COMPARISON OF TONGUE CONTOURS IN CHILDREN, ADOLESCENTS AND ADULTS USING ULTRASOUND IMAGING

Ansu Abraham

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE – 570 006

MAY, 2014

CERTIFICATE

This is to certify that this dissertation entitled "**Comparison of tongue contours in children, adolescents and adults using ultrasound imaging**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Speech- Language Pathology) of the student (Registration No: 12SLP003). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier for the award of any other Diploma or Degree to any other University.

Mysore

May, 2014

Dr. S. R. Savithri
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysore -570 006

CERTIFICATE

This is to certify that this dissertation entitled "**Comparison of tongue contours in children, adolescents and adults using ultrasound imaging**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier for the award of any Diploma or Degree to any other University.

Mysore

May, 2014

Dr. N. Sreedevi

Guide

Reader & Head

Department of Speech Language Sciences

All India Institute of Speech and Hearing

Manasagangothri, Mysore - 570 006

DECLARATION

This is to certify that this dissertation entitled "**Comparison of tongue contours in children, adolescents and adults using ultrasound imaging**" is the result of my own study under the guidance of Dr. N. Sreedevi, Reader & Head, Department of Speech Language Sciences, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier for the award of any Diploma or Degree to any other University.

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May, 2014

Dedicated to

My Lord ***God,***

lovable

Sreedevi

Ma'am *and*

dearest

Irfanechi

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"I solemnly affirm that the writing here that I shall give, shall be the truth, the whole truth and nothing but the truth."

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TABLE OF CONTENTS

Chapter No.	*Contents*	*Page No.*
1.	**Introduction**	1
2.	**Review of literature**	9
3.	**Method**	24
4.	**Results and Discussion**	31
5.	**Summary and Conclusions**	47
6.	**References**	50

LIST OF FIGURES

Figure No	*Title of the figure*	*Page no.*
2.1	Instrumental setup for ultrasound imaging of the tongue	13
3.1	Mindray Ultrasound 6600	26
3.2	Adjustable stabilization headset	26
3.3	Tongue contour as seen in an ultrasound image	27
3.4	2D spline contour for retroflex phonemes	29
3.5	Division of tongue contour into anterior, middle and posterior region	30
4.1	Comparison of tongue contour for /at̲t̲a/ across (a) adults and adolescents (b) adolescents and children (c) adults and children	33
4.2	Comparison of tongue contours of males and females for /at̲t̲a/ in (a) adults (b) adolescents (c) children	34
4.3	Comparison of tongue contours for /aṭṭa/ across (a) adults and adolescents (b) adolescents and children (c) adults and children	35
4.4	Comparison of tongue contours of males and females for /aṭṭa/ within (a) adults (b) adolescents (c) children	36
4.5	Comparison of tongue contours for /akka/ across (a) adults and adolescents (b) adolescents and children (c) adults and children	38
4.6	Comparison of tongue contours of males and females for /akka/ within (a) adults (b) adolescents (c) children	39
4.7	Comparison of tongue contours for /ad̲d̲a/ across (a) adults and adolescents (b) adolescents and children (c) adults and children	40

4.8	Comparison of tongue contours of males and females for /aḏḏa/ within (a) adults (b) adolescents (c) children	41
4.9	Comparison of tongue contours for /aḍḍa/ across (a) adults and adolescents (b) adolescents and children (c) adults and children	42
4.10	Comparison of tongue contours of males and females for /aḍḍa/ within (a) adults (b) adolescents (c) children	43
4.11	Comparison of tongue contours for /agga/ across (a) adults and adolescents (b) adolescents and children (c) adults and children	44
4.12	Comparison of tongue contours of males and females for /agga/ within (a) adults (b) adolescents (c) children	45

LIST OF TABLES

Table No	***Title of the table***	***Page no.***
3.1	Stimuli used in the study	25

CHAPTER 1- INTRODUCTION

"If the tongue had not been framed for articulation, man would still be a beast in the forest": Ralph Waldo Emerson

Speech is the most common medium to express the thoughts of human beings. The simplest speech motor output requires the spatial and temporal coordination of more than 70 muscles and 8 to 10 different body parts, ranging from the abdominal muscles and diaphragm to the lips (Hixon, Mead & Goldman, 1976). Variations in positions and trajectories of the lips, the tongue, the jaw, the velum and the posture of the larynx by the speaker can vary the air pressure and airflow in the vocal tract. These variations in pressure and flow produce the acoustic signal that we hear when listening to speech. Knowledge of the developmental patterns in anatomy and physiology of the speech production system is pre requisite to an understanding of speech motor control, neural processes of speech, and clinical assessment of speech motor behaviour in children. Amongst the muscles for speech articulation, the most active is the tongue. Studies have shown that the tongue development will be rapid from the age of 9 to 13 years and it will continue till 18 years (Caruso & Strand, 1999).

Speech motor control refers to the systems and strategies that control the production of speech. On the development of speech motor control, Kent and Forner (1980) concluded from spectrogram studies that temporo-spatial coordination of the individual components of the speech production mechanism may continue to improve until reliable control of articulatory movements is attained, at approximately 11 years of age. Bose and Square (2001) discussed that basic control competencies for precision of volitional speech and non-speech movements of the articulatory subsystems, i.e., jaw, lips and tongue, are not observed until age four and refinements of these movements continues till the age of seven. A period of rapid growth of vocal tract length and the lower face has been documented from 7 to 10 years by Temple, Hutchinson, Laing and Jinks (2002) and inconsistency in lingual articulations reported in their study was partly ascribed to the articulatory adjustments due to rapid physiological changes, and not only to the immature speech motor control. Cheng, Murdoch, Goozee and Scott (2007) studied tongue tracking and jaw motion using Electromagnetic Articulography and the results suggest that the coordinative organization of the tongue and jaw exhibited changes until the age of 8 to 11 years and continued to undergo refinement into late adolescence.

Research has been carried out in the recent years on different age groups to study the speech motor control. Smith (2010) claims that speech motor control in adolescents is different from that of adults. She suggests that adolescents achieve faster speech rates than younger children at the expense of smaller displacement of lips and jaw. According to her, younger children have relatively larger articulator displacements accompanied by slower speech rates. Walsh and Smith (2002) suggested that overall trajectory variability for the articulators was higher for adolescents compared to young adults by conducting the study on 12-, 14- and 16-year-olds and young adults with mean age of 21.2 years. The researchers in the past several years have studied tongue function and its development using many instruments and imaging techniques like Electropalatography, Electromagnetic Articulography, X-rays, Magnetic Resonance Imaging etc.

Among the imaging techniques, ultrasound is becoming an increasingly popular tool for imaging tongue function in speech research in the recent past because of its biologically safe mode and comfortability for the research subjects as it is placed external to the face and thus non-invasive in contrast to other current visual feedback technologies (EPG, magnetometry, glossometry etc.). Few more advantages of ultrasound of the tongue are that it can be observed dynamically or statically with either mid-sagittal or coronal oblique views, providing alternative perspectives on configurations and movements. The displays are relatively easy to explain to the participants. A sequence of two-dimensional ultrasound images can be used to understand the motion of the human tongue during speech and swallowing. There are portable ultrasound machines which allow treatment to be provided in locations convenient for the client and stationary machines with fixed transducers which allow consistency in data collection for the evaluation purposes.

The ultrasound imaging works on the principle that the ultrasound wave from the transducer probe placed beneath the chin will reach the air column above the upper tongue surface and air being an extremely poor conductor of ultrasound wave, almost all of the ultrasound energy is reflected back and the transmission is effectively ended. The upper tongue surface interface is typically with the palate bone and airway, both of which have very different densities from the tongue and cause a strong echo. When the ultrasound encounters a bone, much of the acoustic energy is reflected, creating a dark shadow in that region. Thus, the palate and teeth do not appear in ultrasound images and the upper tongue surface will be clearly visible as a white line. The tongue contour can be thus plotted.

Studies on tongue contour and tongue positions using ultrasound imaging have been carried out. Zharkova, Hardcastle and Hewlett (2011) supported the hypothesis that the children's tongue positions would be more variable than those of the adults through their ultrasound study where the participants were children aged 6 to 9 years and adults with mean age of 33 years. Zharkova (2013) conducted a study to find the extent of tongue dorsum excursion and the place of maximal excursion. The data was collected from 6 adult speakers of Scottish Standard English without speech disorders and this data was analyzed. The stimuli included a range of consonants in consonant–vowel sequences, with the vowels /a/ and /i/. The measures reliably distinguished between articulations with and without tongue dorsum excursion and produced robust results on lingual co-articulation of the consonants. Parthasarathy, Stone and Prince (2005) have mentioned few things which should be taken care of while using ultrasound or which the results may become erroneous. They are data loss at the tongue tip and tongue root, change in the tongue contour length etc.

Few studies are also conducted in the speech disordered populations using ultrasound which help in the assessment and treatment of communication disorders. Bernhardt, Gick, Bacsfalvi and Bock (2007) recorded the post treatment ultrasound images of two Canadian English-speaking adolescents (12 and 14 years) with residual /r/ impairment. The tongue shapes for /r/ production were more similar to those of typical adults than that had been observed before treatment which suggests that there is a potential utility of ultrasound images for the remediation of /r/ in speakers. Tanja (2010) found that as a group, teenagers with childhood apraxia of speech differed from adults but not from the typically developing children in the syllable duration and in the rate of tongue movement. But they did not differ in the amount of tongue movement from the typically developing children and the adults.

In the recent past there are a couple of studies in the Indian context also using ultrasound to study the tongue contours. One such study in Kannada by Kochetov, Sreedevi, Manjula and Kasim (2012) revealed that the tongue shapes for the four consonant articulations (voiceless dental, retroflex, alveopalatal and velar stops/affricates) were similar across the repetitions and consistently different from each other for four native Kannada speakers aged 24 to 26 years. Extension of the same study by these authors in ten native Kannada speakers (five males and five females in the age range of 21 to 26 years) concluded that the tongue movement for retroflex can begin relatively early and end relatively late compared to that for the dental. The extent of retroflex movement towards and away from the constriction is also much greater than the dental movement. The retroflexes were produced with the overall tongue body fronting and the raising of anterior tongue body and tongue front. It also showed that the retroflex consonants produced by the participants (except one) were sub-apical or they were articulated with the underside of the tongue tip.

An additional study in Kannada by Irfana and Sreedevi (2013) revealed that the tongue contours of children and adults are of similar patterns for the three places of articulation (dental, retroflex & velar), but the overall height of the tongue contour is more in adults especially for the anterior tongue body region. The angle of retroflection was not significantly prominent in both the groups which reveal that retroflex sound production is not always sub-apical. Scobbie, Punnoose and Khattab

(2013) conducted a single speaker ultrasound study in a Malayalam speaking male adult to investigate the lingual shapes of the five liquid phonemes of Malayalam: two rhotics, two laterals and a liquid (/r/, /ɾ/,/l/,/ɭ/ and /ʐ/). The results showed that the retroflex and trill had a retracted tongue root and lowered tongue dorsum, while the three other clear liquids showed advanced tongue root. Sindhusha, Irfana and Sreedevi (2014) conducted a cross-linguistic study to compare the angle of retroflection (angle of curvature beneath the tongue curl) during the production of unvoiced and voiced retroflex speech sounds in two Dravidian languages Kannada and Malayalam using ultrasound imaging. The results showed that the angle of retroflection was significantly greater in Malayalam speakers than Kannada speakers. There was no significant difference in the angle of retroflection within the languages. Ultrasound imaging techniques have been utilized to study the development of tongue as well as a therapy tool for individuals with communication disorders and for studying cross-linguistic difference in the production of lingual sounds.

Need for the Present Study

Among the imaging modalities, ultrasound, which is a non invasive technique, is very feasible for producing a tongue image. It can be used to find the tongue contour during the production of lingual sounds. It provides articulatory and acoustic data on the maturation of lingual coarticulatory patterns from children to adolescent to adult speech, adding to the growing body of information on tongue control development and variability. In the current Indian scenario, there are not many studies using ultrasound and there are no reported studies comparing the tongue contours across children, adolescents and adults using ultrasound imaging. Establishing a bench mark in tongue contours for the typical population in various age groups will help us to serve the population with communication disorders better.

Aim of the Study

The aim of the present study is to obtain and compare the tongue contours across native Kannada speaking children (6-8 years), adolescents (14-16 years) and adults (20-30 years) using ultrasound imaging.

Objectives of the study

- ✓ To obtain the tongue contours for voiced and voiceless lingual stops (/t̠/, /ṭ/, /k/, /d̠/, /ḍ/ and /g/) in native Kannada speaking children (6-8 years), adolescents (14-16 years) and adults (20-30 years)
- ✓ To compare the tongue contours for voiced and voiceless lingual stops (/t̠/, /ṭ/, /k/, /d̠/, /ḍ/ and /g/) across children, adolescents and adults
- ✓ To obtain and compare the angle of retroflection and area of retroflection for the retroflex phonemes (/ṭ/ and /ḍ/) across children, adolescents and adults
- ✓ To compare the tongue contours for voiced and voiceless lingual stops (/t̠/, /ṭ/, /k/, /d̠/, /ḍ/ and /g/) between males and females in all the three age groups

Implications of the study

The current study will help in understanding the developmental changes in tongue shapes for different phonemes. The study also explores the possibility of any gender variation in tongue shapes within the age groups. The findings can be utilized for better assessment and treatment procedures for people with speech disorders.

