TRIGGERING AND MAINTENANCE OF TONGUE BRACING POSTURE IN MULTI-SYLLABLE SEQUENCES

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ABSTRACT

Lateral tongue bracing is a posture that is pervasively maintained in speech across languages, released only for a few select sounds [1]. Previous pilot work with English showed that the lateral tongue maintained a higher position in the bracing-neutral phrase "hubba bubba" when preceded by braced targets, compared to unbraced targets [2]. The present study evaluates a larger number of speakers producing this same sequence with additional analyses. Mean and range results for lateral tongue movement support the view that the lateral bracing posture, once initiated, is maintained through bracing-neutral sounds. No anticipatory (right-to-left) effect was observed.

Keywords: lateral tongue, lingual bracing, speech posture, embodied speech, harmony.

1. INTRODUCTION

Lateral tongue bracing is a lingual posture in which the sides of the tongue are held in contact with the palate and upper molars [3]. Early studies found lateral bracing to be associated with lingual sounds like /s, z, n/ [4]. Gick et al.'s [5] study on English found that lateral tongue bracing was maintained throughout over 97% of continuous speech, released during only laterals and occasional low vowels. Lateral tongue bracing has been found to require dedicated muscle activation [5]. It has been observed in both English-speaking adults and children [6], is robust to perturbation [7] and has been documented across many languages including Akan, Cantonese, English, Korean, Mandarin, and Spanish, suggesting bracing as a universal postural basis for speech [1].

Based on the understanding that postures exhibit interactions over a long distance/time [8], the present study asks how and whether the braced lingual posture is initiated and maintained during long sequences of neutral sounds. A handful of sounds appear neutral to bracing, in that they do not require bracing, but do allow it. These neutral segments include non-lingual consonants, e.g., labials, glottals and the English schwa. This continuation of a tonic movement through neutral sounds is reminiscent of phonetic or phonological harmony processes, sometimes described in terms of spreading of a feature onto non-adjacent segments [9], sometimes passing through neutral segments.

It has long been observed that bracing is required during lingual sounds such as /s, z, n/ [4] for which complete or partial lingual obstruction of air flow is required. These sounds can be thought of as "triggers" for bracing. Bracing has also been found to be consistently released during lateral sounds, in particular the prevocalic English /l/ [5], which can thus be thought of as "opaque" to bracing (i.e., requiring the braced posture to be interrupted). Non-lingual or lingually neutral sounds can be thought of as "transparent" to bracing (i.e., segments that can in principle be produced irrespective of whether the tongue is braced or unbraced).

2. BACKGROUND

In a previous pilot study, [2] presented coronal ultrasound imaging data that observed the tongue movements of eight native North American English speakers. Results showed that the sides of the tongue maintained a higher position during the utterance "hubba bubba" [həbəbəbə] preceded by segments that triggered bracing than by segments that are opaque to bracing. "Hubba bubba" (HB) was chosen as the target utterance as it is made up entirely of transparent (bracing-neutral) sounds ([h], [b], [ə]). However, [2] only analysed lateral tongue height (i.e., no data on tongue medial height were included for comparison), and only measured at the beginning of a HB utterance (i.e., maintenance of bracing over time could not be evaluated). A braced tongue should exhibit a higher tongue position and a smaller range of movement compared to the centre throughout the HB utterance, due to the anchoring of the tongue sides maintained on the palate.

The present study extends [2] by: 1) evaluating a larger number of speakers producing the HB sequence; 2) analysing both lateral and medial tongue movement for mean tongue height and range of displacement; 3) measuring tongue position during the middle syllables of the HB sequence to test maintenance of the bracing posture; and 4) evaluating anticipatory (right-to-left) as well as carryover (left-to-right) effects.

The present study tests the hypothesis that lateral tongue bracing is initiated by a bracing trigger, and is maintained until it is interfered with. This hypothesis predicts that a higher overall height and a smaller movement range of the lateral tongue compared to the medial tongue will be observed during braced vs. unbraced syllables, with this difference being maintained through the middle syllables of the HB sequence; this difference should be initiated by a preceding bracing trigger, but not a following one.

