An EMA examination of liquids in Czech

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ABSTRACT

This paper examines the liquid segments in Czech (/r/ and /l/) using articulography. The mid-sagittal and parasagittal contours of the liquids were compared. 5 speakers of Czech produced nonsense words in three environments: word-initial, intervocalic, and word-final position.

The results indicated that /l/ is articulated further forward in the mouth and has a larger pre-constriction vocal tract volume. The lateral constriction is created on the left side by activation of the styloglossus, forming a constriction approximately 2 cm in width and results in a side-cavity in the anterior portion of the mouth. The side cavity is responsible for the anti-formants characteristic of /l/ sounds.

/r/ is articulated higher in the mouth to create a strong lateral lock, permitting tongue tip trilling. /r/ is also not articulated with a retracted tongue dorsum, resulting in a higher F3 than in English.

Keywords: liquids, Czech, EMA

1. INTRODUCTION

Liquid consonants (laterals and rhotics) pattern together in synchronic and diachronic phonological processes, such as dissimilation, vocalization, and neutralization [19]. Due to the wide variety of segments that fall under this category, it has been difficult to find phonetic justification for this segmental class [10]. Acoustic features which are shared by the entire family of liquids has been difficult to pin down [7]. However, recent work [11] has suggested that the liquids are united in the coordination of the tongue tip and tongue body gestures. The purpose of this study is to examine the tongue shape of the Czech rhotic and lateral to further understand the unifying phonetic features of liquid segments.

Alveolar trills are complex segments which require coordination of the tongue tip and tongue body to create the correct aerodynamic conditions for trilling [16]. McGowan [8] postulates that lateral tongue bracing is an important component for trill production. The lateral lock stiffens the tongue, while restricting the flexible vibrator to the tongue tip. This makes it easier to facilitate tongue tip vibration. The stiff lateral lock also creates a channel to direct the airflow efficiently. Proctor [11] further suggests that a backed tongue dorsum is an important component to rhotic production that creates the sound's vowel-like qualities.

Recasens [13] describes the two traditional divisions of coronal laterals as either clear (/i/-like) or (/u/-like). Clear /l/ involves tongue body raising and fronting, while dark /l/ involves pre-dorsum lowering and post-dorsum retraction. The articulation of dark /l/ creates an oral and pharyngeal subcavity [9], much like /r/ segments [11]. Recasens [13] further describes the difference between 'clear' /l/ and 'dark' /l/ with the tongue-palate contact differences between the two: clear /l/ may involve more laminal tongue-palate contact than dark /l/ resulting in more central contact. Furthermore, the dark /l/ often has a more anterior constriction location than the clear counterpart. These differences also result in different acoustic profiles for clear and dark /l/. Dark /l/ has a much lower F2 (800-1200 Hz) as a result of the half-wavelength resonance of the back cavity. The frequency decreases the further back the tongue body is [4].

Hála [5] describes the lateral, /l/, in Czech as being produced further back than contrastive /r/. /l/ is also made with an apical constriction, although it can be produced with the tongue blade in enunciated articulations. Šimáčková [14] further notes that although /l/ in Czech is categorized as an apico-alveolar, it is frequently produced with secondary velarization. Hála [5] also describes /r/ in Czech as being produced along the edges of the soft palate, with a narrow channel spanning 7-8 mm. Šimáčková, Podlipský, & Chládková [15] further describe /r/ as an apical trill, although it is often reduced to a single contact.

The purpose of this study is to examine the liquids in Czech to see if there is a common feature in tongue shape. Liquid segments are modeled under Articulatory Phonology [1] as stable coordination between a tongue-tip gesture and a tongue-body gesture [2]. Therefore, the expectation is that the tongue-tip gesture will coordinated with a 'vowel-like' tongue body gesture. The lateral motions of the liquids are also being examine to determine the gestures involved in the production of the lateral constriction for /l/. The examination of the parasagittal plane makes this a novel study which is aimed at uncovering more details about the characteristics which seperate the laterals from the rhotics.

2. METHODS

2.1 Participants

One male (C1) and four female (C2-C5) native speakers of Czech participated in this study. The speakers' age ranged from 18-29, with a mean age of 26. They were recruited from the Czech community in Toronto, Ontario and had no self reported speaking or hearing disorders.

