ARTICULATORY STRATEGIES FOR BACK VOWEL FRONTING IN AMERICAN ENGLISH

Jonathan Havenhill

University of Hong Kong
jhavenhill@hku.hk

ABSTRACT

The fronting of the vowels /u/ and /o/ is observed in numerous varieties of English, but has been analyzed mainly in terms of acoustics rather than articulation. Because the acoustic correlate of this change, an F2 increase, can be the result of any gesture that shortens the front cavity of the vocal tract, it is unknown whether speakers achieve this change through tongue fronting, lip unrounding, or a combination of these strategies. This paper presents articulatory and acoustic data on back vowel fronting from two varieties of American English: Southern California and South Carolina. It is shown that speakers of both varieties retain the rounding gesture for /u/ and /o/, and that the F2 increase is achieved by tongue fronting rather than lip unrounding.

Keywords: vowel fronting, articulation, ultrasound, sound change, sociophonetics

1. INTRODUCTION

The fronting of the back vowels /u/ (GOOSE), /o/ (GOAT), and /ʊ/ (FOOT) has been observed in numerous varieties of English, including those of North America [20], Britain [15], Australia [7, 8], New Zealand [12], and South Africa [22]. While this diachronic change has received much attention in the literature, previous research has focused mainly on acoustics rather than articulation. However, given that an increase in F2 can be the result of any gesture that shortens the front cavity of the vocal tract (including tongue fronting or lip unrounding), acoustic studies do not reveal which strategy speakers actually employ to achieve this change. Moreover, it is not known to what extent the articulatory configurations responsible for vowel fronting differ between speakers or dialects.

Previous articulatory study of this change has been limited to British varieties. Using a combination of acoustic, perceptual, and EMMA analysis, Harrington et al. [16] find that the fronting of /u/ in Southern Standard British English (SSBE) is not the result of lip unrounding, but is achieved through fronting of the tongue. In a study of Scottish English, Scobbie et al. [29] show that fronted /u/ is produced with a tongue position that is fronted, but also lowered, setting the Scottish variant of /u/ apart from that found in other parts of Britain. A cross-dialectal study of /u/-fronting by Lawson et al. [21] confirms the articulatory configuration for fronted /u/ found in [29]. They show that the maximum tongue height for /u/ in Scottish English is indeed lower than the maximum tongue height for Anglo and Irish varieties. These results demonstrate that the processes of /u/-fronting throughout English are not monolithic.

In North American English, the fronting of the non-low back vowels has seen a great deal of investigation in the sociophonetic literature [11, 9, 14, 25]. Labov et al. [20] find that the fronting of /u/ is widespread throughout the United States and Canada, occurring to some degree in almost all of the varieties they study. They show that the fronting of /u/ is strongly conditioned by preceding coronal onsets, such that the F2 of /u/ exhibits a three-way split. In pre-lateral environments, /u/ remains in the high back region of the vowel space, with a low F2. Following a coronal onset, /u/ is strongly fronted, exhibiting a mean F2 approaching that of /i/. Following non-coronal onsets, /u/ is fronted to a moderate degree, such that it is realized roughly as [ʉ]. In some (but not all) regions, the fronting of /u/ is also accompanied by fronting of /o/. Parallel fronting of /u/ and /o/ is particularly strong in the Southeast [30, 3], while California English exhibits strong fronting of /u/ and moderate fronting of /o/ [20, 19]. Unlike /u/, the fronting of /o/ has not been shown to be conditioned by onset place of articulation [20, p. 55].

Instrumental articulatory data is lacking, however, and transcriptions and impressionistic observations from previous studies are inconsistent. For instance, Hinton et al. [17, p. 119] write that the California back vowels "are clearly more front and less rounded" and Hagiwara [13, p. 657] describes them as "typically unrounded." Thomas [31, p. 34], on the other hand, writes that he is "skeptical" that fronted /u/ is unrounded. Eckert [9] distinguishes between two types of vowel fronting in California, dubbed the "Surfer" and "Valley Girl" variants. She transcribes the Surfer variant as [y] (as in [dyd] *dude*), also suggesting fronting without unrounding. The Valley Girl variant is diphthongized, with a front unround nucleus and a back round offglide, such that *food* is realized as [fɪwd] and *goes* as [gɛwz].

