# ULTRASOUND STUDY OF THE RETROFLEX PLOSIVES OF NEPALI LANGUAGE


Sabin Sharma Duwadi

**Register No: 18SLP030**


A Dissertation Submitted in Part Fulfilment of Degree of Master of Science

(Speech-Language Pathology)

University of Mysore

Mysuru


ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSURU—570 006


July 2020

# CERTIFICATE

This is to certify that this dissertation entitled "**ULTRASOUND STUDY OF THE RETROFLEX PLOSIVES OF NEPALI LANGUAGE**" is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 18SLP030. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for award of any other Diploma or Degree.

Mysuru

July 2020

**Dr. M. Pushpavathi**

**Director**

All India Institute of Speech and Hearing

Manasagangothri,

Mysuru—570006

## CERTIFICATE

This is to certify that this dissertation entitled "**ULTRASOUND STUDY OF THE RETROFLEX PLOSIVES OF NEPALI LANGUAGE**" is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 18SLP030. This has been carried out under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for award of any other Diploma or Degree.

Mysuru

July 2020


**Guide**

Dr. K Yeshoda

Associate Professor

All India Institute of Speech and Hearing

Manasagangothri,

Mysuru—570006

# DECLARATION

This is to certify that this dissertation entitled "**ULTRASOUND STUDY OF THE RETROFLEX PLOSIVES OF NEPALI LANGUAGE**" is the result of my own study under the guidance of Dr. K Yeshoda, Associate Professor, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for award of any other Diploma or Degree.

***Mysuru*** ***Registration Number: 18SLP030***

***July 2020***

*Dedicated to God, my Parents, my guide Yeshoda ma'am and all the well wishers*

## Acknowledgment

The first gratitude goes to the **God** almighty who has been warding off my every hurdle and bestowing me the divine grace in order to complete the work. Hail to you, the omnipotent one, and please accept this work as an offering from your child.

My full heart thanks go to my beloved dissertation guide **Dr. Yeshoda** not only for the mere completion of this dissertation but for being a guardian, mentor and teacher since the beginning days of mine at AIISH. Ma'am, you are the one to plant the seeds of basic speech science and voice pathology on me. From you we have learnt the ideal professionalism, humanitarianism and discipline of life. You have taught us to face any situations with intellect, rationale, and patience. Hence, I will always be lacking enough words to thank you. I find myself sanctified to have you as my guide.

I would like to thank the Director of AIISH, **Dr. M. Pushpavathi** and the Head of the Department of Speech and Language Sciences, **Dr. Jayakumar T** for providing me the opportunity to conduct the study and for the permission to access the facilities in the department including the phonology lab. I would also like to thank my beloved JC guide **Dr. Sreedevi** for the support in every works of mine.

**Maa and Papu**, you are the one who is supposed to take the sole credit of this work. I do obeisance to you. It's always your blessings and care which has made it possible. I hope I will be able to make you both proud and happy forever. **Mamu**, my maternal grandma, it's your grace and the best wishes which always have been there with me. I know my gratitude to you can't be expressed here in words.**Aama**, my paternal grandma, thank you for well wishes, and I seek your blessings. I also thank my great-grandmother **Hajuri** for the selfless support and love this long.

Thank you my entire family—**Mammam, Appa, Pupa Akki, Mama and Maiju** for your constant love. My sister **Kajol** have been one of my best friends since childhood and her love and support continues even now.**Aadu, Akshaya, Apoor and Nairhitya** love you all my brothers.

Among my teachers, the first and foremost gratitude with due respect goes to **Mr. SureshwarLalKarna**. He holds the title "Father of speech and hearing of Nepal" and I am always proud to have him as my "Guru" and blessed to be known as his product.

Thank you,Karna sir. Similarly, thank you **Khanal sir**, it is you with whom I learnt the ABCs of speech-language pathology. The values, knowledge and motivation you have given have led me to this state to complete my work. I would thank **Sushmita ma'am**and **Krishna ma'am** for the constant support and motivation; I am your student forever. I would also like to thank **Mr. BhojrajGautam**, linguistic researcher, for his help in this work providing certain information on Nepali linguistics.

**Sujaldai**, you are the first one to introduce this field to me. I will never forget your help regarding the knowledge and resources you provided me that has made me capable of being in the position to write this master's dissertation. Still, you have constantly been motivating and guiding me. Thank you dai!

**Kranti, Dibya and Sapana**, the three of you have been more than friends to me as we have come across a very long journey together since the bachelor days. In every step, you all have supported me very much. Hope this relation of ours is everlasting. Thanks a lot to you, girls.

**Prasanna**, you have been my own brother more than a friend, have helped me, and have become with me in every way, which means a lot to me. You have supported me very much not only to complete this work but in a lot of other things, and I thank you for this. Thanks,**Nadeer**, for cherishing me whenever I would get bored, supporting me constantly, and helping me in many ways.

**Nayanika and Anuroopa** are the best dissertation partners I would ever get. The time we spent together, the way we motivated each other, the way we helped each other, which we remember now, will make us believe we trio were the perfect combo for the dissertation and hence true friends.

**Neha**, I am always happy to get a close friend like you—thank you for the company. **Sweekriti (bro),** you have always been a special friend to me and thanks for everything. **Neeraja**, you always have been motivating me and caring me—thanks for everything. **Riddhi** you have helped me in many ways—thank you!**Archu and Pari**, you both are amazing and ever-cool ones.

**Syedaaaaa (Sameera)**, **Sar-eh(Sarah)** and **Hima**, you girls are awesome and thanks for being with me. Thank you **Monika**; you are a hardworking spirit and this will bear fruit soon. **Ankita**, thanks for the Kannada lessons (Haha) and best wishes. **Pauline, Sundu, Roja (Jenny Martin), Sivaranjini and Sashi** you all are sacred-heart girls and I thank you all. **Sreerenthu, Swaliha ,Sudarsana,Rishisha and Reshma** have been very helpful to me, and I thank them. **Akhil, Sachin, Prajwal, Thakur, Ashique,Gowtham, Basih, Ajith, Kiruba, Kalai, Rohith, Rakesh and Shreyas**, thank you guys. I hereby thank my entire batchmates" **BRAINIACS**" for their support for entire two years of AIISH life and this dissertation completion.

Thank you,**AnujDai**—you were the one who always guided me with valuable suggestions and ideas in this place which had been a novel land earlier to me. **Aashish, Biraj, Prabuddha, and Dilli,** we have been together and intimate since so long and this time, the contribution of you guys in my dissertation is incomparable. Thank you, guys. Thank you **Shradha** for your tremendous help in dissertation. **Shashish**, the little brother of mine, how can I forget how much closer you have been to me since my beginning days at AIISH , thanks and God bless you.

Finally, I would like to thank all my faculties of AIISH because of whom I have learnt different aspects of speech language pathology and who have helped me be a better professional and researcher in future. Also to entire students and staffs of AIISH who helped me to complete the dissertation work in a better way. AIISH has always been a haven for those who aspire to learn, research and explore new things; I am always blessed to become a part of it.

## Table of Contents


| Chapter No. | Contents | Page no. |
|---|---|---|
| | List of Figures | ii-iii |
| 1 | Introduction | 1-4 |
| 2 | Review of Literature | 5-19 |
| 3 | Method | 20-25 |
| 4 | Results and Discussion | 26-45 |
| 5 | Summary and Conclusion | 46-48 |
| | References | 49-53 |

## List of Figures


| **Figure No.** | **Figure Name** | **Page No.** |
|---|---|---|
| 3.1 | Mindray Ultrasound 6600 | 21 |
| 3.2 | Tongue Contour in Ultrasound Imaging | 23 |
| 3.3 | Semi-automatic Plotting of Tongue Contour Obtained by Ultrasound Analysis | 24 |
| 4.1 | Tongue Contours of the Production of Target Phonemes of Subject 1 | 27 |
| 4.2 | Tongue Contours of the Production of Target Phonemes of Subject 2 | 28 |
| 4.3 | Tongue Contours of the Production of Target Phonemes of Subject 3 | 29 |
| 4.4 | Tongue Contours of the Production of Target Phonemes of Subject 4 | 29 |
| 4.5 | Tongue Contours of the Production of Target Phonemes of Subject 5 | 30 |
| 4.6 | Tongue Contours of the Production of Target Phonemes of Subject 6 | 31 |
| 4.7 | Tongue Contours of the Production of Target Phonemes of Subject 7 | 31 |
| 4.8 | Comparison of Tongue Contours of /ʈ/ between Male and Female Groups | 33 |

| | | |
|---|---|---|
| 4.9 | Comparison of Tongue Contours of /ʈ$^{h}$/ between Male and Female groups | 34 |
| 4.10 | Comparison of Tongue Contours of /ɖ/ between Male and Female Groups | 35 |
| 4.11 | Comparison of Tongue Contours of /ɖ$^{h}$/ between Male and Female Groups | 36 |
| 4.12 | Comparison of the Tongue Contours of /ʈ/ and /ʈ$^{h}$/ among Males | 38 |
| 4.13 | Comparison of the Tongue Contours of /ɖ/ and /ɖ$^{h}$/ among Males | 38 |
| 4.14 | Comparison of the Tongue Contours of /ʈ/ and /ɖ/ among Males | 39 |
| 4.15 | Comparison of the Tongue Contours of /ʈ$^{h}$/ and /ɖ$^{h}$/ among Males | 40 |
| 4.16 | Comparison of the Tongue Contours of /ʈ/ and /ʈ$^{h}$/ among Females | 41 |
| 4.17 | Comparison of the Tongue Contours of /ɖ/ and /ɖ$^{h}$/ among Females | 42 |
| 4.18 | Comparison of the Tongue Contours of /ʈ/ and /ɖ/ among Females | 43 |
| 4.19 | Comparison of the Tongue Contours of /ʈ$^{h}$/ and /ɖ$^{h}$/ among Females | 43 |

# CHAPTER 1

# INTRODUCTION

Communication is very important in the human race, irrespective of geo-political boundaries, and different tribes and groups among humans. Since the civilization of humans has shown different patterns as per different regions, lifestyle and culture are also different, and so is language. That is the reason why different geographical regions and different cultural groups have different languages. Among such languages, some are spoken by massive populations around the world and are widely studied, whereas some languages have negligible speakers, and detailed studies of such languages have not been done. It is very important for us to gain necessary insight into the different domains of the languages, their specifications, and documentation so as to correlate the findings onto the further descriptive, comparative, or other types of studies. Such findings can also be useful to be interrelated in clinical practices.