Limitations of the study

1. The number of subjects in each group was limited to 10 males and 10 females
2. Only three age groups were considered in the study.
3. The stabilization head set was not easy for use with children

CHAPTER 2- REVIEW OF LITERATURE

Speech is the most common medium through which humans express their thoughts. Mature speech production is a skilled action that requires many years of development and fine-tuning of the human cognitive, linguistic, and motor systems (Cheng, Murdoch, Goozee & Scott, 2007). It is a result of coordination and complex interactions between the respiratory, laryngeal and articulatory subsystems and it is hypothesized that these subsystems may influence each other's courses of development (Thelen & Smith, 1994; Thelen & Smith, 1998). Among the motor systems, articulators play a major role especially lips, tongue and jaw.

The development of speech motor control is an area which is vastly studied in the previous years. Researchers have used several imaging technologies like electropalatography, electromagnetic midsagittal articulography (EMMA), X-ray etc. to study the development of the articulators. Before the research on the control of articulatory movements in late childhood and adolescence was carried out, it was usually assumed that speech motor development will be completed by the age of 10 to 12 years (Tingley & Allen, 1975). But later studies, in which the kinematic parameters of the articulatory system were measured in older children and adolescents, demonstrated that the developmental time course for achieving adult like levels of speech motor control processes extends into late adolescence (Walsh & Smith, 2002; Cheng et al., 2007).

Development of speech motor control

It is evident from the literature that the development of speech motor control can be explained based on physiological studies. Different imaging techniques were used extensively in this regard. Walsh and Smith (2002) examined the movement trajectories of the upper lip, lower lip and jaw to study the development of speech motor control of 12-, 14- and 16-year olds and young adults (mean age 21.2 years), with 15 males and 15 females in each group. The data collection protocol included kinematic, anthropometric, EMG (7 year-olds, 12 year olds and young adults only) and speech acoustic recordings. The stimulus phrase used was 'Buy Bobby a puppy'. A measure reflecting spatiotemporal consistency in trajectory formation for repeated productions of the phrase was calculated for the upper lip, lower lip and jaw movements. Overall trajectory variability was higher for adolescents compared to young adults. Jaw trajectories were less variable than upper lip or lower lip trajectories. Separate temporal and spatial measures revealed that adolescents had significantly longer movement durations, lower velocities, smaller displacements, and greater variability on these measures than young adults. These results indicate that the speech motor control systems develop during the adolescent period also.

Cheng et al. (2007) recorded tongue-to-palate contacts during the production of /t/, /l/, /s/, and /k/ in words in 48 children, adolescents and adults (aged 6–38 years) using the Reading Electropalatograph system with the aim of studying the speech motor control development. The results revealed that significant changes in lingual control occurred until the age of 11 years. The articulatory control continued its refinement in the adolescent ages also. As the age increased, a reduction in the amount of palatal contact and an anterior shift in the place of articulation was evident during anterior consonant productions, whereas the tongue back to palate contact pattern became more consistent for the velar stop /k/. These results concluded that the development of the speech motor system is non-uniform.

Nip, Green and Marx (2009) investigated the developmental trends of speech motor performance in young children and how these trends differ across oro-facial behaviours. Movements of the lower lip and jaw were recorded using a three-dimensional motion capture system. Twenty-four typically developing infants were observed every 3 months, from 9 to 21 months of age. The results showed that jaw and lower lip movement speed increased from 9 to 21 months of age. These results suggest that linguistic demands affect speech movements and also oral motor control develops at differing rates among articulators.

Tongue is the major articulator for the production of speech. So it is essential to study the tongue movements during the production of speech sounds. Many imaging techniques are used to study the tongue movements among which ultrasound is becoming a popular tool.

Principle and functioning of ultrasound imaging

Ultrasound is a non-invasive technique to study tongue movements which is one of the main advantage of it over other imaging techniques. It is user friendly as the radiations emitted are not harmful for the person using it. It works on the principle that an ultrasound which is an ultra high-frequency sound wave emerging from a piezoelectric crystal that produces an image by using the reflective properties of sound waves. A piezoelectric (pressure electric) crystal is a manufactured element, which converts electricity into mechanical vibrations (i.e., sound waves) and vice versa. The crystal is heated to a very high temperature to create a dipolar molecular alignment in which molecules align north to south magnetically. When a voltage is applied to the crystal, the molecules first twist in one direction increasing the crystal's thickness, and then reverse the direction decreasing the thickness. This mechanical vibration creates an ultra-high frequency sound wave at the resonant frequency of the crystal (typically above 1 MHz), which is determined by the thickness of the crystal. Ultra-high-frequency sound waves have the same transmission properties as audible sound, but they have very short wavelengths. Short wavelengths are critical because a short wavelength can resolve a small object, thereby increasing spatial resolution (Stone, 2005).

When using ultrasound to measure the tongue, the transducer is placed beneath the chin which is fixed using the adjustable stabilisation headset. The sound wave travels upward through the tongue body until it reaches and reflects back downward from the upper tongue surface which is received by the transducer itself. The upper tongue surface interface is typically with the palate bone or airway both of which have very different densities from the tongue and cause a strong echo. Within the tongue there are also weaker echoes between muscle, fat and connective tissue interfaces (Stone, 2005).

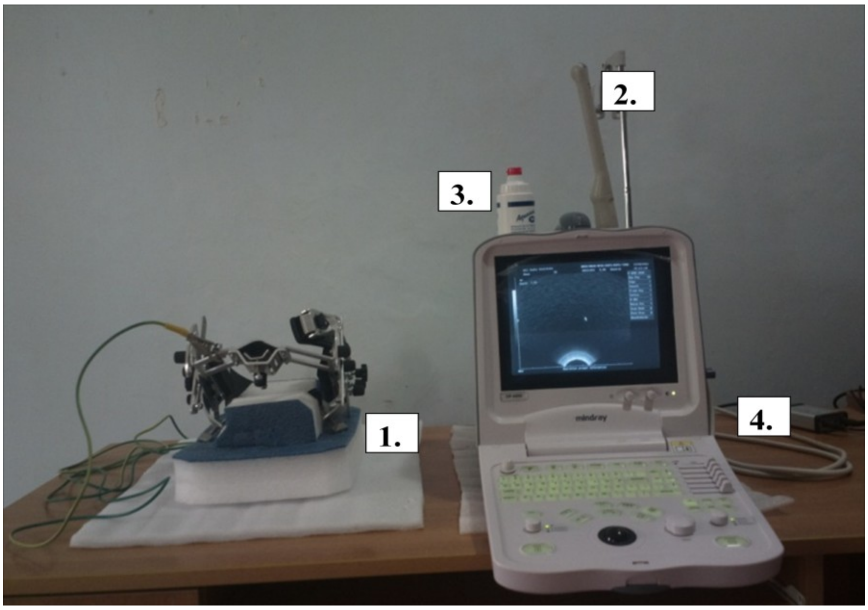


Figure 2.1. Instrumental setup for ultrasound imaging of tongue:

1. Stabilization headset 2. Transducer probe 3. Conduction gel 4. Ultrasound instrument

Ultrasound imaging can be carried out in both sagittal and coronal views. Sagittal view will provide the tongue images from anterior position of the tongue to its posterior position, i.e, from tongue tip to the root of the tongue. Coronal view will provide the tongue images in a horizontal position from left to right side of the tongue.

Applications of ultrasound imaging of tongue

Ultrasound provides the clearest feedback on the tongue shape and place of articulation while phonemes are produced. It may also provide some information about the manner of articulation. It helps in distinguishing velars from alveolars in the sagittal view of the tongue by the tongue tip movement and also the height (Bernhardt, Gick, Bacsfalvi & Bock, 2005).

The advantages of ultrasound on other imaging techniques used to study the tongue movements are many. Ultrasound is a practical tool, since it is readily available unlike Electropalatography (EPG) which usually requires custom-made palates and is relatively inexpensive (costs only about one-third of that of EMMA). Ultrasound does not allow for the tracking of particular flesh points on the tongue as in EMMA. So it is best suited to answer the phonological questions which can be investigated by examining the shape of the whole tongue. This is one of the greatest advantages of ultrasound as it allows the researchers to visualize not just the vertical and horizontal movements of the points where EMMA pellets are placed, but it also allows for the imaging of otherwise indefinable elements such as the tongue root or lateral movement when the tongue is imaged coronally (Davidson, 2005). X-rays are another technique to study the tongue movement. But they emit harmful radiations, so it cannot be used for longer periods and also frequently. X-rays can track single point movements, but cannot provide information about the cross-sectional or pharyngeal surface of the tongue. Ultrasound imaging overcomes both these limitations, thus is a better option than X-ray in studying tongue movements (Stone, 1990). The non-invasiveness and the lesser cost of ultrasound are the most important advantages of it over the other techniques.

Ultrasound imaging has the ability to show the anterior and posterior positions of the tongue simultaneously. While producing some consonants, e.g., /l/ and /r/, the timing of the movements of different parts of the tongue (e.g., the tongue tip, tongue dorsum, and tongue root) is important and depends on the position of the consonant in the syllable—i.e., onset versus coda. Sometimes there will be a mistiming when a second language learner is trying to learn particular phonemes. This can be corrected by the usage of ultrasound and can also be used as a useful diagnostic tool for determining the nature of such errors. Wilson (2006) used ultrasound with bilingual speakers of various proficiencies. In his study, on average, a group of seven monolingual English speakers held their tongue tip significantly higher during inter-utterance pauses than a group of eight monolingual French speakers. Thus ultra sound analysis can evaluate the articulatory proficiency of the second language users also (Wilson & Gick, 2006). Further ultrasound imaging can be used effectively for assessment and treatment of communication disorders which will be reviewed later in this section.

Ultrasound imaging to study articulatory dynamics

Ultrasound is used to study both vowels and consonants of speech. It is used to describe the vowel characteristics. The sagittal ultrasound provides information about the tongue advancement and tongue height for various vowels. Tongue trajectories for diphthongs in terms of backness and height are also clearly visible in the sagittal view. The coronal view shows relative tongue height for the various vowels and its tense-lax cognates (Bernhardt, Gick, Bacsfalvi & Bock, 2005).

Whalen, Noiray and Bolanos (2005) investigated the height distinction in four American English front vowels (/i/, /ɪ/, /e/ and /ɛ/). The stimuli used were /hVd/ sequence where the V in the sequence corresponds to each vowel. Five native adult speakers of American English were asked to repeat the sequence 15 times in random order. The tongue images were collected using Haskins Optically Corrected Ultrasound System (HOCUS, Whalen et al., 2005). The ultrasound probe was used to locate the tongue surface relative to the head and location and shape of the palate were collected on separate trials during the swallowing of a water bolus. One tongue edge from the acoustically-defined midpoint of each vowel utterance was traced with EdgeTrak. The highest point of the tongue was taken from the tracked surface after head correction and rotation to the occlusal plane. Jaw position was estimated from the angle of the ultrasound probe holder. An analysis of formant frequencies (F1, F2) was also conducted using Linear Prediction Coding (LPC). The results indicated that constriction degree may be the best descriptor for height in the front vowels.

Different classes of consonants are studied using ultrasound imaging. Stop consonants require contact between two articulators. Ultrasound images might provide information relative to those contact points which may enhance the manner of articulation. This is important especially when the client has weak or no stop contacts. All alveolar and post-alveolar sibilants and affricates in English have lateral tongue-palate contact and a central groove (depression) which can be observed in the coronal ultrasound images. The depth and width of the tongue groove can be measured at various locations by tilting or dragging the transducer along under the base of the chin antero-posteriorly. The sagittal view shows the relative backness of the tongue tip and blade and helps to discriminate alveolar fricatives from post-alveolar fricatives (Bernhardt, Gick, Bacsfalvi & Bock, 2005).

Affricates are combinations of stops and fricatives. The tongue has to move rapidly from an ungrooved tongue shape (the stop portion), to a grooved tongue shape (the fricative portion). For some speakers, it has been found that the tongue also moves from a more forward (generally alveolar) position to a more clearly post-alveolar position for the affricate /tʃ/ (/t/ to /ʃ/). This transition is clearly observed in the ultrasound images. It is also used as a tool for showing the various lingual constrictions for the approximants /l/ and /r/ which have complex articulations with multiple constrictions that differ across word position and between speakers (Bernhardt, Gick, Bacsfalvi & Bock, 2005).