It is therefore of interest to determine how back vowel fronting in American English is actually achieved in terms of articulation. Do fronted variants of /u/ retain their lip rounding, as has been shown for British English? In addition, does the articulatory strategy for vowel fronting differ by speaker or dialect? This paper considers back vowel fronting in two varieties of American English. The first is that of Southern California, where back vowel fronting is a well known and stereotypical component of the California Vowel Shift. The second is that of South Carolina, which has received attention for exhibiting advanced parallel fronting of both /u/ and /o/.

2. METHODS

2.1. Participants

Twenty-five participants (9 men, 16 women) took part in the study, which was conducted at universities in South Carolina and in San Diego, California. Participants were natives of either South Carolina or of coastal Southern California, having been born and raised in their respective region at least through the age of 18. Fifteen participants (8 women, 7 men) were from Southern California, and ten participants (8 women, 2 men) were from South Carolina.

2.2. Materials

Participants were asked to repeat a list of 203 (mostly) monosyllabic words containing the vowels /i u ɪ ʊ e o ɑ ɔ/. Each word contained one of the onset consonants /p b t d s ʃ k g h/ and one of the coda consonants /# p t k l/. Each word was produced in the carrier phrase "say ____ again," which was repeated three times in succession. This provided 609 tokens per participant, for a total of 15,225 tokens across all participants. Words were presented in pseudo-random order, so that no two words containing the same vowel appeared in successive order. In addition, the vowels /u o ʊ/ did not appear in sequence with their front unround counterpart (/i/, /e/, or /ɪ/) and vice versa.

2.3. Procedure

Recording for this experiment took place in sound-attenuated rooms at both research sites. Identical methods and equipment were used in both locations. Ultrasound data were captured using an Articulate Instruments SonoSpeech Micro ultrasound system with a 20mm radius 2–4MHz transducer. Ultrasound images were captured at an average frame rate of 84 frames per second (fps). A stabilizing headset [1] was used to keep the ultrasound transducer in a constant position with respect to the speaker's head. Sagittal-view video of the speaker's lips was captured at 60 fps using a camera mounted to the ultrasound headset. Audio was captured with an AKG C544 L cardioid headset condenser microphone and recorded at a 48 kHz sample rate and 16-bit sample depth with a Marantz PMD661 Mk2 solid state recorder. Audio was simultaneously recorded to disk in Articulate Assistant Advanced (AAA) [2], which was used to synchronize the audio, video, and ultrasound data streams.

2.4. Data Analysis

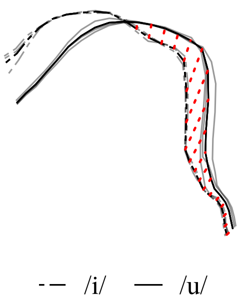
Formant measurements were taken in Praat [4], with LPC coefficients calculated using the Burg algorithm [6, 26]. Formant measurements were taken at 25% of the vowel's duration, as well as the points of maximum labial and lingual articulation. Vowel formant measurements were normalized according to the Nearey1 normalization procedure [23] using the vowels package for R [18, 27].

Lip video data were analyzed with a purpose-built tool written in Python using PsychoPy [24]. The TextGridTools package for Python [5] was used to identify the start and end points of the target vowel intervals, based on TextGrids used for the acoustic analysis. FFmpeg [10] was then used to extract still frames from the portion of the video corresponding to the vowel. For each target vowel, the annotator was prompted to scroll through the extracted video frame-by-frame and identify the point of maximum labial articulation. Points were manually placed at the upper and lower edges of the lip aperture, respectively defined as (i) the boundary between the vermillion border and oral mucosa of the upper lip and (ii) the nearest point on the lower lip. A third point was placed at the oral commissure. In this paper, the measure used to quantify the degree of lip rounding is lower lip protrusion (LLP), which was determined by calculating the horizontal distance of the point placed on the lower lip from the posterior edge of the video frame.