Nepali language belongs to the Indo-Aryan family of languages and is spoken as the first language by 16 million (Census 2011) people in Nepal. Being the official language of Nepal, Nepali is Lingua Franca there. This language is most significantly used in the official works of Nepal and is the most common language form in general communication among the Nepalese population. It is also one of the 22 scheduled languages in India and one of the most spoken languages in Bhutan. There are 29 consonants in the Nepali language, which include those of bilabial, dental, alveolar, retroflex, palatal, velar, and glottal places of articulation (Khatiwada, 2009). These consonants are either voiced or voiceless and aspirated or unaspirated. The Nepali language is transcribed in the Devanagari script, where there are 36 graphemic variations; nevertheless, only 29 consonant sounds are phonemic (Pokharel, 1989). Most of the consonants of Nepali are coronal obstruents for which tongue is a very important active articulator.

A retroflex stop segment is one where the tip of the tongue is curled upwards and backward, such that either the tip or the under-surface of the tip makes an airtight seal at the post-alveolar or palato-alveolar place of articulation (Laver, 1994). Retroflection can also be related to the retraction of the tip of the tongue from the alveolar to post-alveolar position.

The place of articulation of retroflex plosive consonants is between the alveolar ridge and hard palate, and the tongue has flat, curled, or concave shape during the articulation. In such consonants, the point of contact with the tongue can be either apical or laminal or sub-apical. There are four retroflex plosive consonants in the Nepali language—voiceless retroflex plosive /ʈ/, voiceless retroflex aspirated plosive /$ʈ^h$/, voiced retroflex plosive /ɖ/ and breathy voiced retroflex plosive /$ɖ^ɦ$/. At least in the back vowel context, retroflex are consistently post-alveolar with some variation in the active articulator—the tip (apical) or underside of the tongue (sub-apical) (Khatiwada, 2007). When a vowel succeeds voiced retroflex stop consonant, the consonant is phonetically realized as retroflex flap [ɽ] (Khatiwada, 2009).

Nepali retroflexes show a lesser degree of retroflection than other languages of the Indian subcontinent like Marathi, Gujarati, and Tamil (Ladefoged & Bhaskarao, 1983). In Nepali, aspiration is a phonologically contrastive feature among both the voiced and unvoiced obstruents, where the voiced aspirated sounds are termed as breathy voiced sounds (Lageford & Maddieson, 1996). Geminates also occur in the medial positions for the consonants except for approximants and voiced glottal fricative.

These days, because of the evolution of different technologies like Electromagnetic Mid-sagittal Articulograph (EMMA), Magnetic Resonance Imaging (MRI), Glossometry, Ultrasound, X-rays, etc., it has been possible to correlate the acoustic data of speech with its physiological, anatomical and perceptual correlates.

Ultrasound is a safe and non-invasive procedure that creates unique images of the tongue surface by scanning the soft tissue with an ultra-high frequency sound wave (Shawker et al., 1984). It is one of the very important measures for the investigation of the tongue function because it is biologically safe and compatible. Both dynamic and static images of the tongue either in mid-sagittal position or coronal position can be observed in different configurations through ultrasound and are widely used for research purposes. Ultrasound images are two- dimensional and the sequence of which can be used to study the motion of the tongue during speech. In the ultrasound imaging, the upper surface of the tongue will be observed as a white line, and the tongue contour can hence be plotted.

Kochetov, Pouplier, and Truong (2013) investigated the Nepali lingual consonants in terms of differences in tongue shapes in a single native Nepali speaker using ultrasound. The results of the study showed that the apical stops were produced with significantly raised tongue front and retracted tongue tip, and the apical stops that differed in laryngeal features did not show substantial differences in the tongue shape except for the voiced stop.

**The Need for the Study**

The study will be carried out to investigate the articulatory aspects of retroflex consonants of the Nepali language. There are very few studies done on Nepali phonetics, and it is very important to specify the phonemes on the basis of articulatory features as it the official main language of Nepal. Also, very few studies have been done in Nepali language involving imaging techniques and instrumentations due to which the phonetic attribution of the language is yet to be sophistically documented. This study is just a small step in order to explore more into articulatory phonetics of retroflex consonants of the Nepali language on more number of subjects.

In this study, the domain of articulatory phonetics of the Nepali language was investigated. The retroflex plosive consonants of the language will be probed upon using ultrasound imaging by analysing the tongue contours of the speakers using the instrument. This study would be one of the preliminary ultrasound studies in the Nepali language using multiple participants.

# CHAPTER 2

# REVIEW OF LITERATURE

Communication among humans takes place through several modalities, among which speech is the most convenient and common medium. Speech involves the combination of several speech sounds, which are the distinctive phonetic units. Mature speech is the result of coordination and complex interaction between respiratory, laryngeal, and articulatory subsystems, and it is hypothesized that these subsystems may influence each other's course of development (Thelen & Smith, 1994). Speech can thereby be inferred as a complex motor act involving several structures and their functions, among which articulators—lips, tongue, and jaw have a major role.

## 2.1 Preliminary Studies in the Nepali Language

Ayton (1820) is the first in the literature to address the language of Nepal as "The Nepalese language" in his work "A grammar of the Nepalese language." Turnbull (1887) used the term "Nepali language" for the first time in the literature, which is one of the earliest analyses of the language available. Turnbull (1887) stated that the possible pronunciation of common English /ʈ/ is nearer to the Nepali lingual than dental. There is a lack of contrastive vowel length in Nepali (Grierson, 1916). Clark (1963) reported the spirantization of bilabial aspirates and voiced bilabial stops. Further, Clark (1963) also noted the postvocalic and intervocalic flapping of so-called voiced retroflex consonants (Pokharel, 1989). Srivastava (1962) noted /n/ and /l/ as alveolar consonants and, for the first time, located Nepali vowels on the basis of cardinal positions. ɖ/ /ɖʱ/ are initially alveolar or post-alveolar, but post vocalically, they are retroflexed flaps (Clark, 1969). Pokharel (1989) stated that "retroflex plosives of Nepali are not generally retroflexed."

**2.2 Studies related to Retroflex Consonants**

Dave (1977) described retroflexes as the sound produced with the tip of the tongue curled backward behind the alveolar ridge. According to Laver (1994), a retroflex stop segment is one where the tip of the tongue is curled upwards and backward, such that either the tip or the under-surface of the tip makes an airtight seal at the post-alveolar or palato-alveolar place of articulation. By definition, retroflexion also involves a degree of displacement of articulation. Bhat (1974) states that "retraction," which is a secondary feature, plays a very important role in the distinction of retroflexes. The retroflexion, or the curling of the tip of the tongue, is to be correlated with the retraction of the tip from alveolar to post-alveolar position.

Butcher (1995) examined the palatograms and EPG data from single speakers of a number of aboriginal languages of Australia in which it is stated that the retroflexes were most often produced with the underside of the tongue in the post-alveolar or the pre-palatal area of the roof of the mouth. Anderson (2000) conducted a static palatography and acoustic study in Western Arrernte language, one of the Australian languages, involving 12 native speakers of the language. The palatograms obtained from the speakers stated that although the constriction was posterior, the location of the constriction was not particularly far back but in the post-alveolar and even in the alveolar regions. Linguograms of the same speakers were also obtained, which further revealed that retroflexes were produced by the underside or the rim of the tongue.

Svarney and Zvelibel (1955) performed a detailed investigation palatograms, linguograms, and X-ray images obtained from a single speaker of Tamil along with similar data from the speaker of Telugu and Urdu. The aim of the study was to identify the exact part of the tongue involved in the retroflex and dental articulations. It was found that the retroflexes by the Tamil speakers were produced either with the edge of the tip or with the underside of the tip, that is being either apical or sub-apical. The presence of large sub-lingual cavity and the concave shape of the anterior tongue body for retroflexes were observed by the authors during X-ray tracings. When the retroflex tracings are compared to the rest position, the former involved a forward movement of the entire tongue body along with the raising of the anterior body and the front of the tongue.

Ladefoged and Bhaskararao (1982) obtained the X-ray data of five speakers of each of Hindi and Telugu language involving the minimal contrasts among the retroflex and the dental sounds of the two languages. Their results showed that the tongue tip was curled further up and back in Telugu retroflex consonants than in those in Hindi; however, the dental consonants in the two languages were found to be similar.

**2.3 Studies related to the Retroflex Consonants of Nepali Language**

Pokharel (1989) conducted an experimental analysis of the Nepali sound system, which has been one of the preliminary systematic studies in phonology and phonetics of the Nepali language. The participants of the study were nine native speakers of Nepali language belonging to different geographical regions. They were asked to read a word list in a natural way, with a sufficient gap between two items of the data. The study states that plosives and affricates have four-way contrast in the initial position—voiceless unaspirated, voiceless aspirated, voiced unaspirated, and voiced aspirated. Pokharel (1989) reveals that the retroflex plosives of Nepali are not generally retroflexed. Pokharel (1989) finally concluded that there are four retroflex plosive phonemes in the Nepali language-- /ʈ/, /ʈ$^{h}$/, /ɖ/, /ɖ$^{ɦ}$/. The palatographic and linguographic observations made in the study revealed that if the apex of the tongue is the active articulator near the alveolum, the resulting sound is so-called retroflex /ʈ/, /ʈ$^{h}$/, /ɖ/, /ɖ$^{ɦ}$/and if the lamina is the active articulator near the alveo-dental region the resulting sound is so-called dental. He also further stated that the transition for retroflex plosives is longer than that of dental.

Khatiwada (2007) conducted a static palatography study of inter and intra speaker variability of Nepalese retroflex stops in which the participants were eight native speakers of the Nepali language. Two different corpora were investigated in order to study about the articulatory characteristics of retroflex stops of Nepali language among which the first corpus focused upon the differences in the place of articulation in the production of the retroflex stops: voiceless unaspirated, voiceless aspirated, voiced unaspirated and voiced aspirated of Nepali language. The second corpus focused on the influence of vocalic context on the place of articulation and on the amount of lingual contact, and the analysis was restricted to the production of the voiceless unaspirated retroflex stop. Firstly, with the use of a digital camera, both palatograms and linguograms were obtained for both the test items. The place of articulation of the retroflex sounds was on the basis of the dentition plan by Firth (1957)—dental, denti-alveolar, alveolar, post-alveolar and pre-palatal. Two experiments were conducted. According to the experiment 1, it was indicated that the place of articulation of Nepalese retroflex stop productions was realized as post-alveolar. All the retroflex realizations in the experiment were produced behind the alveolar ridge and not produced as apico-alveolar by any of the speakers in the experiment. The voiceless retroflex was found to be more anterior, whereas the voiced retroflex was more posterior, although produced behind the alveolar ridge. Some of the retroflex sounds were produced only with the tip and the rim of the tongue, which indicated that sub-lingual activity might not be necessary to produce retroflex stops in Nepali. However, all the participants had an impression of curling back of the tongue tip. Experiment 2 demonstrated that there was an intra-speaker variation for the retroflexion in the Nepali language. The subjects produced the retroflex segments at the post-alveolar region with the underside of their tongue in the case of the low vowels [a] and against the alveolar ridge in the case of the high vowel [i] which showed there is articulatory variation. Experiment 2 indicated variability in different speakers as well as within the same speaker, depending on the vocalic context. The study finally concluded that retroflex stops studied in the study had both inter-speaker as well as intra-speaker articulatory variation. The retroflex consonants were realized as alveolar in the context of high front vowels and as post-alveolar in the context of back vowels.