3. METHODS

Identical to Ebbutt et al. [2], an ultrasound probe was used to collect coronal plane images of the posterior region of the tongue. An analysis of the vertical tongue position of the sides of the tongue was done to detect the presence of lateral bracing.

A total of 53 participants took part in the ultrasound study. Participants were paid and recruited via word of mouth or via the Linguistics SONA portal at the University of British Columbia and received course credit for their participation. All participants provided informed consent and completed a language background that reported no speech difficulties. Participants were considered native speakers of English if they acquired it before eight years of age and continued to use it as a primary language at work, school, or home. Participant data were excluded if they were not native speakers of North American English or they did not have clear ultrasound imaging. The ultrasound study analysed a total of 12 participants (3 male and 9 female). Seven speakers were excluded because they were not native speakers of North American English, while 34 participants were excluded due to poor ultrasound imaging quality.

The reading stimuli include four blocks of seven sentences, each containing the lingually-neutral target word "hubba bubba" [həbəbəbə]. Preceding or following the target word were words either with lingual consonants known to require tongue bracing (bracing trigger words: chews, wants, has, eats, chewing gum, needs) or words with the lateral /l/, known to interfere with tongue bracing (bracing opaque words: love, lump, plum, lots). The four blocks were given in randomised order, and participants were given one of sixteen possible combinations of the stimuli.

Examples of stimuli from each block:
Block A: Every Monday, he chews Hubba Bubba chewing gum.
Block B: Every Tuesday, we love Hubba Bubba lots.
Block C: Every Wednesday, they lump Hubba Bubba chewing gum.
Block D: Every Sunday, Chris needs Hubba-bubba chewing gum.

Participants were seated in an ophthalmic chair with a 2-cup rear headrest to stabilise their head. A Manfrotto Magic Arm was attached to position an ALOKA ProSound SSD-5000 ultrasound with a 120-degree convex probe. A microphone stand captured acoustic data from participants and a Focusrite preamplifier was used to process the data. A Canopus ADVC-110 box was used to synchronise the audio and video data. iMovie was used to record audio and ultrasound video data. The microphone was held on a stand 2-3 feet in front of the participants and a music stand stood in front of them to hold the stimuli. The ultrasound probe was positioned against the neck behind the chin to show coronal imaging of the posterior region of the tongue, where bracing contact occurs between the tongue and the rear hard palate and molars. The angle of the probe was determined by asking participants to repeat "Mary had a little lamb", a familiar phrase that elicits repeated bracing and release of the lateral tongue [1]. Participants were asked to read the stimuli three times. The study ended with the participant getting debriefed on the nature of the experiment.

Vertical movement was tracked with videokymography (VKG), a technique for plotting video movement over time. Ultrasound video and audio were converted into a .wav file and annotated in Praat [10]. Pilot results showed greater inter-speaker variation for the first repetition, as speakers got used to the unfamiliar and repetitive stimuli. For second and third repetitions, there was found to be more consistency between speakers. As such, the first readings of the stimuli were omitted from the analysis. Each instance of HB was manually annotated using Praat and the corresponding ultrasound imaging video frames were extracted. ImageJ [11] was used to open each set of image sequences where images were adjusted for brightness and contrast in order to get a clearer image of the tongue surface. Finally, images were thresholded and converted into VKG to create an image of the tongue height over time for each utterance of HB. VKGs were created from the side of the tongue that showed the clearest ultrasound imaging (Figure 1). Speckle noise appearing anywhere in the ultrasound imaging was manually removed.

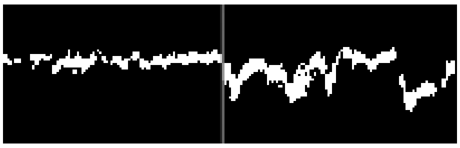

Figure 1: A thresholded VKG showing vertical tongue movement of the left lateral tongue during several repetitions of HB preceded by braced (left) and unbraced (right) words.