Stone (1990) combined ultrasound and X-ray microbeam to study the tongue measures. The limitations of each measure were complimented by combining both. The timing information about structural movements of the tongue was provided by point tracking technique (X-ray microbeam) while information about the cross-sectional and pharyngeal tongue shape and movement was provided by imaging technique (ultrasound). Five pellets on the tongue surface were tracked using x-ray microbeam, and the mid-sagittal and coronal planes of the tongue were imaged using real-time ultrasound. The stimuli were VCVCə combinations where the consonants /s/ and /1/ and the vowels /i/, /a/ and /o/ were produced. Each combination was repeated ten times in a comfortable rate of the participant who was a 26 year old female with no speech, language and hearing problems. The principal results found were that

(i) The tongue did not expand and contract uniformly along its length

(ii) Vowels were more compressed than consonants which reflect a more open vocal tract for vowels

(iii) Vowels reflected consonant expansion and compression patterns

(iv) The tongue attained a convex shape for /l/ and concave shape for /s/. The vowel shapes were not consistent with the consonant shapes, but most of the times, they attained an opposite shape of the consonants.

The findings of the study resulted in a three dimensional model of the tongue movement where tongue has sagittal segment, coronal segment and palatal contact. The movement of the sagittal segment result in local displacement and anterior to posterior tongue rotation. Coronal segments move in unison or in opposition creating mid sagittal grooving and left to right asymmetries. When the tongue is braced against the palate, the shape and tongue relationship of the tongue will be different from those observed during un braced postures where the tongue shape is correlated with position. Anterior bracing increases the number of available posterior tongue shapes.

Ultrasound in assessment of speech motor control

The development of speech motor control can be learned through the extent of co-articulation or the articulatory overlap of the speech sounds. A research by Zharkova, Hewlett and Hardcastle (2011) compared lingual coarticulatory properties of speech of children and adults using ultrasound tongue imaging. Ten adults (mean age = 33 years) and ten children (6-9 years) who were native speakers of Standard Scottish English served as the participants. The stimuli used were consonant-vowel syllables presented in a carrier phrase. Distances between tongue curves were used to quantify coarticulation. In both adults and children, vowel pairs /a/-/i/ and /a/-/u/ significantly affected the consonant, and the vowel pair /i/-/u/ did not. Extent of coarticulation was significantly greater in the children than in the adults, providing support for the notion that children's speech production operates with larger units than adults'. The within-speaker variability was found more in children than in adults.

Zharkova, Hewlett, Hardcastle and Lickley (2013) used high-speed ultrasound to measure lingual coarticulation in the syllables "she", "shah", "sea" and 'Sah', comparing preadolescent children and adults. The tongue position at mid-consonant in both the age groups and both the consonants was affected by the identity of the following vowel. Age-related differences were observed in the onset of coarticulation. The vowel effect was present throughout the consonant for both consonants in adults while the effect was evident later into the first half of the consonant in preadolescent children. This result indicates that preadolescents are still lagging behind adults in terms of speech motor control.

Song, Demuth, Hufnagel, and Ménard (2013) studied the coarticulatory effects during cluster production in 2 year old children and adults with mean age of 23.5 years using ultrasound imaging of the tongue. Imitation task was used to elicit the response where the results revealed that children showed an adult-like pattern in the tongue curvature but had significantly greater tongue height than adults.

Ultrasound studies in the Indian context

There are some Indian studies also using the technique of ultrasound for tongue imaging. Kochetov, Sreedevi, Manjula and Kasim (2012) used an ultra-portable ultrasound system (SeeMore USB probe) to study the production of four lingual consonants [voiceless dental (/t/), retroflex (/ʈ/), alveolo-palatal (/ʧ/) and velar (/k/)] of Kannada. Multiple repetitions of words with these 4 consonants were produced by 4 normal speakers of Kannada. The results revealed that, despite the relatively slow frame rate of the system and in the absence of probe stabilization devices, the tongue shapes for the four consonant articulations were similar across the repetitions and consistently different from each other. The retroflex and alveopalatal consonants showed greater vertical and horizontal displacement of the tongue relative to the neutral position compared to dental and velar consonants which indicates the consonant relative articulatory complexity.

Irfana and Sreedevi (2013) compared the tongue contours for three lingual stops across native Kannada speaking children (9-10 years) and adults (23-25 years) using ultrasound imaging. Both groups consisted of 10 children. The stimuli used were three meaningful Kannada words; /atta/, /aTTa/ and /akka/ incorporating the dental /t/, retroflex/ ʈ / and velar /k/. Mindray ultrasound 6600 was used for recording of the samples and analysis of the samples was completed with the help of the software Articulate Assistant Advanced (AAA). The difference in the tongue contours was obtained from appropriate statistical analysis. The results showed that tongue contours of children and adults are of similar patterns for the three places of articulation studied, but the overall height of the tongue contour is more in adults especially for the anterior tongue body region. The angle of retroflection (AOR) was not prominent in both groups which reveal that retroflex sound production is not always sub-apical. This study helps in our understanding about the similarities and differences in tongue dynamics across children and adults.

A cross-linguistic study by Sindhusha, Irfana and Sreedevi (2014) compared the angle of retroflexion (AOR) of tongue tip during the production of unvoiced and voiced retroflex speech sounds /TT/ and / DD/ in Kannada and Malayalam. The participants were 10 female speakers (5 Kannada and 5 Malayalam native speakers) in the age range of 20-30 years. The tongue movement patterns of target retroflex phonemes were imaged using the Mindray ultrasound instrument 6600 and analyzed using Articulate Assistance Advanced (AAA) software. AOR was analyzed using a

MATLAB based programme. The ultrasound tongue contour in Malayalam speakers showed a significantly higher retroflection curvature than the Kannada speakers. The results of the study concluded that there can be cross-linguistic variations in the tongue movement even if the target sounds occur in the same class.

Applications of Ultrasound imaging in communication disorders

Ultrasound can be used as a tool for the evaluation of tongue function in normal speakers as well as in patients with communication disorders. It provides with real time dynamic images of the tongue that are easy to interpret. It was used with an individual undergoing glossectomy surgery (Bressman, Thind, Catherine, Bollig, Gilbert & Irish, 2005). It allows in capturing and quantifying the postoperative changes that are brought about by a partial lingual resection and the subsequent reconstruction. The quantitative analysis of the ultrasound data also allow to identify and describe changes in the deformation patterns of the operated tongue.

Chi-Fishman (2005) used ultrasound in swallowing research due to its radiation free soft tissue imaging quality. It is used to study lingual, pharyngeal, hyoid, laryngeal, and even esophageal action during swallowing in individuals of all ages. Ultrasound can also be used in correcting the pronunciation of the spoken language by individuals with hearing impairment who may be fluent in sign language (Wilson & Gick, 2006).

Cleft palate population was also assessed using ultrasound imaging. Gibbon and Wolters (2005) used ultrasound imaging to investigate the speech of an adult with repaired cleft palate. Although the study was conducted in one individual, the researchers report that ultrasound has the potential to become a valuable tool for measuring the tongue behaviour in individuals with cleft palate.

Tanja (2010) studied the speech characteristics of childhood apraxia of speech (CAS) by analysing the acoustic and articulatory data obtained by ultrasound imaging. Participants were 3 teenagers with CAS and two control groups (one consisting of 10 typically developing children and other consisting of 10 adults). Results revealed that as a group, teenagers with childhood apraxia of speech differed from the adults but not from the typically developing children in the syllable duration and in the rate of tongue movement. But they did not differ in the amount of tongue movement from the typically developing children and the adults.

Ultrasound has its application in treatment of communication disorders also. Tongue shape and movement patterns of normal speakers are used as target for the client to imitate initially in treatment procedures using ultrasound. The clinician can give verbal feedback as the client improves through treatment. The client's tongue shape and movement patterns that result in the best acoustic productions then become the model for later productions. These may or may not be identical to the templates of the normal speakers (Bernhardt, Gick, Bacsfalvi & Bock, 2005).

Bernhardt, Gick, Bacsfalvi and Bock (2007) aimed to find the potential utility of ultrasound in remediation of /r/ in two Canadian English speaking adolescents (12 and 14 years) who had not acquired /r/. The post treatment ultrasound images of two adolescents for accurate [r] tokens showed tongue shapes to be more similar to those of typical adults than that had been observed before treatment which suggests there is a good usage of ultrasound images for the remediation of /r/ in speakers with residual /r/ impairment.

Ultrasound provides exciting new possibilities for speech scientists and speech language pathologists. The clients and research subjects are able to tolerate the ultrasound examinations. The real time visualization on the screen often creates more interest and is motivating for the research subjects. Currently it is the most cost effective instrumentation for the acquisition of 3D tongue images. It can be used for both typically developing population for studying the development of speech motor control and also in individuals with communication disorders for studying the deviant speech in them and also for the remediation of the speech disorder. It has several other applications in the field of speech science laboratories (e.g., second language acquisition) and also clinical settings.

CHAPTER 3- METHOD

Participants

A total of 60 native Kannada speakers divided into three groups; children (6-8 years), adolescents (14-16 years) and adults (20-30 years) participated in the study. Each group consisted of 10 males and 10 females.

Inclusion Criteria

- Urban native Kannada speakers with no history of any diseases or disorders.
- No structural or functional deficits on oro-motor examination.

Stimuli

A total of six Kannada words were used with unvoiced and voiced stops in three places of articulation (dental-/t̪/, retroflex-/ṭ/ and velar-/k/) (/d̪/, /ḍ/ and /g/ respectively) embedded between vowel /a/ in pre and post positions. Vowel /a/ was used in the pre and post position to reduce the co-articulatory effects. The target phonemes were geminated clusters for better visualization in the ultrasound image. Thus the target phonemes were in VCCV form. All the stimuli are meaningful Kannada words except dental place of articulation (/ad̪d̪a/).

The stimuli used are given in Table 3.1.

Table 3.1

Stimuli used in the study

Target Phoneme	Stimuli	Meaning
/t̪/	/at̪t̪a/	That side
/ṭ/	/aṭṭa/	Attic
/k/	/akka/	Elder sister
/d̪/	/ad̪d̪a/	-
/ḍ/	/aḍḍa/	Across
/g/	/agga/	Cheap by cost

Instrumentation

The instrument Mindray Ultrasound 6600 (Fig 3.1) connected with PC and installed with the software Articulate Assistant Advanced (AAA) Ultrasound module Version 2.14 was used. The tongue contour was analyzed in terms of 60 frames per second using AAA software. The adjustable stabilization headset (Fig 3.2) was placed on the participant's head to avoid the head movements during the recording except for children. The microphone attached to the headphone was used for recording the stimuli. The transducer (Fig. 3.1& Fig. 3.2) which is a long-handled microconvex probe operating at 6.5 MHz emits the Ultrasound wave. It was placed beneath the chin of the participant as shown in Fig. 3.2.

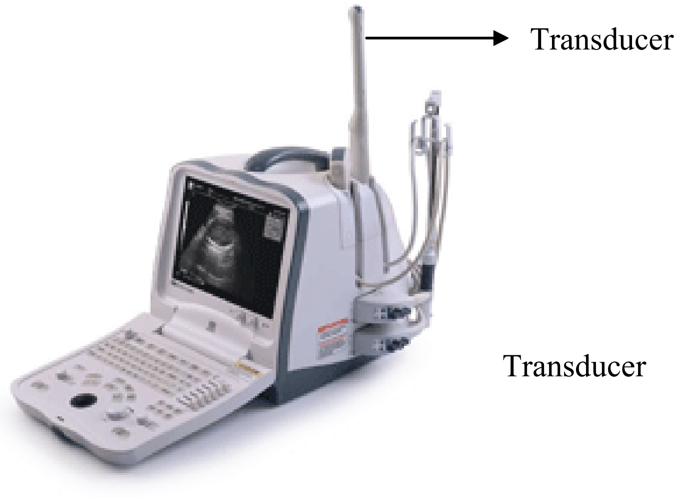


Figure 3.1. Mindray Ultrasound 6600

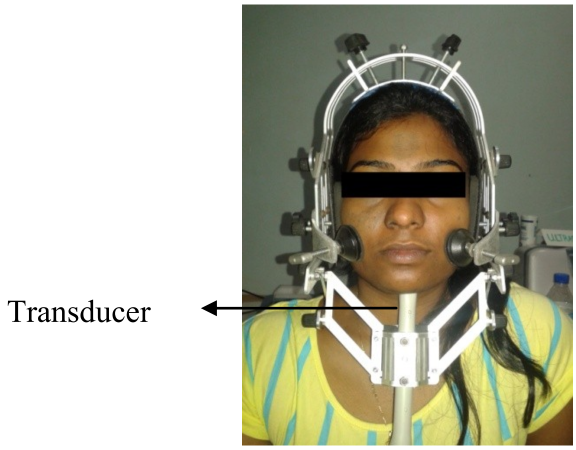


Figure. 3.2. Adjustable stabilization headset

Instructions

The participants were instructed to repeat the target words after the researcher maintaining an inter-response interval of 1000 milliseconds.

Data Recording

The ultrasound recording for each participant was done separately. Each participant was seated comfortably on a high back chair. The transducer probe was placed beneath the chin of the participant with Ultrasound transmission gel (*Aquasonic 100*) smeared on the probe for better tongue imaging. The participants were asked to keep their head steady so as to avoid the ultrasound image becoming erroneous. The transducer probe was fastened using the adjustable stabilization headset for all the participants except for children as it was difficult to place the headset on them. The researcher held the head of the children to reduce their head movements during recording. The headphone with the microphone was placed on the participant's head to record the speech sample. Repetition procedure was used to record the data from the participant. The researcher tapped each time after which the participant had to repeat the stimuli provided by the researcher. Four repetitions of each stimulus were recorded consecutively by maintaining an inter-response interval of 1000 milliseconds. The researcher perceptually evaluated the responses of the participant after the recording. If necessary, the recording was repeated when the stimuli were perceptually unsatisfactory. Thus 24 (6*4= 24) utterances were recorded from each participant. A total of 1440 utterances were collected from 60 participants.