## 2.4 The Studies of Tongue Configuration

Tongue dynamics can be studied using several instruments based on purpose, availability, and convenience. Some of the instrumental tests like X-Ray, MRI, and electropalatography help to obtain the static representation of the tongue, whereas the other instruments like EMMA and ultrasound provide information regarding the dynamics of the tongue. Very few researches have been done in the Nepali language to understand the tongue contours to study the articulatory phonetics of the language.

Proctor et al. (2009) studied tongue dynamics on 4 native Tamil speakers using real-time magnetic resonance imaging (rMRI) protocol to study the tongue dynamics. The stimulus were the VCV combination words including target consonants ɖ/, /l/, /r/, /ɖ /, /ɭ/ and / ɹ /. Each of the words was repeated five times by the participants being in a supine position in an MRI scanner. The upper airways of the subjects were imaged in the mid-sagittal plane and then reintegrated with audio simultaneously recorded to allow for dynamic audio visualization of subjects' speech production. The study reported that stops and retroflexes had subapical palatal production and also a concave shape of the tongue. Dental and retroflex stops were found to have differences in back cavity volume. They were susceptible to coarticulation in the presence of neighbouring vowels assumed to be due to an additional dorsal constraint that is involved in the production of liquids as compared to stops.

Kochetov, Sreedevi, Kasim and Manjula (2014) used a combination of articulography and ultrasound to study the production of geminate retroflex stops in Kannada in ten native speakers of the language of the age range 24-26 years using 3 meaningful Kannada words: /aʈʈa/, /at̪t̪a/, /akka/. The qualitative analysis and the smoothing spline analysis of variance of the tongue contours obtained by ultrasound imaging revealed that the retroflex constriction could be put into the category as sub-apical post-alveolar or palatal for most speakers. The absolute displacement of the tongue was greater for retroflex than for dental, particularly in the vertical direction. The retroflex constants in Kannada had a greater absolute displacement of the tongue than dental, particularly in the vertical direction. The findings of the EMA experiment states that substantial raising and moderate backing of the tongue tip are the characteristics of retroflex, whereas the dentals are characterized by some tip raising and fronting. The EMA study also further showed that retroflex consonants were produced with lower jaw position than dental and such lowering of the jaw was reported to start as soon as the gesture would begin.

Simonsen, Moen, and Cowen (2008) studied the Norwegian retroflex stops and dental stops using EPG and EMA in 4 speakers where they found that two male speakers had a post-alveolar retroflex production whereas two female speakers had more anterior-alveolar/ post-alveolar production. The study stated that the retroflex sounds were produced with the tongue tip by all the speakers, distinguishing them from the dentals, and during tongue tip raising, a lowering and flattening of the anterior body of tongue was observed.

## 2.5 Principle of Ultrasound Imaging

Image is produced by ultrasound using the reflective properties of sound waves. Electric current stimulates the piezoelectric crystal, which results in the emission of ultra-high frequency sound wave that passes through the soft tissue and reflects back when it reaches the tissue of different density or air. A mechanical sector scanner or array transducer is required in order to see the section of the tissue rather than a single point.

The analysis and processing of the returning echoes are done through a computer program and finally is displayed as a video image. In a safe and non-invasive way, ultrasound can image the tongue movements during the production of different speech sounds. It is a biologically non-hazardous method. It provides a mid-sagittal, two-dimensional representation of tongue (Davidson, 2012).

### 2.6 Use of Ultrasound to Study Tongue Contours

Stone (1990) performed a study in a single female subject. This study involved both the point tracking technique using five pellets on the tongue surface and the mid-sagittal, and the coronal planes of the tongue were imaged using real-time ultrasound. The consonants /s/ and /l/ and vowels /a/, /i/ and /o/ in VCVC utterances were used as stimuli. A model of tongue movement was developed in the study in which the tongue can be divided into the functional segments in both the sagittal and the coronal planes. In this model, the tongue opening movement was dominated by critical features of consonant shape and position. The first dimension is the sagittal segment, the second is the coronal segment, and the third dimension is the coronal plane.

Davidson (2006) used the statistical technique smoothing spline (SS) ANOVA to compare the tongue shapes of 3 consonants /k/, /g/ and /z/ in two different word positions. Using SS ANOVA, it can be determined if there are significant differences between the smoothing splines that are best fits for the two data sets to be compared. The subjects of the study were 5 monolingual native speakers of American English. The study concluded that splining splines pin conjunction with Bayesian coefficient interval are the suitable methods to account for the shapes that best fit data and variance in production. Davison (2006) further states that by looking at either the whole tongue curve or a particular region, depending on the researcher’s interest, it can be determined whether the tongue shapes for a given articulation are the same or different when some context is varied. Any changes in shape, rotation, and translation can be taken into consideration in the statistical analysis using SS ANOVA.

Stone and Lundberg (1996) conducted a single case study on a 26-year-old adult female using ultrasound and electrograph to study the tongue shapes of 18 American English sounds. The results of the study showed that there were four classes of tongue shapes—front raising, complete groove, back raising, and two-point displacement, which were adequate to categorize all sounds measured. Stone and Lundberg (1996) finally concluded that the tongue has a limited repertoire of shapes and positions them against the palate in different ways for consonant versus vowels to create narrow channels, divert airflow and produce sound.

## 2.7 Ultrasound Studies in Indian and Nepali Languages

There have been attempts done to study tongue contours during speech sound production using ultrasound in Indian and Nepali languages. Kochetov, Sreedevi, Kasim, and Manjula (2012) conducted a study on four native speakers of Kannada within the age range 24-26 to study the Kannada lingual articulations of the sounds /ʈ/,/t̪/,/tʃ/ and /k/. The stimuli used in the study were the Kannada words /aʈʈa/,/atʃtʃa/,/atta/ and /akka/. The subjects were asked to produce 6 repetitions of the Kannada words, and the tongue was imaged using ultrasound. The tongue contours were plotted for each of the consonants and were averaged. The results of the study showed that retroflex /ʈ/ and alveopalatal /tʃ/ consonants have a greater vertical and horizontal displacement of the tongue relative to the neutral position of dental /t̪/ and velar consonant /k/. A significant fronting of the tongue body was also found for the retroflex /ʈ/ as per the study.

Irfana and Sreedevi (2017) investigated the extent of coarticulation, direction of coarticulation, and coarticulation resistance within the languages i.e., Kannada, Malayalam, and Hindi and across these three languages using ultrasound imaging. The participants in the study were ninety adult native speakers, 30 each in Kannada, Malayalam, and Hindi groups comprising an equal number of males and females in the age range of 20-30 years. The stimuli were V1CV2 sequences with C corresponding to voiced/ unvoiced counterparts of dental (/t̪/,d̪/) or retroflex /ʈ/, /ɖ/ or velar stops (/k/,/g/) in the context of vowels /a/,/i/ and /u/. Tongue contours and the distance between tongue contours of each vowel and consonant were obtained using Mindray 6600 Ultrasound module and was calculated using the software Articulated Assistance Advanced (AAA) based on Root Mean Square method. The parameters measured were the extent of coarticulation, direction of coarticulation, coarticulation resistance of the consonant, and coarticulation resistance of the preceding and the following vowels. The results of the study showed that there were different patterns of the extent of coarticulation in each language, both in preceding and following vowel contexts. Retroflexes were found to have significantly higher coarticulation resistance compared to dentals and velars for all the vowel pair contexts. The direction of coarticulation was significantly anticipatory in all the three languages. Coarticulation resistance of consonants and vowels were different across language families, especially for retroflexes, and proved that both the Dravidian languages exhibited higher coarticulation resistance for consonants than Hindi.

Abraham and Sreedevi (2014) compared the tongue contours in children, adolescents, and adults using ultrasound imaging. There were 60 participants who were native Kannada speakers divided into three groups—Children (6-8 years), adolescents (14-16) years, and adults (20-30) years, where each group consisted of 10 males and 10 females. As per the results of the study, the tongue contours of adults and adolescents were of a similar pattern, but the overall tongue height of adult's tongue contour was revealed little more compared to adolescents. As per the study, there had been a developmental trend observed in tongue contour patterns. The tongue height in adults was prominently greater than children for all the phonemes, and the tongue height in adults was greater than adolescents for all phonemes except /ɖ/ where they overlap each other. 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 /atta/ and also in children for /aɖɖa/. The angle of retroflection and area of retroflection for /ʈ/ and /ɖ/ were obtained using a MATLAB based program. There was a significant difference in the area of retroflection of /ʈ/ between adults and adolescents and also across adults and children. There was no significant difference across age groups for the angle of retroflection of /ʈ/ and /ɖ/. This study finally concluded that the developmental trend was very evident from the results of the study that indicated that adults were significantly different from children in terms of the tongue dynamics and also a marginal difference was found between adults and adolescents that revealed that the developmental trend even continued in the adolescent period.

Joseph and Sreedevi (2014) compared the tongue contours in native and non-native speakers of Kannada using Mindray Ultrasound imaging in 20 subjects, among which 10 were native, and 10 were non-native. The sounds studied were /t/,/ʈ/,/k/,/l/,/L/,/r/ and /tʃ/, and the stimuli were the words in which the above-mentioned sounds were embedded. The results of the study revealed that there were differences in the tongue contours in native and non-native speakers for the sounds. The native Kannada speakers had a higher positioning of the tongue (tongue height) compared to the non-native Kannada speakers. There was a significant difference in tongue height for /L/ which was mainly in the anterior region of the tongue/ tongue front. Also, the results indicated that the overall tongue height was more in native males compared to non-native male speakers for all the sounds. In native speakers, the tongue height was approximately the same in males and females for the sounds /r/,/l/,/ʈ/ and slightly higher in females for /tʃ/ and /k/. In non-native speakers, the overall tongue height was more in male speakers than female speakers for all the sounds studied. From this study, it can be concluded that there are differences in the tongue contours between native and non-native speakers of a language and also across gender; nevertheless, no significant differences were found between native and non-native speakers for angle and area of retroflection which might be because of the high subject variability, gender effect and a low number of participants involved.

