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Analysis of Kannada speaker's tongue profile for articulatory simulation

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Abstract

Improper articulation of the tongue would result in incorrect pronunciation of speech sounds. Articulatory correction involves correcting the positioning and movement of the tongue for each of the misarticulated sounds. The present study attempts to profile the movement of the tongue during the production of selected set of speech sounds uttered by native Kannada speakers, who don't have any speech, language or hearing disorder. Phonemes for the study were selected based on the place and manner of articulation. Ultrasound imaging technique is used to track the tongue contour from the tip to the root of the tongue. The obtained tongue image of each speech sound was segmented into five regions. The shape and movement profile of the segmented tongue were analyzed in terms of the initial position, target position and slope as well as angle of deviation at the root of the tongue, for each segment. Analysis of the segmented profiles showed that the retroflex sounds have relatively maximum angular deviation from the tip of the tongue in rest position. Palatal sounds have maximum deviation from the tongue rest position in terms of coordinates. Documentation of profile in the Cartesian plane paves the way for better understanding of tongue dynamics in speech production. The present study resulted in profiling the contour of tongue based on the angle of deviation and slope of the tongue segments for dental, retroflex, velar and palatal sounds. This would further help in developing robotic tongue movement for articulatory simulation, which can be used as an effective tool for articulatory training of children with articulation disorders.

Keywords: Articulatory simulation, place and manner of articulation, segmentation, angle of deviation, tongue profiling.

1. Introduction

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Articulation is the process of producing speech sounds by the movement of articulators such as tongue, lips, jaw and other speech organs. When a person has articulation disorder, his/her speech may not be intelligible to the listener, which may lead to the poor quality of life of the person with disorder. Incorrect positioning of the tongue is one of the major reasons for articulation disorder, which may result in errors such as substitution, omission and distortion of sounds. Thus, correcting tongue position and movement is essential for treatment planning and posttreatment stability.

Speech-language pathologists (SLPs) correct articulation disorders through several sessions of speech therapy, by using several techniques such as manual demonstration of producing sounds, modelling of the sounds etc. But for effective articulatory correction, demonstration of the precise articulation is important. In the conventional method of articulatory correction, though the speech therapist demonstrates place and manner of articulation, tongue of the therapist is not visible during the production of back phonemes. A dynamic and complete view of production of each sound with three dimensional representation can help children with articulatory disorders to understand the entirety of the speech act (Rathinavelu et al., 2007). This will facilitate in learning the production of speech sounds in a quicker and effortless manner.

Development of technology in health sciences has opened the way for effective services for persons with articulatory disorders (Stokes et al., 2001). To help them attain proper articulation, a robotic model which depicts the tongue movements in real time is planned in the present study. This will facilitate the teaching learning process for effective articulation. The places of articulation include bilabial, dental, alveolar, retroflex, palatal, velar, uvalar, pharyngeal and glottal. It is expected that the robotic model would simulate the tongue movements and facilitate better understanding of the tongue placement during production of these phonemes by children with misarticulation. However, for this purpose, the anatomic aspect of the tongue and the corresponding movements have to be profiled.

Some researchers have made attempts in this area. Vagmi Software, (Voice and Speech Systems, n.d.) displays shapes of tongue and lip for pronunciation of selected phonemes. The persons with the articulation disorder have to see the articulatory movements on the computer screen (2 D images) and try to imitate the same. An audio output is also provided for each sound which can be played as many numbers of times as required. To win the child's attention and wanting the child to participate in the session is a challenge faced while using this software. Stone & Lundberg (1996) reconstructed tongue surfaces in three dimensions from different coronal cross sectional slices of tongue. They classified tongue shapes into four categories and showed that the front raising is for alveolar and palatal sounds, groove shaped movement occurs for alveolar and dental sounds, back raising of the tongue is found in velar and two point displacement occurs for lateral sounds.

Through the analysis of 450 vocalic and consonantal sequences from Canadian and American English, Iskarous (2005) showed that there exists a pivot pattern for tongue movements. The pattern obtained by the edge tracing of tongue from ultrasound motion pictures looked like a rotational movement,