For each HB production, the height of the tongue was determined by the bottom white pixel in each frame in the VKG. For any frame in which a HB production contained no white pixels, linear interpolation was used to predict vertical position from adjacent frames. Mean height of the tongue as well as the range of vertical movement were calculated across all frames for each HB production. Mean height and range of movement were fitted by linear mixed effects models using the *lme4* [12] package in RStudio [13]. Preceding or following conditions (braced vs. unbraced) and regions of the tongue (medial vs. lateral) were fixed effects, and participants were random effects with both random slope and intercept.

4. RESULTS

	Preceding Condition	Tongue Region	Interactions
Mean	$\chi^2(2) = 81.33$, $p < 0.001$	$\chi^2(2) = 87.59$, $p < 0.001$	$\chi^2(1) = 81.33$, $p < 0.001$
Range	$\chi^2(2) = 13.42$, $p < 0.001$	$\chi^2(2) = 14.31$, $p < 0.001$	$\chi^2(1) = 13.42$, $p < 0.001$

Table 1: Table of normalised mean height and range of movement for preceding condition (braced vs. unbraced), tongue region (medial vs. lateral), and their tongue region & preceding condition interactions.

The linear mixed effects model showed that tongue region and preceding bracing condition have a significant effect on the mean height of the tongue. The interactions show significant results, indicating that the tongue region and preceding bracing condition are interdependent.

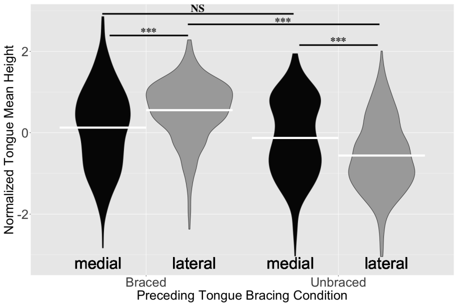

Figure 2: Boxplot comparing normalised mean tongue height of the medial (dark) and lateral (light) regions producing HB with preceding braced vs. unbraced conditions. NS indicates "Not Significant" while *** indicates significance.

The results of a post hoc test using the *emmeans* [14] package revealed no difference for the mean height of the medial tongue (t(15.3)= 0.947, p=0.3582) in the preceding braced condition compared to the unbraced condition. This means that the medial tongue remained at a relatively similar height between conditions (see Figure 2). The lateral tongue had a significantly higher mean height (t(15.3)=4.551, p=0.0004) in the preceding braced condition compared to the unbraced condition.

The preceding braced condition showed a significantly lower mean height for medial vs. lateral tongue (t(49.1)=-6.560, p <.0001). In contrast, the preceding unbraced condition had a significantly higher mean medial (t(49.6)=6.554, p <.0001) vs. lateral tongue in the unbraced condition.

	Following Condition	Tongue Region	Interactions
Mean	$\chi^2(2) = 0.8172$, $p = 0.6646$	$\chi^2(2) = 0.812$, $p = 0.6663$	$\chi^2(1) = 0.812$, $p = 0.3675$
Range	$\chi^2(2) = 2.153$, $p = 0.3408$	$\chi^2(2) = 1.939$, $p = 0.3793$	$\chi^2(1) = 1.939$, $p = 0.1638$

Table 2: Table of normalised mean height and range of movement for following condition (braced vs. unbraced), tongue region (medial vs. lateral), and their tongue region & following condition interactions.

The linear mixed effects model showed no significant effect associated with tongue regions and following bracing conditions on the mean height of the tongue. Regardless of following bracing conditions and regions of the tongue, mean height during a HB utterance remains unchanged.