Thoduvayil and Sreedevi (2014) conducted an ultrasound study of tongue contours during vowel production in children with hearing impairment. The participants were divided into the two groups, both of which consisted of 18 children with an equal number of males and females in the age range of 4-7 years leading to the total number of subjects of 36. Group I was comprised of the children with congenital hearing impairment, and Group II comprised of age and gender-matched typically developing children. The stimuli selected were 5 non-meaningful words incorporating vowels /a:/,/i:/,/u:/,/o:/,/e:/ in the medial position. The results were described and discussed based on the visual inspection of the tongue contours during vowel production. The visual inspections of the tongue contours of target vowels in the three age groups reveal that the younger age group, which includes the children in the range of 4-5 years, demonstrated high variations in terms of both tongue height and advancement compared to the older age groups. Increased tongue height and the advancement of the tongue contours in the 4-5 years group children are explained in terms of their tendency to exaggerate the articulatory movements during speech productions due to inadequate speech training. Participants of the hearing impaired group in the age range of 5-6 years showed fewer differences in tongue shapes compared to the control group across the vowels. Similarly, for the children in the age range of 6-7 years, tongue contours generally showed less arched or flatter tongue contour shape across all the vowels.

Kochetov, Pouplier, and Truong (2013) conducted a preliminary ultrasound study of Nepali lingual articulations using a single subject who was a male native Nepali speaker in his early twenties. The stimuli consisted of dental, retroflex, palatal and velar places of articulation in both the syllable initial and syllable-final positions with altogether of 14 stimuli. The stimulus used in the study was divided into two sets, among which Set 1 was designed to study the place differences in various voiceless stops and affricates, and Set 2 was designed to investigate the effect of laryngeal features on the realization of retroflex place. The subject was seated on a specialized chair, and the recording probe was fitted under his chin to capture the sagittal view of the tongue. The stimuli were presented on the computer screen, and the stimuli list was repeated five times in order to record 90 tokens, out of which only 87 tokens were analyzed. The frames from the ultrasound were extracted at 30 frames per second using MPEG stream clip freeware. The obtained tongue contours stated that the visible part of the tongue tip/blade for the dental consonants extended much further than the other consonants. The front part of the tongue was found to be significantly raised for the retroflex, with the tip of the tongue likely touching behind the alveolar ridge. The four tongue shapes of four retroflex consonants that differ in the laryngeal features were similar, having the front of the tongue in a high and posterior position. As per the place contrast investigations, /ʈ/ and /ʈ/ were not significantly different in terms of the back of the tongue, but were considerably different throughout the rest of the tongue shapes. As per the laryngeal contrast investigations, comparisons among pairs of retroflexes with different laryngeal settings (onset and coda tokens combined) stated that there only small significant differences, mainly in the degree of fronting of the tongue body, and for /ʈ/ vs. /ɖ/ in raising of the tip/blade. Finally, the study concluded that the overall tongue shape of the retroflex stop was quite similar to the more proto-typical sub-laminal retroflexes of Kannada, as investigated in Kochetov, Sreedevi, Kasim, &Manjula (2012). The study supports earlier findings that Nepali retroflexes may involve some curling of the tongue tip, being apical or sub-apical post-alveolars (in the back vowel context).

The literature review indicates that the imaging studies are investigative, focusing on understanding the active articulator, the tongue in an attempt to understand the extent of articulation, intra-subject, and inter-subject variations, and extent of coarticulation.

In this study, an attempt is made to profile the articulatory features of Nepali retroflex plosive consonants using ultrasound imaging.

## 2.8 Aim of the Study

The aim of the present study is to obtain tongue contours during the production of retroflex plosives of Nepali language and analyse the variance of the contours among the cognates that differ in terms of voicing and aspiration in native speakers of Nepali.

## 2.9 Objectives

Following are the objectives of the investigation:

1. To study overall patterns of tongue contours of the retroflex plosives of the Nepali language.

   /ʈ/, /ʈʰ/,/ɖ/,/ɖʱ/ which are distinctive phonemes in the language.
2. To compare the tongue contour of the retroflex plosives /ʈ/, /ʈʰ/,/ɖ/ and /ɖʱ/ among the different gender groups—males and females.
3. To compare the tongue contour of retroflex plosives that differ only in the voicing feature-- /ʈ/ vs. /ɖ/ and /ʈʰ/ vs. /ɖʱ/ by analyzing the variance between these two contours.
4. To compare the tongue contour of retroflex plosives that differ only in aspiration feature-- /ʈ/ vs. /ʈʰ/ and /ɖ/ vs. /ɖʱ/ by analyzing the variance between these two contours.

# CHAPTER 3

# METHOD

## 3.1 Participants

A total of seven native speakers of the Nepali language of Eastern dialect from Kathmandu, Nepal were selected among whom four were males, and five were females. All the subjects were in the age group 20 to 30 years and pursuing their studies in Mysuru.

### 3.1.1 *Inclusionary Criteria*

The participants who were native speakers of the Nepali language (L1) and whose second language was English (L2) were included for the study. The participants were also exposed to other languages, such as Hindi and Kannada. The subjects did not demonstrate any speech, language, hearing, or cognitive impairment during the data collection for the study.

## 3.2 Materials

The four combinations of plosives /ʈ/, /ʈʰ/, /ɖ/, /ɖʰ/ with vowel /a/ were selected to include the target retroflex consonant in the medial position as a geminate counterpart. The combination was such that the geminate counterpart of the retroflex plosive succeeded a neutral vowel /Λ/ and preceded a low mid-vowel /a/ and the following word list was constructed of which only two were meaningful words in Nepali language.

1. /Λʈʈa/ where the target consonant is /ʈ/ in the medial position. (non-meaningful)
2. /Λʈʰʈʰa/ where the target consonant is /ʈʰ/ in the medial position. (meaningful)

3. /Ʌɖɖa/ where the target consonant is /ɖ/ in the medial position. (meaningful)
4. / Ʌɖʰɖʰa/ where the target consonant is /ɖʰ/ in the medial position. (non-meaningful)

The subjects were instructed to read and then repeat the stimuli ten times, and the same was recorded directly on to the Mindray Ultrasound 6600.

### 3.3 Instrumentation

Mindray Ultrasound 6600, with the software Articulate Assistant Advanced (AAA) was used for data recording and analysis. The transducer was a long-handled micro-convex probe operated at 6.5MHz placed beneath the chin prior to the subject beginning the task. The probe was smeared with ultrasonic gel (Aquasonic 100), and a stabilization headset was used to stabilize the head in order to reduce the artifacts that might appear because of head movements. A microphone attached to the headset was used to record the audio stimuli in synchronization with the ultrasound image signal. The AAA analyzed the recorded audio samples and images with the analysis rate of 60 frames per second.

**Figure 3.1**

*Mindray Ultrasound 6600*

### 3.4 Procedure

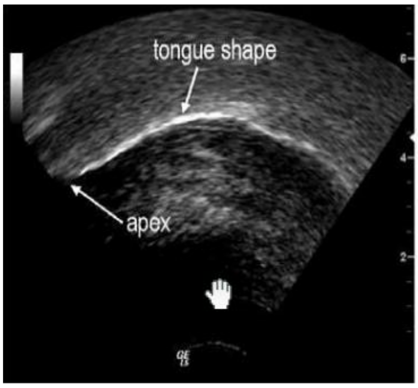
The individual recording was done after the participants were seated comfortably on a high back chair. The transducer probe was fastened to the stabilization headset, and then the headset with the microphone was placed securely on the head of the participant to record the speech sample. After the participants were ready, they were presented the prepared list of words visually on the computer screen and simultaneously by auditory mode through the loudspeakers of the PC. Each word was presented 10 times with an inter-stimulus interval of 1000 ms, and the participants were asked to repeat them, which meant 10 trials for each target sound. Then both ultrasound images of the tongue movements during the production of the particular sound and the audio sample of the participants were recorded simultaneously using Articulate Assistant Advanced (AAA) and saved as tokens.

### 3.5 Parameters Extracted

The parameters analyzed were the tongue contours obtained by ultrasonic imaging. Tongue contour was the 2-D representation of the tongue surface shape, which varied as per the vowel contexts and the place of articulation. In the figure, 3.2, the white curve denoted by the arrow as 'tongue shape' represents the tongue contour. The tongue contours were compared across different laryngeal settings and among aspirated and unaspirated cognates with the same place of articulation.

**Figure 3.2**

*Tongue Contour in Ultrasound Imaging*




**3.6 Analysis**

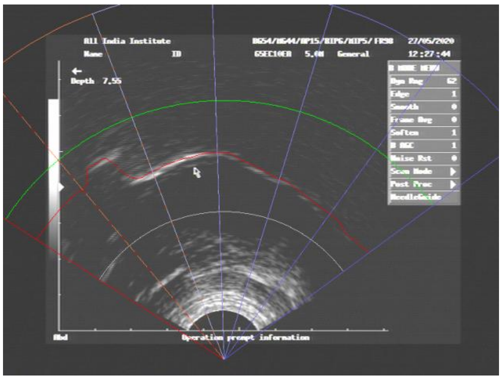
Articulate Assistant Advanced (AAA) was used for data analysis. Each utterance was analyzed individually. A frame at the center of closure duration of the stop was selected, and the point in the frame where the tongue tip achieved maximum contact was analyzed.

Splines are curves, defined by a mathematical function, that are constrained to pass through specified points. In AAA, a fan grid has 42 axes. A fan spline is defined by the 42 control points where the curve crosses these axes. Using 42 splines provides slightly smooth results than joining the 42 points with straight lines. (Articulate Instruments Ltd., 2013).

Using the “Fan spline” technique, which provides 42 axes or points, a contour or line was drawn on tongue body reflection. Fan setup was selected for each utterance, which provided information about the tongue width. Tongue contour was drawn using a computer mouse at the chosen point using semi-automatic contour plotting as shown in figure 3.3.

**Figure 3.3**

*Semi-automatic Plotting of Tongue Contour Obtained by Ultrasound Analysis*




The tongue contours for 10 utterances were exported to another window called workspace where it was averaged, and the statistical mean and standard deviation of the particular phoneme were obtained automatically.The function creates a mean spline from the subset of splines that are selected in the workspace. A mean value is calculated for each of the 42 fan-lines. The 42 means are calculated independently, and the mean contour is drawn based on those 42 points. It is possible to operate in such a way because each spline is defined by points that lie on exactly the same 42 axes (Articulate Instruments Ltd., 2013).

The targeted mean contours were also compared among two in the spline workshop.The comparison was made using an inbuilt function "Diff" of the software AAA. It forms a zero line with spokes on it. The function calculates a T-test for each spoke. If the T-test is significant at 2%, the software draws a thicker spoke. This uses a 2-tailed test assuming unequal variances and unequal sample sizes and uses the Welch-Satterthwaite equation.

