, or acoustic components of vowel sounds. Previous studies have found that in British English dialects, the liquid sounds /r/ and /l/ have long-range acoustic effects, meaning that they affect the quality of vowels for several syllables before and after the liquid. In sentences that are phonetically similar except for a critical consonant (/r/ or /l/), there are significant effects on vowel formant frequencies within a range of two syllables before and after this consonant when compared to a neutral /h/ sound. The pronunciation of [r], particularly, is different in British English than in American English because they do not pronounce a [r] sound at the end of a word (e.g. car). Also, many British speakers pronounce [r] using a different part of the tongue than American speakers. The current project looks for evidence of similar effects in American English, by gathering and analyzing data of one native English speaker who was acoustically recorded pronouncing 3 repetitions of 95 target words that were similar except for a critical consonant, /r/, /l/, or /h/, in a frame sentence. This pilot study found that /r/ and /l/ have anticipatory coarticulatory effects ranging at least one syllable, and probably three syllables, although the trends for the third syllable fall slightly short of significance.

Keywords: phonetics, speech production, coarticulation

1. Introduction

A major problem in speech science is understanding how the articulations of different speech segments are coordinated with one another. It is well known that there is pervasive coarticulation of adjacent sounds: for example, the vowel [ɛ] is nasalized when it occurs before a nasal sound, so that the word *ten* /tɛn/ is phonetically [tɛ̃n]. The same vowel phoneme is non-nasal when it occurs before an oral sound as in the word *tess* /tɛs/. The nasality of the following consonant extends over the vowel and alters its articulation and acoustics, so that the sounds a native English speaker associates with the category /ɛ/ encompass a range of different acoustic signals (allophones).

Most studies of coarticulation concentrate only on interactions between adjacent sounds. However, some sounds are know to have effects that can span several syllables. Languages differ as to which sounds have such long-range effects. In English, the best evidence for long-range coarticulation involves the liquid sounds /r/ and /l/. Previous studies of this phenomenon have focused on a variety of British dialects. The current study extends this line of research to American English.

2. Background

A series of phonetic studies on British English have found that the sounds /r/ and /l/ acoustically influence long stretches of speech, and that listeners use these long-range effects to help perceive the liquids.

2.1 Articulatory And Acoustic Studies

This effect was first noticed by Kelly & Local (1986), who observed that in minimal pairs like *Terry* versus *Telly*, the r/l distinction seemed to alter the timbre of both vowels.[1] The nature of the effect depended on the way that /r/ and /l/ were pronounced in a given dialect. Each of these liquids can be pronounced as 'dark', meaning with a relatively back tongue position and a low F2, or 'clear', meaning with a relatively front tongue position and high F2; dialects differ as to which liquid is clear and which is dark. Kelly & Local refer to the resulting auditory effects as 'resonances.' Based on recordings from speakers of three non-standard British dialects, they suggested that liquid resonances extended within a word, and also to subsequent unstressed syllables. For example, in the sentence *Terry'll be about tomorrow*, the underlined portion reflects the observed resonance of the /r/.

Subsequent studies produced more extensive evidence for the nature and range of the liquids' influence. West 1999a studied the articulations directly, using electropalatography (EPG) and electromagnetic articulography (EMA). She recorded a speaker of standard Southern British English producing six pairs of words, such as *leap / reap*, in the frame sentence *have you uttered a ___ at home?* Both articulatory and acoustic data showed strong local coarticulation effects: vowels adjacent to /r/ had a lowered F3, rounded lips and retracted tongue.[2] There was also a very small but significant difference in the articulation of the last syllable of *uttered*: the speaker produced the schwa with more lip rounding and a higher and backer tongue position before /r/. This difference was less than 1 mm in magnitude.

