An ultrasound exploration of Australian English /CVl/ words

Susan Lin[1], Sallyanne Palethorpe[1,2,3], Felicity Cox[1,3,4]

[1]ARC Centre of Excellence in Cognition and its Disorders, Macquarie University, Australia
[2]Department of Cognitive Science, Macquarie University, Australia
[3]Centre for Language Sciences, Macquarie University, Australia
[4]Department of Linguistics, Macquarie University, Australia
susan.lin@mq.edu.au, sallyanne.palethrope@mq.edu.au, felicity.cox@mq.edu.au

Abstract

We use ultrasound to explore the lingual articulation of /hVd/ and /hVl/ rhymes from an Australian English speaker, focusing on the coarticulatory interactions between the VC rhyme components. Results reveal vowel height as a major factor conditioning lateral undershoot. We also find that back vowel tongue contours overlap extensively with the coda lateral providing a conditioning environment for vocalization. Despite most vowels being resistant to coarticulatory influence from the coda /l/, high central vowels and diphthongs are extensively affected displaying considerable retraction in line with observations from acoustic studies. Results are discussed with reference to Australian English change in progress.

Index Terms: speech production, ultrasound, laterals, sound change, Australian English, coarticulation

1. Introduction

Both onset and coda laterals in English are typically described as having two lingual gestures: tongue tip raising and tongue dorsum retraction [1, 2]. Ample evidence exists, however, that onset and coda laterals in many languages are strikingly distinct with respect to their acoustic properties as well as the extent and relative timing of the composite articulatory gestures. English coda laterals are considered "dark" or velarized, acoustically having a smaller F2-F1 difference than onset laterals. Articulatorily speaking, coda laterals are considered to have a reduced tongue tip gesture and an enhanced tongue dorsum gesture, compared to onset laterals. Additionally, the tongue tip gesture typically follows the tongue dorsum gesture in coda laterals, while in onset laterals, the inter-gestural timing is generally reversed [1, 3, 4, 5]. Coda laterals are also prone to vocalization in many dialects of English, including Southern British English [6], Philadelphia American English [7], and Australian English (AusE) [8] among others. L-vocalization is a process in which coda-final laterals are produced "vocalically." Perceptually, the vocalized variant of /l/ is generally described as sounding "vowel-like," most like a back vowel such as [u], [ʊ], [o] or [ɤ] [6, 8]. The acoustic properties of vocalized laterals have not been well studied, and auditory judgements of vocalized compared to non-vocalized laterals are considered by some authors to be unreliable [6].

On the other hand, the articulatory properties of vocalized laterals have been a topic of great interest to phoneticians, phonologists, sociolinguists, and historical linguists in the last few decades. In spite of this international and cross-linguistic focus, there are some important differences in the way vocalized laterals are described in the literature. Most accounts concur that vocalized laterals involve a reduced or absent tongue tip gesture [9, 8, 10], while some accounts document an additional labial gesture [8, 11], others do not [10]. Furthermore, whether or not this variant is thought to involve a reduced or missing tongue tip gesture appears to be linked, at least tenuously, to whether vocalization is analyzed as a categorical or gradient process.

The apparent inconsistencies in the literature may be largely terminological. Research that targets vocalization as a categorical phonological process, such as [9], [8] and [11], have generally described vocalized /l/ as lacking a tongue tip gesture, resulting in a vowel-like articulation. However, more recent work, such as in [10], [2] and [12], have explored vocalization as a gradient phonetic process, and in particular, an extreme variant of the gradient velarization found in coda laterals [ɫ] described by [3] for American English.

