Maintenance of the COT-CAUGHT Contrast Among Metro Detroit Speakers: A Multimodal Articulatory Analysis

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1 Introduction

The Northern Cities Vowel Shift (NCVS) has been widely studied in the phonetic and sociophonetic literature, having been analyzed from such perspectives as language and gender (Eckert 1989), speech perception and perceptual dialectology (Plichta and Preston 2005, Niedzielski 1999), and sociophonetic theory (Labov et al. 1972, Labov 1994, 2001, 2011), among many others. Like the majority of sociolinguistic phenomena, however, the Northern Cities Vowel Shift is typically described in terms of its acoustic characteristics; the articulatory mechanisms underlying this shift have remained largely unstudied.

The present study considers the Northern Cities Vowel Shift in terms of both its acoustic and its articulatory components. Specifically, this study uses a combination of ultrasound, video, and acoustic measure to investigate the fronting of the low back vowels /ɑ/ and /ɔ/, a change which is described as an increase in the second formant. However, while the value of F2 is strongly correlated with tongue backness, other articulatory gestures such as lip-rounding can also influence the realization of F2.

It is found that Metro Detroit speakers differ in their articulatory realizations of the low back vowels. While some speakers produce fronted /ɔ/ with a combination of tongue-fronting and lip-unrounding, others do so using either tongue-fronting or lip-unrounding alone. For speakers who maintain the contrast through only one articulatory gesture, the acoustic differences between /ɑ/ and /ɔ/ are smaller than for speakers who use multiple gestures. This finding raises a number of questions regarding the perception, acquisition, and transmission of variable and changing linguistic forms. In addition, this study contributes to a growing body of work demonstrating the value of incorporating multiple modes of data collection in sociophonetics.

2 Previous Literature

Despite the extensive literature on the NCVS, descriptions of this change have been based almost exclusively on acoustic measurement. An exception to this generalization is a study by Plichta (2005), who used nasal/oral airflow measurement to investigate the effect of nasalization on /æ/-raising in the NCVS. He suggests that acoustically-raised /æ/ may be an artifact of the high degree of nasal airflow found for Northern Cities speakers in both nasal and non-nasal environments. In the past several years, however, sociophonetic inquiry has seen an increase in the number of studies incorporating articulatory analysis, several of which inform the present study.

De Decker and Nycz (2012) used ultrasound to examine the tense [æ] system characteristic of Mid-Atlantic dialects. Their investigation is motivated by competing articulatory sources for acoustic contrasts, namely a perceptually-higher realization of [æ] that may be associated with either nasalization or tongue raising. They find that at least three variations in articulatory strategy exist: one in which a three-way distinction in tongue position is associated with a three-way distinction in the acoustic signal, one in which a two-way distinction in tongue position is associated with a two-way distinction in the acoustic signal, and one in which a two-way distinction in the acoustic signal is associated with only a single lingual gesture. It appears that in the latter case, speakers must rely on an additional articulatory gesture (here nasalization) to achieve acoustic contrast.

Harrington et al. (2011) performed a set of experiments investigating the role of tongue position and lip rounding in the fronting of /u/ in Standard Southern British English (SSBE). They find that despite being fronted, /u/ remains round, as observed through the acoustic effects of anticipatory

*Many thanks to Jennifer Nycz, Elizabeth Zsiga, and the audience of NWAV 43 for valuable comments on this project. As usual, all errors are my own.

lip-rounding in words like *soup*. In addition, they find that this effect holds across age groups, suggesting that despite an increase in fronting, /u/ has not decreased in rounding over time. This finding is confirmed by an electromagnetic articulometry (EMA) study of five SSBE speakers, in which the degree of lip protrusion in /u/ is compared to that of /i/ and /ɔ/. It is found that /u/ is closer in rounding to /ɔ/ than to /i/ for all speakers, and that the tongue position for /u/ is nearly as high and fronted as that of /i/. Harrington et al. conclude that lip-protrusion has become the primary distinguishing feature between /u/ and /i/.