where one point of tongue body remains fixed, and the other points rigidly rotate around it. They have traced the pattern for [k-a], [ih-t], [u-e], [o-ae] and [a-i]. The authors pointed out that the deformation of the tongue during a transition depends on the starting and ending configurations.
Results of the comparative study of coronal consonants in Arrernte and Kannada (Tabain et al., 2016), showed that when a Kannada speaker produces dental stop, the tongue becomes more flatter compared to the tongue profile for alveolar, nasal and lateral sounds. The study found that the flatter tongue profile seen in Kannada speakers for dental stop is consistent compared to Arrernte speakers while producing stop, nasal and lateral sounds. The study showed that the tongue profile varies across languages.
Shape of the tongue while producing /ʧ/, dental /t̪a/, retroflex /ʈa/and velar /ka/ was investigated by Kochetev et al. (2012) on the basis of ultrasound images. Data from four normal participants (2 females and 2 males) revealed that for phoneme /ʧ/, anterior tongue body showed a significant raising whereas fronting of the tongue was moderate compared to the shape for dental /t̪a/. The authors observed that for /ʧ/ and /t̪a/sounds, the tongue blade was either at the alveolar ridge or very close to it. For /ʧ/ sound, the constriction occurred with greater angle whereas for /t̪a/, the constriction was either at the front part or at the tip of the blade. They showed that the shape and movement of the tongue plays a major role in precise production of the sound.
A systematic and in-depth review of the above studies highlight the influence of tongue profiling of different phonemes in speech articulation. However, specifically for speech sounds in Kannada, only a few studies have been conducted in this direction. The study conducted by Kochetov et al. (2012) has considered only four sounds such as /ʧ/, dental /t̪a/, retroflex /ʈa/, and velar /kɑ/. Moreover their study concentrated on tracing the edge of the tongue blade. Information regarding angles, initial and final positions etc., are missing. The profiling of the tongue based on the angle of deviation and coordinates have not been explored by any of the previous studies. Wei et al. (2012) measured tongue deviation angle from the still photographs of tongue. They attempted to predict the occurrence of stroke by estimating the deviation angle.
Ultrasound has been widely used in speech research and therapy, partly due to its relative non-invasiveness and low equipment cost compared to electromagnetic articulograph (EMA), electropalatograph (EPG), and functional magnetic resonance imaging (Bernhardt et al., 2005). Kansy et al. (2018) found ultrasound as a valid alternative to Magnetic Resonance Imaging to visualize and quantify the movement of the tongue during articulation. Also acquisition of the information regarding shape of the tongue is comparatively easy as there is no need for head to transducer stabilization (Zharkova, 2013). Midsagittal plane is the most meaningful and significant plane for ultrasound imaging. The image obtained would be intuitive and can be compared between different speakers (Bressmann, 2008). The shape of the tongue including root obtained in midsagittal plane is profiled in the present study. With a set of collected ultrasound imaging data, segmentation and profiling of images of the tongue were performed using angle of deviation and co-ordinates obtained during speech production. It is expected that, this work will aid in the

development of an artificial tongue which would further help in the implementation of robotic systems for articulation training which are essential for effective and faster rehabilitation.
Thus the present study attempts to obtain the tongue profile for selected speech sounds expressed in terms of angle of deviation and co-ordinates of five segments of the tongue for native Kannada speakers through ultrasound imaging.

The objectives of the present study are

1.1 To obtain the profile of the tongue in rest position and the target position for each of the selected speech sounds.
1.2 To segment the tongue into five regions and obtain the endpoints for each segment.
1.3 To represent the end points of each segment through [x, y] coordinates and angle of deviation with respect to a fixed reference point.
1.4 To obtain the deviation of tongue profile in terms of coordinates and angle with reference to its initial position.
1.5 To find the sounds having maximum and minimum deviation from the initial position of the tongue for each of the segments.

2. Methodology

2.1 Participants

A total of 10 Kannada speakers were included in the study. The group comprised of equal number of male and female adults in the age range of 23-27 years. Only those adults with no history of sensory, neurological, communicative, academic, cognitive, intellectual or emotional and oro facial abnormalities were included. The mean age of the participants was 25.70 years. Ethical protocol of All India Institute of Speech and Hearing was followed. The purpose and procedures of the study were explained to the participants and an informed verbal and/or written consent was obtained.

2.2 Stimuli

Images of tongue movement corresponding to twelve different speech sounds uttered by the participants were recorded using Ultrasound diagnostic imaging system DP6600. Eleven lingual sounds combined with vowel /ɑ/ as depicted in Table 1 were selected for the study. All the sounds were chosen based on place and manner of articulation (Wayland, 2019).

Table 1
Syllables selected based on place and manner of articulation

Manner of Articulation	**Place of articulation** Dental		Retroflex		Alveolar		Palatal		Velar	
	V	UV	V	UV	V	UV	V	UV	V	UV
Stop Consonants	/d̪ɑ/	/t̪ɑ/	/ḍɑ/	/ṭɑ/					/gɑ/	/kɑ/
Affricates								/ʧ/		
Laterals			/ḷɑ/		/lɑ/					
Glides							/jɑ/ / rɑ/			

Note-V: Voiced sounds, UV: unvoiced sounds, */a/ is used for representing vowels*

2.3 Procedure

The approach used to segment and quantify tongue contour is as follows. A set of Ultrasound images were collected using Mindray DP6600 digital Ultrasonic diagnostic imaging system. The participant was informed to sit straight with the diagnostic ultrasound probe (Ultrasonic transducer with an imaging frequency of 10MHZ) tightly placed below the chin (Figure 1). Then he/ she was instructed to utter each of the twelve sounds three times, one after the other with pauses of 2 seconds in between. Images of the tongue, which appeared on the screen, were recorded with a frame rate of 60 fps. The images obtained were processed using the software, Articulate Assistant Advanced Version 2.14 (Articulate Instruments Ltd., 2012). The midsagittal image obtained for the tongue in rest position is given in Figure 2. Bright white line represents the tongue contour. Left side of Figure 2 represents front of the oral cavity (tongue tip) and right side represents backside of the oral cavity (root).