Figure 1 illustrates the difference between categorical and gradient "vocalization," using tongue contours derived from ultrasound. Speaker B is an AusE speaker from South Australia, a

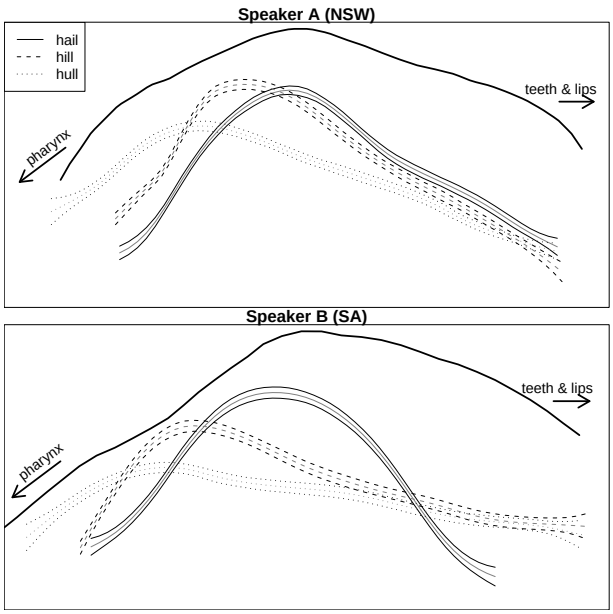

Figure 1: Coda tongue contours from a speaker from New South Wales (top), compared to a speaker from South Australia (bottom). The lighter lines represent mean lingual contours while the darker lines outline 95% confidence intervals of the contours. The thick black line is the palate trace.

region known to be leading the change towards vocalization of coda laterals[8], whereas Speaker A is from New South Wales where vocalization is less prevalent. We would therefore expect to find more frequent or more extreme vocalization in coda laterals produced by Speaker B. In the lingual contours of Speaker B, there is evidence for vocalization indicated by a distinct lack of an alveolar lingual gesture in the production of *hail*, which is present in both *hill* and *hull*[1]. On the other hand, the lingual contours of Speaker A display an alveolar gesture in all three word categories, but its height is greater in *hail* than in *hill*, for instance.

2. Research Aims

L-vocalization is considered a sound change in progress in AusE, yet we know little about the articulatory and acoustic characteristics of coda laterals in this dialect. The following analysis will provide insight into how the constituent elements of the /Vl/ rhyme affect each other leading to some hypotheses about how l-vocalization may develop in a speech community. In this paper we will provide a brief exploration of the lingual configurations of coda laterals in /hVl/ syllables with a variety of vowel contexts as spoken by one speaker of AusE. The emphasis is on the coarticulatory effects of vowels on coda laterals (V→L) and vice versa (V←L).

3. Methods

3.1. Participants and Stimuli

The participant reported on in this paper (Speaker A in Figure 1) is a 20 year old female Macquarie University undergraduate volunteer raised in Liverpool, NSW. The talker represented as Speaker B in Figure 1 is a 19 year old male undergraduate volunteer raised in Mt. Gambier, SA. He performed the same task as Speaker A did, but his data will not be discussed here.

Table 1 lists the word and non-word stimuli elicited in this study. We elicited /hVd/ in addition to /hVl/, in order to provide tongue contours for each elicited vowel in a non-dorsal consonantal context. As including a complete set of AusE vowels was impractical, we chose a subset of vowels that are representative of the parameters: height, backness, length, and rounding.

3.2. Data Collection and Analysis

We used a Terason 3000 running Ultraspeech [13] to simultaneously collect audio, ultrasound, and video data from our participant. An AKG C535 EB microphone was used to collect the audio data, via a TASCAM US-122 USB audio interface. Participants wore an ultrasound stabilization helmet from Articulate Instruments [14] to maintain a fixed ultrasound probe-to-head configuration. In addition to collecting lingual and labial motion during production of the stimuli, the speaker was recorded while swallowing a water bolus. Several bolus traces during swallowing were averaged to create a palate trace [15].

The 24 target stimuli were randomized with 12 filler items, and were elicited 8 times. In the results presented here, the first five productions in which the ultrasound images were clear were used. Due to the volume of data collected from each participant, we chose to have our participants produce the stimuli in isolation, rather than in a carrier phrase. For non-words and words of low lexical frequency, real word rhyme suggestions were provided parenthetically to assist with participants' productions.