Most directly related to the present investigation is a study by Majors and Gordon (2008), who use video recording to perform visual analysis of lip-unrounding in two speakers from St. Louis, where the Northern Cities Vowel Shift is in effect to some extent. They find that /ɔ/ can be fronted while maintaining its rounding, suggesting that /ɔ/-fronting and lowering in the NCVS may be accomplished through tongue position alone. As Labov et al. (2006) argue, St. Louis is the least consistent of the Inland North cities in terms of number of NCVS-related changes and number of speakers exhibiting the shift, while Detroit and Chicago are the most consistent. This provides strong motivation for conducting a similar study on speakers from other NCVS cities, such as Detroit. In addition, because video analysis only allows for measurement of labial articulation, any conclusions drawn by Majors and Gordon (2008) relating to lingual articulation are necessarily speculative. Therefore, it is useful to augment the video analysis techniques used by Majors and Gordon with simultaneous ultrasound tongue imaging, which allows for consideration of both labial and lingual articulation.

Generally, this paper seeks to answer the following question: What strategies for low back vowel fronting do Northern Cities speakers employ? As noted above, accounts of the Northern Cities Vowel Shift are based almost exclusively on the acoustic characteristics of this shift. The change in question here, that of /ɔ/ and /ɑ/-fronting, is typically described as an increase in the second formant. However, it is well known in the phonetic literature that the value of F2 is influenced by a number of articulatory gestures—any gesture which shortens the length of the vocal tract can increase the value of F2. Aside from visual input that may be available for lip-rounding, there is no a priori way for a language learner to know which gesture is the source of a change in F2. This leads to a number of specific questions pertaining to how /ɑ/ and /ɔ/ are realized in the NCVS. First, do Northern Cities speakers differ in the way they achieve fronting of the low back vowels? Second, is interspeaker articulatory variation observable in the acoustic signal? And finally, what effects might this sort of variation have on the progression of the Northern Cities Vowel Shift?

3 Methodology

Data for this study were collected from eight speakers, comprising five men (ages 24–29) and three women (ages 22, 23, and 39). All speakers were born and raised in Metro Detroit,[1] having lived there until at least age 18. Seven of the eight speakers currently reside in the Washington DC region, while one remains in Metro Detroit. In this study, the degree to which participants' productions have changed as a result of having lived outside of Michigan is not considered.

Two speakers were ultimately excluded from analysis. The first, a 29 year-old man, was excluded due to poor ultrasound imaging, which prevented accurate tracking of tongue contours. The second, a 25 year-old man, produced vowels which were not consistent with the Northern Cities Vowel Shift in that his productions of /ɑ/ and /ɔ/ were not fronted. While future analysis of these data may provide additional information about variation in vowel production among Northern Cities speakers, they provide little information with regard to the behavior of fronted /ɔ/.

Tokens were elicited using a wordlist containing 100 monosyllabic words, including 20 words for each of the vowels /i/, /u/, /æ/, /ɑ/, and /ɔ/. /ɑ/ and /ɔ/ were the target vowels, while /i/ and /u/ were included to serve as reference points for lip spread and lip openness, respectively. A subset of /u/ words containing the sequence /ul/ were included to serve as a reference point for tongue backness. Finally, /æ/ was included because it constitutes the initial stage of the Northern Cities

[1] For the purposes of this study, Metro Detroit is defined as the Detroit-Ann Arbor-Flint Combined Statistical Area. One speaker was raised just outside this area in neighboring Jackson County.

Vowel Shift (Labov et al. 2006) and serves as a useful indicator of the degree of participation in the NCVS. Words were embedded in the carrier phrase "say ____ again" and presented in five blocks of 20 words in pseudo-random order.

Data collection took place in a sound-attenuated booth at Georgetown University. Audio was recorded using a Shure SM48 cardoid microphone and an Olympus LS-100 portable digital recorder. Video was recorded at a resolution of 1920×1080 pixels at 30 frames per second using a Canon XA10 camcorder, positioned approximately 1.5 meters in front of the speaker. Ultrasound data were captured using a SonoSite M-Turbo portable ultrasound machine with a SonoSite C60x 5–2 MHz transducer at a depth of 9.2 cm. Ultrasound images were recorded with synchronized audio using an Elgato Video Capture device. To allow for comparison of tongue contours across tokens, the ultrasound transducer was attached to a microphone stand mounted in front of the participant, and head movement was mitigated with a chair-mounted U-shaped headrest. Ultrasound data were recorded at a resolution of 640×480 pixels and a frame rate of 30 fps.