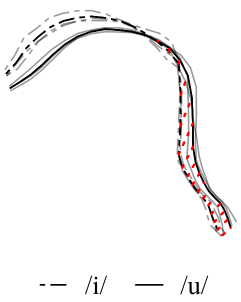
Ultrasound data were analyzed in AAA, with tongue splines automatically fit to the ultrasound images using the Batch Process function. Automatically splined tongue contours were checked for accuracy and manually corrected when necessary. Still images corresponding to each splined frame were ex-

Figure 1: Illustration of the RD-Σ metric for degree of tongue fronting. Gray lines represent individual tokens, black lines indicate mean tongue contours for each phonological environment. RD-Σ is the summed length of the dashed lines. Data from speaker Cal007.

(a) *he* vs. *who*, RD-Σ = 89.03 mm



(b) *tea* vs. *too*, RD-Σ = 57.6 mm



ported along with the tongue spline coordinates, and the frame containing the point of maximum lingual articulation was selected for analysis.

Degree of tongue fronting was determined using a measure of "summed radial difference" (RD-Σ), inspired by the dorsal crescent metrics proposed by Scobbie and Cleland [28]. Ultrasound tongue spline data were exported from AAA in polar coordinates, with each spline comprising forty-two points defined in terms of polar angle (θ) and distance (radius) from the center of the ultrasound transducer (in millimeters). For each speaker, the mean tongue contour for all three repetitions of each word was determined by calculating the mean radius along each polar angle. Then, mean tongue contours for minimal pairs containing the vowels /i/ and /u/, /i/ and /o/, and /i/ and /ʊ/ were compared. The RD-Σ for a given minimal pair (i.e., phonological environment) is the sum of the difference in radius between the two mean tongue contours, for all polar angles where the radius for /u/ (or /o/ or /ʊ/) is greater than that of /i/.

The RD-Σ metric is illustrated in Figure 1, which shows tongue spline comparisons for /u/ in two phonological environments. This figure reveals that the radial difference between /u/ and /i/ is smaller in the t_# environment (Figure 1b) than for the h_# environment (Figure 1a), indicating that the tongue position for /u/ is fronter after /t/ than after /h/. RD-Σ is inversely proportional to tongue frontedness, so fronter tongue positions exhibit a lower RD-Σ.

3. RESULTS

The present paper considers results for the fronting of /u/; findings for the fronting of /o/ are similar.

Figure 2: Histogram of normalized F2 measurements for /u/ by onset, Southern California speakers. Measurements taken at 25% of vowel's duration.

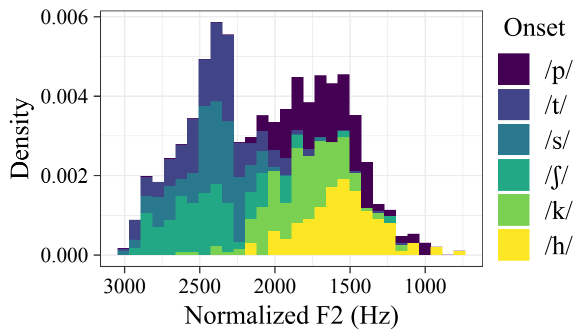
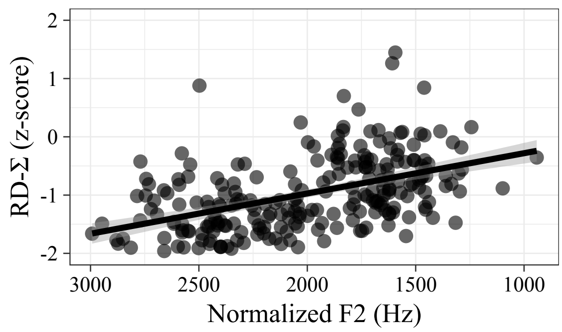


Figure 3: Relationship of F2 to tongue frontedness (RD-Σ) for /u/, Southern California speakers. $r = -.496$, $p < .001$.



