TONGUE CONTOURS DURING VOWEL PRODUCTION IN CHILDREN WITH HEARING IMPAIRMENT: AN ULTRASOUND STUDY

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CERTIFICATE

This is to certify that this dissertation entitled "**Tongue contours during vowel production in children with hearing impairment: An ultrasound study**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (speech - Language Pathology) of the student (Registration No.: 12SLP016). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

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May, 2014

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CERTIFICATE

This is to certify that this dissertation entitled "**Tongue contours during vowel production in children with hearing impairment: An ultrasound study**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Tongue contours during vowel production in children with hearing impairment: An ultrasound study**" 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 in other University for the award of any Diploma or Degree.

Mysore Register No.: 12SLP016

May, 2014.

Dedicated to my lovely parents and sister

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CHAPTER 1 - INTRODUCTION

Speech is a form of verbal communication which is unique to human beings. Speech sounds consist of vowels and consonants. A vowel sound is a product of vocal fold vibration and the resonances of a particular vocal tract shape and length plus an effect of sound radiation at lips (Borden, Raphael & Harris, 2011). Vowels carry maximum energy and play a major role in speech understanding. Consonants carry less energy but have meaningful message in speech communication. The vowel family is mainly divided as front vowels (i, I ë, e) the back vowels (o, u, ö, ü,) and the central vowels (a, Ə). The sounds in the vowel family changes quickly when we move any part of the tongue, lips or jaw.

Vowels are classified based on the tongue height, position of the tongue, lip, soft palate and phonemic length, articulators' tension and pitch. Generally they are classified as high, mid, low based on the relative height of the tongue; front central, back based on the relative position of the constriction of the tongue in the oral cavity; spread, rounded, unrounded based on the relative position of the lips; nasal and oral based on the position of the soft palate; short and long based on the phonemic length of the vowel; lax and tense based on the tenseness of the articulator; and high, mid, low based on the relative pitch of the vowel. In most of the languages including the languages with very rich vowel systems, the principal features that determine vowel quality are tongue height, tongue advancement, labiality, and tenseness.

The literature on speech sound development suggests that the vowels of a language are acquired early, both in production and perception (Locke, 1983; Chen & Kent, 2010). Increased availability of high quality recordings of children's speech and newer technologies like Magnetic Resonance Imaging (MRI) and glossometry enabled the researchers to advocate increased use of acoustic data and its integration with anatomical, physiological and perceptual data to account for speech development and production of speech sounds.

The present study was undertaken to investigate the tongue contours during vowel production in children with hearing impairment using ultrasound in Kannada. Kannada is one of the major Dravidian languages of India and it is the 27th most spoken language in the world (Hemakumar, 2011). Kannada uses 49 phonemic letters, divided into three groups: *Swaragalu* (thirteen letters); *Yogavaahakagalu* (two letters); and *Vyanjanagalu* (thirty-four letters), similar to the vowels and consonants of English, respectively. In Kannada, classification of vowels is based on the position of tongue and lips (Hemakumar, 2011) as seen in Table 1.1

Table 1.1

Kannada vowel classification

Phonetic classification	**Vowels phone**
High Vowels	/ii/ , /uu/
Higher – mid Vowels	/e/ , /o/
Low Vowel	/aa/
Rounded vowels	/u/ ,/o/
Unrounded vowels	/i/ ,/e/, /u/
Diphthong	/ai/ , /au/
Additional Vowel	/I/

Note: From, "Acoustic Phonetic characteristics of Kannada language" by Hemakumar (2011)

Vowels are reported to be minimally kinesthetic and maximally auditory controlled. Therefore the role of auditory feedback in vowel production is very important. The lack of auditory feedback in individuals with profound and severe hearing impairment changes the vowel production space (Ozbic & Kogovsek, 2008). Investigations have shown that vowels are produced correctly more often than the consonants. However, even vowels undergo certain changes in the language of the hearing impaired. These errors include substitutions, diphthongization of vowels, nasalization of vowels and durational distortions of vowels.

Perceptual, acoustic and physiologic descriptions are abundant on the vowel production abilities of speakers with hearing impairment. Several studies have described the typical vowel errors produced by speakers with hearing impairment. These studies usually are dependent on perceptual evaluations. Generally hearing impaired speakers were found to produce back vowels correctly more often than front vowels (Boone, 1966; Geffner, 1980; Mangan, 1961; Nober, 1967 & Smith, 1975) and low vowels correctly more often than those with mid or high tongue positions (Geffner, 1980; Smith, 1975).

Several physiologic studies of speech production by the hearing impaired speakers are also reported. Zimmermann and Retalliata (1981) reported a cinefluorographic study with a single hearing impaired subject. They have accounted the speech movements based on the jaw-opening component and reported that there was minimal change in tongue shape and positioning across vowels. This suggested that for vowel production, hearing impaired speakers were jaw dependent. In an electromyographic (EMG) study by McGarr and Harris (1983), they compared a normally hearing (NH) subject with a hearing impaired (HI) subject. Results showed that the hearing impaired subject had high variability for lingual muscle activity levels, as compared to his own labial levels and to both labial and lingual levels for the NH speaker. It was suggested that this variability was due to the HI person's lack of knowledge about tongue movements because of the tongue's invisibility. Fletcher, Dagenais, and Critz-Crosbyud's (1991) study showed that HI speakers use only the midcavity regions with broad token-to-token variability when producing different vowels. Angelocci (1964) proposed that speaker with hearing impairment uses limited amount of tongue movement and consequently do not achieve vowel differentiation. He stated that children with hearing impairment are inaccurate in placing their articulators to reach the vowel targets. The study also states that child with hearing impairment attempted to achieve vowel differentiation by varying fundamental frequency and amplitude of the voice relatively more than varying the tongue positions. In physiological terms, the participant achieved vowel differentiation by excessive laryngeal variations with only minimal articulatory variations. There are studies which incorporate simultaneous acoustic and articulatory measures of production with listener judgments or perceptual evaluation (Huntington, 1968; Rothman, 1977; McGarr & Gelfer (1983). Acoustic results of these studies also agree with the previous studies by stating reduced vowel space in subjects with hearing impairment.

The researchers in the past several years have studied tongue function and its development by using many instruments and imaging techniques like Electropalatography, Electromagnetic Articulography, X-ray, 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.).

Ultrasound is one of the most recent imaging techniques to study the tongue dynamics. In most speech related applications of ultrasound, researchers have focused on collecting data from the midsagittal contour of the tongue, while coronal slices have also been analyzed (Slud, 2002). Early ultrasound studies of speech (e.g., Kelsey et al. 1969, Skolnick et al. 1975, Zagzebski 1975, MacKay 1977, etc.) used relatively large and cumbersome hospital equipment to produce 1-dimensional (A mode) measurements (recording movement along a single line), usually in the pharyngeal region. Even in the limited 1-D form, the advantages of ultrasound were clear and ultrasound still remains the only available option for safe, non-invasive imaging of real movements of the whole tongue. The principle behind the operation of tongue imaging using ultrasound is that when sound wave travels upward and comes in contact with the tongue body, the upper tongue surface interfaces with the palate bone and airway and causes a strong echo which is reflected back downwards. The reflections of the back signals will be displayed on the computer screen as the tongue image.

Most of the studies in literature on the ultra sound tongue contours are in non Indian languages. Investigative studies using ultrasound are very few across different places of articulation in Indian languages and are mostly limited to selected contrasts produced by single speakers of languages such as Hindi, Tamil, Telugu Kannada and Malayalam. There are no reported studies using ultra sound in the Indian context on disordered population. Hence the present study is planned to investigate the tongue contours during vowel productions of children with hearing impairment using ultrasound imaging system.

Aim of the Study

The present study aims to compare the tongue contours during vowel production in 18 children with hearing impairment in the age range of 4-7 years with their age and gender matched 18 typically developing children using ultrasound imaging.

Objectives of the study

- To analyze the tongue contours in mid-sagittal planes for the vowels /a: /, /I:/, /u:/, /o:/ and /e:/ in children with hearing impairment using ultrasound.

- To analyze tongue contours for the above vowels in typically developing age and gender matched children.

- To compare the ultra sound images of the tongue contours for these target vowels between children with hearing impairment and typically developing age and gender matched children.

Implications of the study

1. The study helps in understanding the differences in tongue contours of vowel production in children with hearing impairment and age and gender matched typically developing children.
2. Study would also help SLPs to make use of visually presented models and feedback on tongue positions by ultra sound images to facilitate more appropriate tongue postures and improve vowel intelligibility in hearing-impaired speakers.
3. This will also help SLPs to make appropriate therapeutic goals for vowel production for the hearing impaired population for their improved articulation skills.

Limitations of the study

1. There were only 18 subjects in the experimental group that includes 3 subjects in each sub group.
2. The age of identification and speech training duration varied in all the participants.
3. The language age of the children with hearing impairment was not matched with the control group, only their chronological age was considered

CHAPTER 2 - REVIEW OF LITERATURE

The review will be dealt under the following headings:

1. Vowel system
2. Vowel production in typically developing children
3. Vowel production in persons with hearing impairment
    - Perceptual, physiological, acoustic studies
4. Advantage of ultrasound method compared to other methods
5. Ultra sound studies in persons with hearing impairment

Speech sounds consists of both vowels and consonants. Vowel sounds are present in both meaningful and non meaningful speech. Vowels carry maximum energy in speech communication and play a major role in speech understanding. Tosi (1979) defines vowel "as a continuant sound (it can be produced in isolation without changing the position of articulators), voiced (using the glottis as the primary source of sound), with no friction (noise) of air against the vocal tract". "Vowel is a conventional vocal sound in the production of which the speech organs offer little obstruction to the air stream and form a series of resonators above the level of the larynx" (Mosby, 2008). During the vowel production, the vocal tract usually maintains a relatively stable shape and offers minimal obstruction to the airflow with voiced excitation. The energy produced radiates through the mouth or nasal cavity without audible friction or stoppage. In other words, during the vowel production, the tongue and articulators are so positioned to create a uniform cross-sectional area along the length of the vocal tract.