LPC formant measurements were taken using the `Formant (Burg)` object in Praat. Except for tokens containing /æ/, measurements were taken at the point of F1 maximum. For /æ/, F2 maximum was used, as suggested by Labov et al. (2006:38). Vowel formant measurements were normalized using the log-mean normalization formula used for the *Atlas of North American English* (*ANAE*; Labov et al. 2006:39–40), as implemented in the R package `vowels` (Kendall and Thomas 2014). While this type of normalization method is typically best suited for large sample sizes, using this method here allows the formant values obtained in this study to be reasonably compared to the values found for Northern Cities speakers in the *ANAE*, providing a useful metric for a speaker's degree of participation in the NCVS. In addition, the *ANAE* methods allow for normalization of F3, unlike other methods such as the Lobanov z-score transformation (Lobanov 1971).

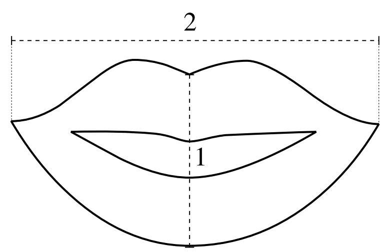
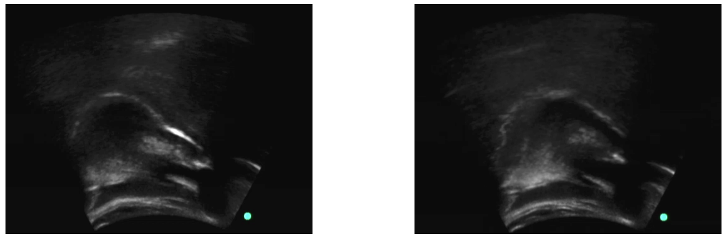


Figure 1: Measurement points for vertical lip opening (1) and lip spread (2).

Frames corresponding to the formant measurement points were extracted from the ultrasound and video recordings and saved as JPEG images. Extracted video frames were analyzed using the vector graphics editor Inkscape. The vertical measurement was taken between the upper and lower vermillion borders, and the horizontal measurement was taken between the left and right corners of the mouth, as shown in Figure 1. A metric ruler held against the speaker's lips at the start of recording was used to convert lip measurements taken in pixels to centimeters.

Ultrasound frames, such as those shown in Figure 2, were imported into EdgeTrak (Li et al. 2005), which was used to generate contour data for each token. Several points were placed manually along the lower edge of the visible tongue surface, and the `Optimize` function was used to improve the fit of the contour to this edge. From this contour, EdgeTrak extrapolated a total of 100 points along the tongue surface, which were exported and analyzed using smoothing spline analysis of variance (SS ANOVA). SS ANOVA is a statistical method for determining whether significant differences exist between best-fit smoothing splines for two or more sets of data. SS ANOVA is described by Gu (2002) and has been used in linguistic research to analyze both ultrasound tongue contour data (Davidson 2006, Chen and Lin 2011, De Decker and Nycz 2012, Lee-Kim et al. 2013, 2014) and formant measurements (Baker 2006, Nycz and De Decker 2006, Fruehwald 2010). However, SS ANOVA is applicable to comparison of curves more generally. Here, the SS ANOVA model was generated using the `ssanova` function of the `gss` package for R (Gu 2014).[2]

[2]The implementation of `gss::ssanova` used here is based on code provided by Fruehwald (2010).



(a) caught (b) odd

Figure 2: Extracted ultrasound frames for the tokens *caught* and *odd*, as produced by Speaker 6. The right side of the image corresponds to the front of the mouth. The tongue surface is visible as the white line near the center of the image.

4 Results

Based on canonical descriptions of /ɑ/ and /ɔ/, we expect these vowels to differ along two articulatory dimensions. /ɑ/ should be articulated with a low tongue height and unround lips, while /ɔ/ should have a somewhat higher tongue position and lip rounding. However, for Northern Cities speakers, both of these vowels exhibit a higher F2 than in other North American English dialects. For this change to occur, the tongue position for /ɑ/ must move forward, given that it is already unround (barring the possibility of an increase in lip spread).