Parameters Analyzed

The parameters analyzed were tongue contour, angle of retroflection and the area of retroflection. Tongue contour is the 2-D representation of the tongue surface shape. It can be varied according to place of articulation, vowel context etc. Angle of retroflection is the angle of curl of the tongue tip contacting the palate and area of retroflection is the area beneath the curl of the tongue tip.

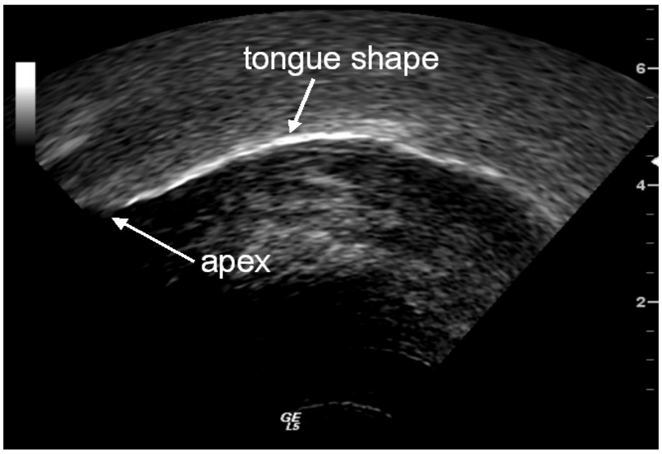


Figure 3.3. Tongue contour as seen in an ultrasound image

Data Analysis

The data analysis was carried out using the AAA and MATLAB softwares. The tongue contours as shown in Figure 3.3 were analyzed using the AAA software and the angle of retroflection was obtained using MATLAB based indigenous software.

Steps in ultrasound analysis:

- The option 'Analyze Ultrasound' from the task bar was selected
- The token containing the Ultrasound image of the utterance of the participant was selected. Only one utterance was analyzed at a time.
- The frame at the centre of the closure duration of the stop was selected. The point in the frame where the tongue tip has achieved maximum contact was analyzed.
- The software AAA used the technique 'fan spline' for analysis which had 42 axes or points which can be drawn on the tongue body reflection. Fan setup was selected for each utterance which indicates a rough idea about the tongue width for each production. Fan set up was different for each individual and each sound as the tongue cavity is different. It was kept same for each stimuli production by the participant.
- The tongue contour (Figure 3.3) was drawn at the chosen point using semi-automatic contour plotting where the researcher draws it by using the computer mouse (visually, under the bright white line seen in the Ultrasound image). Similarly, the next two utterances were also analyzed from that particular token which had 4 repetitions of the same utterance. The last utterance was not analyzed as there can be a variation in the intonation for the last utterance for some participants as he or she knows it is going to end and this can reduce the possibility of error in the results.

- The tongue contours for the three utterances were then exported to another window called Workspace where it was averaged and created the mean and standard deviation of that particular phoneme. Likewise, the average mean value for all the sounds for all the participants was found.
- The averaging of all the mean values of a particular phoneme for all the male participants from each age group gave the mean value for that particular phoneme for males in that age group. Likewise the mean values for other phonemes and that for females were also found. The difference between each phoneme across groups was also found.
- Each of these images was exported to another window called Publisher where they were stored as images in Pixels which can be later used for MATLAB analysis.
- With 2-D spline (Figure 3.4) 7 points were drawn using manual contour plotting for finding the angle of retroflection and the area of retroflection (the space below the tongue tip and tongue body) for the retroflex phonemes (/ṭ/ and /ḍ/). The images were copied using Publisher window and analyzed in MATLAB software (Version 7.9.0.529).

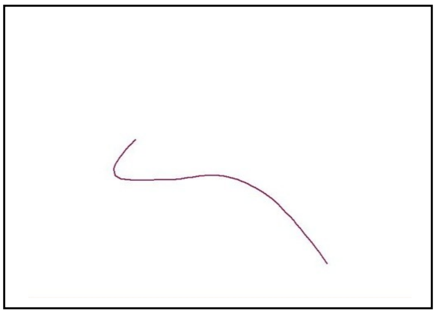


Figure 3.4. 2D Spline tongue contour for retroflex phonemes

- The tongue contours exported to Publisher were compared on visual observation for finding the difference between the tongue contours.

- The publisher images for the retroflex phonemes were saved in JPEG format and were fed to the MATLAB software which was specifically programmed to measure the angle of retroflection and area of retroflection.
- The values for angle of retroflection and area of retroflection created by MATLAB were not the actual value but a relative value which can be used to compare the values of different utterances.
- The tongue contours were described visually by dividing the tongue contour into three regions (anterior, middle and posterior) as shown in Figure 3.5. It is also described based on the tongue height and tongue advancement.

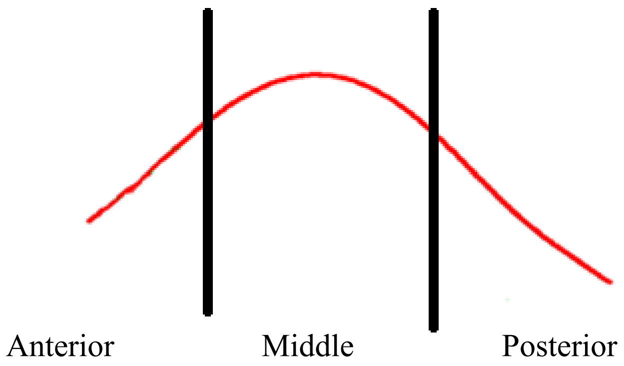


Figure 3.5. Division of tongue contour into anterior, middle and posterior region

Statistical analysis

The values of angle of retroflection and area of retroflection obtained using MATLAB based software was subjected to statistical analysis using SPSS-16 version.

CHAPTER 4- RESULTS AND DISCUSSION

The aim of the present study was to compare the tongue contours across native Kannada speaking adults, adolescents and children using ultrasound imaging. There were 10 males and 10 females in each group. The tongue contours were plotted for stop consonants (‘C’) in the context of aCCa where C represents voiceless dental /t̠/, retroflex /ṭ/, velar /k/ and their voiced counterparts /d̠/, /ḍ/ and /g/ respectively. The target phonemes were geminated clusters for better visualization of the ultrasound images. The tongue contours were analyzed on visual observation. Retroflex sounds were also evaluated based on the angle of retroflection and the area of retroflection.

The results of the present study are discussed under the following sections:

I. Tongue contours for all the target phonemes

(a) Comparison of tongue contours between adults and adolescents, adolescents and children and adults and children

(b) Comparison of males and females within each group

II. Angle and area of retroflection for /ṭ/ and /ḍ/

(a) Comparison of area of retroflection of /ṭ/ and /ḍ/ across adults, adolescents and children

(b) Comparison of angle of retroflection of /ṭ/ and /ḍ/ across adults, adolescents and children

I. Tongue contours for all the target phonemes

1. **/at̲t̲a/** - dental place of articulation (voiceless)

(a) Comparison of tongue contours between adults and adolescents, adolescents and children and adults and children for /t̲/ are shown in Figures 4.1 (a), (b) and (c) respectively. In all the figures discussed in this section, tongue advancement is represented on x-axis and tongue height on y-axis. The scale represents a relative unit and not an absolute unit. The tongue contour is divided into anterior, middle and posterior portion for ease of description.

The tongue contours of adults and adolescents are of similar pattern but the overall tongue height of adult's tongue contour is a little more compared to adolescents [Figure 4.1 (a)]. The tongue contours for adolescents and children and also adults and children follow a similar pattern but the overall height of the adults' and adolescents' tongue contour is relatively higher than that of the children [Figure 4.1 (b) & (c)]. The tongue advancement which is indicated by the broadness of tongue contour is almost similar in adolescents and adults and also adolescents and children. On comparing tongue advancement, the broadness is found to be lesser for children than adults [Figure 4.1 (c)] which is in accordance with the results of Irfana et al. (2013) and Song et al. (2003). These results imply that the size of the oral cavity is larger in adults and adolescents than children. There is a small difference in tongue height between adults and adolescents which suggests that adolescents are still in the developing stage of speech motor control and there is a considerable variation of their tongue movement from adults (Walsh and Smith, 2002 & Smith, 2010).

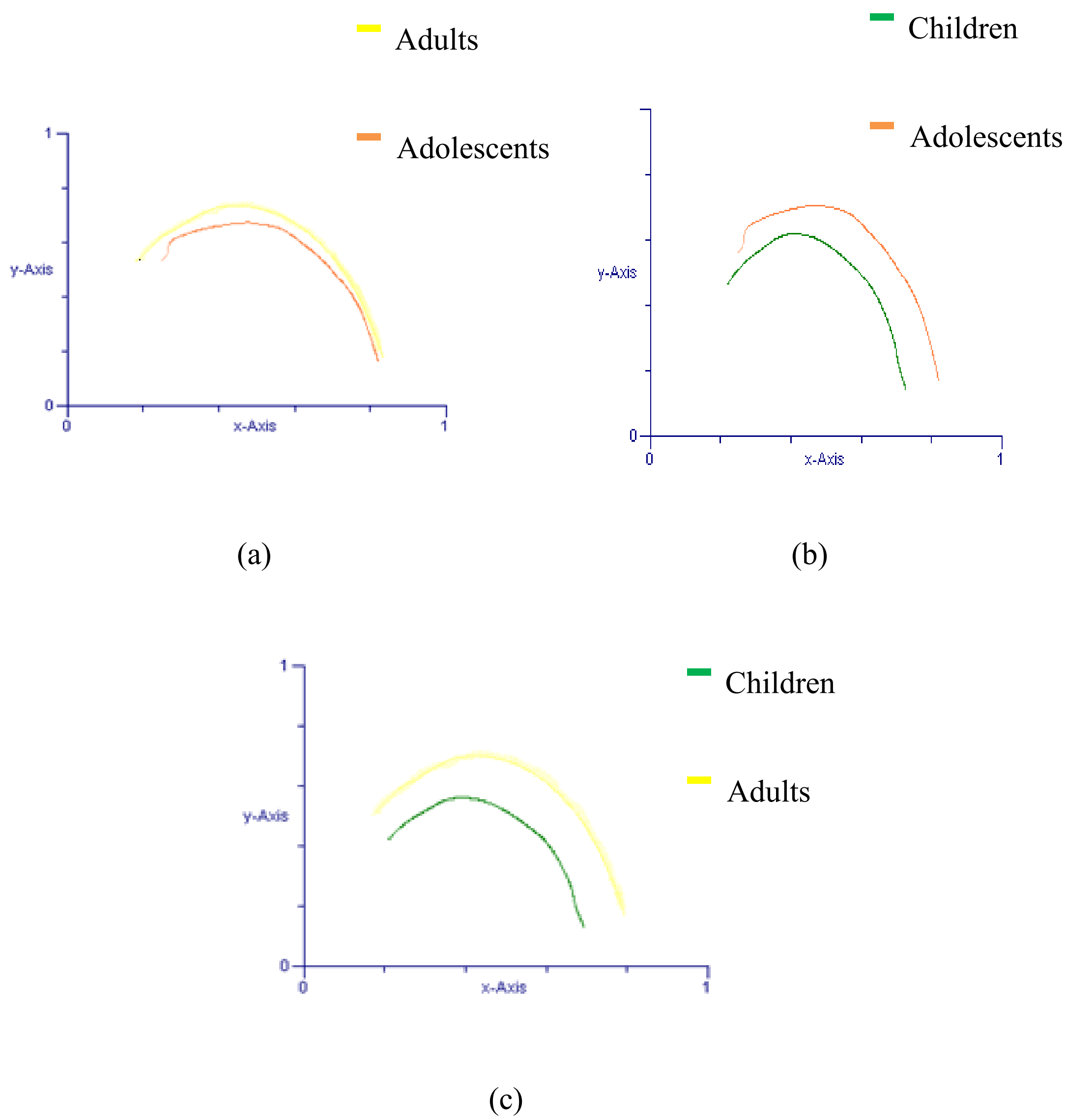
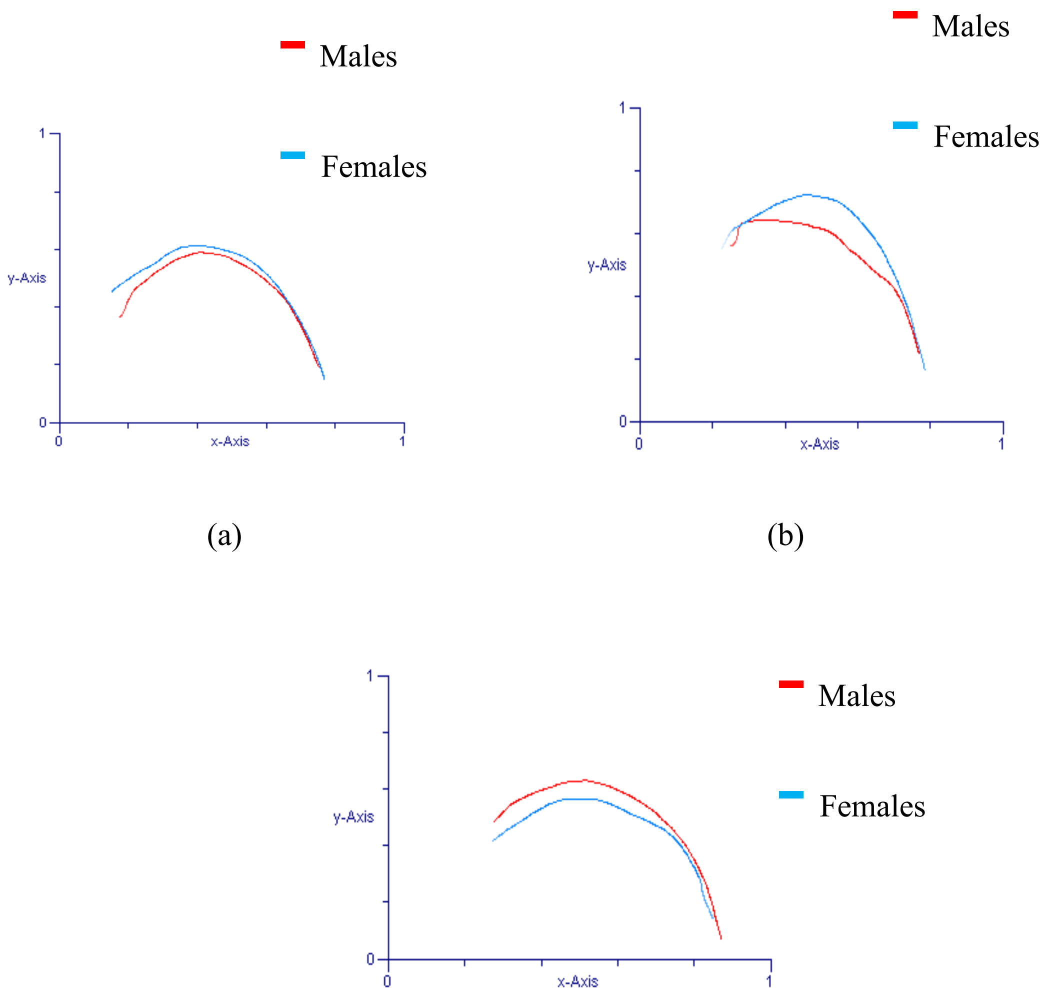