3.1. Southern California

Results for speakers from Southern California are considered first. Figure 2 displays normalized F2 measurements for non-pre-lateral /u/, with tokens categorized by preceding consonant. It is observed that the distribution of F2 for /u/ is bimodal, with higher values for F2 following coronal onsets and lower values for F2 following non-coronal onsets. Following coronal onsets, including /t/, /s/, and /ʃ/, the mean F2 for /u/ is 2385 Hz. Following non-coronal onsets, the mean F2 is 1811 Hz. The acoustic data show that, in general, /u/ is quite strongly fronted for Southern Californians.

Figure 3 presents the RD-Σ metric for each word containing /u/, plotted against the mean F2 for that word. F2 and RD-Σ are negatively correlated (Pearson's $r = -.496$, $p < .001$), indicating that the closer the tongue position for /u/ is to that of /i/ (resulting in a lower RD-Σ), the higher the value of F2. This correlation demonstrates that the fronting of /u/ is at least partly the result of tongue fronting.

In order to assess whether /u/ has lost its lip rounding, normalized F2 measurements were also fit

Figure 4: Relationship of F2 to lip protrusion (LLP) for /u/, Southern California speakers. $r = -.042$, $p = .541$.

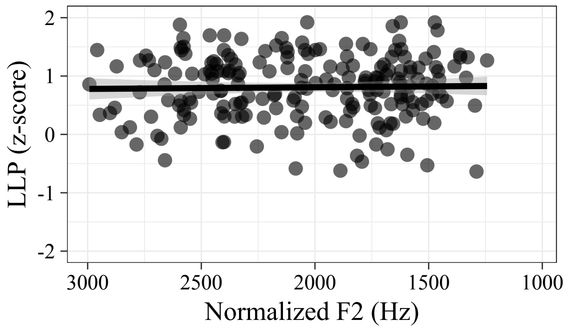
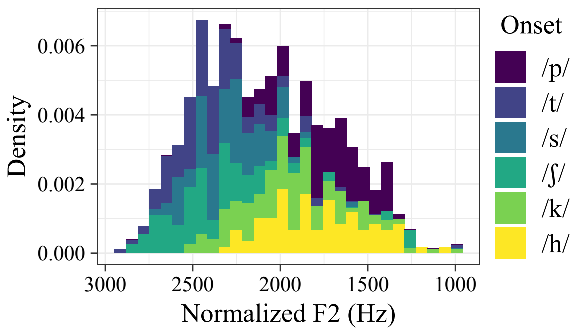


Figure 5: Histogram of normalized F2 measurements for /u/ by onset, South Carolina speakers. Measurements taken at 25% of vowel's duration.



against z-score normalized lip protrusion measurements. If acoustic fronting of /u/ is the result of lip unrounding, the degree of lip protrusion should be lower for tokens with high values of F2 than for tokens with low values for F2. The relationship between F2 and lip protrusion for /u/ is shown in Figure 4. No correlation is observed ($r = -.042$, $p = .541$), indicating that tokens that are acoustically more front are not less round than tokens that are acoustically more back. These findings therefore suggest that the fronting of /u/ in Southern California is the result of fronting of the tongue, rather than unrounding of the lips.

3.2. South Carolina

Acoustic results for speakers from South Carolina are presented in Figure 5. As with /u/ in Southern California, fronting of /u/ is more advanced in post-coronal environments, but the distribution of F2 in South Carolina is far less bimodal. The mean F2 for post-coronal /u/ is 2309 Hz, while the mean F2 for /u/ in all other environments is 1923 Hz. Notably, a number of post-glottal, post-velar, and post-labial tokens of /u/ exhibit an F2 well past the centerline of the vowel space, with a small number exceeding 2500 Hz.