For articulatory change in /ɔ/, however, three possibilities exist. First, the tongue position for /ɔ/ may move forward, approaching that of /ɑ/, while the lips remain round. This is the change found by Majors and Gordon (2008) for /ɔ/ among St. Louis speakers and by Harrington et al. (2011) for fronted /u/ in Standard Southern British. A second possibility is that /ɔ/ becomes unround with no change in tongue position. Third, speakers may distinguish between /ɑ/ and /ɔ/ through both lip configuration and tongue position. In these data, all three configurations are found. For purposes of space, I will first present representative articulatory data for one speaker exhibiting each of these patterns before turning to an analysis of the effect of these differences on the acoustic signal.

Three of the six speakers in this study distinguish between /ɑ/ and /ɔ/ through both tongue position and lip rounding, including Speaker 1, a 26 year-old man, Speaker 2, a 29 year-old man, and Speaker 3, a 39 year-old woman. Tongue contours for Speaker 1 are presented in Figure 3. As in the ultrasound images above, the right side of the plot corresponds to the front of the speaker's face. Here, it is clear that this speaker uses different tongue shapes for producing /ɑ/ and /ɔ/. The constriction for /ɑ/ is higher than that of /ɔ/, while /ɔ/ exhibits a greater degree of pharyngeal constriction.

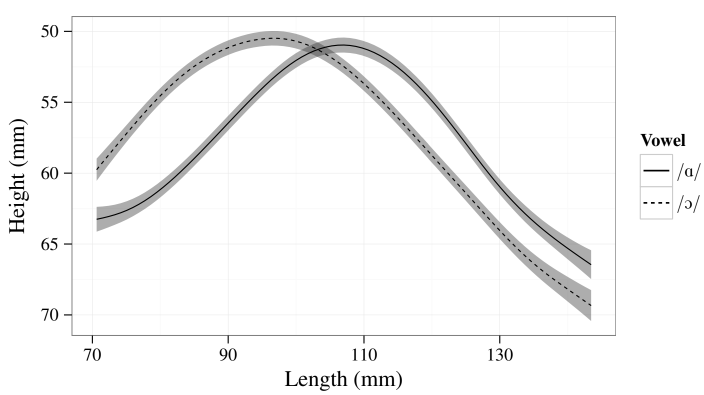


Figure 3: Main effect curves for SS ANOVA model of /ɑ/ and /ɔ/, Speaker 1. Shading indicates 95% Bayesian confidence interval.

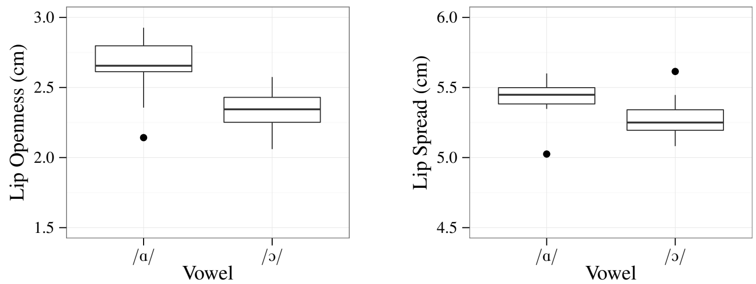


Figure 4: Lip measurements for Speaker 1.

Lip rounding measurements for Speaker 1 are given in Figure 4. For both vertical lip openness and horizontal lip spread, a smaller value indicates a greater degree of lip rounding. A one-way ANOVA test was performed for each measure. For this speaker, vowel class is a significant predictor of both lip openness ($F_{4,95} = 74.5$, $p < 0.001$) and lip spread ($F_{4,95} = 63.4$, $p < 0.001$). The difference between /ɑ/ and /ɔ/ in both lip spread and lip openness is significant, as revealed by a Tukey post hoc test. For Speakers 2 and 3, /ɑ/ and /ɔ/ differ significantly in lip openness, but not in lip spread. Ladefoged and Maddieson (1996:326) argue that the feature [±rounding] encompasses both lip protrusion and lip compression (referred to here as openness). For the purposes of this study, it is assumed that both labial gestures fall under [±rounding], and a significant difference in either measure is treated as a lip-rounding contrast.