Figure 4.1. Comparison of tongue contour for /atta/ across (a) adults and adolescents (b) adolescents and children (c) adults and children

(b) Comparison of tongue contours of males and females for /t/ within adults, adolescents and children are shown in Figures 4.2 (a), (b) and (c) respectively. The tongue contours for males and females in all the three groups follow a similar pattern. The tongue height is more for females in adults and adolescents while it is more for males in children. The tongue advancement or the broadness of the tongue is similar for males and females in all the three groups. Females had greater tongue height than males in adolescents and adults possibly because females may have exaggerated articulatory manoeuvres during the recording task to achieve more precision. This area should be explored further which may provide evidences for the current result.



(c)

Figure 4.2. Comparison of tongue contours of males and females for /at̲t̲a/ in (a) adults (b) adolescents (c) children

2. **/aṭṭa/-** retroflex place of articulation (voiceless)

(a) Comparison of tongue contours between adults and adolescents, adolescents and children and adults and children for /ṭ/ is represented in Figures 4.3 (a), (b) and

(c) respectively. It is observed that adults have greater tongue height than adolescents especially in the anterior and middle portion [Figure 4.3 (a)]. Similarly adolescents have greater tongue height than children and adults have more tongue height than children which is more prominent in the anterior, middle and posterior portions [Figure 4.3 (b) & (c)]. This result is in contradiction with the results of Cheng et al. (2007). As age increases, the precision in the articulatory dynamics improve (Kent, 1983) which is observed in all three comparisons. It is also observed that adolescents and children have lesser proximity at the posterior portion of the tongue [Figure 4.3 (b)]. The comparison across the three groups for /ṭ/ reveals that all the contours are of similar pattern especially in the tongue advancement dimension.

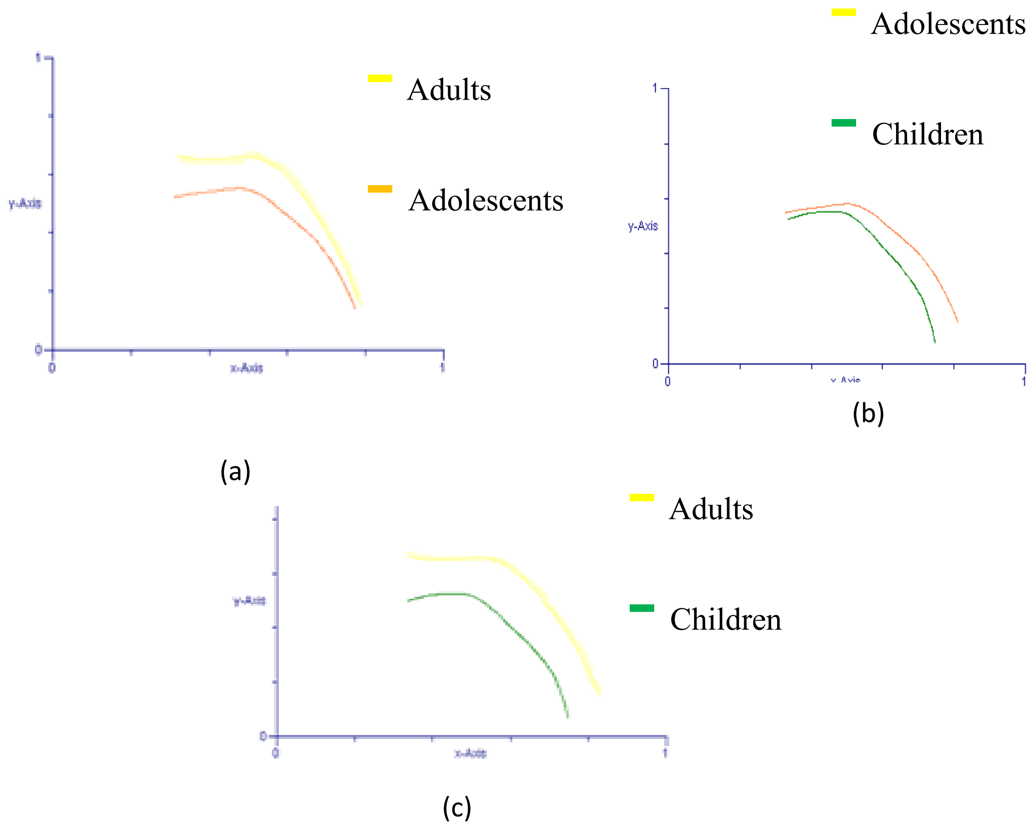


Figure 4.3. Comparison of tongue contours for /aṭṭa/ across (a) adults and adolescents (b) adolescents and children (c) adults and children

(b) Comparison of tongue contours of males and females in adults, adolescents and children for /ṭ/ are represented in Figures 4.4 (a), (b) and (c) respectively. As in

/atta/, the tongue height is more for males than females in children which was not observed in adults and adolescents. The tongue advancement was similar for males and females in all the three groups studied.

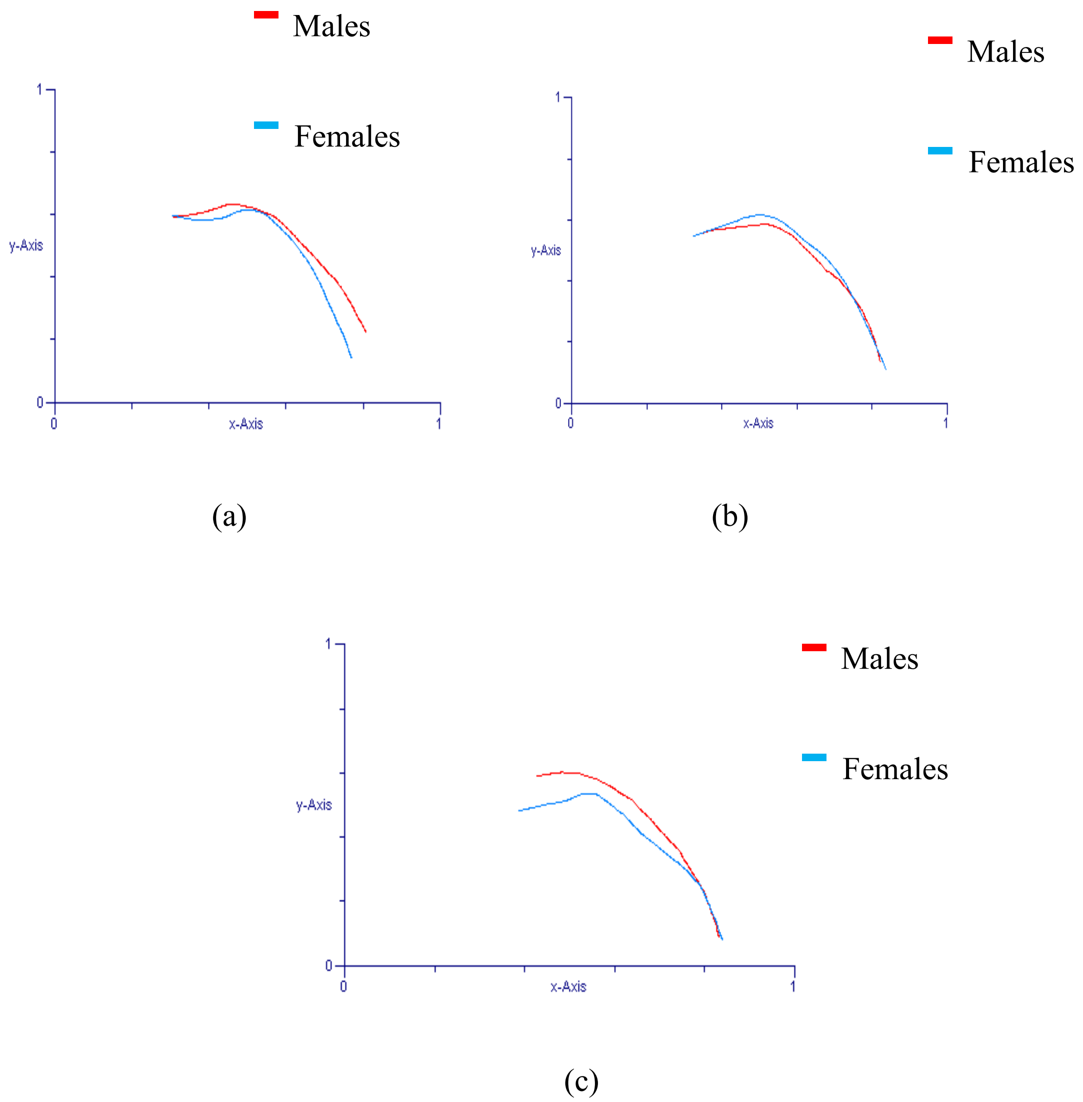


Figure 4.4. Comparison of tongue contours of males and females in (a) adults (b) adolescents (c) children

3. **/akka/-** voiceless velar place of articulation

(a) Comparison of tongue contours between adults and adolescents, adolescents and children and adults and children for /akka/ are shown in Figure 4.5 (a), (b) and (c) respectively. Adults and adolescents have a similar pattern of tongue contour. The tongue height is not distinctly variant in the posterior portion of the tongue while there is a distinct variation in the anterior and middle portion of the tongue [Figure 4.5 (a)]. The tongue height is more for adults in the anterior and middle portion of the tongue which can be due to the better precision of the articulatory control in adults (Kent, 1983). Tongue advancement is found to be slightly more for adults than adolescents. This may be attributed to the reason that a clear maturational trend of speech motor control can happen across age and it may lead to an ambiguous shift of locations of the articulation (Cheng et al. 2007). The overall tongue height is more for adolescents and adults than children [Figure 4.5 (b) & (c)] particularly in the anterior and middle regions due to the same reason mentioned above (Kent, 1983). The present results support the notion that speech motor development is nonuniform, with a refinement period from mid-childhood to late adolescence (Cheng et al. 2007). The broadness of the tongue contour was more for adults than children which is in accordance with the results of the study by Irfana et al. (2013).

