The role of palate shape in individual articulatory and acoustic variability

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Background. This ultrasound and acoustics study considers the role of individual anatomy in articulatory and acoustic variation and variability in the production of American English /r/ and /s/. Individual variation in the production of these consonants is a well-documented phenomenon (Mielke et al., 2010; Lawson et al., 2011; Bladon and Nolan 1977). /r/ falls on a continuum whose two endpoints are retroflex, in which the tongue tip points up, and bunched, where the primary constriction is formed by a raised tongue body (DeLattre and Freeman 1968); /s/ lies on a similar continuum from apical (tip points up) to laminal (tip points down).

In their study of front vowels, Brunner et al. (2009) found that flatter palates require greater articulatory precision than domed palates to achieve acoustic consistency because, all else being equal, smaller changes in articulation result in greater changes in acoustics for flatter palates than for domed.

Hypotheses. The present study hypothesizes that (1) palate shape might be related to the variant of /r/ or /s/ and (2) people with flatter palates will be more articulatorily consistent in their /r/ and /s/ to maintain acoustic consistency.

Procedure. Twenty-eight speakers (18 analyzed here; two excluded because of poor image-ability) of American English speakers participated in a word-reading task. Stimuli consisted of monosyllabic words containing /r/ or /s/ in onset or coda, and in the context of the vowels {a,i,o}, spoken in the carrier phrase “I’m a ______.” Simultaneous and time-synchronized lingual ultrasound images and audio were collected. Casts of participants’ palates were made after the reading task.

Analysis. The quality of /r/ or /s/ was determined visually using frames from the entire /r/ or /s/ segment. For each utterance, a frame corresponding to the acoustic midpoint of the segment was determined, and principal components analysis (PCA) was performed on /r/ and /s/ frames for each participant. PCA is a dimensionality reduction analysis technique for data such as numbers or images that finds components along which variance in the data can be accounted for. The first principal component (PC1) accounts for the majority of the data. The extreme values of PC1 represent an individual’s most different tongue shapes for a segment. These values were traced (Figure 1a), and the area between them was automatically detected and calculated (Figure 1b) to serve as a metric of articulatory variability for a speaker. Acoustic measurements were also taken at the midpoint; a Python script took F3 measurements for /r/ and the spectral peak frequency for /s/. Flatness of palate was determined by a ratio of depth to width after Brunner et al. (2009).

Results. There was a relationship between palate shape and articulatory and acoustic variability, as shown in Figure 2. People with flatter palates had increased articulatory precision for /r/ (nearly significant, \( p = .14 \)). Predictions are only made for flat palates, and domed palates are not necessarily predicted to be associated with less precision), but participants had similar acoustic variability. In contrast, for /s/, people were articulatorily similar to each other, but people with flatter palates had significantly (\( p < .05 \)) increased acoustic variability. Palate shape is linked to the amount of variability in speech production, but not articulatory variant.

1The present study builds on a smaller study with 12 speakers Bakst and Lin (2015).
In order to understand the ways individuals pattern together, multidimensional scaling (MDS) analysis and a cluster analysis was performed on the articulatory and acoustic variability data for /r/ and /s/, reducing four factors to two. Two major groups emerged. One group was defined primarily by articulatory consistency in /r/ and variable /s/ acoustics, and they tended to have flatter palates. The other group was acoustically consistent in their /s/ and slightly more articulatorily variable in their /r/; they tended to have more domed palates.

Conclusions. The type of influence of palate shape on articulatory and acoustic variability depends on the segment. Although speakers may adjust the precision of their articulations to maintain acoustic consistency, for some segments, like /s/, the shape of the palate dictates acoustic variability beyond a speaker’s control.

![Articulatory variability as a function of palate shape](image1)

![Acoustic variability as a function of palate shape](image2)

(a) Nearly significant for /r/: r = -0.36, p = 0.14

(b) Significant for /s/: r = 0.49, p = 0.036

Figure 2: Figure 2a shows articulatory variability graphed against palate shape for /r/ and /s/, and 2b shows the same for acoustic variability. All measures have been z-scored to allow for comparison across segment and variability type. Solid lines indicate significant correlations.

References.


Boersma, Paul, and David Weenink. 2009. Praat: doing phonetics by computer (Version 5.1.05)[computer program].