Figure 1. Participant with ultrasound probe

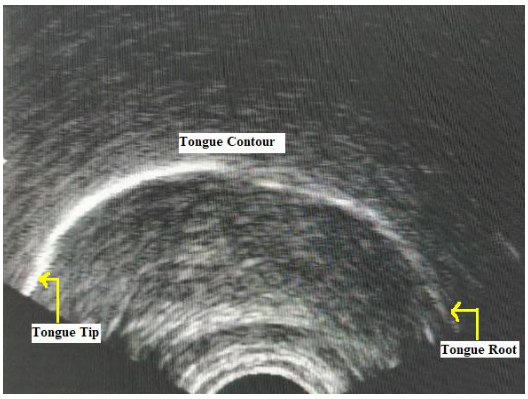

Figure 2. Ultrasound Image taken for the tongue in rest position

The tongue contour was highlighted and segmented into five [A-B], [B-C], [C-D], [D-E], [E-F] as shown in Figure 3. Yellow line highlights tongue contour with A B C D E F segmented points (6 points). Segmentation was performed using Digimizer software version 4.3 (Digimizer, n.d.) For each of the segments, corresponding [x, y] coordinates and angle of deviation were found with respect to the reference point (0,0) as the tip of the tongue. Tangents for all the segments and a vertical reference line through the tip of the tongue were made. The angle of deviation was calculated from vertical reference line to the marked tangent. The reference line and tangent were made manually whereas angle was found by means of the digimizer software. Slope is calculated by taking the ratio of difference of x coordinates and y coordinates of the end points of each segment. Graphs representing the mean slope and angle of deviation were plotted for all the twelve sounds with reference to the tongue in rest position.

