ULTRASOUND STUDY OF TONGUE CONTOURS OF TONAL WORDS OF MANIPURI

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All INDIA INSTITUTE OF SPEECH AND HEARING

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JULY, 2024

CERTIFICATE

This is to certify that this dissertation entitled "**ULTRASOUND STUDY OF TONGUE CONTOURS OF TONAL WORDS OF MANIPURI"** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Speech-language Pathology) of the student Registration Number P01II22S123014. This has been carried out under the guidance of a faculty member of this institute and has not been submitted earlier to any other university for an award of any other diploma or degree.

Mysuru

July 2024

Dr. M. Pushpavathi

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DECLARATION

This is to certify that this dissertation entitled "**ULTRASOUND STUDY OF TONGUE CONTOURS OF TONAL WORDS OF MANIPURI"** is the result of my study under the guidance of Ms Sindhusha Chandran, Assistant 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 an award of any other Diploma or Degree.

Mysuru **Registration Number: P01II22S123014**

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However, he said, “My grace is sufficient for you, for my power is made perfect in weakness.” Therefore, I will boast all the more gladly about my weaknesses so that Christ’s power may rest on me - 2 Corinthians 12:9

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"The ambition of the greatest man of our generation has been to wipe 'every tear from every eye', which may be beyond us, but so long as there are tears and suffering… our work will not be over." -Nehru

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ULTRASOUND STUDY OF TONGUE CONTOURS OF TONAL WORDS OF MANIPURI

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Abstract

Introduction: Manipuri is a tonal language with conflicting tonal organisation, and recent studies highlighted two distinctive tones, i.e., level and falling tones (Singh, 2019; Devi & Das, 2021). Syllabic and tonal knowledge is crucial to distinguish a spoken word in a tonal language. Studies to date have not explored tongue dynamics in Manipuri. Very few studies have explored the laryngeal and extra- laryngeal structures contributing to tone differentiation in tonal languages like Burmese and Chinese using acoustical and physiological methods (Erickson et al., 2004; Shastri & Kumar, 2015; Moisik et al., 2014). However, there is no physiological study conducted to understand the articulatory dynamics of the tongue in Manipuri.

Aim and objectives: The current study aimed to understand the tongue contours of monosyllabic level and falling tonal counterparts in Manipuri. The objectives were 1) To obtain tongue contours during the production of monosyllabic level and falling tonal counterparts in Manipuri. 2) To compare the horizontal tongue dynamics across anterior r, mid and posterior tongue regions between level and falling tonal counterparts. 3) To compare the vertical tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.4) To find any effect of gender on the horizontal and vertical tongue dynamics of the two tonal words.

Method: A total of 10 healthy native speakers of Manipuri, 5 males and 5 females between the age ranges of 20-35 years were enrolled in the study. The Mindray Ultrasound 6600 and Articulate Assistant Advanced (AAA) software were used to record 20 sentences of 10 monosyllabic tonal words (V, CV and CVC) each in level and falling tone. AAA software was used to analyze the acquired tongue images based on the (x-y) coordinates of the tongue's anterior, mid, and posterior regions.

Results: The findings of the study revealed significant differences in horizontal tongue dynamics between level and falling tone at tongue mid region with no significant difference in anterior and posterior tongue region. Vertical tongue dynamics were not significantly different for the tonal counterparts. There were no gender effects in tonal differentiation in Manipuri.

Discussion: The present study provided insight into the involvement of articulatory dynamics for various tones in Manipuri. The finding revealed a significant mid-tongue retraction phenomenon for tone differentiation. While there was a significant change in horizontal tongue dynamics, the vertical counterpart, i.e., tongue height, did not show any significant difference.

Conclusion: This is the first study to provide insights on tone differentiation using ultrasound tongue imaging techniques in Manipuri. The study provides visualizations of tongue contours that can be used for assessment and intervention of tone differentiation in native or new language learners in Manipuri.