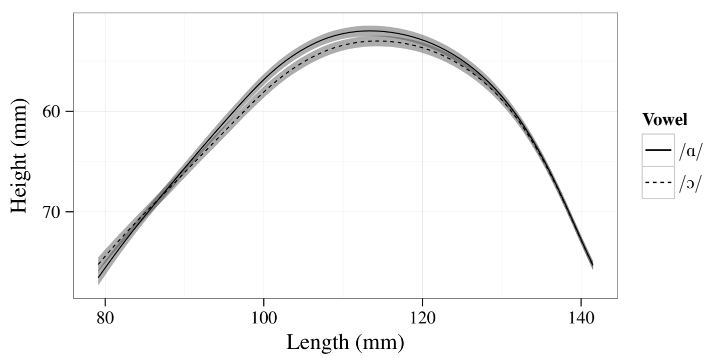


Figure 5: Tongue contours for /ɑ/ and /ɔ/, Speaker 4.

For Speaker 4, a 22 year-old woman, and Speaker 5, a 26 year-old man, /ɑ/ and /ɔ/ differ in lip rounding, but not in tongue position. Smoothing spline estimates for /ɑ/ and /ɔ/, as produced by Speaker 4, are presented in Figure 5. Except for a small region near the tongue dorsum, the smoothing splines for /ɑ/ and /ɔ/ do not differ significantly.

However, this speaker maintains a contrast between /ɑ/ and /ɔ/ in lip openness, as observed in Figure 6. Vowel class is a significant predictor of lip openness ($F_{4,95} = 35.93$, $p < 0.001$) and lip spread ($F_{4,95} = 27.8$, $p < 0.001$). Tukey post hoc test results show that /ɑ/ and /ɔ/ differ significantly in lip openness, but not in lip spread. The opposite holds for Speaker 5, for whom /ɑ/ and /ɔ/ differ significantly in lip spread, but not in lip openness.

For Speaker 6, a 21 year-old woman, /ɑ/ and /ɔ/ differ in tongue position but not in lip rounding. Smoothing splines for /ɑ/ and /ɔ/ as produced by Speaker 6 are presented in Figure 7. For this speaker, tongue contours for /ɑ/ and /ɔ/ differ significantly throughout the tongue root and body.

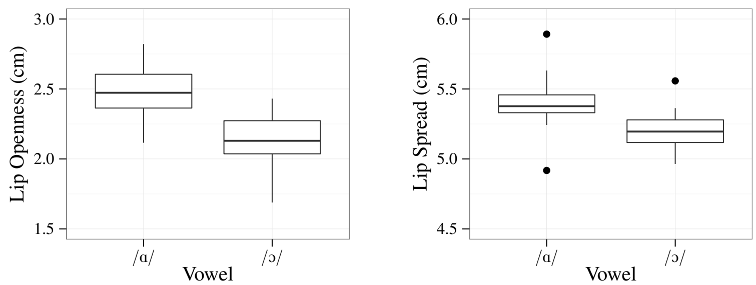


Figure 6: Lip measurements for Speaker 4.

This speaker does not maintain a significant contrast between /ɑ/ and /ɔ/ in either lip spread or openness, although /ɔ/ is slightly more round than /ɑ/. These results are presented in Figure 8. For Speaker 6, vowel class is a significant predictor of both lip openness ($F_{4,93} = 13.74$, $p < 0.001$) and lip spread ($F_{4,93} = 35.24$, $p < 0.001$). However, a Tukey post hoc test reveals that /ɑ/ and /ɔ/ do not differ significantly in either measure.