Vowels are described in terms of:

a) The relative position of the constriction of tongue in the oral cavity(front, central and back)
b) The relative height of the tongue in the oral cavity (high, mid and low)
c) The relative shape of the lips (spread, rounded and unrounded)
d) The position of the soft palate (nasal and oral)
e) The phonemic length of the vowel (short and long)
f) The tenseness of the articulators (lax and tense).

Vowel system of Kannada Language

Kannada is the official and local language of Karnataka State in India and spoken by nearly 36.5 million people (Census of Government of India, 1991). Nayak (1967), Upadyaya (1972), Schiffman (1979), Andronov (1982), Rajpurohit (1982) and Venkatesh (1995) have given description about the vowels of Kannada language. Detailed descriptions of the vowels present in Kannada are given below:

/a/ short low central vowel	/a: / long low central vowel
/i/ short high front unrounded vowel	/I: / long high front unrounded vowel
/u/ short high back rounded vowel	/u: / long high back rounded vowel
/e/ short mid – front unrounded vowel	/e: / long mid-front unrounded vowel
/o/ short mid-back rounded vowel	/o: / long mid-back rounded vowel

Studies on human vocalizations show that from birth till one year of age, infant vocalization is dominated by vowel production (Oiler, 1980). Literature on vowel development suggests that the vowels of a language are acquired early, both in production and perception (Locke, 1983; Chen & Kent, 2010). Vowels are the first sounds to be mastered by the infants, who acquire most of the vowels and half of the consonants in the second quarter of the first year. In a study by De, Boysson – Bardies, Sagart and Durand (1989), they have analyzed 10 month old infants' vowel production from four linguistic communities- Arabic, Chinese, English, and French and accounted that the categories of front- low and mid – central vowels were the vast majority of vowels from all four groups. Davis and Mac Neilage's (1995) longitudinal study with six infants (3 males & 3 females) from monolingual English- speaking homes revealed much individual variability in the use of vowels. The vowel data in the study was analyzed according to the tongue height and tongue advancement dimensions. In relation to the tongue height, the vowels were grouped into high, mid and low. For tongue advancement, the vowels were categorized as front, mid, and back. They identified some common trends in the production and concluded that the most commonly used vowels in the canonical babbling period were (^, ə, U, ␣ and ˙.˙).

A larger study by Otomo and Stoel-Gammon (1992) describes the acquisition of American English vowels /i, ɪ, e, ɛ, æ, ɑ/ by six normally developing children at 1;10, 2;2, and 2;6 years of age. /i/ and /ɑ/ were mastered early but /ɪ/ and /ɛ/ were least accurate throughout the study. Variability decreased as the subjects matured and a few context-sensitive vowel substitution patterns were observed. Studies on developmental milestones of language acquisition in Hindi, Kannada and Malayalam revealed that cardinal vowels /i/, /e/, /a/, /u/ appeared in younger age when compared with other vowels (Shyamala &

Basanti, 2003- Hindi & Kannada; Sreedevi & Jyothi ,2012- Kannada; Irfana , 2012- Malayalam).

Vowel production in persons with hearing impairment

Vowels are minimally kinaesthetically and maximum auditory controlled, therefore the role of the auditory feedback in vowel production is very important. The lack of the auditory feedback in individuals with profound and severe hearing impairment changes the vowel production space (Ozbic & Kogovsek, 2008). Hudgins (1934) and Hudgins and Numbers (1942) were the pioneers to study systematically the production of vowels and diphthongs in the speech of hearing impaired children. They collected the recordings of 1200 sentences from deaf pupils between 9 and 12 years. They classified the vowel errors in five major types as (1) Substitution of one vowel for another (2) Neutralization of vowels (3) Diphthongization of vowels (4) Nasalization of vowels (5) Errors involving diphthongs were that either the diphthong was split into two distinctive components or the final member of the diphthong was dropped. Similar pattern errors were replicated in other studies of hearing impaired speakers. Vowel substitutions in the hearing impaired children are said to be typically towards more central vowel (Angelocci, 1964; Levitt, 1972; Levitt, Smith and Stromberg, 1976; Smith, 1975; Levitt, Stromberg, Smith and Gold 1980). All Vowels are substituted by the vowel ∂ fairly often (Smith, 1975; Levitt, 1972; Levitt, Stromberg, Smith & Gold 1980) and by /Λ/ slightly less frequently (Smith, 1975).

While considering the frequency of occurrence of vowel versus consonant errors, Vowel errors are reported to be fewer than consonant errors. The finding is reported to be influenced by variables in both production and perception. Vowel production is easier for hearing impaired speakers than consonants since the production require less precise artticulatory position (Brannon, 1966). Perceptually Hugins and Numbers (1942; Monsen, 1976) suggested that listeners will tolerate a greater degree of distortion in vowels than in consonants.

Increased availability of high quality recordings of children's speech and newer technologies like MRI and glossometry enabled the researchers to advocate increased use of acoustic data and its integration with anatomical, physiological and perceptual data to account for speech development and production of speech sounds. Perceptual, acoustic and physiologic descriptions are abundant on the vowel production abilities of hearing – impaired speakers. Several studies have described the typical vowel errors produced by speakers with hearing impairment. These studies usually depended on perceptual evaluations Generally hearing- impaired speakers were found to produce back vowels correctly more often than front vowels (Boone, 1966; Geffner, 1980; Mangan, 1961; Nober, 1967; Smith, 1975) and low vowels correctly more often than those with mid or high tongue positions (Geffner, 1980; Smith, 1975).

Another perceptual study of Yoshinaga-ltano, Stredler-Brown, & Jancosek, (1992) states that regardless of the specific degree of hearing loss, vowel production of children with hearing impairment of 6 to 42 months age mostly included neutral vowels (i.e., / a / and / A). /e/ was the only vowel that differed significantly in production by degree of hearing loss. The vowel /e/ was observed to be produced more in children who had better hearing thresholds (less than 70 DB hearing level) than the children who were considered as deaf with the hearing threshold of greater than 70 dB hearing level.

The acoustic characteristics of vowels and diphthong production are discussed in literature in terms of vowel formants, timing characteristics (i.e, duration) and segmental influences on fundamental frequency. There is a general tendency towards lengthening of vowels and consonants in the deaf (Angelocei, 1962; Boone, 1966; Levitt, et al. 1974; sheela, 1988; Rashitha, 1994). Shukla (1987) compared vowel duration and consonant duration in 30 normal and hearing impaired individual matched for age and sex. The results revealed that the duration of the vowel /a/ in the medial position was longer in the speech of the hearing impaired and /i/ and /u/ were also tended to be longer in them.

Angelocci et al. (1964) found vowel formants of hearing impaired adolescent between 11-14 years. He found that means of formant frequency (F1) for deaf were higher than for normal hearing for the vowels /i/, /u/ and lower for the vowel /a/ and also F2 for deaf was lower than for the normal hearing for the front vowel /i/. F2 for the deaf was higher than for the normal hearing for the back and neutral vowel Ə and /u/. " Deaf speakers who produce vowel distinctions do so by exaggerated variations in F0, particularly for high vowels such as /i/ and /u/" (Bush, 1981; Martony, 1968).

There are several acoustic studies on persons with hearing impairment in Indian languages also. Acoustic analysis of vowel productions in persons with hearing impairment shows higher mean F2 values compared to their control group. (Grover, 1998- Punjabi;, Paul 1998- Malayalam; Rathna Kumar 1998- Telugu). The higher F2 indicates more tongue advancement anteriorly in them.

Several physiologic studies of speech production by the hearing impaired speakers are also reported. Zimmermann and Retalliata (1981) reported a cinefluorographic study with a single hearing impaired subject. They have accounted the speech movements based on the jaw-opening component and reported that there was minimal change in tongue shape and positioning across vowels. This suggested that for vowel production hearing impaired speakers were jaw dependent.

There are studies which incorporate simultaneous acoustic and articulatory measures of production with listener judgments or perceptual evaluation (Huntington, 1968; Rothman, 1977; McGarr & Gelfer (1983). In an electromyographic (EMG) study by McGarr and Harris (1983), they compared a normally hearing (NH) subject with a hearing impaired (HI) subject. Results showed that the hearing impaired subject had high variability for lingual muscle activity levels, as compared to his own labial levels and to both labial and lingual levels for the NH speaker. It was suggested that this variability was due to the HI person's lack of knowledge about tongue movements because of the tongue's invisibility.

Critz Crosby and Dagenais (1991) examined the glossometric measures of tongue positions of 10 normal hearing and 10 profoundly hearing-impaired children during the production of the eight vowels /i,',e,ae,u,U,o/. The glossometry system (Flege, Fletcher, McCutcheon, & Smith, 1986; Fletcher, 1983) allows for the direct collection of physiologic data describing tongue positioning within the oral cavity. The results were as follows as the vertical range of tongue positions for the front vowels was greater for the NH than the HI subjects. The NH group had a rounded tongue shape for all vowels as compared to the flat tongue shape used by the HI group. The roundness of the shape used by the NH group decreased as the tongue position lowered in the oral cavity. The HI subjects had the same flat tongue shape for all the front vowels, with the tongue having a high back orientation. For the lower /I,c,a/ vowels, the groups performed similarly with regard to tongue positions. The NH and HI subjects used different tongue shapes and different ranges of vertical tongue positioning for the front vowels. The NH group had more variety of tongue shapes-slightly curved for /u/, flat for /U/ and /o/, and with a lowered tongue tip for /a/ as compared to the uniform flat, high-back tongue shape used by the HI group.