The distance between these two curves determines the extent of the significant difference of the contours of the target sounds (Articulate Instruments Ltd., 2013). Then the images were again exported to another window called publisher in which the images were stored in the form of pixels. The tongue contours were described visually by dividing the tongue contour into 3 regions—anterior, middle, and posterior. The tongue contours for each of the consonants were thus obtained. Then the comparison of tongue contours of all the target phonemes varying in terms of voicing and aspiration was carried out across the gender groups.

# CHAPTER 4

# RESULTS AND DISCUSSION

The present study was aimed to study the tongue contours of the retroflex plosives /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ of Nepali language using ultrasound imaging. The participants of the study were 7 native speakers of Nepali language in the age group of 20 to 30 years, among which 3 were females, and 4 were males. The results of the study are described and discussed based on the visual inspection of the tongue contours. Further, the results are presented in terms of the comparison of the tongue contours of the same target sounds across two gender categories and among the sounds that vary only in terms of aspiration and voicing features across gender groups. The tongue was divided into three regions in order to describe the tongue contours—theposterior tongue body, the anterior tongue body, and the tongue front (Davidson, 2006).

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

- Description of tongue contours for production of all the target phonemes in all the participants
- Comparison of the tongue contours of the same target phonemes across gender groups
- Comparison of the tongue contours of all the target phonemes that differ only in one feature among males
- Comparison of the tongue contours of all the target phonemes that differ only in one feature among females

The description of the tongue contours for the retroflex plosive sounds is presented below. In all the figures discussed in the following sections, tongue advancement is represented on the x-axis and tongue height on the y-axis. The scales represent relative values and not absolute values. The curves in dotted lines represent the standard deviation across all the repetitions of the particular sound.

### 4.1 Description of Tongue Contours for the Production of all the Target Phonemes in all the Participants

The tongue contours for different sounds are represented in specific colors, as defined in the respective figures. The dotted lines represent the standard deviation. The tongue contours are represented in axes, i.e., for each subject four contours representing the target sounds --/ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/. The results of the tongue contours for all the seven participants of the study have been discussed below using figures 4.1-4.7.

#### *4.1.1 Subject 1 (Male)*

**Figure 4.1**

*Tongue Contours of the Production of Target Phonemes of Subject 1*

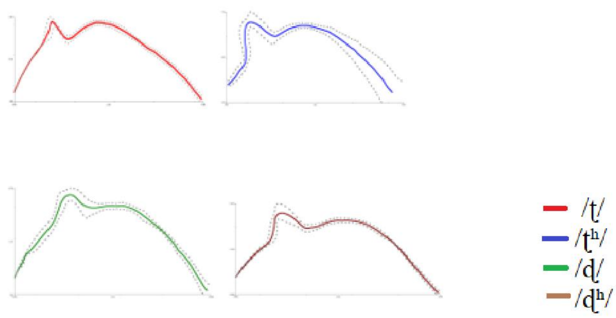
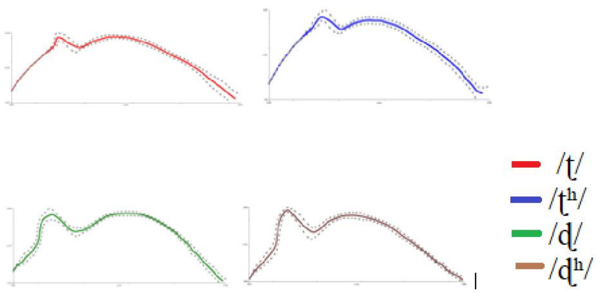


Figure 4.1 represents the tongue contours of all the target phonemes /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ for the subject 1(male).The standard deviation was the most significant for /ʈʰ/ sound for the tongue front and the posterior tongue body, whereas it was minimal for /ʈ/ sound. The standard deviation was higher for the tongue front for /ɖ/ and/ɖʰ/ sound.

### *4.1.2 Subject 2 (Male)*

**Figure 4.2**

*Tongue Contours of the Production of Target Phonemes of Subject 2*

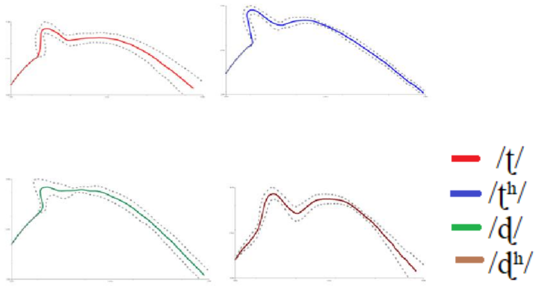



The tongue contours of all the target phonemes /ʈ/,/ʈʰ/,/ɖ/ and /ɖʰ/ for subject 2 (male) are represented in figure 4.2. There was minimal variation in the standard deviation across all the four target sounds, which suggested consistency in the production of the same sounds based on lingual positions.The tongue front was less raised in the production of the voiceless /ʈ/ and /ʈʰ/ sounds compared to their voiced cognates, /ɖ/ and/ɖʰ/ sounds.

### *4.1.3 Subject 3 (Male)*

**Figure 4.3**

*Tongue Contours of the Production of Target Phonemes of Subject 3*

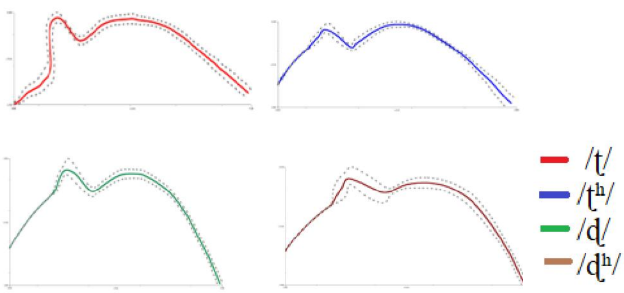



The tongue contours of all the target phonemes /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ for subject 3 (male) are shown in figure 4.3. The standard deviation was comparatively higher for /ɖ/ in the tongue front portion, whereas for /ʈ/ at the posterior tongue body portion. Similarly, the standard deviation was minimally varying for /ʈʰ/ sound and reported across all the three portions in /ʈ/ sound. Also, the tongue front was inconsistently raised during curling while producing /ɖ/ phoneme.

### *4.1.4 Subject 4 (Male)*

**Figure 4.4**

*Tongue Contours of the Production of Target Phonemes of Subject 4*

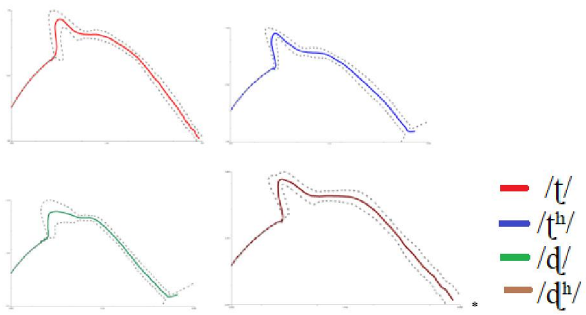


The figure, 4.4, represents the tongue contours of all the target phonemes /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ for subject 4 (male). The standard deviation was comparatively more significant for /ɖʰ/ phoneme in the tongue front portion, which implied the inconsistencies in the curling of the tongue and rising of the tongue front during the productions. In contrast, the standard deviation was noticed to be very less for /ʈʰ/, /ɖ/ and/ɖʰ/ sounds. This implied that the participant had less consistent productions of /ɖʰ/ sound compared to /ʈ/, /ʈʰ/ and/ɖ/.

### *4.1.5 Subject 5 (Female)*

**Figure 4.5**

*Tongue Contours of the Production of Target Phonemes of Subject 5*

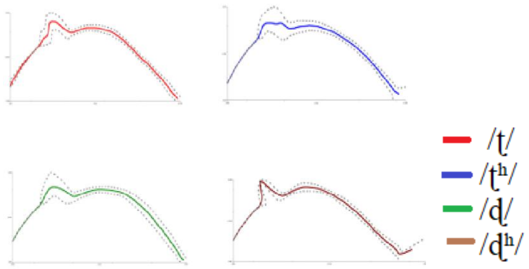



The tongue contours of the target phonemes /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ are shown in figure 4.5 for subject 5 (female). The tongue contours were steeper relative to the contours of other subjects.The standard deviation for /ɖ/ in the tongue front was the greatest among all the target sounds. Similarly, for all the target sounds, more variation was seen in the tongue front portion compared to the anterior tongue body and the posterior tongue body.

*4.1.6 Subject 6 (Female)*

**Figure 4.6**

*Tongue Contours of the Production of Target Phonemes of Subject 6*

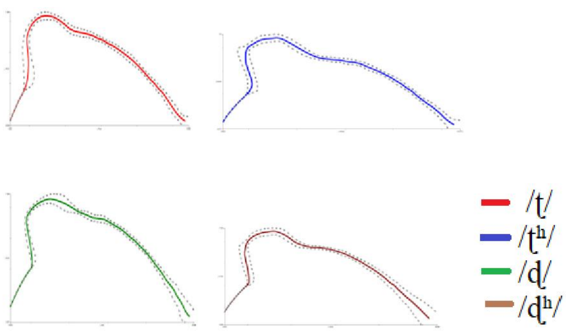



The figure 4.6, represents the tongue contours of all the target phonemes /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ for subject 6 (female). The standard deviation was higher during the rising of the tongue in the tongue front region in /ʈ/, /ʈʰ/ and /ɖ/ sounds, which showed the inconsistent extent of retroflexion for those sounds. In contrast, for /ɖʰ/ sound, the standard deviation was very less relative to other target sounds that implied the consistent production of the sound for the participant.

*4.1.7 Subject 7 (Female)*

**Figure 4.7**

*Tongue Contours of the Production of Target Phonemes of Subject 7*



The above figure 4.7 represents the tongue contours of /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ sounds of subject 7 (female). The standard deviation for all the target soundswas very less with consistent productions of the sounds across all the repetitions. The tongue front was raised with a prominent curling configuration for all the sounds, which showed the phenomenon of retroflexion. The contour of /ʈ/ and/ɖ/ was noticed to be steeper than /ʈʰ/ and/ɖʰ/.

The tongue contours of all the target retroflex sounds /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ showed a similar pattern with the front part of the tongue in a high and posterior position as studied by Kochetov, Pouplier& Truong (2013).The standard deviation showed variations in the productions within subjects. Similar findings were also reported in the palatographic study of Khatiwada (2007), wherein it was stated that some variations among speakers could be observed, as a single speaker may vary with respect to the place of articulation across repetitions.The variations across different repetitive productions of the same sounds were reported within the subjects and across subjects in this study. It might have resulted due to the inconsistency in the productions of the sounds by the same speaker. This also might be because of the anatomical variations of the articulators as well as the size and volume of the oral cavity of the speakers. This type of variation was also documented by Khatiwada (2007) that the retroflex stop productions showed a considerable degree of articulatory variation both inter-speakers as well as intra-speaker variations.