Edgetrak [16] was used to obtain tongue traces from the ultrasound video. For each word and non-word, one frame from each consonant and one frame from each vowel (two from each dipththong) were chosen to represent the segments. Frames were selected visually, at the midpoint of the most stable portion of a given segment. We used the SSANOVA function in R on the vowel and lateral tongue traces for all productions, to determine the mean contours and 95% confidence intervals for each category [17].

[1] We note here that for both Speakers A and B, the jaw shadow prevented us from obtaining a more accurate image of the tongue tip. Presence and height of the tongue tip gesture is therefore inferred by position of the tongue blade at the right-most (anterior-most) edge available.

V	hVl	hVd	vowel quality		length
iː	heel	heed	high	front	long
ɪ	hill	hid	high	front	short
oː	hall	horde	high	back	long
ʊ	*hooll	hood	high	back	short
ʉː	Hoole	who'd	high	central	long
ɐː	*harl	hard	low	central	long
ɐ	hull	*hud	low	central	short
æ	Hal	had	low	front	short
ɔ	*hol	hod	mid	back	short
æɪ	hail	hade	high	front	diphthong
æɔ	howl	*howd	mid	back	diphthong
əʉ	hole	hode	high	central	diphthong

Table 1: /hVl/ and /hVd/ words and non-words elicited in this study. In the case of diphthongs, vowel quality listed reflects the quality of the second vocalic target. *Non-words.

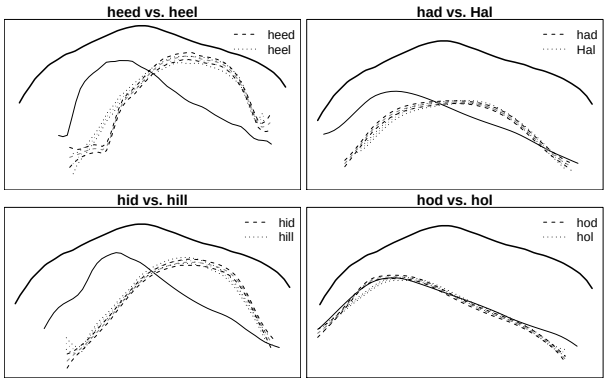

Figure 2: Mean tongue contours with 95% confidence intervals during vowel production for several vowel contexts: [iː], [æ], [ɪ] and [ɔ]. The heavy solid line represents the talker's palate trace, while the thinner solid line represents the mean tongue contour of the coda lateral during production of the indicated /hVl/ stimulus item.

4. Results

4.1. Coarticulatory effect of coda laterals on vowels (V←L)

In our results, we found that, compared with the /hVd/ context, most of the vowels in /hVl/ words and non-words remain relatively unaffected by the presence of a following coda lateral. Figure 2 depicts tongue contours during vowel production from four /hVl/ – /hVd/ word pairs: *heed* vs. *heel*, *had* vs. *Hal*, *hid* vs. *hill*, and *hod* vs. *hol*. In each plot, the thick solid line is a trace of the speaker's palate, while the thinner solid line is the average tongue trace during production of the coda lateral in the pair's

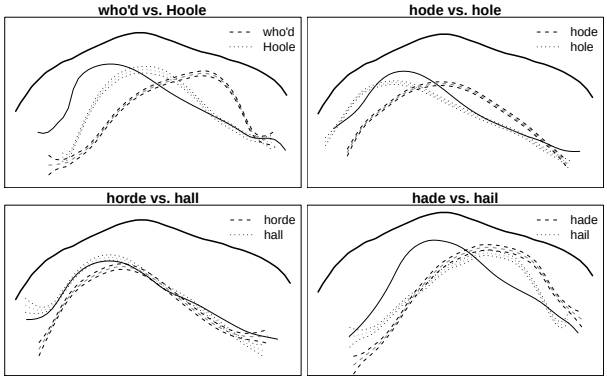

Figure 3: Mean tongue contours with 95% confidence intervals during vowel production for several vowel contexts: [ʉː], [ɔʉ] [oː] and [æɪ]. (For diphthongs, the vowel contours plotted represent the second vocalic target of the diphthong.)