Fletcher, Dagenais and Critz-Crosby (1991) used glossometry to teach the four point vowels (/i,ae,u,a/) to 6 profoundly hearing-impaired children. Prior to treatment Subjects evidenced centralized tongue positions during vowel productions. After training sessions they showed greater diversification of tongue postures for the vowels, especially in tongue height. The training results suggested that visually presented models and feedback of tongue positions can facilitate more appropriate tongue postures and improve vowel intelligibility by hearing-impaired speakers.

Several authors claim that speech production of individuals with severe prelingual hearing impairment is different from the speech of individuals with profound hearing impairment and from those of normal hearing subjects. Ozbic (2008) investigated the differences in vowel formant production in 156 speakers, exactly between 46 individuals with normal hearing, 36 with severe and 74 with profound hearing impairment. Results revealed that normal hearing speakers show larger range in F2 formant production from anterior to posterior vowel (2875 Hz - 1554 Hz) in comparison with speech production in individuals with severe (2458 Hz - 1538 Hz) and profound hearing impairment (2281 Hz - 1646 Hz). Formant space is least in profound hearing impaired group followed by severe hearing impairment and normal hearing group. The greatest differences were in anterior vowel production as normal hearing individuals differentiated the three anterior vowels much greater than those with severe and profound hearing impairment. In the three groups, the only formant value that is equal was the first formant of the vowel /a/ which is the most central vowel, where the auditory control is minimal and where the only movement required is a jaw vertical movement with minimal tongue movement. They also mentioned the closed relation of the frequencies of vowel formants of the individuals with hearing impaired with the degree of hearing loss. As hearing loss increased, the second formant of the front vowels decreased and those of the back values increase, the first formants increase in the extreme back and front vowels and decrease in the middle low vowel; in addition, standard deviations increase in all variables, due to the great variation in the speech production. Hearing impairment changes the monitoring of speech production and consequently the formant frequencies and the variability of speech production.

Studies investigating the development of the vowel formant regions and tongue positions in children with hearing loss have found reduced vowel formant regions and less distinct tongue positioning compared to those of children without hearing loss (Dagenais & Critz-Crosby, 1992; Kent et al., 1987).

Several different imaging methods are available for linguistic research. Each has its own set of advantages and disadvantages. X-ray movies also show tongue movements in real time, but the equipment is expensive, immobile, and the radiation presents a danger to subjects A safer means of generating detailed images of the tongue is MRI, but MRI imaging also requires expensive and immobile equipment which is also noisy, requires a subject to lie inside a machine, and suffers from poor temporal resolution.

Electromagnetic midsaggital articulometry (EMMA) allows points on the tongue to be tracked safely and in real time, but is expensive, invasive, and is impossible to affix pellets (necessary for imaging) to the back of the tongue. Static palatography and electropalatography show areas of contact between the tongue and palate, but also have difficulty with the back of tongue, and show little or no information about vowels. Ultrasound is one of the most recent imaging techniques to study tongue dynamics. Ultra sound instrumental measures records visual images of body primarily for medical diagnosis and have subsequently been used to record the movement and position of the articulators in particular, the tongue. In most speech-related applications of ultrasound, researchers have focused on collecting data from the midsagittal contour of the tongue, while coronal slices have also been analyzed (Slud, 2002). Early ultrasound studies of speech (e.g., Kelsey et al. 1969, Skolnick et al. 1975, Zagzebski 1975, MacKay 1977, etc.) used relatively large and cumbersome hospital equipment to produce 1-dimensional (A mode) measurements (recording movement along a single line), usually in the pharyngeal region. Even in the limited 1-D form, the advantages of ultrasound were clear and ultrasound still remains the only available option for safe, non-invasive imaging of real movements of the whole tongue. Ultrasound imaging employs high-frequency sound waves to generate images of objects, relying on echoes caused by abrupt changes in density. The tongue-air interface is strongly echogenic (because of the large distance in density between air and muscle); therefore an ultrasound transducer placed beneath the chin can produce a real-time movie of the full length of the tongue surface. The ultrasound unit is small and portable, and relatively inexpensive, and the imaging technique is quiet, non-invasive, and non-toxic. These benefits set ultrasound apart from other articulatory imaging methods.

In studies on speech disorders, Shawker and Sonies (1984) found significant difference in articulation of the vowels /a/ and /i/ between three speakers with neurological disease and dysarthria and 10 control participants. Keller (1987) observed irregularities in tongue movement over repetitions of the syllable /ka/ in two speakers with Parkinson's Disease, a speaker with senile dementia and speaker with mild stuttering. Bressmann, Ackloo, Heng and Irish (2007) found decreased midsagittal grooving and increased lingual asymmetry in 12 people who had undergone partial glossectomy. Gibbon and Wolters (2005) reported backing of tongue placement during the production of vowels /I,a,u/ in an adult male with repaired cleft lip and palate.

Research has shown that visual feedback technologies can be effective tools for speech (re)habilitation, whether the feedback is acoustic (e.g., Maki, 1983; Bernstein, 1989; Volin, 1991) or articulatory (e.g., Fletcher, Hasegawa, McCutcheon, & Gilliom, 1980; Shawker & Sonies, 1985; Gibbon, Hardcastle, Dent, & Nixon, 1996; Michi, Yamashita, Imai, & Yoshida, 1993; Bernhardt, Fuller, Loyst, & Williams, 2000). Following to that tradition Bernhardt, Adler-bock & Bacsfalvi (2005) had given an overview of techniques using ultrasound in speech (re)habilitation. They also report about ultrasound's excellent visualization of tongue shape features, which is especially useful for feedback during speech. In their study, they made use of electropalatography (EPG) and ultrasound imaging in vowel remediation for three adolescents with severe hearing impairment. Three 18-year-olds from an oral programme for the deaf and hard of hearing participated in the study. All three participants were diagnosed with severe- to-profound sensorineural hearing loss before the age of 2;6 years. Aided thresholds for the three participants were in the moderate to severe range. The subjects participated in a 6-week vowel remediation programme using electropalatography (EPG) and dynamic two-dimensional ultrasound as adjuncts to speech therapy. Pre- and post-therapy speech productions were evaluated in terms of vowel formant values, EPG tongue to palate contact patterns and phonetic transcription. Notable changes were observed for all vowels across speakers, with most changes in the direction of the adult English target vowels. Visual feedback as provided by EPG and ultrasound can be facilitative in promoting vowel development in adolescents with hearing impairment. In Whalen's (2005) ultra sound study investigated height distinction in American English front vowels. Stimuli consisted in /(h)Vd/ sequences with V corresponding to one of the front vowels /i, ɪ, e, ɛ/. Five adult speakers of American English (Connecticut dialect) were asked to repeat each sequence 15 times in random order. Tongue images were collected via the Haskins Optically Corrected Ultrasound System (HOCUS, Whalen et al., 2005) at a 127Hz sampling rate. Location and shape of the palate was collected on separate trials during the swallowing of a water bolus. 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. results indicate that taking the highest point of the tongue as defining height did not account for as much of the variability (in either articulation or acoustics) as the narrowest constriction between the tongue and the hard palate. Estimates of jaw position, though somewhat inferential, accounted for an amount similar to that of the highest point of the tongue. It appears that constriction degree may be the best descriptor for height in the front vowels.

There are limited studies in the Indian context using ultrasound to study the tongue contours. A study was carried out in Kannada, a Dravidian language of India by Kochetov, Sreedevi, Manjula and Kasim (2012). The results of this study 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. Another 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 and velar) studied, but the overall height of the tongue contour is more in adults especially for the anterior tongue body region.

Ultrasound imaging is not without challenges. Ultrasound images are grainy compared to x-ray movies and MRI images. Most significantly, ultrasound images offer no fixed point of reference, and passive articulators such as the palate and velum cannot be imaged at the same time as the tongue. Thus, just like other imaging methods, ultrasound has serious complications. The difference is that unlike danger and expense and the other drawbacks discussed above, ultrasound's complications are not inherent to the technology, and so can be remedied.

The review of literature indicates that most studies in literature on ultra sound tongue contours are in non Indian languages and there are no reported studies using ultra sound in the Indian context on disordered population. Hence the present study is planned to investigate the tongue contours during vowel productions of children with hearing impairment using ultrasound.

CHAPTER 3 – METHOD

Participants

Two groups of children participated in the study. Both groups consisted of 18 children in with equal number of males and females in the age range of 4 – 7 years. Hence the total numbers of subjects are 36. Children with congenital hearing impairment formed Group 1 and Group 2 was formed by age and gender matched typically developing children. Group 1 and Group 2 were further divided in to six sub groups based on their age range as Group A of age range 4 – 4.11 years, Group B of 5 – 5.11 years and Group C of 6 - 6.11 years. The inclusion criteria for Group 1 participants were:

- Native speakers of Kannada
- Diagnosed with congenital severe to profound sensorineural hearing loss.
- Hearing loss identified before the age of 3 years.
- Regularly using bilateral behind the ear digital hearing aid since the identification of hearing loss.
- Attended speech and language therapy and listening training for minimum period of one year.
- Perceptually correct production of vowels in Kannada.

The children with hearing impairment were students enrolled at the AIISH preschool. Table 3.1, describes the details of the participants. The participants were included in the study after obtaining a signed consent from their parents/care-givers/teachers.