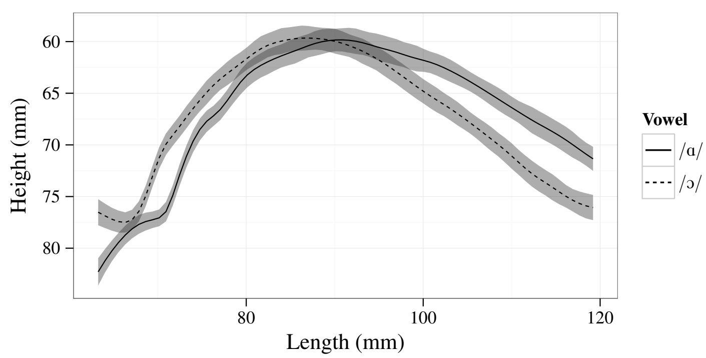


Figure 7: Tongue contours for /ɑ/ and /ɔ/, Speaker 6.

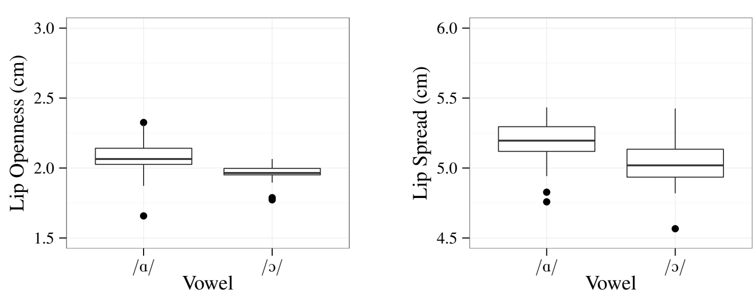


Figure 8: Lip measurements for Speaker 6.

Vowel formant measurements are presented in Figure 9, which uses kernel density estimation to plot the distribution of each vowel for each speaker in F1×F2 space. Speaker 1 has the widest distribution of tokens for /ɑ/ and /ɔ/, which may be accounted for by the fact that this speaker distinguishes between these vowels through tongue position, lip rounding, and lip spread. Speaker 5 and Speaker 6 appear to have the greatest amount of overlap in the distribution of these vowels.

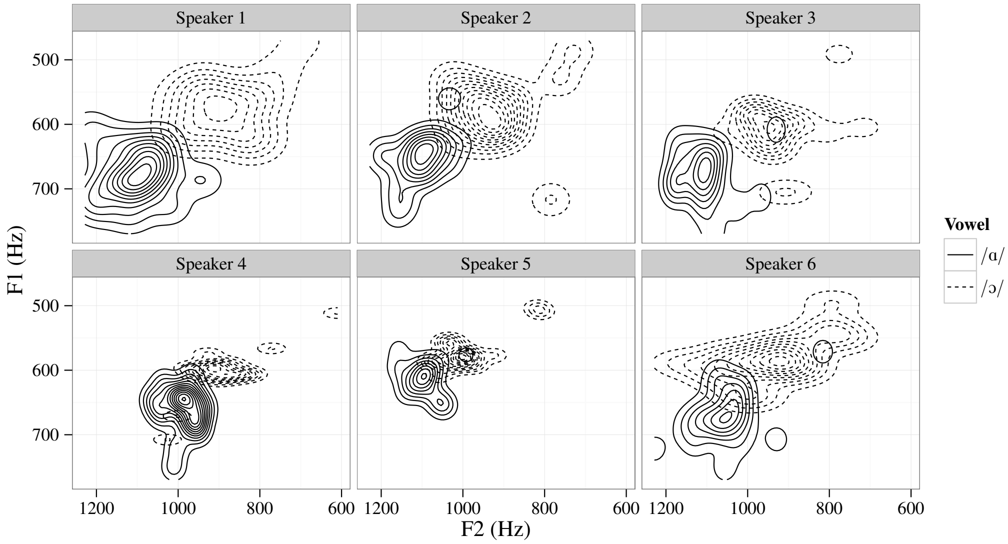


Figure 9: Formant density plot for /ɑ/ and /ɔ/, all speakers. F1, F2, and F3 Labov *ANAE* normalized with Telsur G value.

In order to quantify the degree of overlap, a Pillai-Bartlett trace (Pillai score) was calculated for each speaker, quantifying the difference between /ɑ/ and /ɔ/ in F1, F2, and F3, while taking into account preceding and following phonological environment. The Pillai score method was first used for sociophonetic research by Hay et al. (2006), and has since been highlighted by Hall-Lew (2010) and Nycz and Hall-Lew (2014). A Pillai score is the output of a Multivariate analysis of variance (MANOVA), which allows for statistical analysis of multiple dependent variables. This method returns a score ranging from 0 to 1, where 0 indicates that the two distributions are identical and where 1 indicates no overlap at all.