Tunley (1999) found that /r/ raised the frequencies of F2 and F3, while /l/ lowered the same frequencies, compared to a neutral /h/. The effects extended at least two syllables on either side; she did not examine more distant syllables.[3]

Kelly & Local suggested that liquid resonances only affected one phonological foot (a stressed syllable plus an unstressed syllable, such as *Terry*), plus any unstressed syllables that were adjacent to the foot. However, Heid & Hawkins (2000) found that resonances could spread through stressed vowels. They recorded one speaker producing 106 words, most of them minimal r/l pairs such as *ram* / *lamb*, in 8 frame sentences such as *We heard that it could be a _____*. Significant resonance effects were found on *it*, *be*, and *a*---although not on *could*. The fact that resonances could 'pass through' *could* was particularly surprising given that the [k] articulation involves the tongue body, and hence might be expected to override any influence of the liquid on tongue body shape.[4]

2.2 Perceptual Studies

Given that liquid resonances have been found in speech from a variety of talkers and dialects, a natural question is whether listeners are able to use these resonances to enhance perception. If listeners are able to detect liquid resonances, and know that they signal the presence of an upcoming liquid, then perhaps listeners can exploit resonances to improve speech perception in noisy conditions, where the local effects of the liquids might be obscured.

West (1999b) found that this is in fact the case. She had speakers of two British dialects (Manchester, and Received Pronunciation or RP) listen sentences of the form *Have you uttered ____ today?*, where the blank was filled by 36 minimal r/l pairs such as *berry* / *belly*. Varying amounts of linguistic material, including the liquids, were deleted and replaced by white noise. Even when the entire syllable containing the liquid was deleted, as well as the syllable before and the syllable after, listeners were able to choose between [r] and [l] words with greater than chance accuracy.[5] This shows that listeners must be attuned to the long-distance liquid effects. Interestingly, speakers of both dialects did better in identifying the liquid that has a low F2 in their dialect (/r/ for RP; /l/ for Manchester).

2.3 British versus American English

Although liquid resonances have been studied in diverse British dialects, we are unaware of any studies of such long-range effects in American dialects. The phonology and phonetics of liquids are quite different in American than in any of the British dialects studied. In particular, American English has /r/ in two positions where it does not occur in British: both /r/ and /l/ can be 'syllabic', meaning the liquid serves as the nucleus of a syllable and has vowel-like properties, as in words like *pull* and *purr*. Americans also pronounce /r/ at the end of syllable, as in *car*, whereas most British speakers only pronounce /r/ when it is before a vowel.

3. Methodology

Our pilot study utilized a recording of one female native English speaker, a resident of Southern California who had learned no other languages before the age of five, and had no hearing or speech impediment. The speaker read a list of 95 randomized target words consisting of pairs or triplets that were similar except for a critical consonant:

1. [r] vs. [l] vs. [h]
2. [r] vs. [l]

A baseline example with [h] was included if the liquids were onset position, as in the triplet below. Sample item sets included:

1. *read* [ɹɛd] *lead* [lɛd] *head* [hɛd]
2. *bar* [bɑɹ] *ball* [bɑl]

Each word was inserted into the frame sentence *'It sounded as if it said* _____ *about then*.' The list was repeated three times for a total of 285 sentences. This paper, however, analyzes only 42 pairs of words with /r/ and /l/ (84 words, 3 repetitions each, for 252 total sentences). Words with /h/, as well as words with /r/ and /l/ in certain conditions such as long clusters, are left for future analysis.

Audio was recorded in a sound booth on CSU Long Beach campus using a Marantz PMD660 solid state recorder and a Shure PG81 microphone. The recordings were analyzed in Praat.[6] Only the five vowels preceding the target word were analyzed (i.e., the stretch *…ed as if it said*). Vowel boundaries were initially placed by EasyAlign, and manually adjusted where needed.[7] Formant values were collected through a Praat script written by Katherine Crosswhite. Outlying values were examined and manually corrected as needed. In some vowels, formants could not be confidently identified due to devoicing, influence of neighboring nasals or fricatives, or exceptionally short vowel durations; such measurements were excluded from the analysis. This was particularly an issue with the vowel in *if*, which occurred between two fricatives. In general, we found that this frame sentence did not yield particularly clear vowel tokens.

4. Results

In each sentence, we measured the F1, F2 and F3 of the five vowels before the target word. Measurements for all three repetitions of each sentence were averaged. A series of paired t- tests were done (a = 0.05) on these averages, comparing the pre-/r/ means and pre-/l/ means according to the word pairs.

