CROSS-LINGUISTIC BRACING: ANALYZING VERTICAL TONGUE MOVEMENT

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1 Introduction

The vocal tract has often been described as a tube that is shaped to produce different speech sounds [1]. The oral part of this tube is formed by the sides of the tongue making contact with the lateral teeth or palate. This tongue-palate contact has been described as "lateral bracing" [2]. Gick et al. [3] demonstrated that tongue bracing is maintained continually throughout running speech, hypothesizing that bracing is a key component of the basic posture underlying speech production. A limitation of their study, however, is that this kind of pervasive bracing has only been observed for a single language, English. If tongue bracing is fundamental to speech production, then it is expected to be a pan-linguistic phenomenon. The proposed work aims to test whether bracing occurs cross-linguistically.

A pilot study conducted by Cheng et al. [4] initially explored this question using ultrasound imaging; the authors hand-traced vertical movements of the sides of the tongue during continuous speech, and found preliminary support for the hypothesis that tongue bracing exists across six different languages. However, there were some methodological concerns that limited the interpretation of Cheng et al.'s [4] study, most notably that the movement of the centre of the tongue was not analyzed, and the hand measurements were so time-consuming that it was impractical to collect and analyze the large amount of reliable cross-linguistic data needed to test the hypothesis.

To address these limitations and test the cross-linguistic bracing hypothesis, we developed a new image processing-based technique that to improve the efficiency of data analysis. This approach allows us to examine data from a much larger number of speakers, and analyze both the center and the sides of the tongue.

This study aims to examine the hypothesis that tongue bracing is observed cross-linguistically for a significant sample of speakers of a number of different languages. The study tracks vertical positions of the tongue using automatic analysis of ultrasound imaging.

2 Method

Eight to ten native speakers of five different languages (English, Cantonese, Korean, Mandarin, and Spanish) were recruited to take part in the study. The languages were selected primarily because of their diverse phonetic systems and because of the availability of large numbers of speakers in Vancouver. The participants were asked to read aloud a translation of the passage "The North Wind and the Sun" [5] in their respective native languages. Each participant read the passage three times while a coronal section of their tongue was imaged using an ultrasound probe positioned under the posterior part of the chin and aimed roughly at the upper molars, a frame of the video collected is shown in Figure 1.

Figure 1: A frame of ultrasound video. The white curly line shows the coronal slice of the tongue.

In order to test for the presence of bracing, it is necessary to identify the most stable vertical location and its relative height for the sides and the centre of the tongue. Ultrasound data was analyzed using vertical movement tracking as follows. First, vertical movement of each of the three regions of interest (the left and right edges and the centre) of the tongue will be tracked over time throughout speech. For each of these three locations, the range of the stable area is defined as an error range above and below the most stable position. Figure 2 illustrates the tracking of one side of the tongue. The most stable position is defined as the horizontal row of pixels with the highest luminance value over the entire experiment indicating the location at which each tongue region spends the most time. The stable range is defined as ±10 percent of the total range of vertical movement of that tongue region (within speaker). The amount of time that the tongue stays above, within and below the stable position area were recorded within each region (hereafter referred to as proportion above (PA), proportion within (PW) and proportion below (PB)) to determine whether the stable area is relatively high or low in the total movement space.

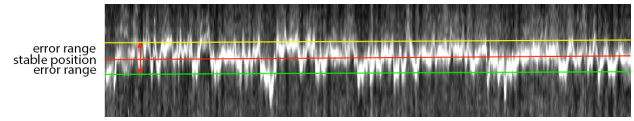

Figure 2: This kymograph illustrates the stable position (red line), error bars (red arrow), and the stable range (between the yellow line and the green line).

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3 Results

We determined PA, PW and PB by calculating the percentage of high white instances observed in each area. The white instances refer to the white pixels on the kymograph indicating tongue position. For example, PW of the left side is obtained by dividing the number of high white instances within the stable area by the total number of white instances. Figure 3 shows the value of PA, PW and PB in the three different regions of the tongue.

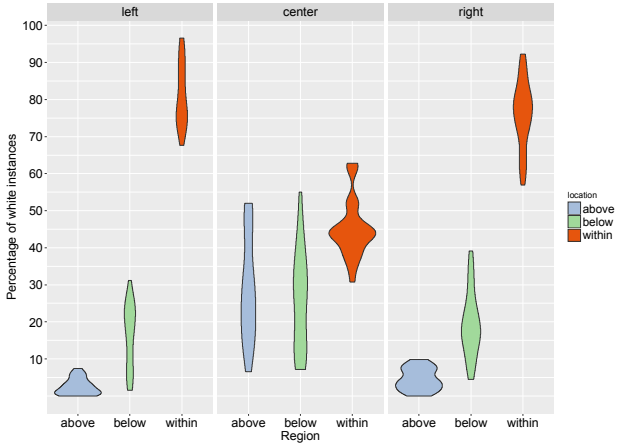

Figure 3: Percentage of white instances above, within and below the vertical stable area at different regions of the tongue.

The results showed that the left and right sides of the tongue had the highest PW. In other words, the sides of the tongue spent the least amount of time above and below the vertical stable area ($p<0.0001$), with PA having the least value. Also, very few amount of variations are observed of the PA value of sides compared to the PW and PB value. Further, the pattern of movement between the sides of the tongue was distinctly different from that of the center of the tongue. While the results showed that the center of the tongue also had the highest PW value over PA and PB ($p<0.0001$), there was no significant difference between PA and PB ($p=0.609$). This pattern was true across attested languages, as shown in Figure 4

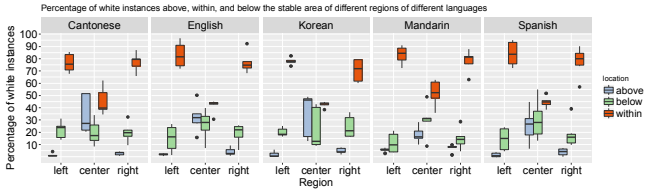

Figure 4: Value of PA, PW, PB at different regions of the tongue in different languages.

Figure 4 indicate that the sides of the tongue has very small PA value, slightly higher PB value, and the highest PW value for each individual language. Two different patterns of the vertical position where the center of the tongue stays at are presented in Figure 3. For Mandarin and Spanish speakers, their center of the tongue has a higher PW value than PB, with PA having the least value. However, for the other languages, speakers has higher PW than PA, with PB having the least value.

While the sides of the tongue behave the same way across different languages, some individual variation was seen in the amount of the time spent below the stable area. Within each language, for some speakers, the left side of the tongue stays in the below area more than their right side, while others display the same pattern but on the right.

4 Discussion

The results indicate that during speech production, the sides of the tongue (1) stay mainly within the vertical stable area (2) stay below the vertical stable area some of the time, and (3) stay above the vertical stable area occasionally. This implies that the sides of tongue positioned within a narrow area at a relatively high space in the mouth most of the time. This corresponds to the high percentage of time spent within the vertical stable position (where the sides of the tongue are during bracing) and the very low percentage of time spent above the stable position. We interpret these observations as indicating the bracing gesture of the tongue during speech and cross-linguistically.

The release of the bracing gesture was also examined. Release is indicated by observing the sides of the tongue which sometimes remain below the stable area. This occurs during the production of lateral sounds and low retracted vowel across different languages. These findings give support to the results of Cheng et al.'s [4] study and Gick et al.'s [3] study.

The finding that speakers tend to use one side more than the other during release suggests a high system tolerance for asymmetry. Further research could examine this asymmetrical pattern of lateral release in bracing.

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