2.2 Stimuli

The target stimuli were nonsense words with the two target phonemes, /r, l/, in the word-initial (#_a; Rap vs. Lap), intervocalic (a_a; Parab vs. Balap), and word-final contexts (a_#; Par vs. Pal). Distracter tokens were also presented during elicitation. The participants repeated each set 8 times, for a total of 40 productions of each item for a total of 240 tokens from each speaker (8 repetitions x 3 environments x 2 phonemes x 5 participants). Each set was presented to each speaker in the same randomized order.

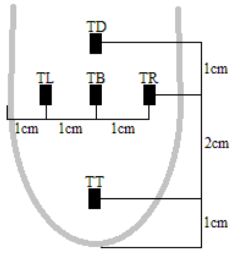
2.3 Instrumentation

Articulatory data was collected with a Carstens Medizinelektronik AG500 electromagnetic articulograph (EMA) at the Oral Dynamics Lab, Speech Language Pathology Department, University of Toronto. The AG system has 12 channels which record horizontal (x), lateral (y), and vertical (z) displacement of the sensors attached to points of interest. Data was recorded with a sampling rate of 200 Hz, and audio data with a sampling rate of 16 kHz and 16 bit.

2.4 Procedure and analysis

The participants had 5 EMA sensors glued to the tongue with periAcryl blue glue. The 5 sensors had the following configuration: tongue tip (TT), approximately 1 cm from the tongue tip; tongue body (TB), approximately 3 cm from the tongue tip; tongue dorsum (TD), approximately 4 cm from the tongue tip; tongue right (TR) and tongue left (TL), approximately 1 cm from the side of the tongue and 1 cm from the centre sensor; TT, TB and TD were along the mid-sagittal plane (Figure 1).

Figure 1. EMA sensor configuration.



A Country Man ISOMAX E60P5L microphone was placed 6 inches in front of the participant to capture audio data. A computer screen which presented Powerpoint slides of the target words was placed approximately 2 feet in front of the participant. The participants began by reading Aesop's *The North Wind and the Sun* [3] in Czech twice to habituate themselves to the EMA sensors.

Raw articulatory data was corrected for head movement by rotating and transposing the data to a reference position, such that the x-y plane coincided with the subject's occlusal bite plane at a bubble level [20]. The results were compared using a Welch two-sample t-test. For each of the mid-sagittal sensors, TT, TB, and TD, the horizontal (x-axis) and vertical (z-axis) coordinates were compared. For the parasagittal sensors, TL and TR, the horizontal (x-axis), lateral (y-axis) and vertical (z-axis) coordinates were compared. The reason for comparing the lateral coordinates only on the parasagittal sensors was because there was no expectation for the trill to be distinguished from the lateral along the mid-sagittal plan by lateral movement. The peak velocity - the maximum velocity of an articulator during a gesture - was also calculated. These results were also compared using Welch's two-sample t-test.

Mview [18], a toolbox for MATLAB, was used to calculate the point of maximum constriction for the TT, TB, TD, TL, and TR sensors. Mview calculates pre-defined gestural landmarks, such as the point of maximum constriction for selected articulators based on known landmarks. The point of maximum constriction refers to the maximum displacement of an articulator during a gesture. The results were compared using Welch's two-sample t-test in R [12].

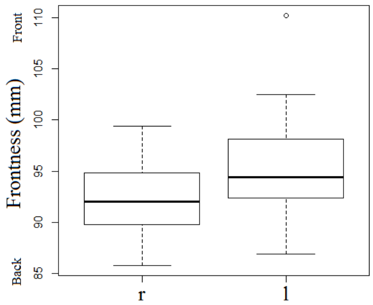
3. RESULTS

3.1 Gestural results for the horizontal plane

The gestural analysis of the horizontal plane revealed that the tongue tip for /l/ was approximately 3 mm further forward than /r/ [$t(232) = 6.22$, $p < 0.0001$] (Figure 2), the tongue body for /l/ was approximately 2 mm further forward than /r/ [t(236)

= 5.71, p < 0.0001], and the tongue dorsum for /l/ was approximately 2 mm further forward in the mouth than /r/ [t(236) = 3.88, p = 0.0001]. The analysis of the parasagittal plane revealed that the left and right sides of the tongue for /l/ were further forward than /r/ by approximately 4 mm [t(234) = 7.80, p < 0.0001; t(235) = 7.77, p < 0.0001].