Figure 6: Relationship of F2 to lip protrusion (LLP, $r = -.113$, $p = .101$) and tongue fronting (RD-Σ, $r = -.208$, $p < .01$) for /u/, South Carolina speakers.

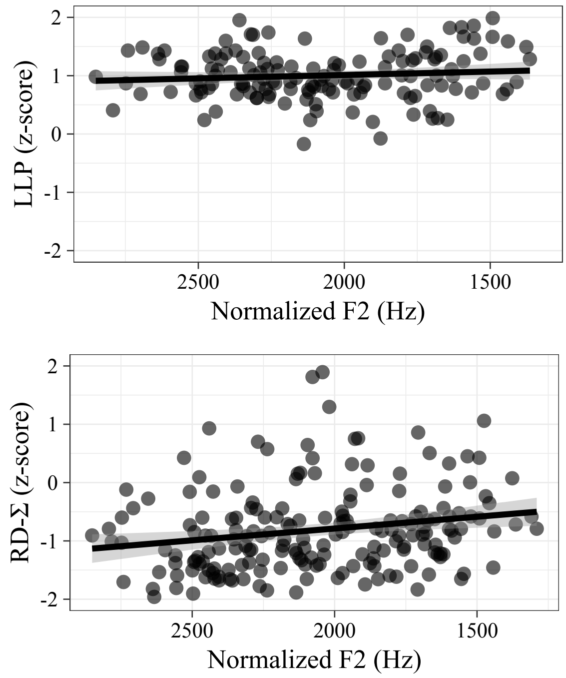


Figure 6 presents the relationship between RD-Σ and lower lip protrusion with F2 for /u/, as produced by speakers from South Carolina. It is observed that F2 does not change as a function of lower lip protrusion ($r = -.113$, $p = .101$); tokens with high and low values for F2 exhibit similar degrees of lip rounding, suggesting that acoustically fronted tokens are not unround. As for the speakers from Southern California, RD-Σ and F2 are negatively correlated ($r = -.208$, $p < .01$), with fronter tokens exhibiting a higher F2 than backer tokens. However, the correlation is weaker for the South Carolina speakers than for the Southern California speakers, as a result of interspeaker variation.

4. DISCUSSION

This paper has shown that the acoustic fronting of /u/ in two varieties of American English is achieved by fronting the tongue, rather than by unrounding the lips. These findings are thus similar to those for SSBE [16] and Scottish English [29], which likewise show no unrounding for fronted tokens of /u/. However, the two varieties considered here differ with respect to the degree of interspeaker variability, which will be discussed in detail in future analyses.

5. REFERENCES

[1] Articulate Instruments Ltd., 2008. Ultrasound stabilisation headset users manual: Revision 1.4.

[2] Articulate Instruments Ltd., 2012. Articulate Assistant Advanced user guide: Version 2.14.

[3] Baranowski, M. A. 2008. The fronting of the back upgliding vowels in Charleston, South Carolina. *Language Variation and Change* 20(3), 527–551.

[4] Boersma, P., Weenink, D. 2017. Praat: Doing phonetics by computer (version 6.0.36).

[5] Buschmeier, H., Włodarczak, M. 2013. TextGridTools: A TextGrid processing and analysis toolkit for Python. *Proceedings der 27. Konferenz zur Elektronischen Sprachsignalverarbeitung* 152–157.

[6] Childers, D. G. 1978. *Modern spectrum analysis*. IEEE Computer Society Press.

[7] Cox, F. 1999. Vowel change in Australian English. *Phonetica* 56(1-2), 1–27.

[8] Cox, F., Palethorpe, S. 2001. The changing face of Australian English vowels. In: Blair, D., Collins, P., (eds), *English in Australia* number 26 in Varieties of English Around the World. Amsterdam: John Benjamins 17–44.