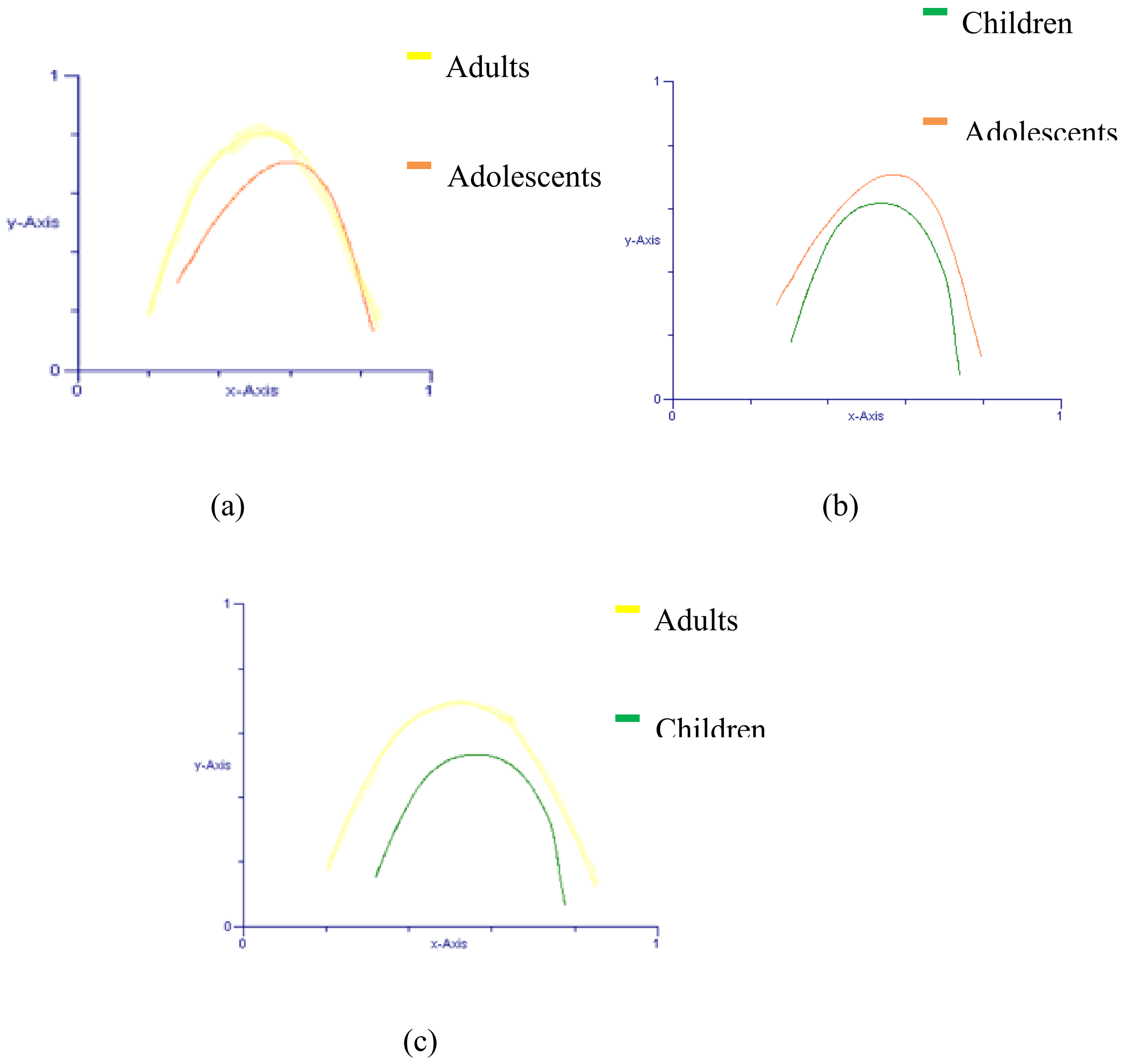


Figure 4.5. Comparison of tongue contours for /akka/ between (a) adults and adolescents (b) adolescents and children (c) adults and children

(b) Figures 4.6 (a), (b) and (c) represent the comparison of tongue contours of males and females for the velar stop phoneme /k/ in adults, adolescents and children respectively. The tongue contours follow a similar pattern in adults, adolescents and children. The tongue height and advancement does not have any major difference within the three age groups. This result for the adolescent group is consistent with the results of Walsh and Smith (2002) where there were no gender differences in the adolescents' articulatory measures suggesting that peripheral growth factors do not account for the protracted developmental time course

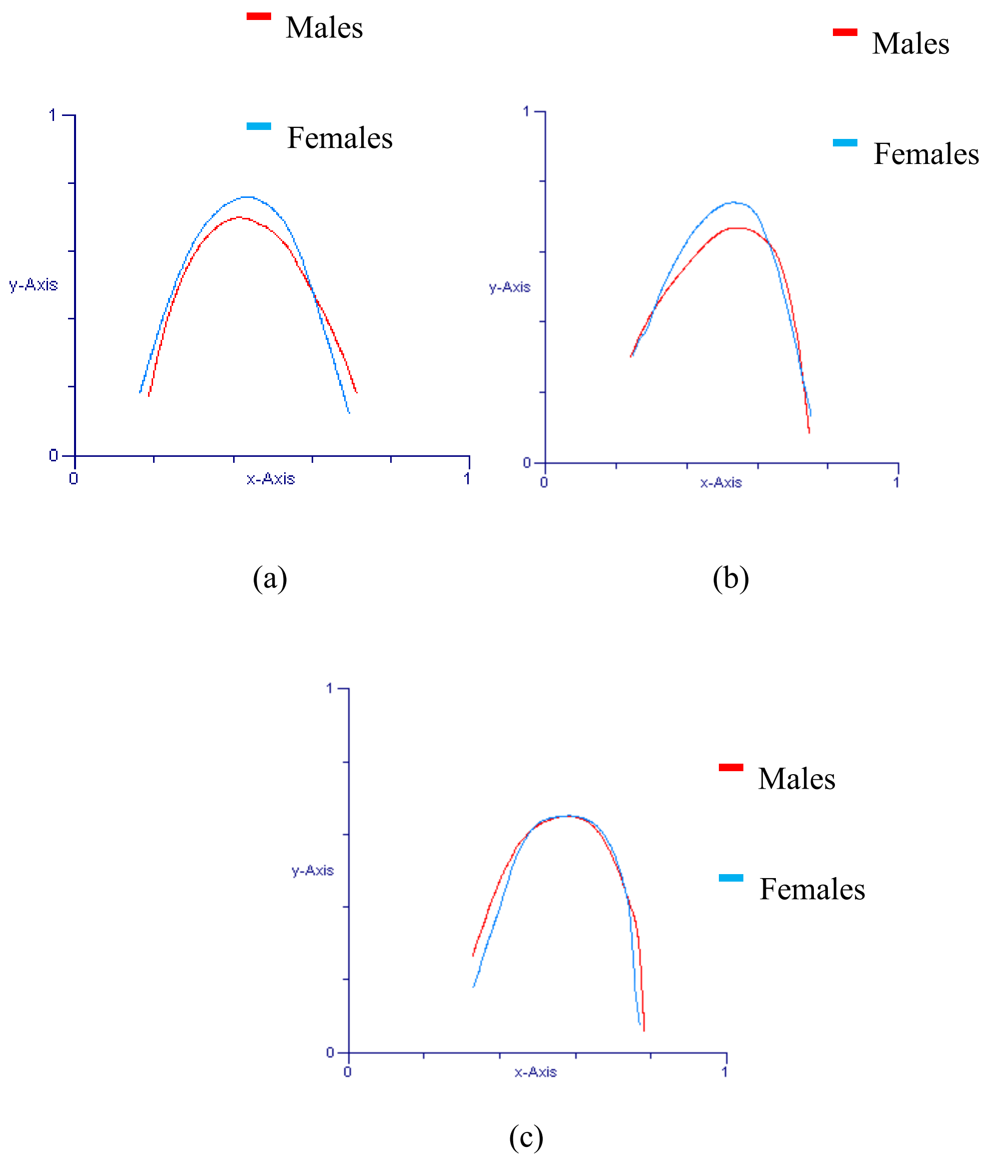
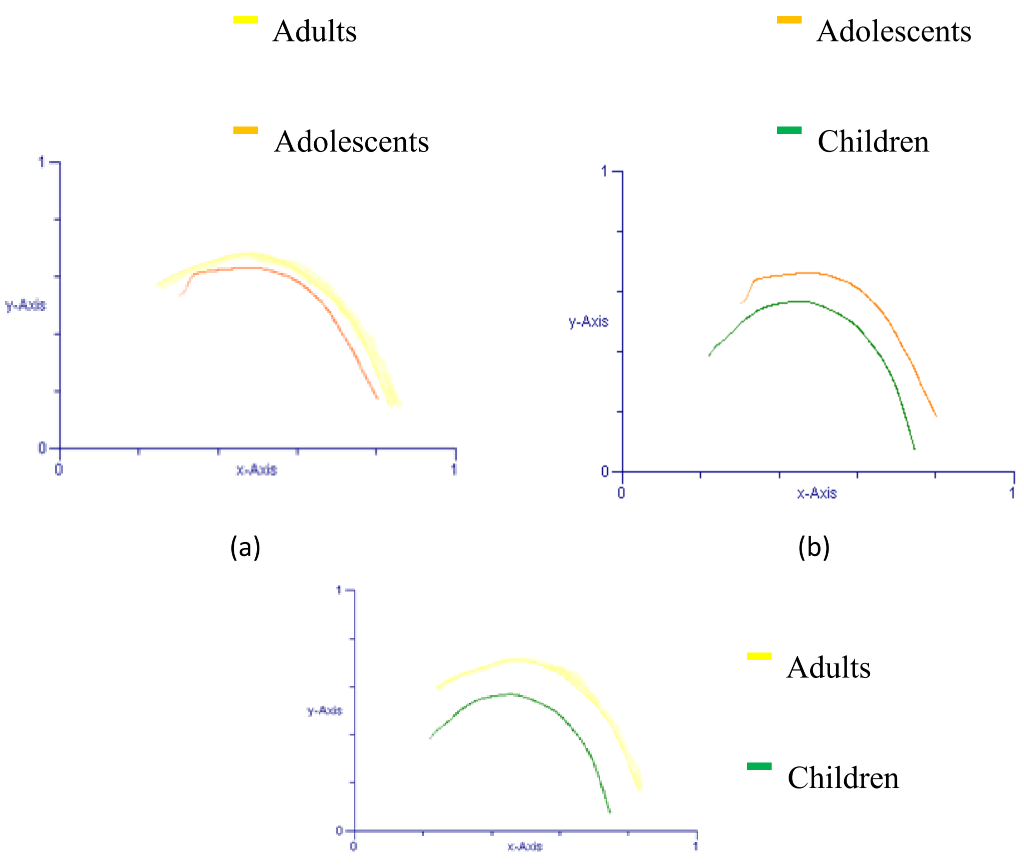


Figure 4.6. Comparison of tongue contours of males and females for /akka/ between (a) adults and adolescents (b) adolescents and children (c) adults and children

4. **/ad̲d̲a/-** voiced dental place of articulation

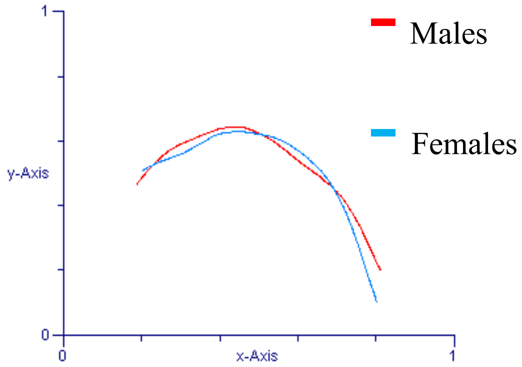
   (a) Figures 4.7 (a), (b) and (c) show tongue contours for (/d̲/) for adults and children, adolescents and children and adults and children respectively in the word /aḏḏa/. The tongue contours followed a similar pattern but the overall height of the adult's tongue contour is more to some extent compared to adolescents [Figure 4.7(a)] which can be in consonance with the results of Smith (2010) who says adolescents vary from adults in terms of tongue height. The tongue height for adolescents and adults is prominently greater compared to children [Figure 4.7 (b) & (c)] since the articulatory precision is better for adults and adolescents than children (Kent, 1983). The broadness of tongue contour or tongue advancement is similar across all three comparisons.



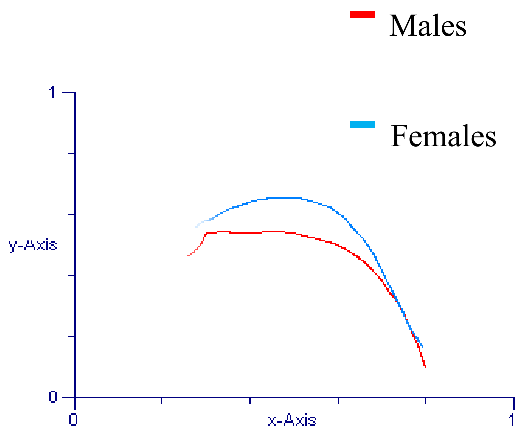
(c)

Figure 4.7. Comparison of tongue contours for /aḏḏa/ between (a) adults and adolescent (b) adolescents and children (c) adults and children

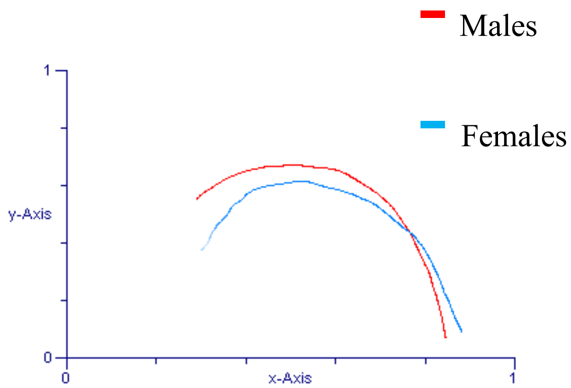
(b)Comparison of tongue contours of males and females within adults, adolescents and children are represented in Figure 4.8 (a), (b) and (c) respectively. The tongue height is similar for males and females in adults, more for females in adolescents particularly in the anterior and middle portion of the tongue contour and a reverse pattern was observed in children. The tongue advancement or the broadness of the tongue is similar for males and females in adults, adolescents and children which correlate with Irfana et. al (2013) findings.