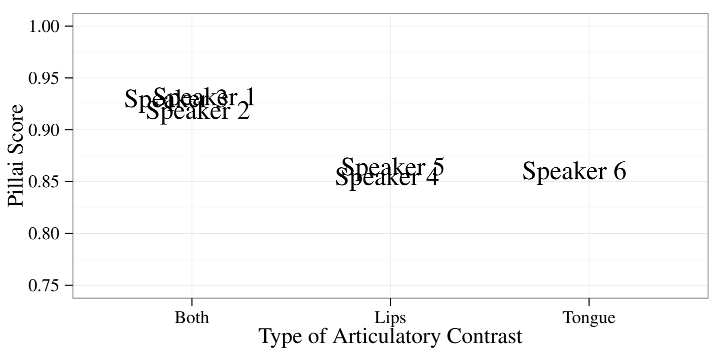


Figure 10: Pillai score for each speaker, by articulatory configuration.

The results are presented in Figure 10, where the Pillai score for each speaker is plotted with speakers grouped by articulatory configuration. First, observe that for all speakers, the Pillai score is at least 0.85, which is close to the maximum score of 1.00, indicating that these vowels are distinct for all speakers. While Pillai scores may not be directly comparable across studies, Nycz and Hall-Lew (2014) found Pillai scores of less than 0.25 for Canadian and Scottish speakers, for whom a merger of these vowels is attested. Nevertheless, a clear pattern is observed: The Pillai score is lower for speakers who make use of only one articulatory gesture to distinguish between /ɑ/ and /ɔ/ than it is for speakers who produce a contrast along multiple articulatory dimensions, indicating that the use of only a single gesture results in a greater degree of acoustic overlap.

5 Discussion

The results of the articulatory analysis suggest that a three-way pattern exists among Northern Cities speakers. Speakers 1–3 exhibit a significant difference between /ɑ/ and /ɔ/ in both lip spread and tongue position, with Speaker 1 producing an additional distinction in lip openness. Neither Speaker 4 nor Speaker 5 produce a significant difference between /ɑ/ and /ɔ/ in tongue position. At the very least, any difference is exceptionally small. However, both speakers produce a significant contrast between these vowels in lip rounding, with Speaker 4 producing a lip openness contrast, and Speaker 5 producing a lip spread contrast. While Speaker 4 and Speaker 5 differ with respect to the particular labial gesture used to distinguish /ɔ/ from /ɑ/, both speakers do indeed make a labial distinction between these vowels. Finally, Speaker 6 produces a significant contrast only in tongue position; for this speaker, the differences between /ɑ/ and /ɔ/ in both lip openness and lip spread fail to achieve significance.

Despite a three-way pattern in articulatory strategy, we observe a two-way pattern in the acoustic signal. By calculating a Pillai score for each speaker, we obtain an indication of the difference between the distributions for /ɑ/ and /ɔ/ for each speaker. For speakers exhibiting both tongue position and lip rounding contrasts, the mean Pillai score is 0.927, indicating that these vowels are quite distinct. However, for speakers producing only one type of articulatory contrast, the mean Pillai scores are 0.86 for speakers producing a lip rounding contrast, and 0.861 for Speaker 6, who produces only a tongue position contrast. These lower scores suggest that the distributions of /ɑ/ and /ɔ/ are more similar for speakers who produce these vowels using fewer articulatory gestures. It therefore appears that the use of additional articulatory gestures serves to enhance the acoustic contrast between /ɑ/ and /ɔ/.

These findings raise a number of questions regarding how these articulatory and acoustic differences are acquired and how they are perceived, which may be addressed by future research. First, the direction of the relationship between articulation and the acoustic signal is not yet entirely clear. It may be the case that speakers who produce a contrast between /ɑ/ and /ɔ/ with fewer articulatory gestures intend to produce these vowels more similarly, using an appropriate number of articulatory contrasts to achieve this. This might occur in the case of a trend toward merger of /ɑ/ and /ɔ/ in the community. Alternately, in order to produce /ɔ/ with a high F2, children might adopt an articulatory strategy where either the tongue position or lip configuration of /ɔ/ is similar or identical to that of /ɑ/, resulting in a more similar acoustic distribution.