Table 3.1

Details of the Group 1 participants (Children with hearing impairment)

No	Participants	Age/ Gender	Hearing aid model	Age of identification	Age of hearing aid fitting	Duration of therapy
1	Subject 1	4.8 years/ Male	Electone eclipse	2.8 years	3 years	1.5 years
2	Subject 2	4.5 years/ Male	Electone eclipse	2.6 years	3 years	1 year
3	Subject 3	4.5 years/ Male	Phonak Una SP	2 years	2 years	2 years
4	Subject 4	4 .2 years/ Female	Oticon go pro	1 year	1.5 years	2 years
5	Subject 5	4.5 years/ Female	Electone eclipse	1.8 years	2 years	2.3 years
6	Subject 6	4.2 years/ Female	Electone eclipse	1.6 years	2 years	2 years
7	Subject 7	5.10 / male	Electone eclipse	11 months	1 year	4 years
8	Subject 8	5.9 years/male	Phonak Una SP	8 months	1 years	4.6 years
9	Subject 9	5.10 years/ male	Oticon go pro	1.6 years	1. 6 years	3.6 years
10	Subject 10	5.3 years	Electone eclipse	2 years	2 years	3 years
11	Subject 11	5.9 years/ female	Phonak Una SP	3 years	3 years	2.6 years
12	Subject 12	5.8 years	Phonak Una SP	2.6 years	2.8 years	3 years
13	Subject 13	6 years/ male	Electone eclipse	3 years	3.2 years	2.6 years
14	Subject 14	6.5 years/male	Oticon go pro	3 years	3 years	2 years
15	Subject 15	6 years/male	Seimens	3 years	3 years	2.6 years
16	Subject 16	6.2 years/female	Phonak Una SP	2 years	2 years	3.6 years

17	Subject 17	6 years	Riva 2 HP audio service	3 years	3 years	3 years
6	Subject 17	6.6 years	Phonak Una SP	3 years	3.2 years	3 years

Group 2 participants were so selected that their mother tongue/ first language is Kannada, belong to urban set up and are devoid of any speech, language, sensory, motor or cognitive deficits.

Stimuli

The test material (Table 3.2) consisted of 5 non- meaningful words incorporating the vowels /a:/,/i/,/u:/,/o:/,/e:/ in the medial position.

Table 3.2

List of stimuli words

No.	***Targeted Vowel***	***Stimuli***
1	/a/	/pa:pa/
2	/i/	/pi:pa/
3	/u/	/pu:pa/
4	/e/	/pe:pa/
5	/o/	/po:pa/

The preceding and the following consonants were kept constant in the stimuli so as to control the co-articulatory influence on tongue position for the target vowels.

Perceptual Evaluation

Children with hearing impairment were asked to produce the target sounds to see the vowel production abilities and the same was audio recorded using Sony IC recorder ICD – UX533F. Recorded sample of 27 children with hearing impairment was considered for the perceptual analysis. Three speech language pathologists transcribed these samples and identified the vowels. The 18 participants whose vowel productions were rated as perceptually the intended vowel by the judges were selected as participants for the ultra sound recording.

Instrumentation

The ultra sound instrument Mindray ultrasound 6600 (Fig.3.1) connected with a 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 microphone attached to the headphone was used for recording the stimuli. The transducer was a long-handled micro convex probe operating at 6.5 MHz placed beneath the chin of the participant. The sound wave travels upward through the tongue body until it reaches and reflects back downward from the upper tongue surface. 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.

Figure3.1. Mindray ultrasound 6600 instrument

Data Recording

The 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. The stimulus list was read out and each participant was asked to repeat each stimulus word 3 times. Three repetitions of each prompt were considered for further analysis. Thus 15 (5*3=15) utterances were recorded from each participant including three repetitions of five target samples. Repetitions of each stimulus were recorded consecutively with a minimum inter stimulus interval of approximately 350 milliseconds. The participants with hearing impairment were provided with additional visual and tactile cues when they faced difficulty to produce the target words. Figure 3.2 is an ultrasound image of a child's tongue contour. The lower edge of the bright white curve is the surface of the tongue. The tongue tip is on the left and the black area below is caused by the bone of the chin.

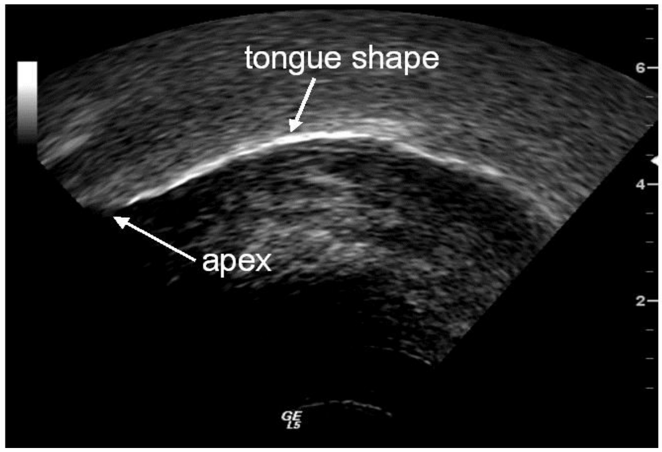

Figure 3.2. Tongue contour as seen in an ultrasound image.

Data Analysis

Fan spline setups were decided based on the advancement of the tongue for vowel category. For front vowels, the fan was more towards the anterior region and for back vowels more towards the posterior region. Semiautomatic contour plotting was used in this study. The three frame images of each utterance were averaged in workspace to minimize the variation. After averaging the mean contour of each vowel comparison between groups were carried out. The averaging of all the mean values of a particular vowel for all the male participants from each age group gave the mean value for that particular vowel in that age group. Likewise the mean values for other vowels and that for females were also evaluated. The difference in tongue contour for each vowel was determined across age groups and across normal and hearing impaired groups. Each of these images was exported to another window called Publisher where they were stored as images in Pixels. To describe the tongue contours, the tongue was divided in to three regions- the posterior tongue body, anterior tongue body and the tongue front (figure3.3) (Davidson, 2006).

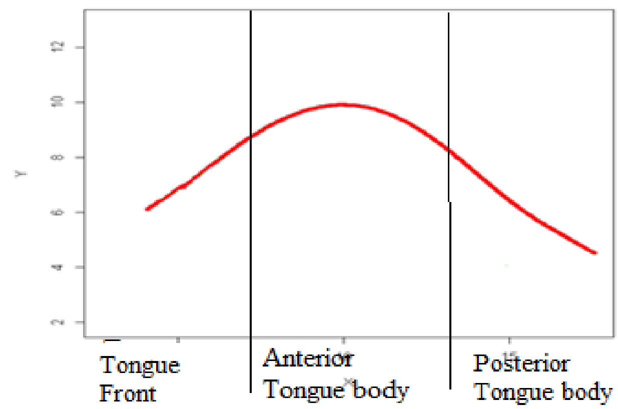

Figure 3.3. Schematic representations of divisions of tongue contour into three regions- the posterior tongue body, anterior tongue body and the tongue front. The vertical and horizontal (X) scale is in mm.

Formal Statistical analysis was not used in the study. The results of tongue height and comparison between the vowel productions of participants are discussed based on visual examination of the tongue contours.

CHAPTER 4 - RESULTS AND DISCUSSION

The present study aimed to compare the tongue contours during the production of vowels in 18 children with hearing impairment and their age and gender matched typically developing children using ultrasound imaging. Hence the total numbers of participants were 36 children. The vowels studied and compared are /a: /, /I: /, /u: /, /o: / and /e: /. The results of the study are presented in terms of comparison of tongue contours across males of the HI and normal group and similarly across females of both the groups. The results are described and discussed based on visual inspection of the tongue contours during the vowel production. To describe the tongue contours, the tongue was divided in to three regions- the posterior tongue body, anterior tongue body and the tongue front (Davidson, 2006) as shown in Fig 1.

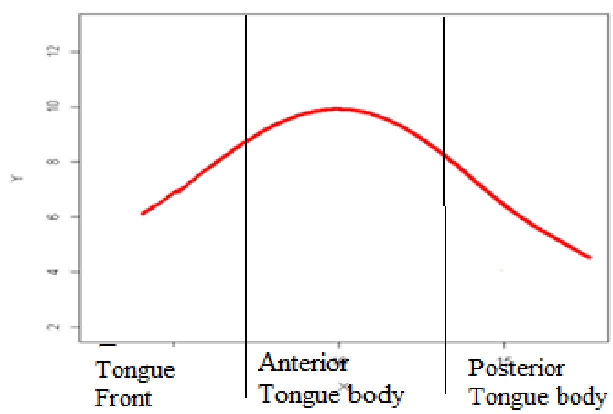

Figure 4.1: Schematic representations of divisions of tongue contour into three regions- the posterior tongue body, anterior tongue body and the tongue front.

The description of the tongue contours for the vowels studied are presented below.

1. Tongue contours for long low central vowel /a: /

a) Fig.4.2 shows the comparison between tongue contours of vowel /a: / of children with hearing impairment and age matched control participants in the age range of 4 -5 years. There were prominent changes in the pattern of the tongue contour. In both male and female hearing impaired participants, tongue contour shows higher tongue height and more anterior positioning than the control group.