(a)



(b)

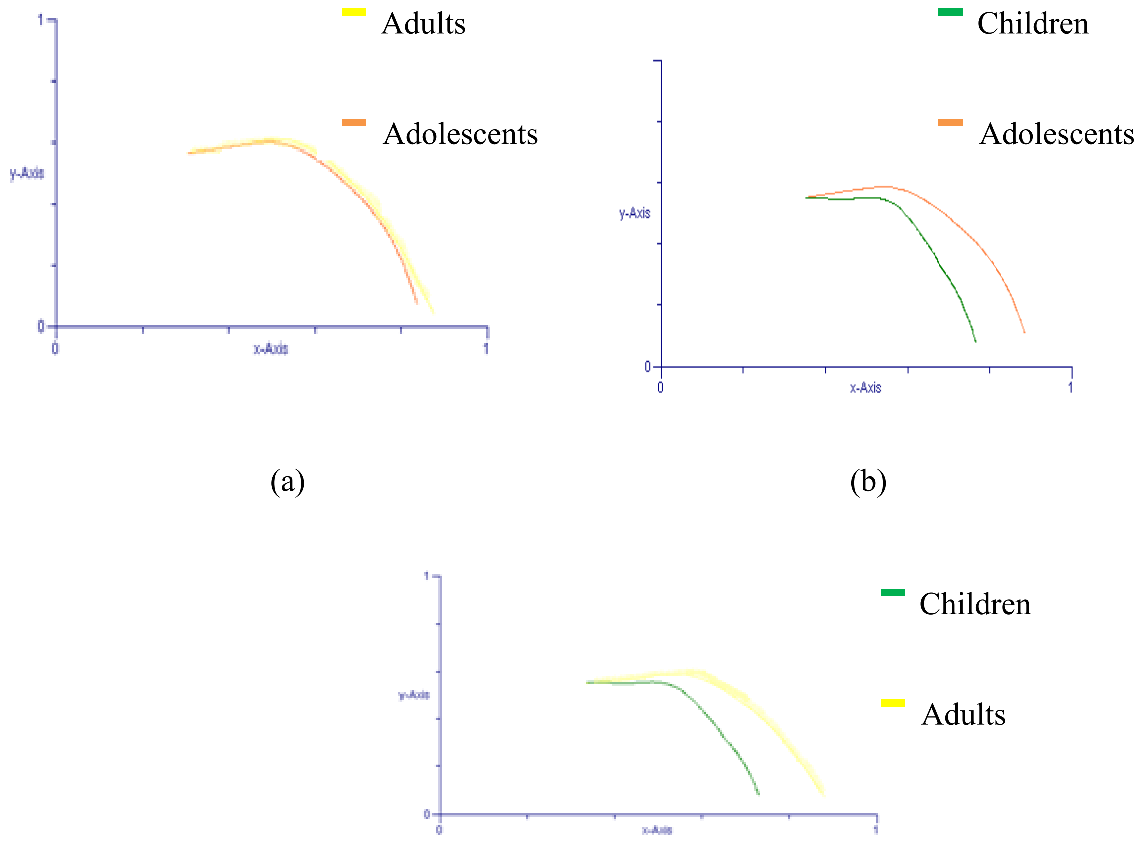


(c)

Figure 4.8. Comparison of tongue contours of males and females for /ad̲d̲a/ within (a) adults (b) adolescents (c) children

5. **/aḍḍa/-** voiced retroflex place of articulation

(a) Comparison of tongue contours between adults and adolescents, adolescents and children and adults and children for /ḍ/ are represented in Figures 4.9 (a), (b) and (c) respectively. The tongue contour for adults and adolescents almost overlap [Figure 4.9 (a)]. The tongue height and advancement is similar in them. The tongue contours for children and adolescents and also children and adults overlap at the tip of the tongue [Figure 4.9 (b) & (c)]. The above two results could be attributed to the reason that the articulatory dynamics are not predicted by the cessation of peripheral growth (Walsh & Smith, 2002). Tongue advancement is more for adults and adolescents compared to children except in the anterior portion [Figure 4.9(b) & (c)].

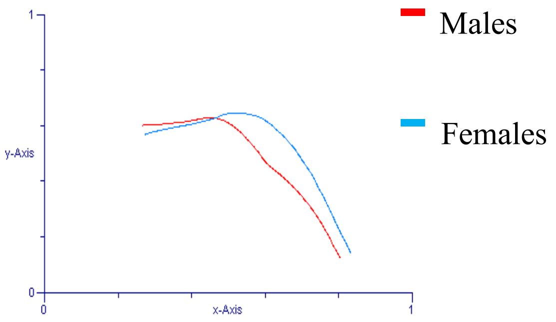


(a) (b)

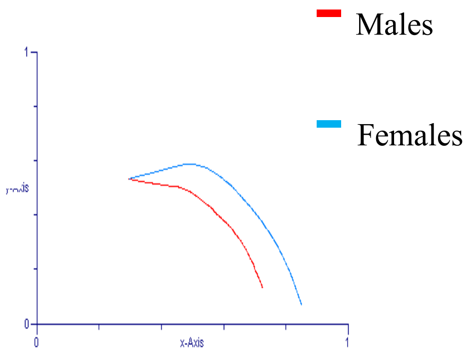
(c)

Figure 4.9. Comparison of tongue contours of /aḍḍa/ between (a) adults and adolescents (b) adolescents and children (c) adults and children

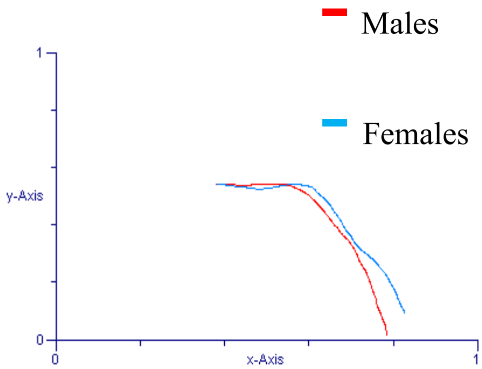
(b) Comparison of males and females for /aḍḍa/ within adults, adolescents and children are shown in Figures 4.10 (a), (b) and (c) respectively. All the groups followed similar tongue contour patterns and females had greater tongue height except in the anterior portion. Tongue advancement was also alike in all the three groups as in results reported by Irfana et. al (2013).



(a)



(b)



(c)

Figure 4.10. Comparison of tongue contours of males and females for /aḍḍa/ within (a) adults (b) adolescents (c) children

6. /agga/- voiced velar place of articulation

(a) Comparison of tongue contours between adults and adolescents, adolescents and children and adults and children for /agga/ is represented in Figures 4.11 (a), (b) and (c) respectively. The tongue height is distinctly more for adults in the anterior and middle portion of the tongue than adolescents [Figure 4.11(a)]. The tongue advancement or the broadness of the contour was less for adolescents compared to adults. This can be explained based on the reason that articulatory maturation happens on a protractory time course (Cheng et al., 2007). The tongue contours follow a similar pattern where the tongue height is more for adolescents and adults than children except for a small range in the anterior portion while comparing adolescents and children due to the above mentioned reason. The tongue advancement or the broadness of the tongue is considerably more in adults than children which is again in congruence to the results of the research by Irfana et al. (2013) [Figure 4.11 (c)].

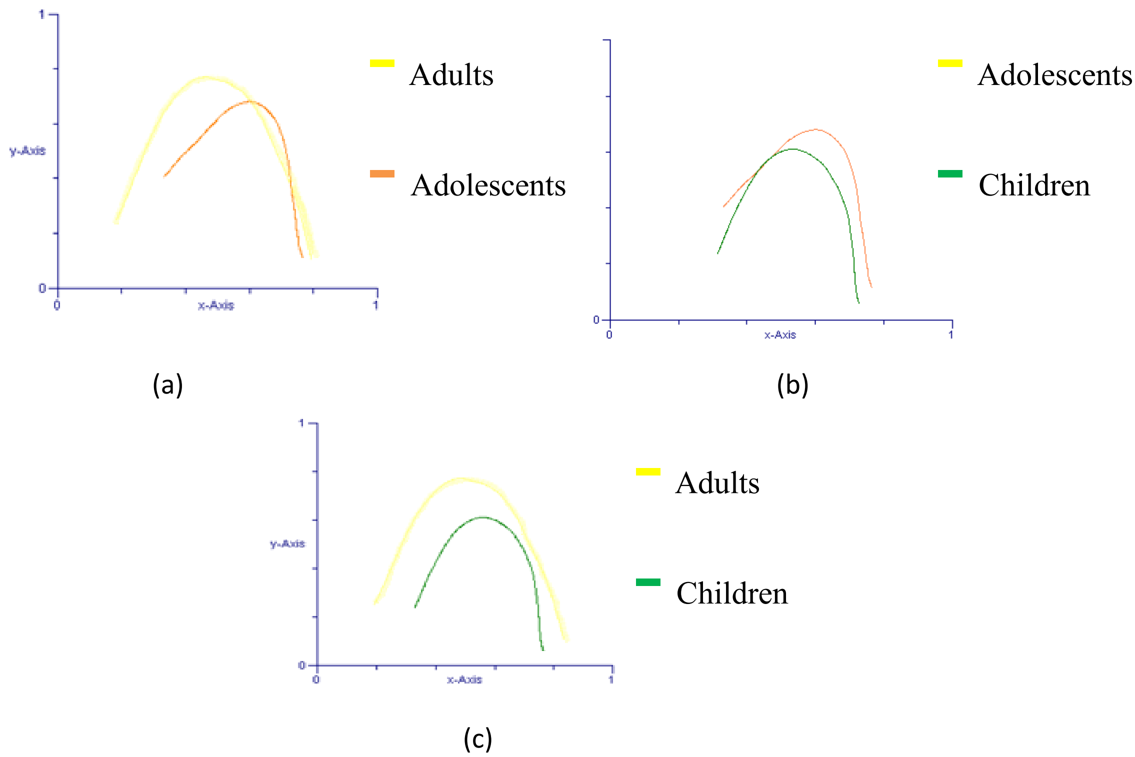


Figure 4.11. Comparison of tongue contours for /agga/ between (a) adults and adolescents (b) adolescents and children (c) adults and children

(b) Comparison of tongue contours for males and females for /agga/ within adults, adolescents and adults are represented in Figures 4.12 (a), (b) and (c) respectively where the tongue height and advancement followed a similar pattern. There is no exploration done in adults and children in this context. Walsh and Smith (2002) suppors that there is no gender difference in adolescent group which is replicated in the current study also.