/hVl/ stimulus. Each utterance is depicted with three lines. The lightest of the lines represents the mean tongue contour during vowel production, and the darker lines outline the 95% confidence interval. Each pair of contours in Figure 2 demonstrates considerable overlap between /hVl/ and /hVd/ vowel contours. This overlap is representative of the majority of the twelve vowels investigated in this study, and suggests that these vowels are resistant to coarticulatory influence from the following lateral.

There are four exceptions, depicted in Figure 3: *who'd* vs. *Hoole*, *hode* vs. *hole*, *horde* vs. *hall* and *hade* vs. *hail*. The difference between the tongue contour during vowel production is particularly substantial in *who'd* compared to *Hoole*. The speaker produced *Hoole* as [hʉːɬ], but *who'd* as [hyːd], with a front high rounded vowel[2], as is common for younger speakers of AusE [18]. Our data support an account in which pre-lateral retraction can be largely attributed to effects of coarticulation: the tongue dorsum gesture in the coda lateral preserves a more retracted articulation of the vowel which, in non-lateral contexts, is shifting towards [yː]. The differences in production of [ɔʉ] in *hode* compared with *hole* are similar in magnitude, and fall in the same direction.

The other vowels shown in Figure 3 do exhibit some coarticulatory effects from the following [ɫ]. The talker's tongue body during production of the vowel [oː] is raised in *hall* compared to *horde*. In fact the bulk of the tongue body during vowel production in *hall* overlaps completely with the tongue body during lateral production. Conversely, the tongue body during production of [æɪ] is lower in *hail* compared to *hade*, as would be expected due to coarticulatory undershoot.

It is also worth noting here that for the most part, back vowels and their following laterals have nearly identical lingual configurations in the stimuli collected from this talker. As can be seen in Figures 2 (bottom right) and 3 (bottom left), the primary difference between vowel and lateral in these productions, as represented by *hol* and *hall*, is in a raised tongue tip in laterals.

4.2. Coarticulatory effect of vowels on coda laterals (V→L)

In order to determine the extent of vowel to lateral coarticulation, we determined the mean lingual contours during /l/ production by vowel height, length, and front/backness. These results are displayed in Figures 4 and 5, and discussed briefly below.

[2]We verified in the video that this speaker rounded her lips during the vowel in *who'd*, but we present no quantitative analysis of it here.

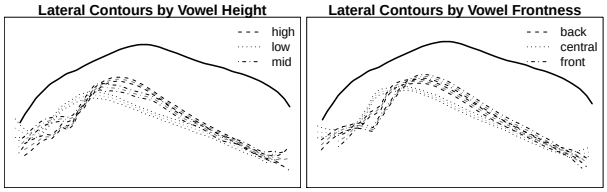

Figure 4: Mean lingual contours during coda /l/ production, by preceding vowel height (top) and front/backness (bottom).

4.2.1. *Vowel quality*

As demonstrated by Figure 4, lingual configuration during production of coda laterals is affected by preceding vowel height. In particular, the tongue body is highest when preceded by high vowels, and lowest when preceded by low vowels, with mid vowels in between. Vowel front and backness also affects productions of coda laterals. Not surprisingly, tongue contours for coda laterals in the context of front vowels are slightly more anterior than those in the context of back vowels. However, laterals in the central vowel context appear to be even more retracted than in the back vowel context.

4.2.2. *Vowel length*

As shown in Table 1, our study included three paired short and long vowels: [iː] and [ɪ], [oː] and [ʊ], [ɐː] and [ɐ]. The tongue contours in Figure 5 show that the effect of vowel length is of a different quality in the context of the different vowel categories.