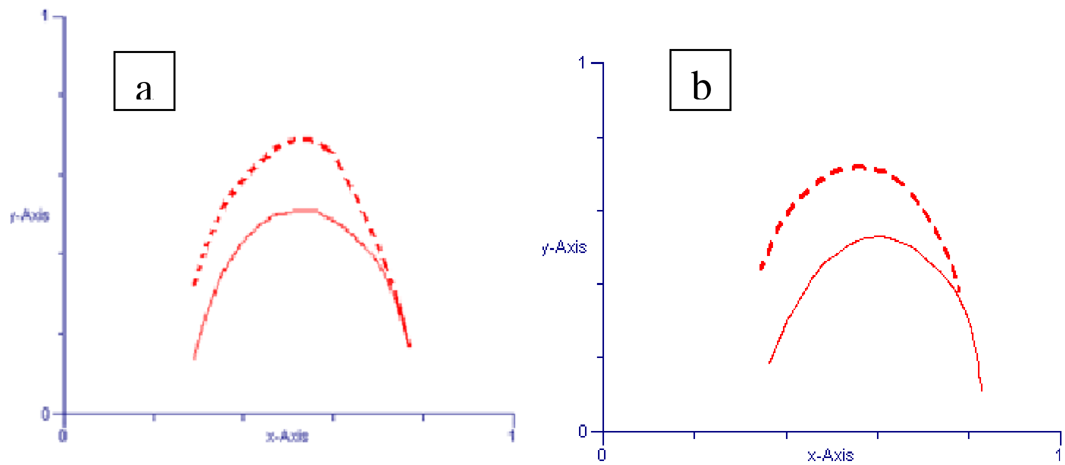

Figure 4.2: Shows the tongue contours of vowel /a: / in a) Males and b) Females with hearing impairment (dotted lines) and normal children (solid lines) in the age range of 4 – 5 years.

Tongue contours of both the genders also showed larger variation in their tongue height and advancement. McGarr and Harris (1983) reported about large token-to-token variability in the hearing impaired speaker while attempting to speak. They reason out the variability in the speech production based on combination of several factors such as residual hearing level, age of acquisition of the hearing loss, intelligence, and the speech training program the individual is exposed to.

In the present study the youngest participants in the age range of 4 – 5 years were enrolled in the speech training program for a year or so. It is observed that during the initial stages of speech therapy, children tend to use exaggerated articulatory movements for attaining correct speech production. This is possibly a reason for the high positioned and advanced tongue shape in the hearing impaired children compared to their normal controls.

b) Fig.4.3 depicts the comparison between tongue contours of vowel /a:/ of children with hearing impairment and age matched control participants in the age range of 5 -6 years. Even though the curvature of the contour looks similar in both the groups, the position is observed to be more towards anterior region and the tongue height is reduced in the hearing impaired male group. Compared to the male group, contours of the females in the hearing impaired group (Fig 4.3b) were more similar to the female control group. .

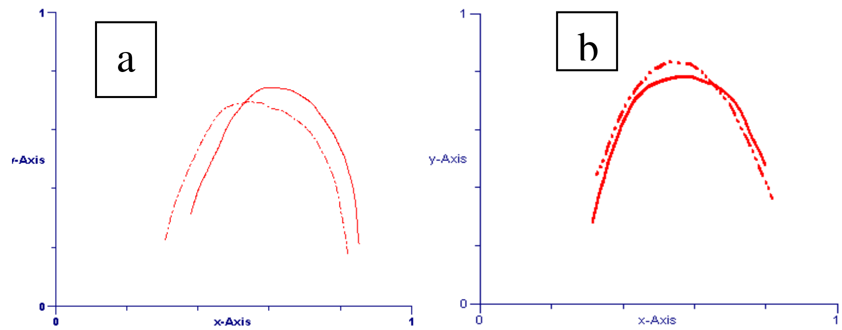

Figure 4.3. Shows the tongue contours of vowel /a: / in a) Male and b).Female children with hearing impairment (dash-dotted lines) and normal children (solid lines) in the age range of 5 – 6 years.

When we consider the intervention details of the participants in the age range of 5 – 6 years, all the participants had the benefit of early identification of hearing loss followed by early intervention programme. The participants were enrolled in the therapy programme at an early age and they have better speech production skills which facilitated their near normal tongue placement during vowel production.

c) Fig.4.4 depicts the comparison between tongue contours of vowel /a: / of children with hearing impairment and age matched control participants in the age range of 6 -7 years. In Fig 4.4a, tongue contour of male children with hearing impairment are lower in terms of vowel height and curve is flat compared to tongue contour of the control group. The difference occurs in the tongue front and anterior tongue body region, where as the countours coincide in the posterior tongue region. But female children with hearing impairment of the same group showed contradictory results, as difference was seen in the posterior tongue region and it coincides in the anterior tongue body and tongue front regions.

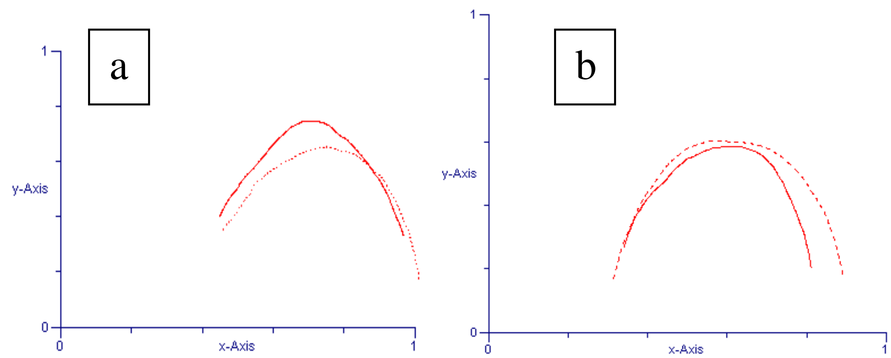

Figure 4.4: Shows the tongue contours of vowel /a: / in a) Male and b).Female children with hearing impairment (dash lines) and normal children (solid lines) in the age range of 6 – 7 years.

There are numerous studies which explain the restricted articulatory movements of the hearing impaired children during speech production. McGarr and Harris (1983) suggest that for HI persons there is minimal tongue positioning differentiation during vowel production that is independent of jaw placement. Further, while range of positioning appears minimized, variability within that range is broad. It was recommended that this variability was due to the HI person's lack of knowledge about tongue movements because of the tongue's invisibility.

2. Tongue contours for long high front unrounded vowel /I: /

a) Fig.4.5 depicts the comparison between tongue contours of vowel /I: / of children with hearing impairment and age matched control participants in the age range of 4 -5 years. Overall, contour patterns were similar in male hearing impaired and normal children However, higher tongue height was noted in the hearing impaired compared to matched controls. Contours for females in the same age group showed less arched and more anterior tongue advancement in the hearing impaired group.

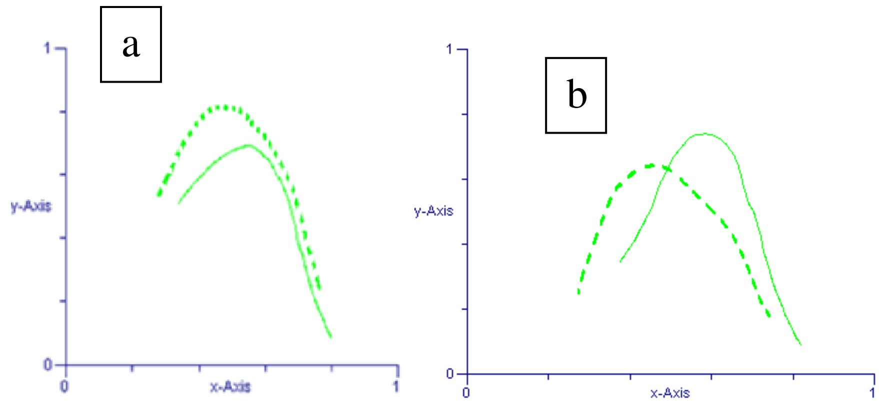

Figure 4.5. Shows the tongue contours of vowel /I: / in a) Male and b).Female children with hearing impairment (dotted lines) and normal children (solid lines) in the age range of 4 – 5 years.

As discussed earlier, younger age group children's exaggerated articulatory movements for the speech production can be a reason for the presence of higher tongue height and extra advancement in the tongue contours of male children with hearing impairment compared to the control group. Another reason can be discussed based on the production difficulty of the front vowel /I: / compared to other low vowels because of its less visibility.

b) Fig.4.6 depicts the comparison between tongue contours of vowel /I: / of children with hearing impairment and age and gender matched control participants in the age range of 5 -6 years. In figure 4.6a, the tongue contour is observed to be more towards anterior region in the control group compared to the experimental group in males. Fig 4.6b shows higher tongue height and broader tongue shape in hearing impaired female children compared to the control group.

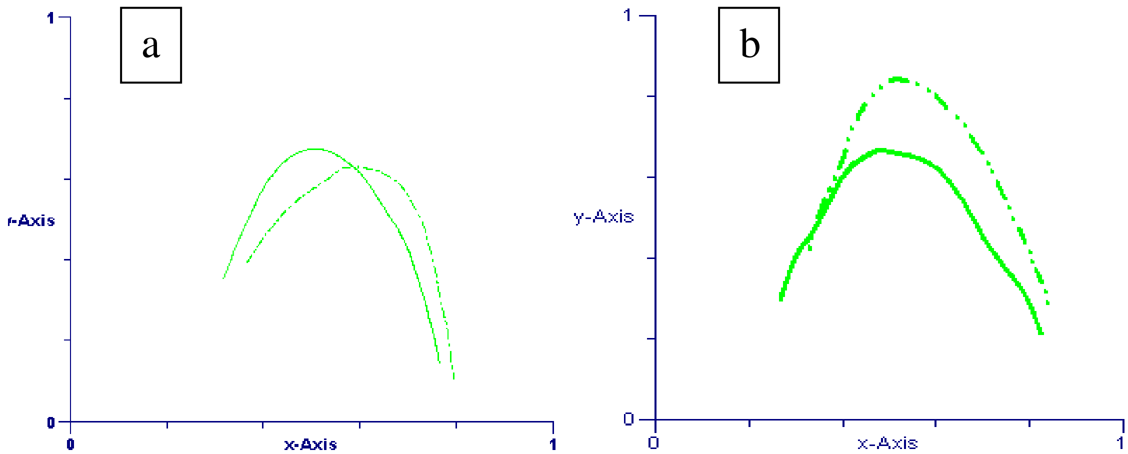

Figure 4.6: Shows the tongue contours of vowel /I: / in a) Male and b).Female children with hearing impairment (dash-dotted lines) and normal children (solid lines) in the age range of 5 – 6 years.

c) Fig.4.7 shows the comparison of tongue contours of vowel /I: / of children with hearing impairment and age and gender matched control participants in the age range of 6 - 7 years. In figure 4.7a, there is variation in the tongue shape as normal children used more arched tongue position which is different from the comparatively flat tongue shape used by the hearing impaired subjects. Vowel height is also seen to be lower in them. Tongue contours of the female children with HI also showed a more flat tongue shape and lower vowel height compared to the normal group.