Finally, the results for the range of movement show that the medial tongue shows a similar range in preceding and following braced vs. unbraced conditions ($t(17.5) = 0.212, p = 0.8348$; $t(40.9) = -0.558, p = 0.5796$). No significant difference in

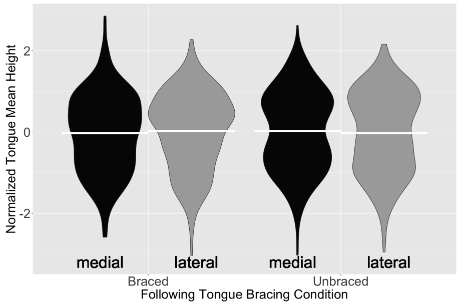

Figure 3: Boxplot comparing normalised mean tongue height of the medial (dark) and lateral (light) tongue producing HB with following braced vs. unbraced conditions. All conditions were found to be not significant.

movement range is observed for the lateral tongue in the preceding and following braced condition compared to the unbraced condition ($t(17.5) = -2.072, p = 0.0533$; $t(40.8) = 1.246, p = 0.2198$), i.e., the sides of the tongue show similar stability across the two conditions. The preceding braced condition shows a significantly higher range of motion for the medial tongue ($t(48.6) = 2.627$, $p = 0.0115$) compared to the lateral tongue; such an effect is not observed in the following braced condition ($t(46.2) = -0.982, p = 0.3312$). The preceding unbraced condition shows a significantly lower range of motion for the medial tongue ($t(49.1) = -2.633, p = 0.0113$) which implies more movement for the lateral tongue when preceded by an unbraced condition. This is also what would be expected if the lateral tongue is not anchored to the palate as during lateral tongue bracing. However, no such an effect is found in the following unbraced condition ($t(45.5) = 0.975, p = 0.3345$).

5. DISCUSSION

The present study investigated the initiation and maintenance of lateral tongue bracing using ultrasound imaging.

Results for mean tongue height show that the medial tongue is consistent irrespective of surrounding bracing triggers. In contrast, the lateral tongue changed height depending on the preceding bracing condition (higher in the preceding braced condition and lower in the preceding unbraced condition). The finding that the lateral tongue maintains a relatively higher position than the medial when preceded by a bracing trigger is consistent with the hypothesis that the lateral bracing posture, once triggered, is maintained throughout neutral syllables. Additionally, the results show that only the preceding braced targets introduce this braced posture, as no significant differences are shown to be associated with a following bracing trigger.

Results for the range of vertical movement of medial tongue were similar to those for mean height, showing that the medial tongue had a similar range of movement across preceding and following bracing conditions. The lateral tongue had a smaller range of vertical movement than the medial tongue when preceded by braced targets, which indicates that the side of the tongue remained more stable.

Given the braced and unbraced behaviour of mean and range of heights, these findings support the hypothesis that tongue bracing triggers a braced tongue posture which is maintained through subsequent bracing-neutral (transparent) syllables. This maintenance of tonic muscle activations across non-adjacent segments is reminiscent of some long-distance phonetic or phonological phenomena such as those relating to harmony processes. These findings advance our understanding of tongue posture and the biomechanics of speech, particularly outside the sagittal plane.

Models of speech planning and production will need to allow for a system in which a single utterance may be implemented in two such dramatically different ways — one with the lateral tongue held in a braced position and one unbraced (e.g., the kinematics and muscle activations for these two sequences would be quite different). We suggest that speech models incorporating posture will be better able to handle such results. An understanding of the fundamentals of posture in speech is important when investigating speech movements, as posture is a critical component of movement, providing a stable substrate upon which intentional movements are built.

Our study has limitations. Due to the nature of ultrasound studies, only tongue position can be measured, not tongue-palate contact. Additionally, only one side of the tongue was analysed and lateral bias exists in tongue movements [15], though lateral bracing is actively maintained for both sides of the tongue [1, 7]. While analysing VKG of individual speakers, distinct patterns across braced and unbraced conditions among individual speakers were observed. Future studies could look into speaker independent patterns and interspeaker variations. Future studies can also consider whether the unbraced posture itself functions as a distinct posture, as similar stability was observed among production of HB between braced and unbraced conditions.

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