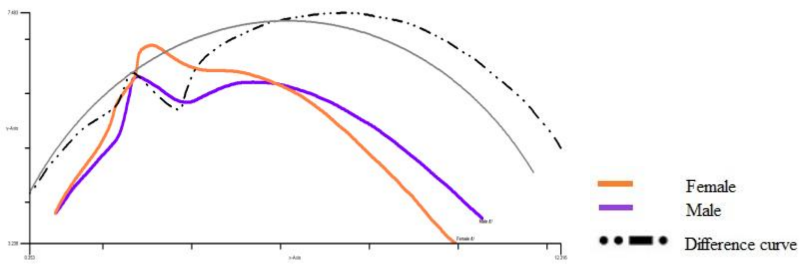
## 4.2 Comparison of the Tongue Contours of the Same Target Phonemes across Gender Groups

For the comparison across gender groups, first of all, the mean tongue contours of each of the sound of all the male participants were imported in a spline workshop window after which the mean was obtained. A similar process was done for the production of each of the target sounds of female speakers. The results are summarized in the figures 4.8-4.11.

### *4.2.1 Comparison of the Tongue Contours of the Target Phoneme /ʈ/ Between Male and Female Groups*

**Figure 4.8**

*Comparison of Tongue Contours of /ʈ/ between Male and Female Groups*




The comparison of tongue contours of the production of /ʈ/ across two gender groups—male and female is shown in figure 4.8. The dotted line refers to the significant difference between the two curves. The tongue contours depicted that the height of the tongue at the tongue front portion was greater in female speakers, whereas the height of the tongue at the posterior part was greater in the case of male speakers. The significant difference was noted on the tongue front and the posterior portions of the tongue contours of male and female speakers.

### *4.2.2 Comparison of tongue contours of the target phoneme /ʈʰ/ between male and female groups*

**Figure 4.9**

*Comparison of Tongue Contours of /ʈʰ/ between Male and Female Groups*

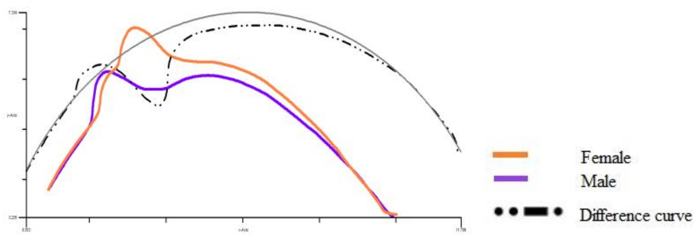



Figure 4.9 represents the comparison of tongue contours of /ʈʰ/ across the two gender groups. The significant difference is depicted by the dotted line along with the solid grey curve, which is the zero line for reference. The tongue contours showed that the height of the tongue at the tongue front portion was greater in female speakers. The significant difference in terms of tongue height and advancement was greater in the tongue front region and lesser in the anterior tongue body portion in the tongue contours of male and female speakers. In contrast, no significant difference for the same was observed in the posterior portion.

### *4.2.3 Comparison of the tongue contours of the target phoneme /ɖ/ between male and female groups*

**Figure 4.10**

*Comparison of tongue contours of /ɖ/ between male and female groups*

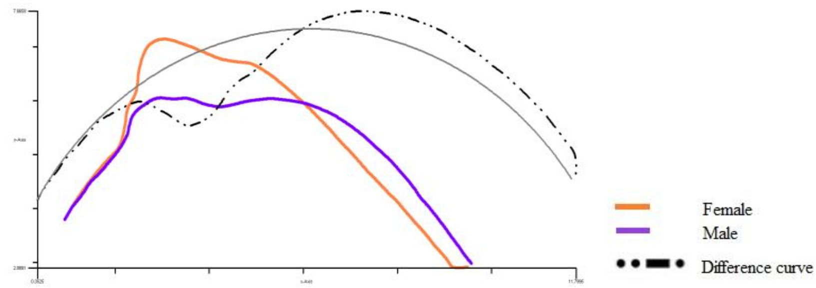



Figure 4.10 represents the comparison of tongue contours of /ɖ/ across two gender groups—male and female along with a dotted line representing the significant difference between the two contours. The tongue contours depicted that the height of the tongue at the tongue front portion was greater in female speakers, whereas the height of the tongue at the posterior part was greater in the case of male speakers. There is a significant difference in the part of the tongue contour representing the tongue front, the anterior tongue body, and the posterior tongue body among male and female participants. Among the two curves, the variance was visualized more in the tongue front of the contours.

### *4.2.4 Comparison of the tongue contours of the target phoneme /ɖʰ/ between male and female groups*

**Figure 4.11**

*Comparison of tongue contours of /ɖʰ/ between male and female groups*

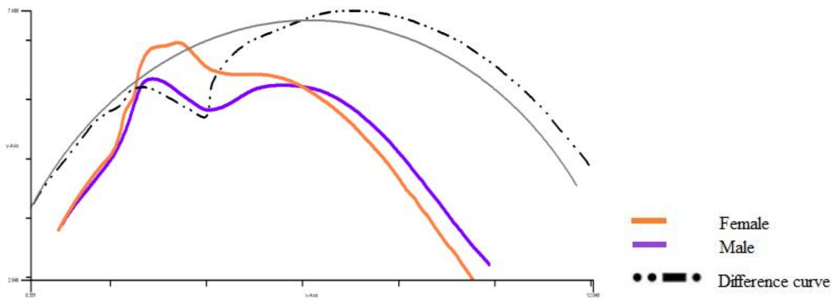



Figure 4.11 represents the comparison of tongue contours of the production of /ɖʰ/ across two gender groups—male and female. The dotted line refers to the significant difference between the two curves. The tongue contours depicted that the height of the tongue at the tongue front was greater in female speakers, whereas the height of the tongue at the posterior part was greater in the case of male speakers. There was a significant difference in the tongue contour representing the tongue front, the anterior tongue body, and the posterior tongue body among male and female participants.

In general, on visual inspection of the tongue contours of the targeted retroflex sounds, it could be stated that in the production of retroflex plosives of Nepali language, the tongue height in the front region was more for the female speakers whereas, in the posterior region, male speakers had greater tongue height. The findings for greater tongue height in the case of female speakers during the production of retroflex sounds were reported by Abraham, A. (2014) as "females showed exaggerated movements to achieve more precision in articulation".

On comparing the overall tongue contours of the male and female participants, the curling of the tongue could be implied by the raise of the tongue front, which did not show any specific pattern across gender groups. However, the tongue curling was less evident in the production of the aspirated voiced retroflex plosive sound. Similar to the reports of Khatiwada (2007), all the subjects reported the sensation of curling of the tongue tip during the production of retroflex sounds.

## 4.3 Comparison of the Tongue Contours of all the Target Phonemes that Differonly in one Feature Among Males

The mean tongue contour for multiple productions of the each target phoneme in all the male participantswere averaged again. The two curves representing the tongue contours of the respective target phonemes are shown in two axes along with the difference curves showing the extent of variance in figures 4.12-4.15.

### *4.3.1 Comparison of the tongue contours of the target phonemes that differ in aspiration only*

#### 4.3.1.1 Comparison of the Tongue Contours of the Voiceless Retroflex Plosive /ʈ/ and the Aspirated Voiceless Retroflex Plosive /ʈʰ/

**Figure 4.12**

*Comparison of the Tongue Contours of /ʈ/ and /ʈ$^h$/ Among Males*

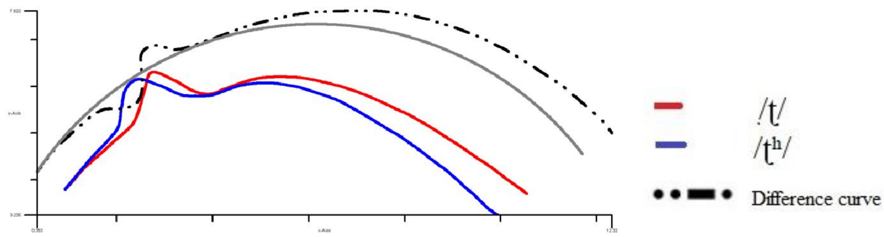



Figure 4.12 represents the tongue contours for the production of /ʈ/ and /ʈ$^h$/ for male participants. The tongue in the curve was more advanced anteriorly for /ʈ$^h$/ but no significant difference was noted in that region. In contrast, the tongue height in the posterior tongue body was greater for /ʈ/ with a significant difference.

#### 4.3.1.2 Comparison of the Tongue Contours of the Voiced Retroflex Plosive /ɖ/ and the Aspirated Voiced Retroflex Plosive /ɖ$^h$/

**Figure 4.13**

*Comparison of the Tongue Contours of /ɖ/ and /ɖ$^h$/ Among Males*

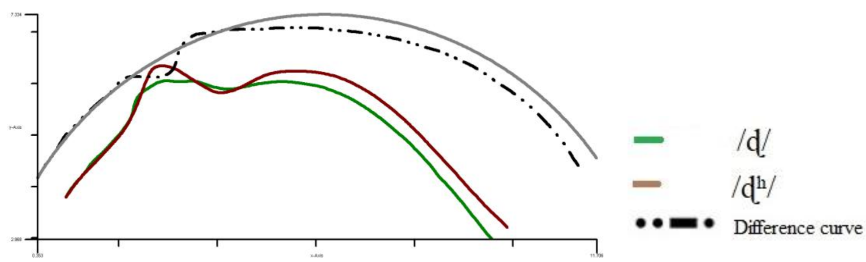


Figure 4.13 represents the tongue contour of /ɖ/ and /ɖʰ/ among the male participants. The tongue was more curled and raised for /ɖʰ/ sound production in the tongue front portion and posterior tongue body with significant difference in height of the tongue.

### *4.3.2 Comparison of the tongue contours of the target phonemes that differ in voicing only*

#### 4.3.2.1 Comparison of the tongue contours of the voiceless retroflex plosive /ʈ/ and the voiced retroflex plosive /ɖ/.