Figure 2. Boxplot of the tongue tip results.



3.2 Gestural results for the vertical plane

The gestural analysis of the vertical plane revealed that there was no significant difference in the height of the tongue tip for /l/ compared to /r/ [t(237) = -0.31, p = 0.7573]. However, the tongue body for /r/ was approximately 3 mm higher than for /l/ [t(237) = -2.72, p = 0.0069]. The tongue dorsum for /r/ was also approximately 3 mm higher than contrasting /l/ [t(237) = -2.39, p = 0.0178]. The parasagittal analysis revealed that both the left side of the tongue [t(238) = -3.06, p = 0.0025] and the right side of the tongue [t(237) = -3.35, p = 0.0009] were approximately 4 mm higher for /r/ than for /l/.

3.3 Gestural analysis of the lateral plane

The gestural analysis of the lateral plane revealed a significant difference in the lateral position of the left side of the tongue [t(181) = -2.87, p = 0.0046]. The tongue position for /r/ was approximately 2 mm further to the left than /l/ (Figure 4). However, there was no significant difference in the lateral position of the right side of the tongue for /r/ and /l/ [t(228) = 0.161, p = 0.8722].

Figure 3. Boxplot of the tongue body results.

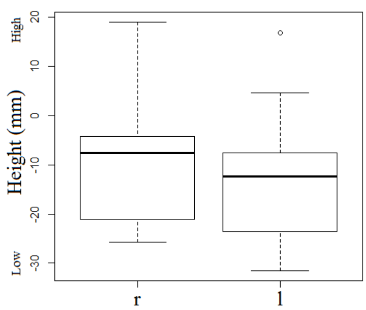
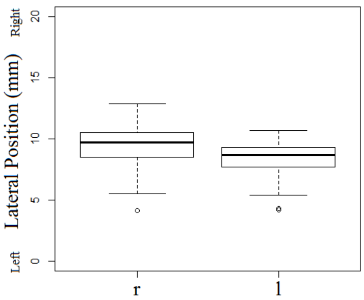


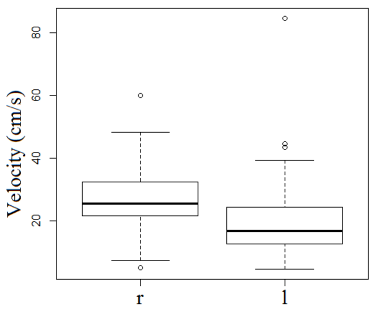
Figure 4. Boxplot of the left side of the tongue results.



3.4 Gestural analysis of the peak velocity

The statistical analysis of the peak velocity of tongue tip revealed that /r/ was approximately 10 cm/s faster (Figure 5) than /l/ [t(230) = -6.51, p < 0.0001]. The tongue body [t(232) = -5.12, p < 0.0001] and the tongue dorsum [t(238) = -4.47, p < 0.0001] for /r/ were approximately 2 cm/s faster than /l/.

Figure 5. Boxplot of the tongue tip results.



4. DISCUSSION

The results revealed that /l/ is articulated significantly further forward in the mouth compared to contrasting /r/. This is unexpected given Hála's [5] palatograms show /r/ more anterior than /l/. However, all participants showed this direction of difference between /r/ and /l/, aside from C3 who showed no significant difference between the place of articulation between both phonemes. The analysis of the tongue dorsum did not reveal a significant amount of retraction compared to /l/, which suggests there is not a significant amount of tongue dorsum retraction for /r/ in Czech. The lack of tongue dorsum retraction implies a higher F3 than is characteristic of rhotics found in languages such as English [7]. The findings also suggest a larger pre-constriction vocal tract volume for the lateral, /l/, compared to the rhotic, /r/. The larger vocal tract volume for /l/ suggests that there is also a lower F2 than contrasting /r/. These findings also support Lindau's [7] assertion that retraction of the dorsum into the pharyngeal cavity is largely responsible for the lowered F3 observed in English rhotics. This is contrary to Stevens [18] who suggests the subapical cavity is largely responsible for lowered F3. The lack of tongue dorsum retraction, but the presence of retroflexion required for apical trilling suggests that tongue dorsum retraction causing a secondary constriction in the pharyngeal cavity is responsible for lowered F3.