In either case, there remains the question of how a speaker's particular articulatory strategy is determined, especially among the single-gesture speakers. Do these speakers "choose" from between the lip-rounding and tongue-fronting strategies, or is the strategy determined by the speaker's community? Replicating this type of study both with a greater number of Southeast Michigan speakers, and with speakers in other Inland North cities such as Chicago or Buffalo, would give insight into whether speakers vary in articulatory strategy idiosyncratically, or whether these patterns are determined by geographic or socioeconomic factors.

It seems that an acoustic distinction is necessary for social stratification of articulatory strategy to arise, as in the case of postvocalic /r/ in Scottish English (Lawson et al. 2011). However, it may be the case that the strategies found in the present study differ in how they are perceived, due either to a greater acoustic contrast, or to the integration of visual lip-rounding cues. Kleber et al. (2010) suggest that for RP speakers, the presence of lip-rounding in fronted /u/ prevents perceptual confusion with /i/, resulting in a preference for retention of lip-rounding in /u/. While Speakers 4 and 5 of the present study produce a relatively smaller acoustic contrast between /ɑ/ and /ɔ/, their use of lip-rounding might result in a more perceptually robust contrast than that of Speaker 6, who produces a similarly small acoustic contrast with little visible lip rounding.

The present study naturally has limitations that may be addressed in future research. First, it is likely that the speech recorded in the lab is not entirely reflective of the speech used by these speakers in natural conversation. Ideally, ultrasound data would be collected during conversational speech, such as during a sociolinguistic interview. Otherwise, future studies may combine articulatory study with more traditional sociolinguistic fieldwork methods, in order to gain a fuller picture of the phonetic situation in the NCVS.

Second, while the sample size of this study is comparable with many previous studies of articulation, it is to some extent difficult to make generalizations on the basis of these findings. Notably, among the participants in this study, there is only one speaker who contrasts /ɔ/ from /ɑ/ through tongue position alone. It is therefore not clear whether this articulatory pattern is widespread or whether this is an idiosyncracy of this particular speaker. As noted above, expanding this research to additional speakers both in Michigan and throughout the region would provide additional insight.

Finally, the measurement techniques used in this study may not be precise enough to capture all the details of articulatory movement. Lip measurements in particular were taken only along the horizontal and vertical dimensions, and both ultrasound and lip measurements were made at only a single point in the vowel's production. Incorporating additional measures of labial articulation and taking articulatory measures throughout the vowel's duration would provide a greater understanding of how labial and lingual gestures combine to result in the observed acoustic signal. In addition, video and ultrasound data were captured at 30 frames per second, resulting in one frame for every 33.4 ms of speech. While Gick et al. (2013) suggest that this speed is sufficient for observation of most articulatory gestures, Shosted (2011), who also recorded at 30 fps, shows that changes in articulatory gesture tend to happen quite quickly, sometimes occurring between frames. In future studies of this type, high-speed recording may be used to overcome this limitation.

6 Conclusion

In this study, we have observed that Northern Cities speakers are not homogenous with respect to either their acoustic realizations of the NCVS, or to the articulatory strategies which underlie the acoustic signal. While all of the speakers in this study make an acoustic contrast between /ɑ/ and /ɔ/, this contrast varies in its strength. For those speakers who produce a smaller contrast between /ɑ/ and /ɔ/, the production of these vowels is accompanied by a reduction in the number of articulatory contrasts that are made. These speakers may produce the contrast between /ɑ/ and /ɔ/ either with a difference in tongue position or a difference in lip rounding, but not both. This finding raises a number of questions with regard to how fronted /ɑ/ and /ɔ/ are perceived, and how they are acquired by children. This study contributes to a growing body of articulatory research in sociophonetics, and demonstrates that this type of analysis can uncover patterns that may not necessarily be observed in the acoustic signal alone. Therefore, a comprehensive account of language variation and change must also take articulatory patterns into account.

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