[9] Eckert, P. 2008. Where do ethnolects stop? *International Journal of Bilingualism* 12(1-2), 25–42.

[10] FFmpeg Developers, 2018. FFmpeg v3.4.2 [computer software].

[11] Fought, C. 1999. A majority sound change in a minority community: /u/-fronting in chicano english. *Journal of Sociolinguistics* 3(1), 5–23.

[12] Gordon, E., Campbell, L., Hay, J., Maclagan, M., Sudbury, A., Trudgill, P. 2004. *New Zealand English: Its Origins and Evolution*. Cambridge: Cambridge University Press.

[13] Hagiwara, R. 1997. Dialect variation and formant frequency: The American English vowels revisited. *The Journal of the Acoustical Society of America* 102(1), 655–658.

[14] Hall-Lew, L. 2009. *Ethnicity and phonetic variation in a San Francisco neighborhood*. Doctoral dissertation Stanford University Stanford, CA.

[15] Harrington, J., Kleber, F., Reubold, U. 2008. Compensation for coarticulation, /u/-fronting, and sound change in standard southern British: An acoustic and perceptual study. *The Journal of the Acoustical Society of America* 123(5), 2825–2835.

[16] Harrington, J., Kleber, F., Reubold, U. 2011. The contributions of the lips and the tongue to the diachronic fronting of high back vowels in Standard Southern British English. *Journal of the International Phonetic Association* 41(2), 137–156.

[17] Hinton, L., Moonwomon, B., Bremner, S., Luthin, H., Van Clay, M., Lerner, J., Corcoran, H. 1987. It's not just the Valley Girls: A study of California English. *Annual Meeting of the Berkeley Linguistics Society* 13, 117–128.

[18] Kendall, T., Thomas, E. R. 2014. *vowels: Vowel manipulation, normalization, and plotting*. R package version 1.2-1.

[19] Kennedy, R., Grama, J. 2012. Chain shifting and centralization in california vowels: An acoustic analysis. *American Speech* 87(1), 39–56.

[20] Labov, W., Ash, S., Boberg, C. 2006. *The Atlas of North American English*. Berlin: Walter de Gruyter.

[21] Lawson, E., Stuart-Smith, J., Mills, L. 2017. Using ultrasound to investigate articulatory variation in the GOOSE vowel in the British Isles. Paper presented at Ultrafest VIII, Potsdam, Germany.

[22] Mesthrie, R. 2010. Socio-phonetics and social change: Deracialisation of the GOOSE vowel in South African English. *Journal of Sociolinguistics* 14(1), 3–33.

[23] Nearey, T. M. 1978. *Phonetic feature systems for vowels*. Doctoral dissertation University of Alberta.

[24] Peirce, J. W. 2007. PsychoPy: Psychophysics software in Python. *Journal of Neuroscience Methods* 162(1-2), 8–13.

[25] Podesva, R. J. 2011. The California Vowel Shift and gay identity. *American Speech* 86(1), 32–51.

[26] Press, W. H., Teukolsky, S. A., Vetterling, W. T., Flannery, B. P. 1992. *Numerical recipes in C*. Cambridge: Cambridge University Press 2 edition.

[27] R Core Team, 2018. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing Vienna.

[28] Scobbie, J. M., Cleland, J. 2017. Area and radius-based mid-sagittal measurements of comparative velarity. Paper presented at Ultrafest VIII, Potsdam, Germany.

[29] Scobbie, J. M., Lawson, E., Stuart-Smith, J. 2012. Back to front: A socially-stratified ultrasound tongue imaging study of Scottish English /u/. *Rivista di Linguistica* 24(1), 103–148.

[30] Thomas, E. R. 1989. The implications of /o/ fronting in Wilmington, North Carolina. *American Speech* 64(4), 327–333.

[31] Thomas, E. R. 2001. *An acoustic analysis of vowel variation in New World English*. Number 85 in Publications of the American Dialect Society. Durham, NC: Duke University Press.