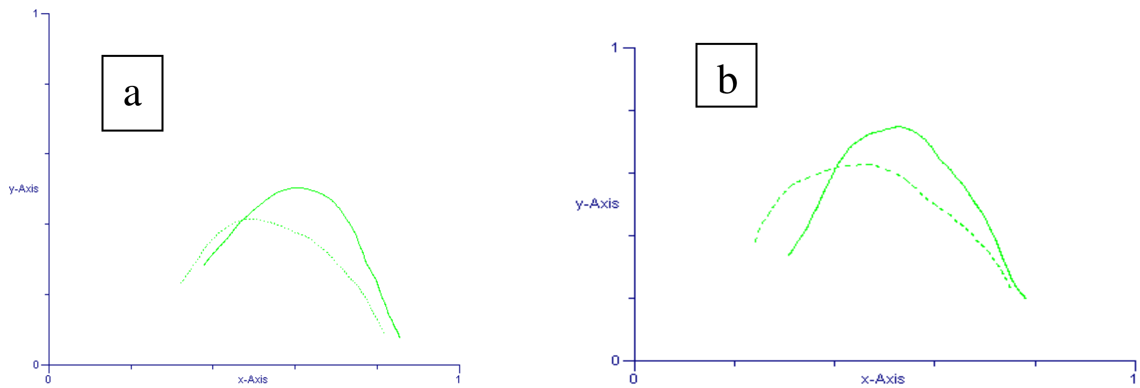

Figure 4.7. Shows the tongue contours of vowel /I: / in a) Male and b).Female children with hearing impairment (dotted lines) and normal children (solid lines) in the age range of 6 – 7 years.

3. Tongue contours for long high back rounded vowel /u: /

a) Fig 4.8a depicts the comparison between the tongue contours of vowel /u: / of children with hearing impairment and age matched control males in the age range of 4 – 5 years. The overall pattern was similar in the tongue contours of male children. However the tongue height and tongue advancement are more for the hearing impaired children than the normal group. Tongue contours of the hearing impaired females children shows comparatively low tongue height with more anterior position compared to normal controls.

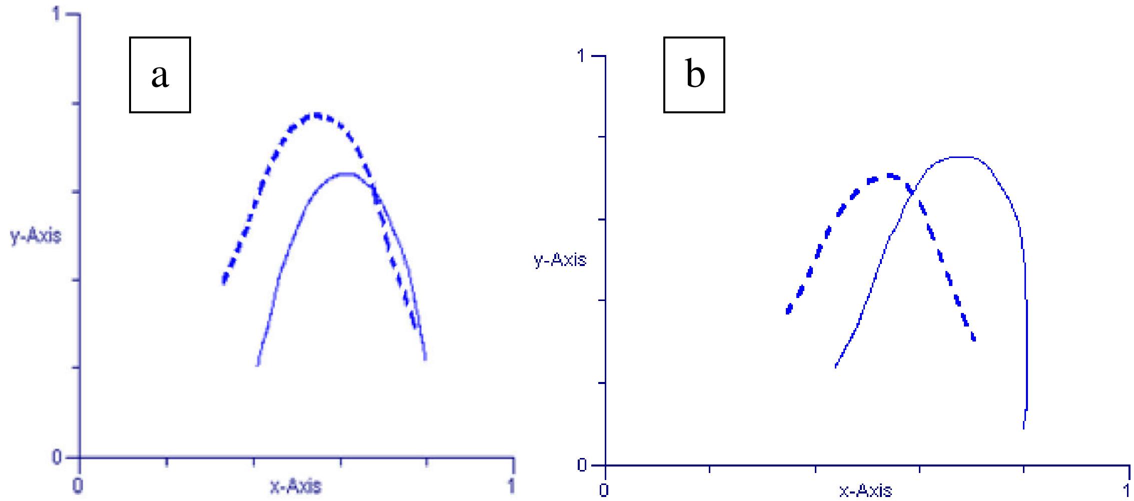

Figure 4.8. Shows the tongue contours of vowel /u: / in a) Male and b).Female children with hearing impairment (dash lines) and normal children (solid lines) in the age range of 4 – 5 years.

b) Fig. 4.9a depicts the comparison between the tongue contours of vowel /u: / of children with hearing impairment and age matched control males in the age range of 5 – 6 years. In figure 4.9.a, both the groups showed similar pattern of tongue contours. Hearing impaired female children showed clearly more anterior tongue position and higher tongue height compared to the control group.

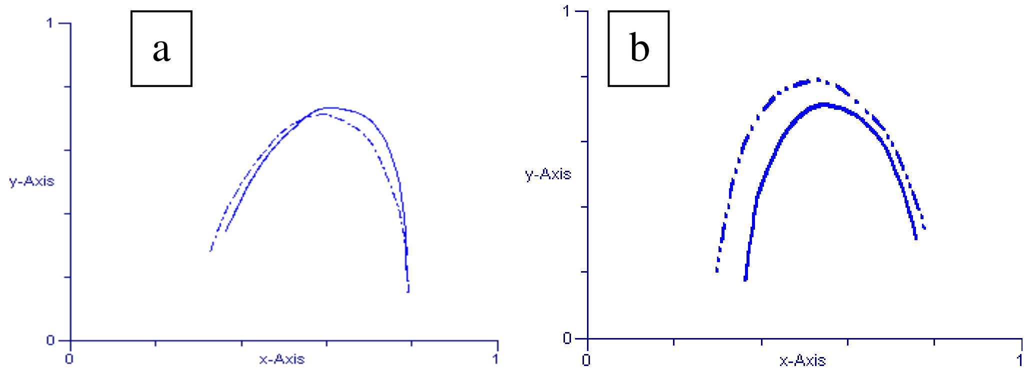

Figure 4.9: Shows the tongue contours of vowel /u: / in a) Male and b).Female children with hearing impairment (dot- dash lines) and normal children (solid lines) in the age range of 5 – 6 years.

The near normal tongue positioning of the male children with hearing impairment in this group can be related to the early intervention and less severity of their hearing loss. All three male participants had only severe degree of hearing loss. Ozbic's (2008) study of vowel formant production in normal, severe and profound hearing loss participants discusses about the better performance in participants with severe hearing loss compared to profound. They mentioned the closed relation of the frequencies of vowel formants of the individuals with hearing impaired with the degree of hearing loss. As the hearing loss increased, the second formant of the front vowels decreased and those of the back vowels increase, the first formants increase in the extreme back and front vowels and decrease in the middle low vowel. Their conclusion states that hearing impairment changes the monitoring of speech production and consequently the formant frequencies and the variability of speech production. Thus lesser hearing loss and advantage of early intervention would have helped the participants in this group for the near normal tongue positioning for the production of vowels.

c) Fig.4.10a depicts the comparison between the tongue contours of vowel /u: / of children with hearing impairment and age matched control males in the age range of 6 – 7 years. The broadness of the tongue contour of hearing impaired males was more compared to the control group. Tongue contours for the females in the same group showed more similar tongue height and arch but showed large difference in the advancement as hearing impaired children were observed to have more anterior position.

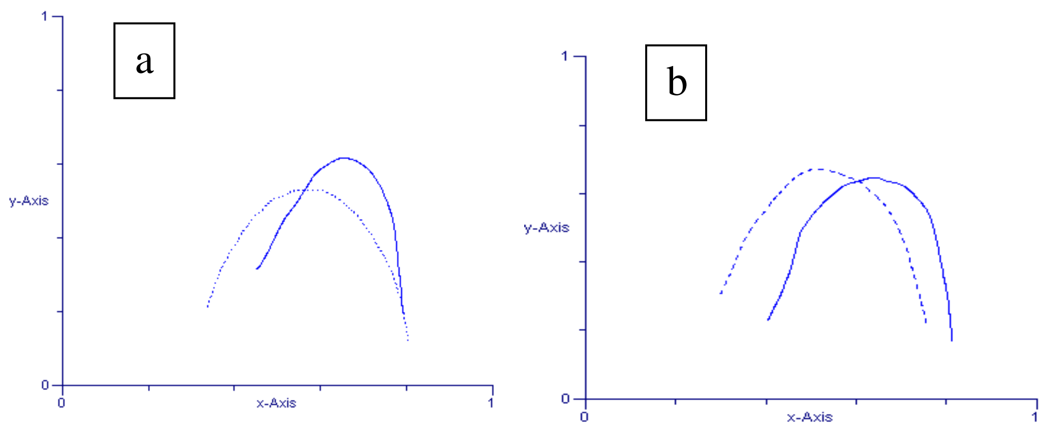

Figure 4.10: Shows the tongue contours of vowel /u: / in a) Male and b).Female in children with hearing impairment (dash lines) and normal children (solid lines) in the age range of 6 – 7 years.

For the production of high back vowel /u: /, lip rounding is a major production cue. We have already discussed the tendency of children with hearing loss to exaggerate their articulatory movements to achieve correct articulation. Hence, due to the presence of exaggerated lip rounding the tongue may also have an effect leading to the more anterior positioning.