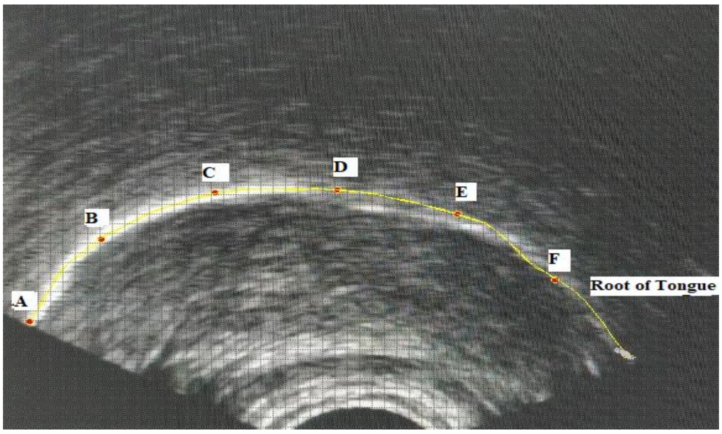

Figure 3. Segmented Ultrasound Image for the tongue rest position

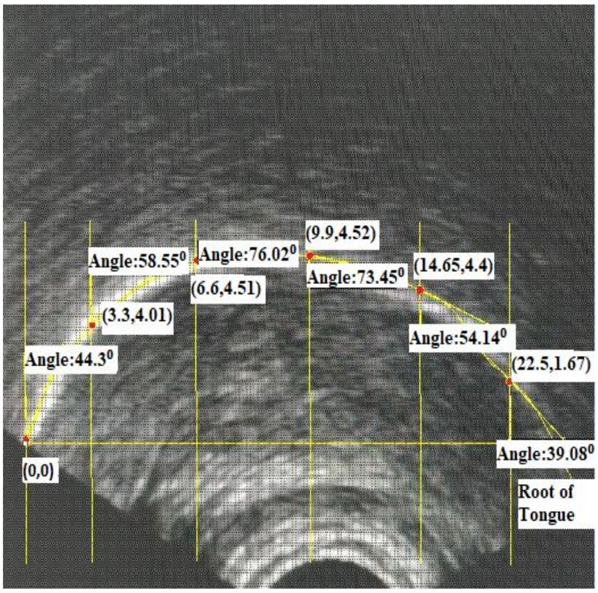

Figure 4. Angle of Deviation and cordinates marked for tongue in rest position

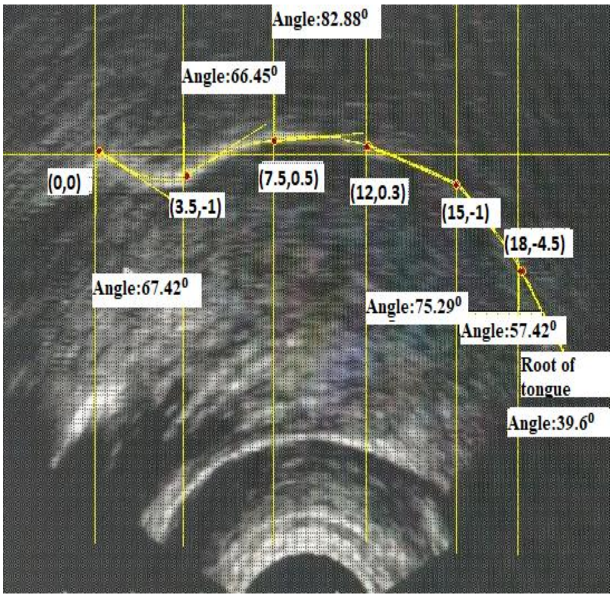

Figure 5. Angle of deviation and coordinates marked for /tɑ /

Angle of deviation and coordinates were marked for the tongue rest position (Figure 4) and for each sounds. Figure 5 represents the angle of deviation and coordinates marked for the speech sound /t̪a/. Negative sign for the coordinates indicate that the x coordinate is towards the left with respect to the zero reference line and y coordinate is down from the zero reference line.

3. Results and Discussion

3.1 Mean slope for the tongue

The mean slope of the coordinates [x,y] for the tongue in rest position at each point was calculated and is tabulated in Table 2. Slope values in the rest position of the tongue is taken as the reference for depicting the change in slope of each segment during production of target sounds. The slope at F is negative as F represents the root of the tongue and has a negative slope at rest position as evident in Figure 3.

Table 2
Mean slope values obtained for tongue in rest position.

	A	B	C	D	E	F
Slope	0.82	1.46	2.18	3.32	17.47	-7.94

Table 3
The deviation for maximum and minimum slope at each point from the tongue rest position.

A		B		C		D		E		F	
Max	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
/d̪a/ 19.18	/ka/ 0.11	/la/ 21.54	/ka/ 0.01	/ɭa/ 27.32	/ka/ 0.02	/ʧ/ 52.18	/ka/ 1.18	/ka/ 16.53	/ja/ 3.47	/ka/ 6.49	/ɑ/ 3.51

The maximum and minimum mean slope of the coordinates [x, y] at each point during the production of target sounds were calculated and has been tabulated in Table 3. For points B and C maximum slope is observed for /la/ and minimum slope for /ka/. /ka/ has minimum slope in points A and D, maximum slope in points E and F. /d̪a/ shows maximum slope for point A and /ʧ/ for point D. For points E and F, /ja/ and /ɑ/ phonemes show minimum slope respectively.

Figure 6 was obtained by plotting the mean slope of all coordinates for the tongue in rest position and the target positions. Each point for each sound (in each line) represents dental, alveolar, retroflex, palatal and velar zones respectively. Dotted line represents the slope plot in rest position and solid line represents the target contour of tongue during the production of different speech sounds.

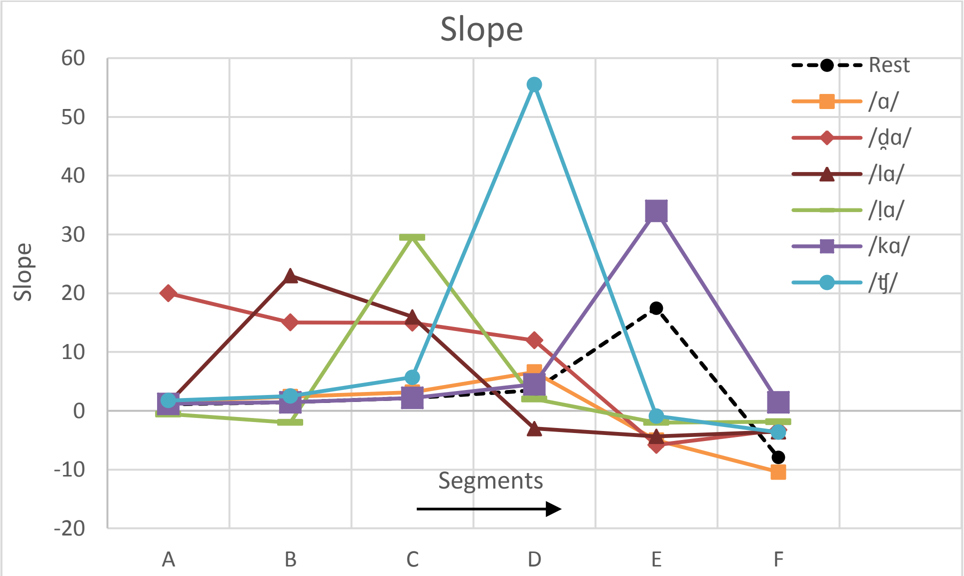

Figure 6. Mean slope plot for selected phonemes along with tongue in rest position

Point A in Figures 6 and 7 depicts the dental zone where the tip of the tongue acts. From both the plots it is evident that, compared to all phonemes /d̪ɑ/ has maximum mean slope value at the point A. /d̪ɑ/ is a dental sound for which the tongue tip is raised to touch the back of the upper front teeth to obstruct the airflow. Zhao (2010) reported that, for dental sounds the tongue touches behind the back of the upper teeth. The speech sound/t̪ɑ/ also belongs to dental place of articulation and has values nearing the /d̪ɑ/ value, though slightly lesser. Figure 7 depicts the plot of mean slope obtained from coordinates [x, y] for dental sounds /t̪ɑ/ and /d̪ɑ/.