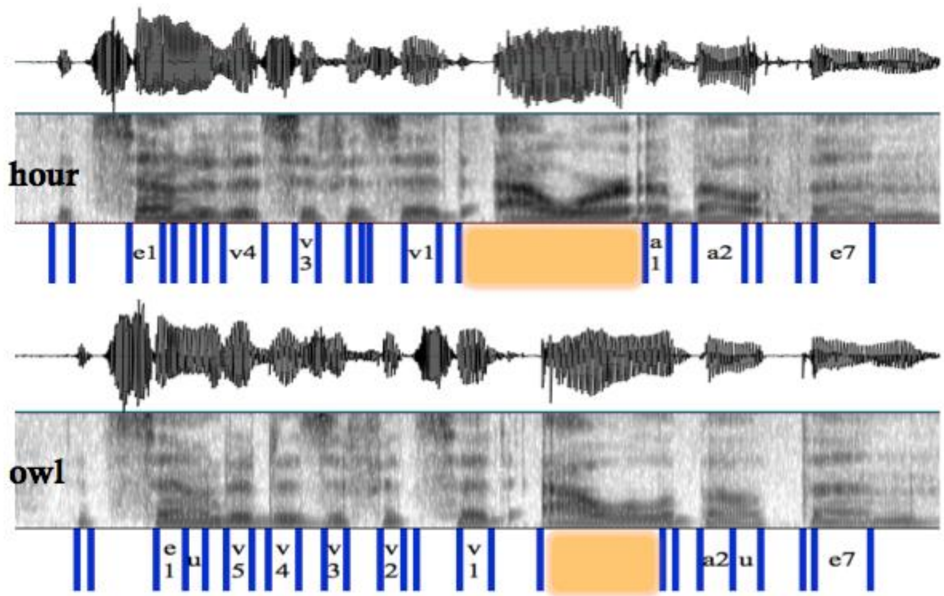

Fig. 1: An example of two target words, their vowel divisions, and the waveform and spectrogram as seen in Praat. The space highlighted in yellow was the target word in the sentence.

Table 1 shows the mean formants for each vowel before /r/ and before /l/. Vowels are identified according to their distance from the target word: for example, V1 is the vowel of *said*.

The F1 patterns follow no consistent trend: F1 is higher before /l/ than before /r/ in V1, but virtually identical before /r/ and /l/ in all other vowels. F2 is usually higher before /r/, except in V3. The most consistent pattern concerns F3, which is lower before /r/ than before /l/ in every vowel.

Table 1: Mean formant values before /r/ and /l/.

(42 pairs of means per vowel)	F1		F2		F3	
	l	r	l	r	l	r
V1 (said)	438	425 (p = .004)	1750	1793 (p < .001)	2947	2923 (p = .024)
V2 (it)	332	333	1735	1740	2887	2864
V3 (if)	333	336	1790	1757 (p = .054)	2969	2929 (p = .076)
V4 (as)	332	334	1748	1757	3018	3014
V5 (sounded)	377	376	1706	1710	2896	2889

Only the formants of *said* were significantly different before /r/ and /l/. The vowel of *if* showed nearly significant differences in F2 and F3; curiously, the F2 difference is in the opposite direction of that seen in *said*. For *said*, F2 is higher before /r/, but for *if*, F2 is higher before /l/.

4.1 Breakdown By Liquid Position

Because /r/ and /l/ may have different acoustic qualities in different positions in the syllable, we further broke down results by the environment of the liquid. There were 10 word pairs for each position: unstressed syllabic, syllable-final, syllable-initial, and part of a syllable-initial consonant cluster. An additional 2 pairs involving stressed syllabic vowels are not shown here.

Due to the small number of pairs per comparison (df = 9 for each paired t-test on item means), differences of small magnitude (such as are typically reported for long-range liquid resonances) are somewhat unlikely to reach signficance. However, this exploration of the data allows us to identify trends that might prove significant in a higher-powered experiment.

Table 2 shows the mean formant values before unstressed syllabic liquids, as in *cancer* vs. *cancel*. None of the formants in any vowel were significantly different before /r/ versus /l/. Note that since the liquid occurs in the second syllable of the target word, it is one syllable more distant from each vowel below than liquids in other positions. I.e., the vowel of *said* is two syllables away from the target liquid, not one syllable away as in all other sentences.

F1 is lower before /r/ in 4 of the 5 vowels. F2 is higher before /r/ in 3 vowels; the differences in both directions are mostly of very small magnitude. F3 is lower before /r/ in 4 of the 5 vowels.

Table 2: Mean formant values for vowels before unstressed syllabic liquids (*cancer, cancel)*. No differences between pre-/r/ and pre-/l/ position were significant in paired t-tests (df = 9).