**Figure 4.14**

*Comparison of the tongue contours of /ʈ/ and /ɖ/ among males*

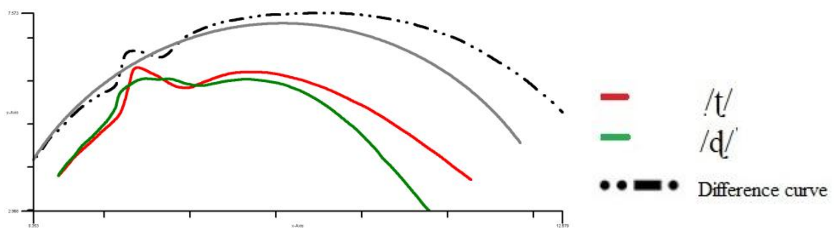
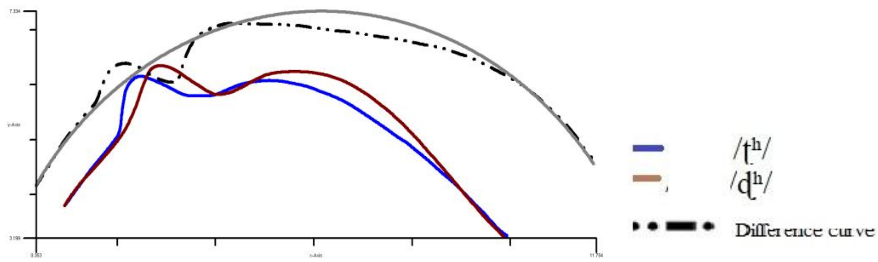



Figure 4.14 represents the tongue contours of the production of /ʈ/ and /ɖ/ sounds among the male subjects. The curling of the tongue was more evident in /ʈ/ and the height of the tongue during the production of /ʈ/ was greater with a higher significant difference compared to the production of /ɖ/ sound.

#### 4.3.2.2 Comparison of the Tongue Contours of the Aspirated Voiceless Retroflex Plosive /ʈʰ/ and the Aspirated Voiced Retroflex Plosive /ɖʰ/.

**Figure 4.15**

*Comparison of the tongue contours of /ʈʰ/ and /ɖʰ/ among males*




The tongue contours of the production of /ʈʰ/ and /ɖʰ/ are represented in figure 4.15. The tongue advancement was more in the anterior portion during the production of /ʈʰ/ with no significant difference in the height of the tongue in the tongue front. The tongue position was higher for /ɖʰ/ in the anterior tongue body with a significant difference.

These findings on comparison of retroflex plosives with difference in only voicing i.e.,/ʈ/ vs. /ɖ/ and/ʈʰ/ vs./ɖʰ/ was consistent with the finding of Kochetov, Pouplier& Truong (2013) in their single-subject study in a male native Nepali speaker that the comparison among such pair of retroflexes revealed small significant differences mainly in the degree of fronting of the tongue body and in raising of the tip blade especially for /ʈ/ and /ɖ/.

The visual inspection and analysis of the tongue contours of the male subjects of the study supported the findings of Kochetov, Pouplier& Truong (2013) in the male native

Nepali speaker that the tongue shape for the voiced /ɖ/ was somewhat more front and lower than the others, while the tongue root for the voiceless aspirated /ʈʰ/ was more retracted.

## 4.4 Comparison of the Tongue Contours of the Target Phonemes that differ only in one Feature Among Females

### *4.4.1 Comparison of the Tongue Contours of the Target Phonemes that differ in Aspiration only*

#### 4.4.1.1 Comparison of the Tongue Contours of the Voiceless Retroflex plosive /ʈ/ and the Aspirated Voiceless Retroflex Plosive /ʈʰ/.

**Figure 4.16**

*Comparison of the Tongue Contours of /ʈ/ and /ʈʰ/ Among Females*

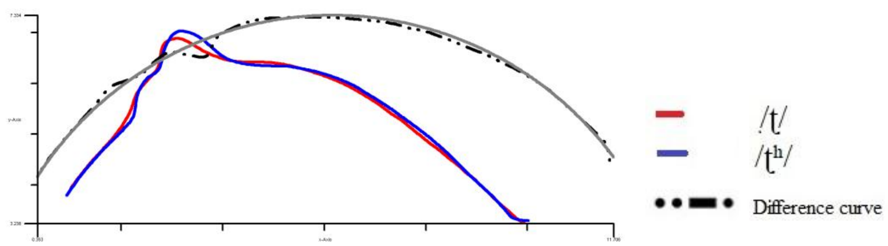



Figure 4.16 represents the tongue contours of the target sounds /ʈ/ and /ʈʰ/ phonemes of the female participants of the study. This showed a similar pattern across the production of two sounds except for some difference in the tongue height in the tongue front portion. Tongue contour of /ʈʰ/ had a greater height than /ʈ/ with a smaller significant difference.

#### 4.4.1.2 Comparison of the Tongue Contour of the Aspirated Voiceless Retroflex Plosive /ɖ/ with Aspirated Voiced Retroflex Plosive /ɖʰ/.

**Figure 4.17**

*Comparison of the Tongue Contours of /ɖ/ and /ɖʰ/ Among Females*

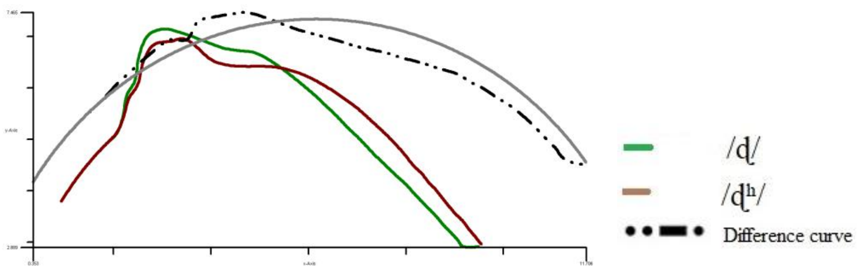



Figure 4.17 represents the tongue contours of the production of /ɖ/ and /ɖʰ/ sounds by the female speakers. The tongue height in the tongue front and the anterior regions was more for unaspirated /ɖ/ sound whereas, that for aspirated /ɖʰ/, was more in posterior tongue body portion during the production of the sounds with a significant difference. The curling of the tongue was more prominent for /ɖʰ/ sound.

### *4.4.2 Comparison of the Tongue Contours of the Target Phonemes that Differ in Voicing only*

#### 4.4.2.1 Comparison of the Tongue Contours of the Voiceless Retroflex Plosive /ʈ/ and the Voiced Retroflex Plosive /ɖ/.

**Figure 4.18**

*Comparison of the Tongue Contours of /ʈ/ and /ɖ/ among Females*

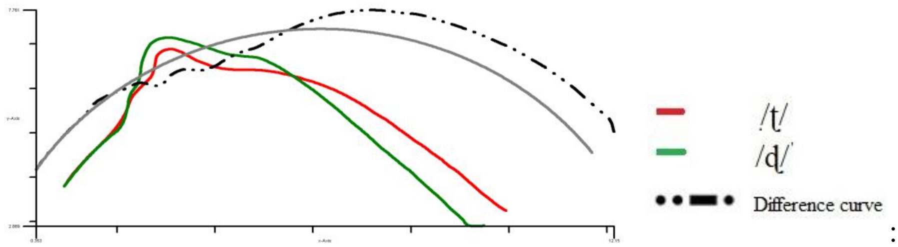



Figure 4.18 represents the tongue contours of the sounds /ʈ/ and /ɖ/. The height of the tongue was more in the tongue front for /ɖ/ with a significant difference. In contrast, the tongue height was more for /ʈ/ sound in the posterior tongue body with a significant difference. The tongue curling was observed more for /ʈ/ sound. This finding did not support the claim of Khatiwada (2007).

#### 4.4.2.2 Comparison of the Tongue Contour of the Aspirated Voiceless Retroflex Plosive /ɖ/ with Aspirated Voiced Retroflex Plosive /ɖʰ/.

**Figure 4.19**

*Comparison of the Tongue Contours of /ʈʰ/ and /ɖʰ/ among Females*

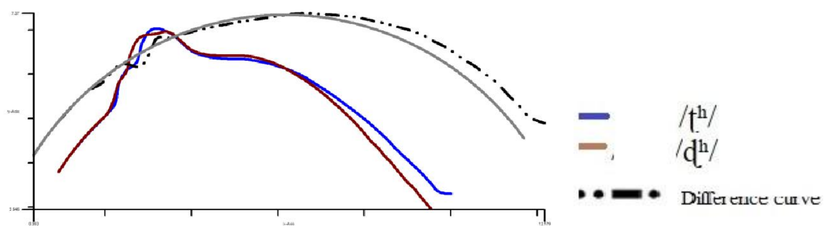


Figure 4.19 represents the tongue contours of the target sounds /ʈʰ/ and /ɖʰ/ among the female participants. There was no significant difference in the extent of tongue curling and tongue height in the tongue front. Still, the height of the tongue in the posterior region was greater in the case of the production of /ʈʰ/ with a significant difference.

The supporting studies with regard to the tongue contours of the phoneme productions among female native Nepali speakers have not been published yet.

The comparison between the contours of voiced retroflex /ɖ/ and voiceless retroflex /ʈ/ in both of the gender groups implied that the curling backward movement or retroflexion was prominent for the unvoiced retroflex. This finding goes against the statement of Khatiwada (2007) that there was a tendency towards greater retroflexion for voiced stops than for voiceless ones which was stated in the context of the Nepali language.

Among the contours of the same sound across the gender groups, the significant difference between the curves of productions by male and female speakers was more on the tongue front portion compared to the anterior tongue body and the posterior tongue body. Similarly, the comparison of the contours of the voiceless sounds and the voiced sounds showed a higher significant difference in tongue advancement and tongue height. In contrast, for the voiced sounds, a higher significant difference was reported only for tongue height.

By the visual analysis of the tongue contours of the targeted sounds, it can be stated that all the sounds presented a similar pattern of curling of the tongue front or a rise in the height of the tongue in that region. This refuted the claim of Pokharel (1989) that the production of Nepalese retroflex stops was 'apico-alveolar', whichsuggested that, there was no curling backward movement of the tongue, and the segment was articulated directly at the alveolar ridge, rather than further back in the vocal tract as is the case with most Indo-Aryan retroflex stops like those of Hindi. The results of this study agreed with the conclusion of Khatiwada (2007) that the retroflexes of the Nepali language, which could be apical or sub-apical, could involve the curling of the tongue tip.

# CHAPTER 5

# SUMMARY AND CONCLUSION

Articulatory dynamics is an area that is less explored with reference to the Nepali language. Every language has its phoneme inventory and the production of which determines the unique articulatory dynamics. The articulatory dynamics during the production of speech sounds across different languages can be studied using different imaging techniques, among which ultrasound is one such method. Hence, there is a dire need for ample studies in the Nepali language, addressing the documentation of the dynamics of articulators during the production of such sounds. This study aimed to describe the tongue contours of the retroflex plosive consonants of Nepali language across the gender groups using ultrasound technology.