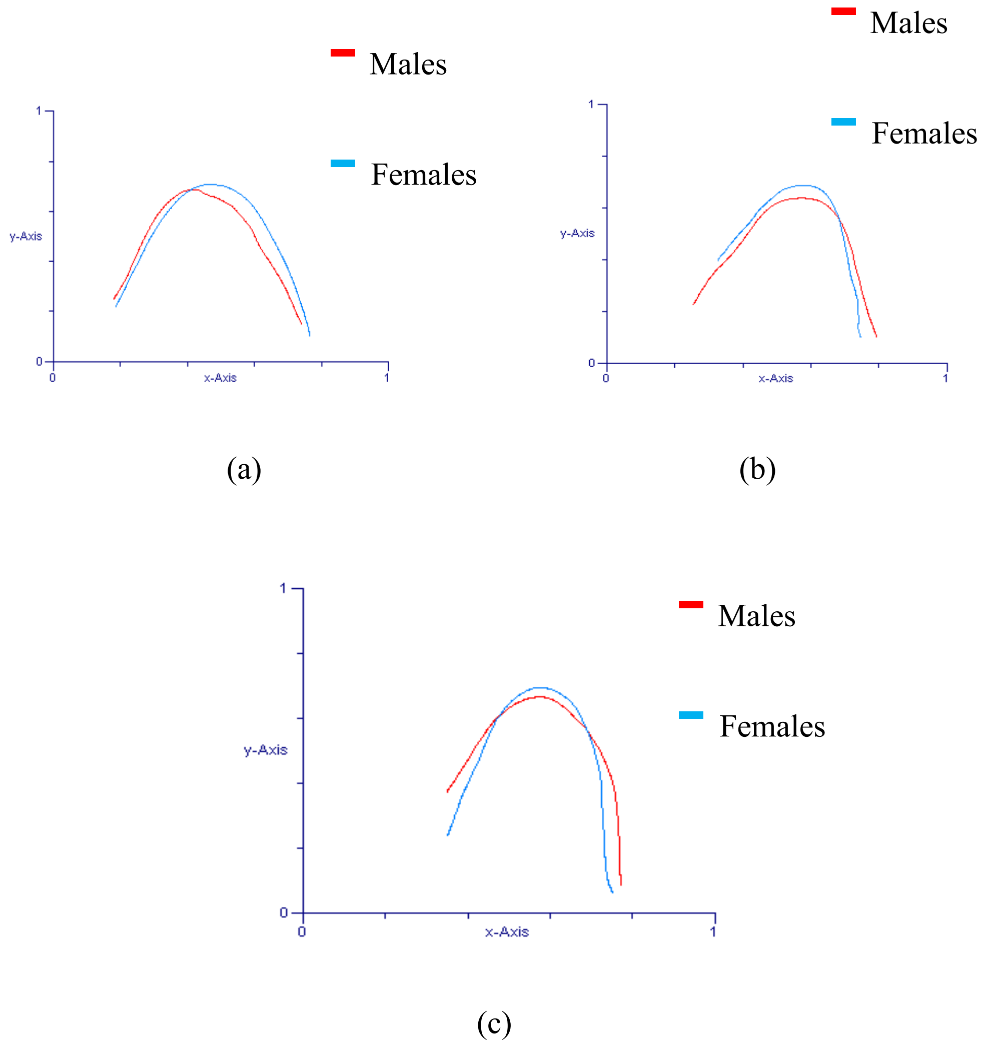


Figure 4.12. Comparison of tongue contours of males and females for /agga/ within (a) adults (b) adolescents (c) children

Angle and area of retroflection of /ṭ/ and /ḍ/

(a) Comparison of area of retroflection of /ṭ/ and /ḍ/ across adults, adolescents and children

Between group effect was compared using MANOVA where the results showed a significant difference in area of retroflection of /ḍ/ ($F = 7.575$, $p = 0.001$). There was a significant difference between gender in area of retroflection of /ṭ/ ($F = 12.731$, $p = 0.001$) and /ḍ/ ($F = 10.227$, $p = 0.002$). Duncan's post hoc analysis revealed that adults are significantly different from adolescents and children for area of retroflection of /ṭ/ and there was no significant difference for area of /ḍ/ though the placement of articulation for /ṭ/ and /ḍ/ are the same.

(b) Comparison of angle of retroflection of /ṭ/ and /ḍ/ across adults, adolescents and children

Mixed ANOVA was used to compare the angle of retroflection of /ṭ/ and /ḍ/ across the three age groups. There was no significant effect of angle of retroflection of /ṭ/ and /ḍ/ across the three age groups. Between group comparison revealed that there was a significant difference of angle of retroflection of /ṭ/ and /ḍ/ ($F = 5.443$, $p = 0.007$). MANOVA was used to compare between group effect and the results showed a significant difference in angle of retroflection of /ṭ/ ($F = 5.417$, $p = 0.024$) and /ḍ/ ($F = 5.414$, $p = 0.024$) between gender. Significant interaction effect was present for angle of retroflection of /ḍ/ across groups and gender.

CHAPTER 5- SUMMARY AND CONCLUSIONS

Articulatory dynamics is an area which is studied vastly in the past using many imaging techniques which have their own advantages and disadvantages. One of the emerging techniques in this field is ultrasound imaging which is non invasive in nature. Among the articulators, tongue plays the major role in speech production. But tongue dynamics is not a well established area compared to jaw and lips. Research on tongue dynamics will provide an insight into the development of speech motor control. There is dearth of studies using ultrasound imaging in this context. So with the same objective, the present study aimed to compare the tongue contours across typically developing children, adolescents and adults using ultrasound imaging.

Participants included native Kannada speaking children (6-8 years), adolescents (14-16 years) and adults (20-30 years). Each group consisted of 10 males and 10 females each. A total of six Kannada words were used in which voiceless stops in three places of articulation (dental-/t̪/, retroflex-/ṭ/ and velar-/k/) and their voiced counterparts (/d̪/, /ḍ/ and /g/ respectively) were embedded between vowel /a/ in the pre and post position. The target phonemes were geminated clusters for better visualization in the ultrasound image. Participants were made to sit comfortably on a high back chair and the target utterances were recorded using repetition procedure. The ultrasound probe was placed under the chin of the participant using head stabilization system (except for children) and a microphone attached to the headphone was used for recording the stimuli. The parameters analyzed were tongue contour, height and advancement of the tongue, angle of retroflection and the area of retroflection. Tongue contours were obtained using a technique of fan splines. It was plot, based on relative axes of tongue advancement and tongue height. Retroflex phonemes were plot, based on 2D splines also. Tongue contours were analyzed on visual observation and later angle and area of retroflection were analyzed statistically using SPSS-16.

The results of the study revealed that there is a developmental trend observed in tongue contour patterns. The tongue height in adults was prominently greater than children for all the phonemes. Similarly, the tongue height in adolescents was consistently greater than children for all the phonemes. The tongue height in adults was greater than adolescents for all phonemes except /ḍ/ where they overlap each other. This trend can be attributed to the improvement in the articulatory precision as age increases.

The tongue advancement indicated by the broadness of the tongue contour had different patterns across age. Adults had greater advancement than children for /at̲t̲a/, /akka/, /aḍḍa/ and /agga/. Similarly, they had greater advancement than adolescents for /akka/ and /agga/. Adolescents have greater tongue advancement than children for /aḍḍa/. As observed, the tongue advancement was greater in the older group in all the above mentioned comparisons. This may be again because of the same reason cited above for the tongue height.

The comparison of tongue contours between males and females within each group showed that females had greater tongue height than males in adults and adolescents for /at̲t̲a/ and also in children for /aḍḍa/. All other comparisons reveled that there is no gender difference for tongue height and tongue advancement.

The angle of retroflection and area of retroflection for /ṭ/ and /ḍ/ were obtained using a MATLAB based programme. The statistical measures used to compare were mixed ANOVA, MANOVA and Duncan's post hoc analysis. There was a significant difference in area of retroflection of /ṭ/ between adults and adolescents and also across adults and children. There was no significant difference across age groups for angle of retroflection of /ṭ/ and /ḍ/.

The developmental trend is very evident from the results of the current study indicating that adults are significantly different from children in terms of the tongue dynamics and also a marginal difference is found between adults and adolescents which reveal that the developmental trend even continues in the adolescent period.

The limitations of the study include smaller sample size in each group. So the future researches can replicate the study in a larger sample focusing on the difference across age groups, across gender and also in disordered population. Literature reports are ample on articulatory dynamics studies of jaw, upper lip and lower lip using different imaging techniques. There is dearth of studies undertaken on tongue dynamics especially in the Indian context where abundant language families are present. Hence future studies can focus on all these areas.

REFERENCES

Bernhardt, B.,Gick, B., Bacsfalvi, P & Bock, M. A. (2005). Ultrasound in speech therapy with adolescents and adults, Clinical Linguistics and Phonetics, 19(6/7): 605–617.

Bernhardt, B. M., Bock, M. A., Gick, B., & Bacsfalvi, P. (2007). The use of ultrasound in remediation of North American English /r/ in two adolescents. *American Journal of Speech-Language Pathology*, 16, 128-139.

Bose, A., & Square, P. A. (2001). Clinical assessment of speech motor performances of children with moderate to severe articulation disorders. *PROMPT Treatment Method and Apraxia of Speech,* 11, 5-8.

Bressman, T., Thind, P., Catherine, U. Y., Bollig, C., Gilbert, R. W., & Irish, J. C. (2005). Quantitative three-dimensional ultrasound analysis of tongue protrusion, grooving and symmetry: Data from 12 normal speakers and a partial glossectomee. *Clinical Linguistics & Phonetics*, 19 (6/7), 573-588.

Caruso, A. J., & Strand, E. A. (1999). Clinical management of motor speech disorders in children. Thieme Medical Publishers. Inc., New York.

Cheng, H. Y., Murdoch, B. E., Goozee, J. V., & Scott, D. (2007). Physiologic Development of Tongue–Jaw Coordination from Childhood to Adulthood. *Journal of Speech, Language, and Hearing Research,* 50, 352-360.

Chi-Fishman, G. (2005). Quantitative lingual, pharyngeal and laryngeal ultrasonography in swallowing research: A technical review. *Clinical Linguistics & Phonetics*, 19 (6/7), 589-604.

Davidson, L. (2005). Addressing phonological questions with ultrasound. *Clinical Linguistics & Phonetics*, 19(6/7): 619–633.

Gibbon, F. E., & Wolters, M. (2005). A new application of ultrasound to image tongue behaviour in cleft palate speech. Poster Presentation at the Craniofacial Society of Great Britain and Ireland Annual Scientific Conference, Swansea, UK (13-15 April 2005).

Hixon, T. J., Mead, J., & Goldman, M. D. (1976). Dynamics of the chest wall during speech production: Function of the thorax, rib cage, diaphragm, and abdomen. *Journal of Speech and Hearing Research*, 19, 297–356.

Irfana, M. & Sreedevi, N. (2013). Comparison of tongue contours in children and adults: A preliminary ultrasound study. *Journal of All India Institute of Speech and Hearing.*

Kent, R. D., & Forner, L. L. (1980). Speech segment durations in sentence recitations by children and adults. *Journal of Phonetics, 8,* 157-168.

Kent, R. D. (2000). Research on Speech motor control and its disorders: A review and prospective. *Journal of Communication disorders*. Vol 33. Pg 391-428.

Kochetov, A., Sreedevi, N., Manjula, R., & Kasim, M. (2012). A pilot ultrasound study of Kannada lingual articulations. *Journal of Indian Speech and Hearing*, *26*, 38-49.

Lofqvist, A. & Lindblom, B. (1994). Speech motor control. *Current opinion in neurology*. Vol 4. Pg 823-826.

Nip, I. S. B., Green, J. R., & Marx, D. B. (2009). Early speech motor development: Cognitive and linguistic considerations. *Journal of Communication Disorders*, 42, 286-298.

Parthasarathy, V., Stone, M., & Prince, J. L. (2005). Spatiotemporal Visualization of the Tongue Surface using Ultrasound and Kriging (SURFACES). *Clinical Linguistics & Phonetics,* 19 (*6/7*), 529–544.

Sindhusha, C., Irfana, M., & Sreedevi, N. (2014). A cross linguistic comparison of angle of retroflexion using ultrasound imaging. *Proceedings of the Frontiers of Research and Music (FRSM- 2014)*, 178-182.

Scobbie, J.M., Punnoos, R. & Khattab, G (2013). Articulating five liquids: a single speaker ultrasound study of Malayalam. In Rhotics: New data and perspectives. BU press, Bozen- Bolzano.

Smith, A. (2010). Development of neural control of orofacial movements for speech. In W.J. Hardcastle, J. Laver, & F.E. Gibbon (Eds.), *The Handbook of Phonetic Sciences* (2nd ed), 251–296.

Stone, M. (1990). A three-dimensional model of tongue movement based on ultrasound and x-ray microbeam data. *Journal of Acoustic Society of America*, 87 (5).

Stone, M. (2005). A guide to analyzing tongue motion from ultrasound images. *Clinical Linguistics and Phonetics*, 19, 455–501.

Tanja (2010). Ultrasound and acoustic analysis of lingual movement in teenagers with childhood apraxia of speech, control adults and typically developing children. *A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy.*

Temple, E.C., Hutchinson, I., Laing, D.G. & Jinks, A.L. (2002). Taste development: differential growth rates of tongue regions in humans. *Developmental Brain Research,* 135*,* 65–70.

Thelen, E. & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge, MA: The MIT Press.

Thelen, E. & Smith, L. B. (1998). Dynamic systems theory. In W. Damon (Series Ed.) & R. M. Lerner (Vol. Ed.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (5th ed., pp. 563–633).New York: Wiley.

Tingley, B. M & Allen, G.D. (1975). Development of speech timing control in children. *Child Development*, 46, 186-194.

Walsh, B., & Smith, A. (2002). Articulatory movements in adolescents: Evidence for protracted development of speech motor control processes. *Journal of Speech, Language, and Hearing Research*, 45, 1119–1133.

Wilson, I., & Gick, B. (2006). *Proceedings of the 8th Generative Approaches to Second Language Acquisition Conference (GASLA)*, 148- 152.

Whalen, D. H., Noiray, A., & Bolanos, L. (2005). Articulation of Vowel Height in English Front Vowels: An Ultrasound Study

Zharkova, N., Hardcastle, W.J. & Hewlett, N. (2011). Coarticulation as an indicator of speech motor control development in children: An ultrasound study. *Motor Control*, 15, 118-140.

Zharkova, N. (2013). A normative-speaker validation study of two indices developed to quantify tongue dorsum activity from midsagittal tongue shapes. *Clinical Linguistics & Phonetics,* 27(*6–7*), 484–496.

Zharkova, N., Hewlett, N., & Hardcastle, W.J., Lickley, R. (2013). Lingual coarticulation in preadolescents and adults: an ultrasound study: Full Research Report ESRC End of Award Report, RES-000-22-4075. Swindon: ESRC.

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