4. Tongue contours for long mid-front unrounded vowel / e: /

a) Fig.4.11a depicts the comparison between the tongue contours of vowel /e: / of children with hearing impairment and age matched control males in the age range of 4 - 5 years. In Fig 4.11a, there is considerable variation in the tongue height and broadness of the tongue contour as hearing impaired showed higher tongue height and increased broadness in tongue shape. Figure 4.11b, shows prominent difference between both the groups in terms of tongue shape, tongue height and advancement. Normal children used more arched tongue position compared to the flat tongue shape used by the hearing impaired subjects. The vowel height is also seen to be lower in the hearing impaired group.

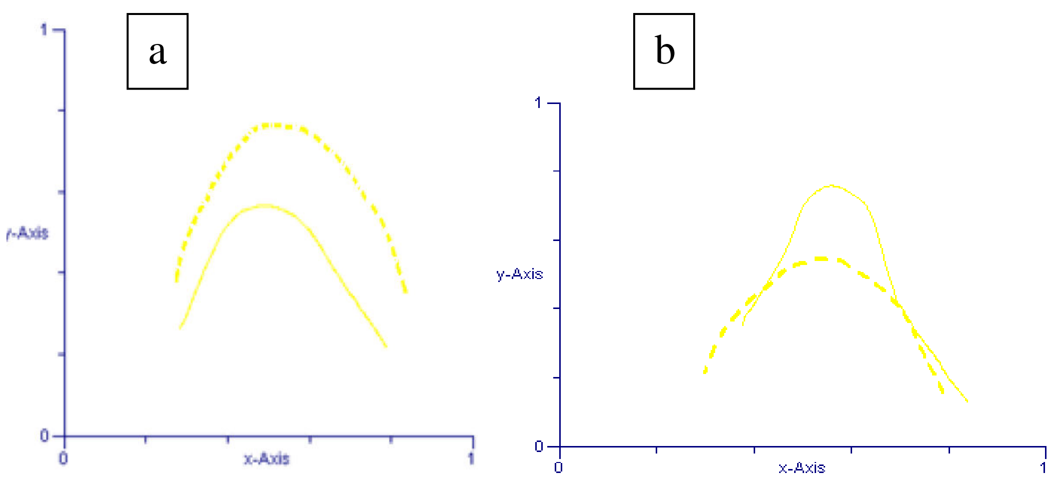

Figure 4.11: Shows the tongue contours of vowel /e: / in a) Male and b).Female children with hearing impairment (dash lines) and normal children (solid lines) in the age range of 4 – 5 years.

Similar to the production of other vowels, higher tongue height and broader tongue shape in hearing impaired children in the current age group can be explained in terms of exaggerated articulatory movements due to the initial level of training. And previous studies also confirm the usage of different ranges of vertical tongue positioning for the front vowels in hearing impaired subjects (Critz Crosby & Dagenais ,1991).

b) Fig.4.12a depicts the comparison between the tongue contours of vowel /e: / of children with hearing impairment and age matched control males in the age range of 5 - 6 years. In male children, both the groups showed similar tongue shape and tongue height except in terms of advancement, where contours of hearing impaired had more anterior positioning compared to the control group. In case of females as in Fig 4.12b, tongue contours for both the groups had similar pattern in terms of tongue advancement, tongue shape and tongue height.

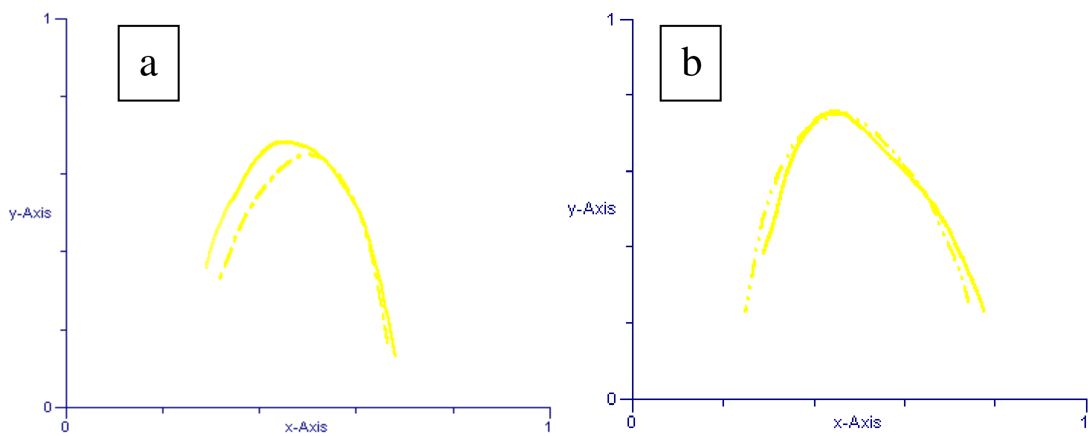

Figure 4.12: Shows the tongue contours of vowel /e: / in a) Male and b).Female children with hearing impairment (dot-dash lines) and normal children (solid lines) in the age range of 5 – 6 years.

As mentioned earlier, the better production and near normal tongue shape of the current group can be correlated with the factors like lesser degree of hearing loss, longer period of exposure to natural speech and better intervention.

c) Fig.4.13 depicts the comparison between the tongue contours of vowel /e: / of children with hearing impairment and age matched control males in the age range of 6 - 7 years. Similar to other vowels, production of /e: / in male hearing impaired children also showed flatter and less arched tongue shape compared to matched controls. Tongue contours of the female group showed similar tongue shape in both the groups with advanced anterior positioning in the contour of hearing impaired children.

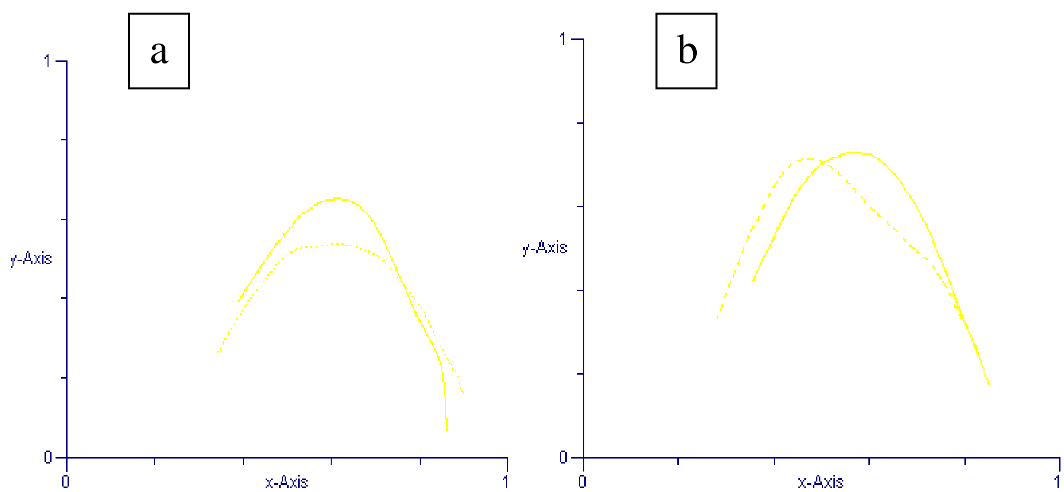

Figure 4.13: Shows the tongue contours of vowel /e: / in a) Male and b) Female in children with hearing impairment (yellow dot-dash lines) and normal children (yellow solid lines) in the age range of 6 – 7 years.

For this age group, the shapes of the tongue contours are observed to be similar for normal children in both males and females.

5. Tongue contours for long mid-back rounded vowel /o: /

a) Fig.4.14 depicts the comparison between the tongue contours of vowel /o:/ of children with hearing impairment and age matched controls in the age range of 4 - 5 years. Fig.4.14a shows contours of male hearing impaired children with similar tongue shape, higher tongue height and advanced positioning compared to the matched normal group. Tongue contours for the female children with hearing impairment in the same group showed tongue contour with similar tongue height, broader arch and anteriorly positioned compared to the control group.

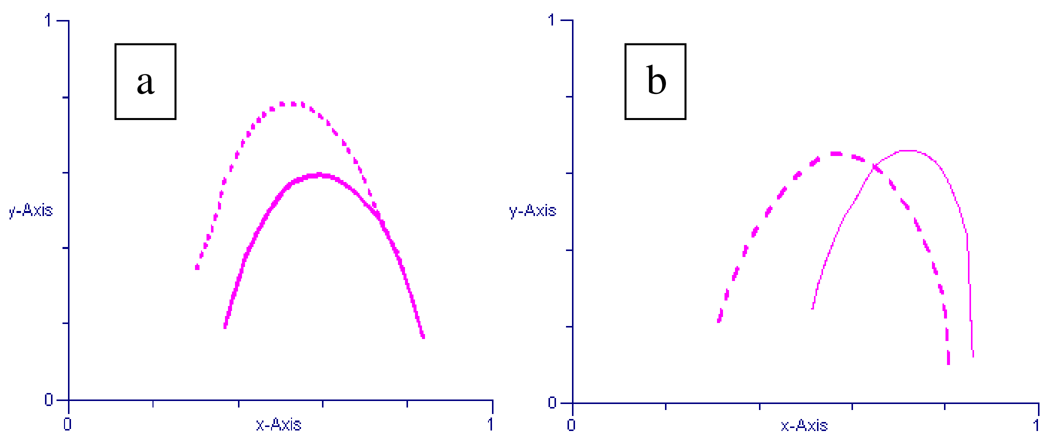

Figure 4.14: Shows the tongue contours of vowel /o: / in a) Male and b).Female children with hearing impairment (dot lines) and normal children (solid lines) in the age range of 4 – 5 years.