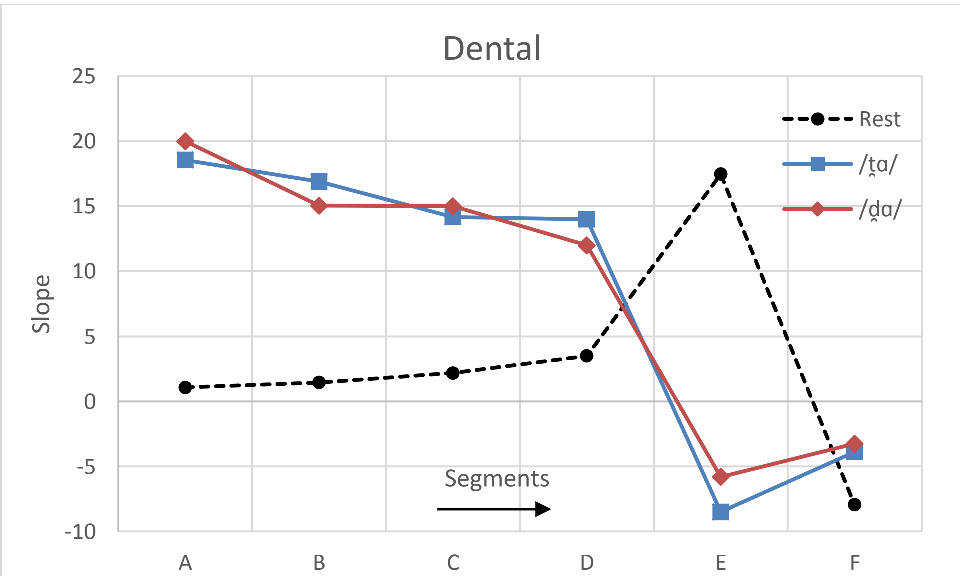

Figure 7. Mean slope plot for dental sounds such as /t̪ɑ/ and /d̪ɑ/

Point B in Figure 6 depicts the alveolar zone of articulation, where the phoneme /lɑ/ has maximum mean slope value compared to all the other phonemes. According to Edwards (1999), the tongue tip and part of blade comes in contact with the upper ridge behind the front teeth during the production of alveolar sound /lɑ/. Point C in Figure 7 depicts the retroflex zone of articulation. According to Hamann and Fuchs (2010), the retroflex sounds are produced with raised and retracted tongue tip. The retroflex sounds have maximum value for slope in the plot at the point C, in comparison to all other categories of phonemes. Amongst the retroflex sounds, the sound /ḷɑ/ has maximum slope at point C, though the phonemes /ṭɑ/, /ḍɑ/ have near similar values to that of /ḷɑ/ as depicted in Figure 8, as all these three phonemes comes under retroflex place of articulation.