	F1		F2		F3	
Target consonant	l	r	l	r	l	r
V1 (s<u>ai</u>d)	435	416	1833	1831	2978	2966
V2 (<u>i</u>t)	327	338	1731	1739	2891	2866
V3 (<u>i</u>f)	332	322	1778	1762	2940	2929
V4 (<u>a</u>s)	330	326	1747	1752	2988	2994
V5 (sound<u>e</u>d)	378	366	1736	1708	2914	2896

Table 3 shows results for the 10 word pairs where the liquid was in final position, such as *bar* versus *ball*. There is no consistent pattern of formant differences conditioned by the r/l distinction (the single result of p=.033 is likely to be a fluke; notice that the trend for F1 is very inconsistent in direction.) For F1 and F3, there is no consistent direction of trend. F2 is higher before /r/ in 4 of 5 vowels.

Table 3: Mean formant values for vowels before liquids in final position (*bar, ball*).

	F1		F2		F3	
Target consonant	l	r	l	r	l	r
V1 (s<u>ai</u>d)	425	425	1782	1799	2936	2917
V2 (<u>i</u>t)	326	344 (p = .033)	1725	1758	2855	2877
V3 (<u>i</u>f)	336	337	1779	1764	2991	2961
V4 (<u>a</u>s)	338	330	1744	1772	3029	3032
V5 (sound<u>e</u>d)	380	374	1702	1718	2907	2854

Table 4 shows the results for vowels before a word-initial liquid, as in *lock* versus *rock*. V1 shows a significantly higher F2 and lower F3 before /r/ compared to /l/. For F1, the trends are in inconsistent directions. An F1 difference reaches significance in V4, but given the lack of any effect in closer syllables, we suspect this is a fluke.

Table 4: Mean formant values for vowels before word-initial l/r.

	F1		F2		F3	
Target consonant	l	r	l	r	l	r
V1 (s<u>ai</u>d)	457	447	1643	1758 (p<.001)	2965	2899 (p = .011)
V2 (<u>i</u>t)	348	324	1740	1763	2920	2866
V3 (<u>i</u>f)	337	345	1778	1759	2947	2913
V4 (<u>a</u>s)	325	345 (p = .017)	1776	1756	3011	3024
V5 (sound<u>e</u>d)	384	380	1718	1695	2899	2898

Table 5 shows results for vowels before liquids that occupy the second position of an onset cluster, as in *pray* versus *play*. V1 shows significantly lower F1 and higher F2 before /r/ compared to /l/. For F3 there are no significant differences, but 4 of 5 vowels have lower F3 before /r/.

Table 5: Mean formant values for vowels before second position of an onset cluster l/r.

	F1		F2		F3	
Target consonant	l	r	l	4	l	r
V1 (s<u>ai</u>d)	429	409 (p = .056)	1729	1774 (p = .002)	2918	2915
V2 (<u>i</u>t)	330	326	1750	1715	2889	2851
V3 (<u>i</u>f)	325	346	1819	1734	3001	2896
V4 (<u>a</u>s)	334	332	1738	1738	3035	3018
V5 (sound<u>e</u>d)	371	376	1686	1712	2858	2912

In short, there are more significant differences in vowel formants before liquids that belong to the syllable onset than before liquids that belong to the syllable nucleus or coda. This could, however, be simply due to greater proximity, since fewer segments intervene between the liquid and V1 in such words.

Although significant results are few and mostly confined to V1 position, there are repeated trends towards higher F2 and lower F3 before /r/. F2 seems to show the most consistent effects across liquids in different positions. Higher F2 is associated with a relatively 'clear' pronunciation of /r/, with the tongue body in a front position.

5. Conclusion

These results show that liquids certainly affect at least the immediately preceding syllable in American English, and in some cases may possibly extend as many as three syllables (given the near-significant results for V3 *if* in the pooled data).

It should be noted that this study was far lower in power than Heid & Hawkins's study of /r/ and /l/: they analyzed 848 sentences, whereas we analyzed 252. Thus, null results should not be taken as proof that long-range resonances are weaker in American than British English.

In future research, we plan to increase the number of items, eliminate confounds between liquid position and distance from the preceding vowels (i.e., use syllabic liquids in the first rather than second syllables of target words), and choose frame sentences that yield clearer vowel tokens.

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