The tongue body and dorsum were found to be higher for /r/ than contrasting /l/. This is most likely related to the lateral bracing requirements for trill production. McGowan [8] and Ladefoged & Maddieson [6] both suggest that lateral tongue bracing is an important mechanism for trill production; McGowan [8] suggests that the lateral tongue bracing allows the tongue stiffness to be controlled, while allowing the flexible articulator (the tongue tip in this case) to vibrate because it is left unbraced. In order to achieve a firm lateral lock, the tongue is raised slightly to allow more contact with the teeth. /l/, on the other hand, is only required to make a closure and does not require the same level of stability and control as a trill does.

The tongue body and dorsum for /l/ were also found to be anterior to the contrasting /r/. This gives /l/ a more mid-central vowel-like quality and /r/ a more mid-back vowel-like quality. This is similar to the findings in Proctor [11] for Spanish. However, they are clearly different than the findings for Russian, which indicated a uvular-pharyngeal target for the lateral and a mid-central target for the rhotic. However, further temporal analyses need to be conducted to determine the precise gestural coordination of the liquids in Czech and if that coordination can adequately capture the phonological patterning of the liquids in Czech.

The lateral results suggest that /l/ forms the constriction on the left side of the mouth via contraction of the styloglossus muscle. This gesture draws the lateral side of the tongue towards the medial portion of the tongue, creating an opening of approximately 2 cm in width. The lateral opening creates a resonance cavity which creates the clear formant structure characteristic of laterals. Furthermore, the anterior part of the vocal tract acts as a side cavity, creating distinct anti-formants, which Narayanan et al. [10] describe as one of the features that distinguishes laterals from rhotics. The individual results, however, suggest that there is significant variation in how the constriction is formed for the lateral. C2 contracted the lateral portion of the right side of the tongue to form the constriction, instead of the left side. C3 contracted both the left and the right side of the tongue to draw it inwards, suggesting a constriction on both sides of the tongue.

An informal analysis of the peak velocity revealed that for the rhotics, the peak velocity was most commonly during the vibrations of the tongue for trilling. /r/ was also found to have a higher peak velocity than /l/. This follows Narayanan et al.'s [10] findings that the more posterior the tongue tip is during the constriction, the greater the peak velocity of the gesture is. However, the magnitude of the difference between the two is much larger than the findings in Narayanan et al. [10], given the two are articulated only a few mm apart. This suggests that rhotics may require faster constriction formation to facilitate the necessary conditions for trilling.

The overall tongue shape and gestural coordination between the Czech rhotic and lateral appear to share a number of similarities (Figure 6 and Figure 7). The tongue dorsum is retracted to a certain degree, with a similar degree of tongue dorsum raising, resulting in a vowel-like dorsal gesture. The tongue dorsum gesture is coordinated with a tongue tip gesture in the case of both the rhotic and the lateral.

Figure 6. Mid-sagittal contour for the Czech trill, /r/, produced by C2. The tongue tip is on the right.

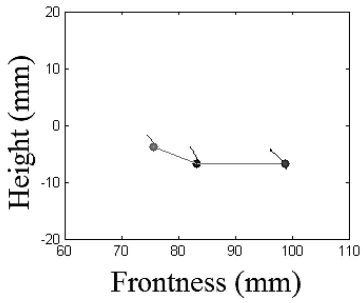
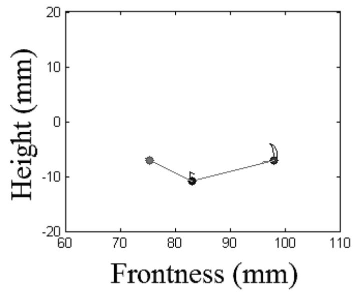


Figure 7. Mid-sagittal contour for the Czech lateral, /l/, produced by C2. The tongue tip is on the right.



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