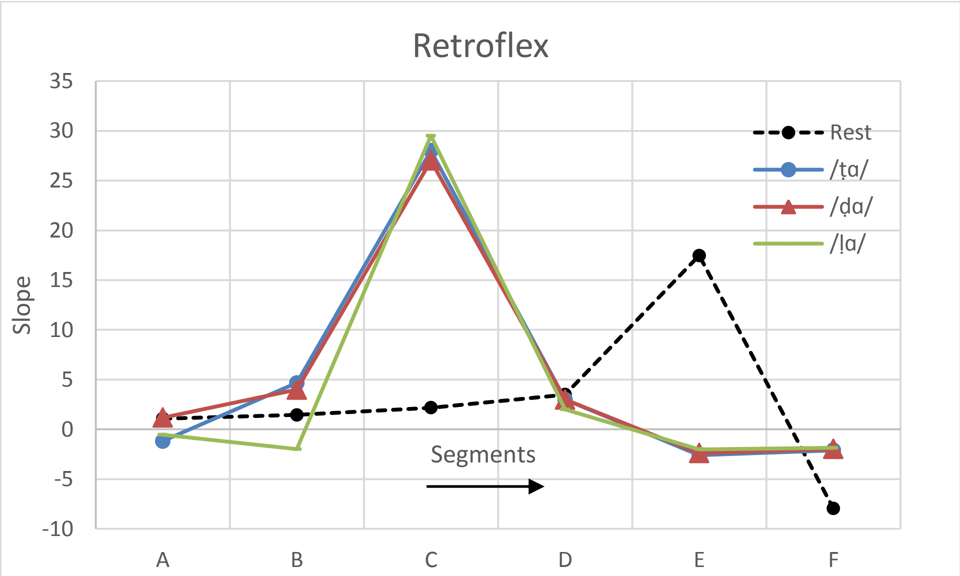

Figure 8. Mean slop plot for retroflex sounds such as /ṭɑ/,/ḍɑ/ and /ḷɑ/

Upadhyaya (1972) classified /ʧ/ as voiceless palatal phoneme for which the tongue is raised towards the hard palate, just behind the alveolar ridge. Hence compared to the rest of the phonemes, the sound /ʧ/ has maximum slope at point D [palatal zone]. Also, /ʧ/ and /jɑ/comes under same place of articulation and for both the phonemes tongue raises to touch the hard palate in the similar pattern. The mean slope values are almost similar and the contour for /ʧ/ and /jɑ/does not show much variations. Figure 9 depicts the mean slope plot for palatal sounds.

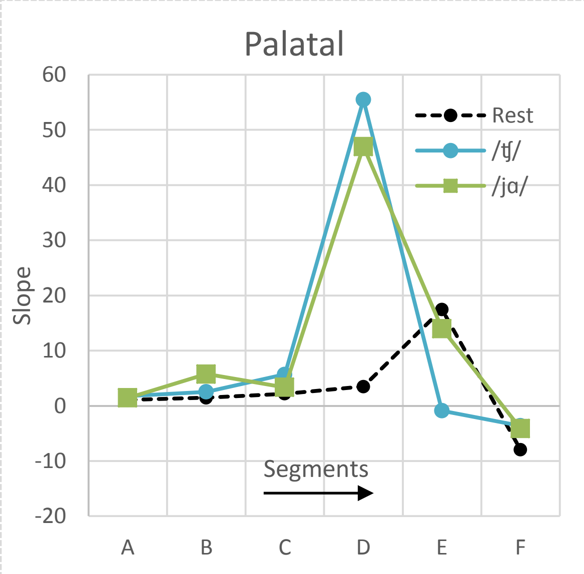

Figure 9. Plot of mean slope for palatal sounds such as /ʧ/and /jɑ/

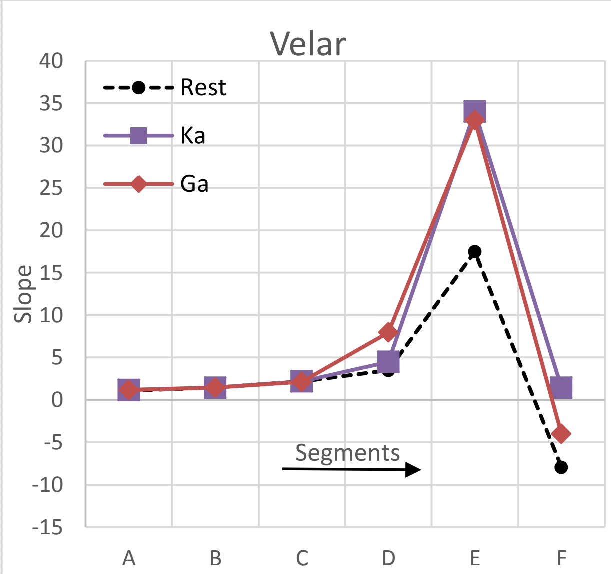

Figure 10. Plot of slope for velar sounds such as /kɑ/ and /ga/

Deviation for /kɑ/ and /ɡɑ/ phonemes are clearly visible from E and F zones in Figure 10. In agreement with the findings made by Kochetov et al. (2012), points E and F represents velar place of articulation, where the phonemes are produced with the back of the tongue raised towards soft palate. The mean slope plot for both of these phonemes reveals that the tongue is raised at point E to the maximum compared to rest of the phonemes to touch the velar region. Figure 12 depicts the slope plot for velar sounds such as /kɑ/ and /ɡɑ/. /kɑ/ and /ɡɑ/ have near similar values as both of these phonemes belongs to velar place of articulation.

Minimum mean slope values were also analyzed. As /kɑ/, /ɡɑ/ and /ɑ/ phonemes does not have significant movement for the tip of the tongue, these phonemes have minimum deviation from the tongue rest position. This is true for the points A, B, C, and D. Also from the analysis of the plots, it is evident that the phonemes /jɑ/ and /ɑ/have minimum values at points E and F respectively.

3.2 Mean Angle of deviation

Figure 11 has been obtained by plotting the angle of deviation values for both the tongue in rest position and for the chosen twelve phonemes. It represents the degrees up to which tongue is bent or curled from the rest position to touch the mouth ridge for the production of each of the twelve phonemes. As in the slop plot, each point in the graph for angle of deviation [A, B, C, D, E, F] represents dental, alveolar, retroflex, palatal and velar zones respectively. Dotted line represents the angle of deviation in rest position of tongue and solid line represents the target contour of tongue during the production of different speech sounds. Table 4 represents the maximum angle of deviation from the tongue rest position for each point.

Table 4
Maximum angle of deviation at each point with respect to the reference [tongue rest position].