The shape and positioning of the tongue contours of the vowel /o: / is observed to be similar to the production of back vowel /u: / in the same group (17a and 17b).

b) Fig.4.15a depicts the comparison between the tongue contours of vowel /o: / of children with hearing impairment and age matched control males in the age range of 5 - 6 years. In both the figures (Fig. 4.15a and Fig. 4.15b) shape of the tongue contours and advancement are observed to be similar in both the groups with difference in tongue height only. Hearing impaired male children show lower tongue height and female children show higher tongue height than their controls.

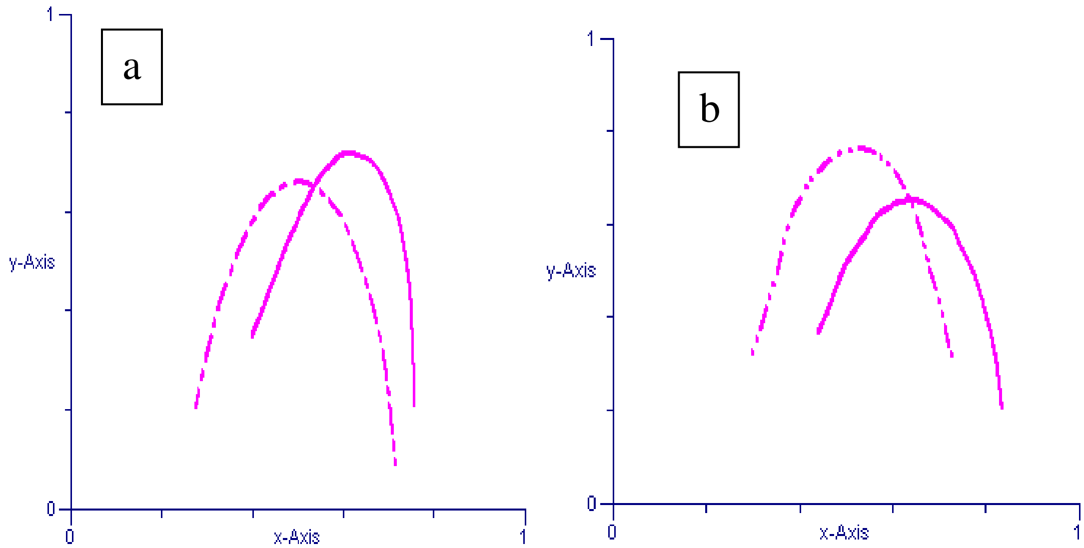

Figure 4.15: Shows the tongue contours of vowel /o: / in a) Male and b).Female children with hearing impairment (dash lines) and normal children (solid lines) in the age range of 5 – 6 years

b) Fig.4.16 depicts the comparison between the tongue contours of vowel /o: / of children with hearing impairment and age and gender matched controls in the age range of 6- 7 years. Hearing impaired male children show comparatively flatter and somewhat advanced tongue contour than the normal group. The female hearing impaired children's tongue contour has comparatively similar tongue height with broader shape and advanced anterior position than the control group. More tongue advancement in children with hearing impairment may be correlated with their higher mean F2 values (Grover, 1998- Punjabi; Paul 1998- Malayalam; Rathna Kumar 1998;- Telugu).

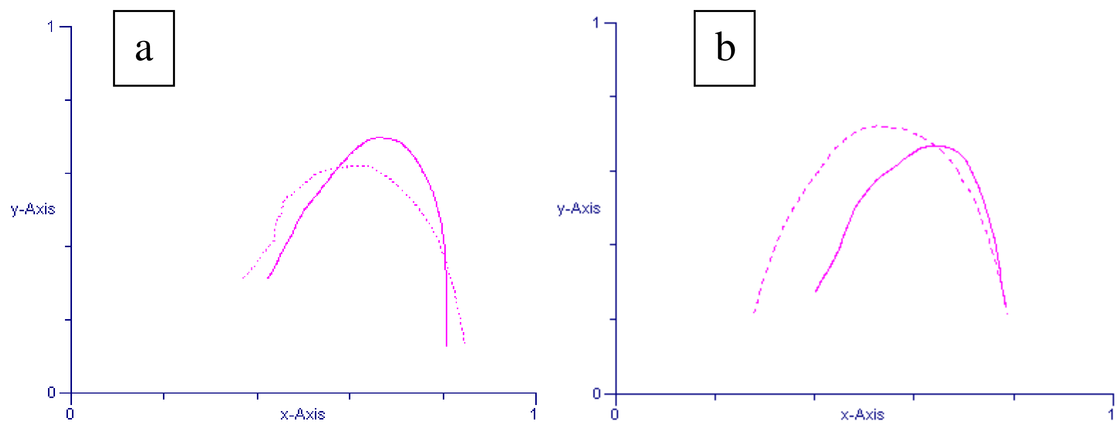

Figure 4.16: Shows the tongue contours of vowel /o: / in a) Male and b).Female children with hearing impairment (dotted lines) and normal children (solid lines) in the age range of 6 – 7 years

To summarize the results of the present study indicated that children with hearing impairment demonstrated somewhat deviant patterns in terms of tongue height and advancement though perceptually the correct production of the target vowel was considered for the ultrasound analysis.

CHAPTER 5- SUMMARY AND CONCLUSIONS

Vowels are speech sounds which are minimally kinesthetic and maximally auditory controlled. Therefore the role of auditory feedback in vowel production is very important. Perceptual, acoustic and physiologic descriptions are abundant on the vowel production abilities of hearing –impaired speakers. Increased availability of high quality recordings of children's speech and newer technologies like MRI and glossometry enabled the researchers to advocate increased use of acoustic data and its integration with anatomical, physiological, and perceptual data to account for speech development and production of speech sounds. Ultrasound imaging is a non-invasive technique that can visualize in real time internal soft tissues of the articulators involved in speaking. Most of the studies in literature on the ultra sound tongue contours are in non Indian languages. Investigative studies using ultrasound are very few across different places of articulation in Indian languages and are mostly limited to selected contrasts produced by single speakers of languages such as Hindi, Tamil, Telugu Kannada and Malayalam. There are no reported studies using ultra sound in the Indian context on disordered population. Hence the present study is planned to investigate the tongue contours during vowel productions of children with hearing impairment using ultrasound imaging system.

Participants included 18 native Kannada speaking children with hearing impairment and 18 age and gender matched typically developing children that includes 36 participants. The vowels studied and compared using ultrasound are /a: /, /I: /, /u: /, /o: / and /e: /.

Perceptual evaluations of the vowel production of the experimental group were carried out by three Masters level speech language pathologists. Recordings of target vowels produced correctly by children with hearing impairment based on a perceptual evaluation were only considered for ultrasound analysis. Mindray ultrasound 6600 connected to a PC and installed with the software Articulate Assistant Advanced (AAA) ultrasound module Version 2.14 was used for data recording and analysis. Participants were made to sit comfortably on a high back chair and the five target utterances were recorded using repetition procedure. Three repetitions of five target stimulus were also recorded. The ultrasound probe was placed under the chin of the participant and a microphone attached to the headphone was used for recording the stimuli. Three repetitions of the five target stimuli were also recorded. The results of the study are presented in terms of comparison of tongue contours across males and females separately between children with hearing impairment and matched normal controls in the three age groups. The results are described and discussed based on visual inspection of the tongue contours during the vowel production.

To summarize the results, the tongue contour during vowel production on comparison between children with hearing impairment and their age and gender matched control group, shows that

- Changes in the tongue contours are in terms of three dimensions as tongue shape or pattern of the contour, tongue height and tongue advancement.
- Visual inspections of the tongue contours of target vowels in the three age groups revealed that the younger age group which includes children in the range of 4 -5

years demonstrated high variations in terms of both tongue height and advancement compared to older two age groups.

- Increased tongue height and advancement of tongue contours in the 4-5 years group children are explained in terms of their tendency to exaggerate the articulatory movements during speech production due to inadequate speech training.
- Participants of the hearing impaired group in the age range of 5 -6 years showed less differences in their tongue shapes compared to control group across the vowels. Better performance of these participants was explained in terms of their reduced degree of hearing loss, long time exposure to natural speech and better intervention which are inferred from their demographic details.
- For children in the age range of 6 -7 years, tongue contours generally showed less arched or flatter tongue contour shape across all the vowels. This trend is discussed in terms restricted tongue movements in hearing impaired children.
- Visual inspection of the tongue contours of the vowel /a/ gives a developmental trend across the age group. It was observed that as age range increased the tongue contours of hearing impaired showed better correlation with the control group. Considering the remaining vowels /i/, /u/, /e/ and /o/, it was observed that tongue height correlated better with normal group as age increases whereas the tongue advancement was more deviant with increase in age.

The present study helps in understanding the differences in tongue contours of vowel production in children with hearing impairment and age and gender matched typically developing children. The discussed dimensions, tongue shape, tongue advancement and tongue height can be explored in normal population and applied in speech sound disordered population to improve their tongue dynamics. They can be used as a visual feedback for clients with speech sound errors during treatment since they are visually depictable for better feedback about their vowel production pattern. Thus this will help SLPs to make appropriate therapeutic goals for vowel production for the hearing impaired population for their improved articulation skills.

Future directions

- Conduct study in larger sample population focusing the difference across age groups, between genders and also in different communication disordered population in Indian context.
- Future studies have to be conducted to explore the efficiency of ultrasound imaging as a visual feedback approach.
- Use of Ultrasound imaging in the Pre-post evaluations of tongue movements of person with different communication disorder.
- Scope of ultrasound imaging as a diagnostic tool by designing measures which can produce quantitative results.
- Impact of Ultrasound imaging measures with the combination of other available imaging techniques like EMMA.

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