In the case of [iː] vs. [ɪ], in *heel* vs. *hill*, coda laterals in the long vowel context have a lower tongue dorsum gesture. For [oː] vs. [ʊ], in *hall* and *hooll*, coda laterals in the long vowel context have a lower and slightly posterior tongue dorsum gesture. For [ɐː] vs. [ɐ], in *harl* vs *hull*, the effect of vowel length on some portions of the lateral tongue contour is apparent, and lower in the context of the long vowel. This suggests that, in our data, the long vowel exerts a stronger coarticulatory pull than the short vowel (in this case, lowering the tongue dorsum).

5. Discussion

In this study, we found little evidence for coarticulatory effects of coda laterals on the lingual configuration of the preceding vowel. Only four vowel contexts, [ʉː], [ɔʉ] [oː] and [æɪ], showed an effect of the coda lateral on tongue body position in the expected direction. Conversely, we found stronger evidence of effects of vowel quality on lingual configuration during coda /l/s. Taken together, these findings question the results from previous studies that laterals, especially velarized coda laterals, are resistant to coarticulation [19].

Horvath and Horvath [8] found that for AusE speakers, singleton coda laterals following long vowels were consistently more often perceived as vocalized than those following short vowels. Of course, the data collected by [8] was not controlled for vowel quality, limiting the comparability between their findings are our study. Despite that, we found that phonemic vowel length did have an effect on tongue contours of the following laterals, with laterals after long vowels generally showing some lowering or "reduction." There is also more extreme coarticulation towards the front or back place of the preceding long

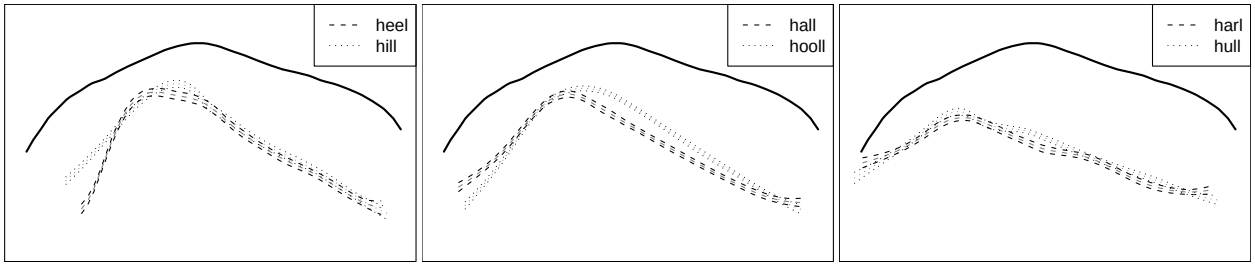

Figure 5: Mean lingual contours during coda /l/ production, by preceding vowel length, and vowel quality.

vowel

In terms of understanding vocalization as a current sound change, we need to consider its origin. It has been previously suggested that the origin of vocalization is reduction of one or both of the lingual gestures in coda laterals [12, 20], resulting in a lower than typical tongue tip or tongue dorsum gesture, and we interpret our findings as corroborating this account. Furthermore, our findings suggest that in the context of certain vowels (particularly back vowels) the articulations (and therefore the acoustics) of the vowel and a following [ɫ] are so similar that listeners may become incapable of distinguishing between vowel and consonant, thus seeding the sound change.

Moving forward, we believe that this study highlights the importance of being cautious when describing laterals as being "vocalized." The literature has clearly not converged on a single definition for this curious process. Caution is particularly important when describing l-vocalization in Australian English, as it is for any language in which this is considered a change in progress, especially as individual speakers may be at different stages of the change. As such, this study should be considered a launchpad for a series of follow-up tests that we feel are integral to our goal of a more complete understanding of l-vocalization as a sound change. These tests include acoustic measures of the data collected, including data from more speakers, to examine acoustic similarity or dissimilarity between laterals in different vowel contexts, and perceptual tests to examine auditory similarity and the perception of vocalization.

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