A	B	C	D	E	F
/d̪ɑ/ 68.42	/lɑ/ 72.51	/ḷɑ/ 88.74	/rɑ/ 86.03	/lɑ/ 58.3	/lɑ/ 43.28

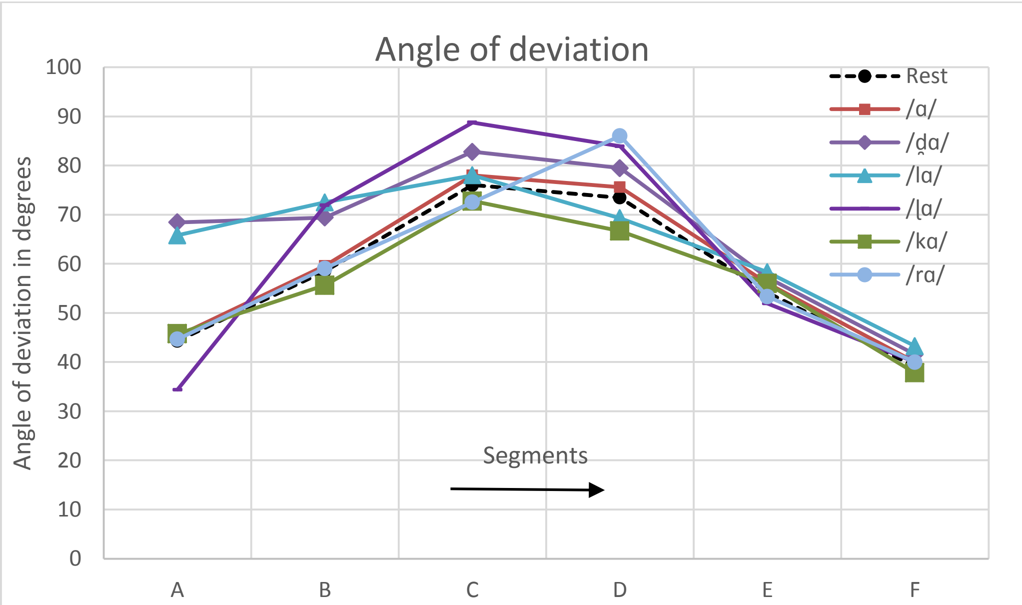

Figure 11. Angle of deviation of the selected sounds and tongue in rest position

The results obtained from the analysis of maximum angle of deviation correlates with the analysis of slope plot at the points A, B and C (dental, alveolar, retroflex zones respectively). The phonemes /d̪ɑ/, /lɑ/ and /ḷɑ/ show maximum angle of deviation at points A, B and C respectively. Among those points, when compared to all the twelve phonemes, point C is the point at which maximum value for angle of deviation is obtained. This is obtained for the phoneme /ḷɑ/ as the production of retroflex sounds involves the bending or curling of the tongue at the peak. At point D /rɑ/ has maximum angle of deviation. Adler-Bock at al. (2007) also showed that, for the adult speakers /rɑ/ is produced by both anterior and posterior constriction with the tip of the tongue touching a point near the palate. For rest of the phonemes such as /kɑ/, /gɑ/ and /ɑ/ even if there are significant changes in slope values, with respect to the tongue in rest position there is no significant deviation for angle. Therefore the tongue path (angle of deviation) follows the same path as obtained for the tongue in rest position.