The total participants of the study were 7, of which 4 were male, and 3 were female. All of them belonged to the age group 20 to 30 years. The target sounds to study were the retroflex plosives of Nepali language: /ʈ/, /ʈʰ/, /ɖ/ and /ɖʰ/ which were embedded in between vowels in a geminate form. For each of the participants, the 10 tongue contours were obtained for the production of each of the target sounds, which means a total of 280 tokens were obtained for 4 sounds from 7 participants. The mean of the tongue contours for each of the sounds for each of the gender groups was taken separately.

Firstly, the average tongue contours of the targeted sounds of each of the subjects were presented in order to describe the standard deviation, which suggested the intra-subject variation of the sounds. All the tongue contours obtained for the targeted retroflex sounds showed a similar pattern of raise of the tongue front or the curling of the tip of the tongue and lowering the anterior body of the tongue.

Secondly, the mean of the same targeted sound across two gender groups was compared. The comparison of the tongue contours for all the sounds along with their difference curve reported that the tongue height for the female speakers was higher at the tongue front region, whereas it was higher for the male participants in the posterior tongue body.

Finally, the tongue contours of the sounds which showed a difference in only one feature—either aspiration or voicing, were compared. The results showed that for the voiceless sounds they differed only in aspiration and the tongue front was more advanced for /ʈʰ/ and the tongue height was greater for /ʈ/ in the case of male participants, whereas, both the contours showed similar results across female participants. When the voiced sounds differing only in aspiration was compared among gender groups, the aspirated voiced sounds showed more tongue height and more curling in the tongue front in male participants. In contrast, in the case of females, the unaspirated voiced sound had more tongue height in the tongue front region, and in the aspirated voiced sound the tongue height was more in the posterior region. When the unaspirated voiceless sound /ʈ/ was compared with the unaspirated voiced sound /ɖ/, the contour of /ʈ/ was reported to have more tongue height in males; however, in female participants, the unaspirated voiced /ɖ/ had more height in the tongue front, and the unaspirated voiceless /ʈ/ had more height in the posterior tongue body. When the aspirated unvoiced sound /ʈ/ was compared with aspirated voiced sound /ɖ/, the anterior advancement was more for the unvoiced sound and the tongue height was more in the anterior tongue body in male subjects, whereas, there was significant difference only in the tongue height in the posterior tongue body in case of female subjects.

This study can be regarded as one of the preliminary ultrasound studies of Nepali language. This investigation can help add to the descriptions of the articulatory properties of Nepali retroflex plosive consonants, of which detail profiling can be done.The results of the study will contribute to the documentation of phonetic features of the retroflex consonants for comparison among different cognates – voiced vs. voiceless and aspirated vs. unaspirated among different gender groups. Similarly, the results of the work could be applied clinically to provide a baseline (norms) for comparisons with the profile of clients with communication disorders.

The limitations of the study are the smaller sample size in each of the gender groups and the investigation of only one class of sounds- retroflex plosives. Further, the curling of tongue and extent of retroflexion was only discussed qualitatively without any quantitative measures. Also, the anatomical differences of the structures for articulation in the case of each subject were not considered that might have resulted to some extent of inter-subject variations. In the future, this study can be replicated, adding more target sounds with a larger sample size involving the measure of the angle of retroflexion. Furthermore, future studies can focus on the comparison of the tongue contours among different age groups and the clinical population among the speakers of Nepali language.

## REFERENCES

Abraham, A. (2014), Comparison of Tongue Contours in Children, Adolescents, and adults using Ultrasound Imaging. *An Unpublished Dissertation Submitted to the University of Mysore for the Part Fulfilment of Master Degree.*

*Articulate Assistance Advanced user guide*, Version 2.14 (2013), Articulate Instrument Limited: Musselberg, UK.

Anderson, V. B. (2000). Giving Weight to Phonetic Principles: The Case of Place of Articulation in Western Arrernte. *A Doctoral Dissertation submitted to University of California, Los Angeles.*

Ayton, J. A. (1820). *A Grammar of the Népalese Language*. Printed at the Hindoostanee Press, by Philip Pereira.

Bernhardt, B., Gick, B., Bacsfalvi, P., & Adler-Bock, M. (2005). Ultrasound in Speech Therapy with Adolescents and Adults. *Clinical Linguistics and Phonetics*, *19*(6–7), 605–617. https://doi.org/10.1080/02699200500114028.

Bhat, D. N. S. (1974). Retroflexion and Retraction. *Journal of Phonetics*, *2*(3), 233–237. https://doi.org/10.1016/s0095-4470(19)31273-2.

Butcher, A. (2006). Australian Aboriginal Languages: Consonant-Salient Phonologies and the ‘Place-of-Articulation Imperative.’ *Speech Production: Models, Phonetic Processes and Techniques*, (January 2006),10-38.

T. W. Clark: Introduction to Nepali: A first-year language course. xvii, 421 pp. Cambridge: W. Heffer and Sons Ltd., 1963. *Bulletin of the School of Oriental and African Studies, 28*(3), 641-642. doi :10.1017/S0041977X00071573.

Clark, T.W. (1969). Nepali and Pahadi. *In: Thomas A. Sebok (ed) Current trend in linguisticsvol V. The Hague: Mouton*, 249-76.

Clements, G. N., &Khatiwada, R. (2007). Phonetic realization of contrastively aspirated affricates in Nepali. *Proceedings of International Congress of Phonetic SciencesXVI*, 629-632.

Dave, R. (1977). Retroflex and Dental Consonants in Gujarati. A Palatographic and Acoustic Study. *Annual Reports of the Institute of Phonetics, University of Copenhagen*, 11, 27-155.

Davidson, L. (2006). Comparing Tongue Shapes from Ultrasound Imaging using Smoothing Spline Analysis of Variance. *The Journal of the Acoustical Society of America*, *120*(1), 407–415. https://doi.org/10.1121/1.2205133.

Firth, J. R. (1948). Word-palatograms and Articulation. Bulletin of the School of Oriental and African Studies, University of London, 12(3/4), 857-864.

Hamann, S., & Fuchs, S. (2010). Retroflexion of Voiced stops: Data from Dhao, Thulung, Afar and German. *Language and Speech*, *53*(2), 181–216. https://doi.org/10.1177/0023830909357159.

Irfana, M. (2017). A Cross-Linguistic Study of Lingual Coarticulation in Kannada, Malayalam and Hindi Languages using Ultrasound Imaging Procedure. *A Thesis* *submitted to the University of Mysore for the fulfilment of the degree of Doctor of Philosophy.*

Irfana, M., &Sreedevi, N. (2013). Comparison of Tongue Contours in Children and Adults: A Preliminary Ultrasound Study. *Journal of the All India Institute of Speech & Hearing*, 32, 18-22.

Irfana, M., &Sreedevi, N. (2018). Consonantal Coarticulation Resistance in Hindi: An Ultrasound Imaging Study. *The Linguistics Journal*, 12 (1), 6-21.

Joseph, A. (2014). Comparison of Tongue Contours in Native and Non-native Speakers of Kannada using Ultrasound Imaging. *An Unpublished Dissertation Submitted to the University of Mysore for the part fulfilment of Master Degree*.

Khatiwada, R. (2007). Nepalese Retroflex Stops: A Static Palatography Study of Inter- and Intra-speaker Variability. *8th Annual Conference of the International Speech Communication Association, Interspeech 2007*, *3*(January), 2137–2140.

Khatiwada, R. (2009). Nepali. *Journal of the International Phonetic Association*, 39(3), 373-380.

Kochetov, A., Sreedevi, N., Kasim, M., &Manjula, R. (2012). A Pilot Ultrasound Study of Kannada Lingual Articulations. *Journal of Indian Speech and Hearing Association*, 26, 38-49.

Kochetov, A., Sreedevi, N., Kasim, M., &Manjula, R. (2014). Spatial and Dynamic Aspects of Retroflex Production: An Ultrasound and EMA Study of Kannada Geminate Stops. *Journal of Phonetics*, 46, 168-184.

Ladefoged, P., & Bhaskararao, P. (1983). Non-quantal aspects of consonant production: a study of retroflex consonants. *Journal of Phonetics*, *11*(3), 291–302. https://doi.org/10.1016/s0095-4470(19)30828-9.

Ladefoged, P., &Maddieson, I. (1996). *The sounds of the world's languages* (Vol. 1012). Oxford: Blackwell.

Laver, J., & John, L. (1994). *Principles of Phonetics*. Cambridge university press.

Pokharel, M. P. S. (1989). Experimental analysis of Nepali sound system. *A Thesis Submitted to the University of Pune for the Fulfilment of the Degree of Doctor of Philosophy.*

Proctor, M., Goldstein, L., Byrd, D., Bresch, E., & Narayanan, S. (2009). Articulatory Comparison of Tamil Liquids and Stops using Real-time Magnetic Resonance Imaging. *The Journal of the Acoustical Society of America*, *125*(4), 2568–2568. https://doi.org/10.1121/1.4783732.

Shawker, T. H., Sonies, B. A. R. B. A. R. A., Hall, T. E., &Baum, B. F. (1984). Ultrasound Analysis of Tongue, Hyoid, and Larynx Activity during Swallowing. *Investigative radiology*, 19(2), 82-86.

Simonsen, H. G., Moen, I.,& Cowen, S. (2008). Norwegian Retroflex Stops in a Cross Linguistic Perspective. *Journal of Phonetics*, 36(2), 385-405.

Srivastava, D. (1962). *Nepali Language: its History and Development*. Calcutta University.

Stone, M. (2005). A Guide to Analysing Tongue Motion from Ultrasound Images. *Clinical Linguistics & Phonetics,* 19(6-7), 455-501.

Stone, M., & Lundberg, A. (1996). Three□dimensional Tongue Surface Shapes of English Consonants and Vowels. *The Journal of the Acoustical Society of America*, 99(6), 3728-3737.

Kocjancic, T. (2010). Ultrasound and Acoustic Analysis of Lingual Movement in Teenagers with Childhood Apraxia of Speech, Control Adults and Typically Developing Children. *A Doctoral Dissertation submitted to the Queen Margaret University*.

Thelen, E., & Smith, L. B. (1994). *A Dynamic Systems Approach the Development of Cognition and Action*. MIT Press/Bradford book series in cognitive psychology.

Thoduvayil, N. (2014), Tongue Contours during Vowel Production in Children with Hearing Impairment: An Ultrasound Study. *An Unpublished Dissertation Submitted to the University of Mysore for the Part Fulfilment of Master Degree.*

Turnbull, A. (1982). *Nepali Grammar & Vocabulary*. Asian Educational Services.

Zvelbil, K. (1955). Some Remarks on the Articulation of the" Cerebral" Consonants in Indian Languages, Especially in Tamil (Plates I-XII). *ArchívOrientální*, 23(3), 374-434.