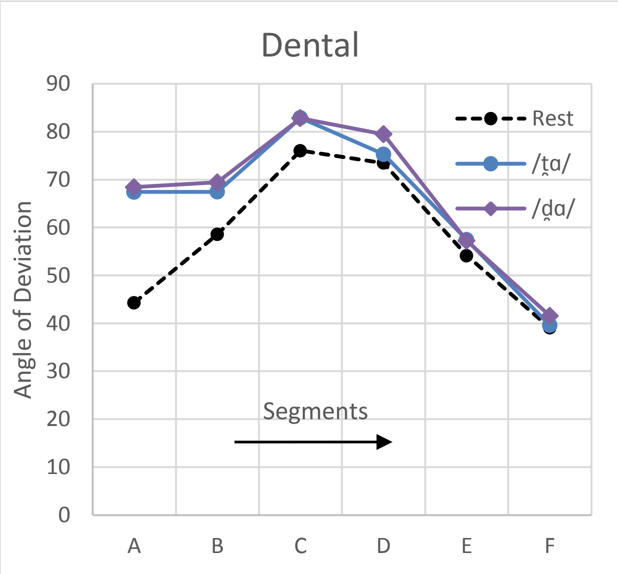

Figure 12. Plot of angle of deviation for dental sounds such as /tɑ/ and /dɑ/

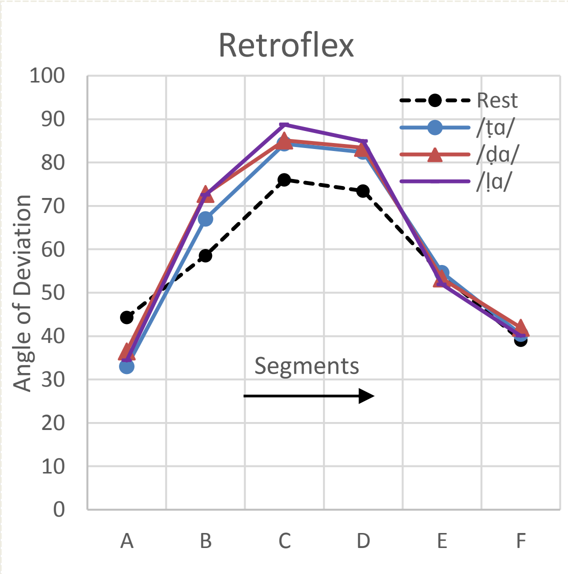

Figure 13. Plot of angle of deviation for retroflex sounds such as /ʈɑ/, /ɖɑ/and/ɭɑ/

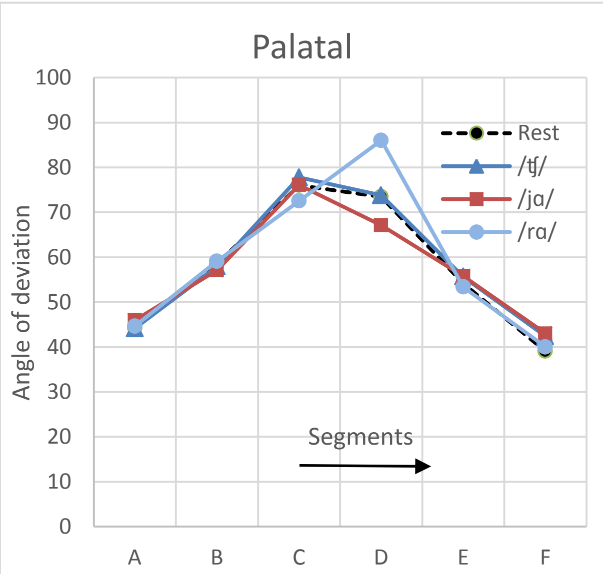

Figure 14. Plot of angle of deviation for palatal sounds such as /ʧ/, /jɑ/and /rɑ/

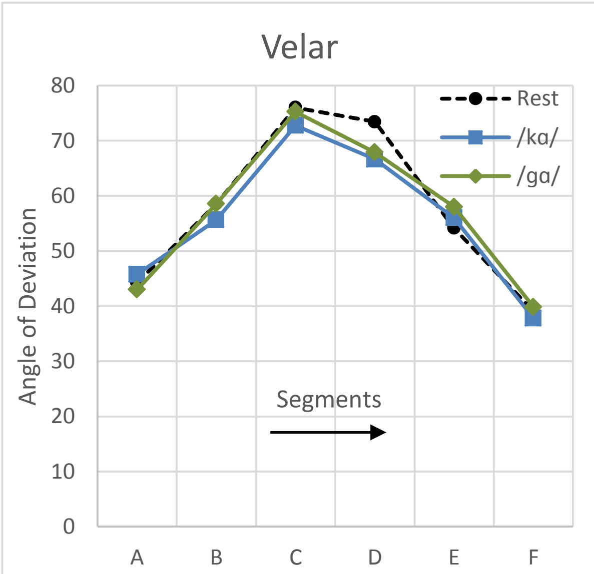

Figure 15: Plot of angle of deviation for velar sounds such as /ka/ and /gɑ/

Figure 12-15 represents the contour of tongue based on the angle of deviation for dental, retroflex, velar and palatal sounds respectively. This data will provide sufficient information in modelling 3D tongue, as this provides precise representation of each point in terms of its slope and angle.

4. Conclusions

The tongue profile obtained for the selected phonemes in the study is in agreement with the previous studies. In this study, we obtained end to end tongue profile of Kannada speakers with segmentation of ultrasound tongue images using an image processing and analysis tool. Analysis of the tongue contour for different phonemes was carried out with the acquired tongue profile of native Kannada speakers. The tongue contours for different places of articulation such as dental, alveolar, retroflex, palatal and velar, and the range of deviation in terms of coordinates and angles with respect to the tongue in rest position for native Kannada speakers were obtained. From the results, it is evident that there is a specific pattern which determines where the tongue should touch and how much should the tongue curl or bend for different phonemes with respect to the tongue rest position. We have also found the phonemes with maximum values of slope and angle of deviation at each of the five segments. It is observed that the retroflex sounds have comparatively greater deviation in angle from the tongue in rest position (88.74 degrees). Palatal sounds have maximum deviation in slope in comparison with the rest of the phonemes (52.18). Also velar sounds have minimum displacement from tongue rest position and minimum deviation in slope and angle compared to other phonemes considered in the study. It is expected that our present work will help in implementation of an automatic tongue in intelligent robotic systems for articulation training which would help in effective and faster rehabilitation of children with articulation disorders.

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