CHAPTER I

INTRODUCTION

Speech is a unique ability of humans for oral communication. It is a complex process and requires highly coordinated movements of the articulators synchronised with the neural command. The tongue is one of the prime active articulators for speech production, which is crucial for accurate verbal language output. The tongue's placement is diverse in terms of tongue height and advancement. Each region of the tongue plays a different role in different speech sounds (Temple, 2002). For example, the anterior/tip of the tongue is essential for producing dental and alveolar sounds, while the posterior tongue region produces velar sounds. These variations in tongue region and its configuration give the dynamic nature of speech production. Psychological factors such as emotions and consciousness also influence tongue configurations, as seen in stress vs unstressed, low vs high tone utterances, over-articulated or exaggerated during anger, consciously trying to make speech more intelligible, etc. The tongue may change the shape and size of the oral cavity, enabling speech production based on the suprasegmental requirements. Understanding the intricate nature of human articulation requires an understanding of the movements made by the tongue during speech production. The knowledge of tongue contour during average speech production will enhance the ability to analyse any deviations in tongue dynamics, which will help correct individuals with speech sound errors more easily.

1.1 Imaging Techniques

The variety of imaging and tracking technologies readily accessible to measure the physiological aspects of speech production is getting broader. Specifically, methods such as Videofluoroscopy, Magnetic Resonance Imaging (MRI), Lateral Cephalogram, Computed Topography (CT), Ultrasound, Electromyography (EMG), Electromagnetic Articulography (EMA) and Electropalatography (EPG) are the primary imaging techniques used to understand the articulatory dynamics. Videofluoroscopy is an invasive technique that provides visualisation of the vocal tract during speech and swallowing. However, it requires the intake of radio-opaque substances. EMG and EPG techniques have been employed for scientific studies that used bio-signal sensors to track the dynamic nature of the various parts of the tongue during speech. However, the method of administration is complex and takes time for the entire process. These imaging techniques have limited applications in clinical populations and are available only in research settings. X-rays-based methods involve harmful radiations and have a reasonably lower temporal resolution of the image. It can take only a static image at a time, and this instrument cannot capture the dynamic nature of the tongue (Kent, 1972; Fujimura et al.,1973). Similarly, CT scans and MRIs were based on static images, and repeated usage of instruments is not permissible (Chen et al., 2019; Isaieva et al., 2020; Scoppa et al., 2020).

1.2 Ultrasound

Ultrasound imaging techniques have been used since they came into regular clinical use in the 1970s. It captures the dynamic tongue configurations that enable the measurement of lingual features during speech and provides precise and identical information on various lingual speech sounds. This tool has been implemented extensively due to its cost-effectiveness and biological safety. It is non-invasive and displays images that are relatively easy to explain. It does not require harmful radiation exposure as it does in X-rays, and there is no need for custom-made palates and numerous electrodes as it does in EPG and EMA, respectively. The availability of portable ultrasound is an added advance. It makes the tool a convenient and efficient real-time image processor of the tongue inside and outside the clinical settings.

1.3 Tonal Language

Consonants and vowels constitute distinct and contrastive segments of the fundamental components of words in all languages. These two phoneme classes are the differentiating factor between words, such as "pat" vs. "cat" or "pet," where meanings can be altered entirely by changing even a single vowel or consonant. Along with these segmental features, tonal languages have tonal variation as distinctive characters that vary the word's meaning based on its lexical tone. In tonal language, sub-syllabic fundamental frequency variations, referred to as tonemes, differentiate words and their meanings (Jones, 1944). For those languages, tone is considered a third class of phonemic elements. Researchers often assume tones as suprasegmental based on perceptual evaluation (So & Best, 2014; Liu et al., 2022). Indeed, several tone phonologists claim that lexical tones function as segments in tone languages (Duanmu, 2007, 1994). They are employed in 60–70% of existing languages (Yip, 2002), including many Asian, African and indigenous American languages and a few European and South Pacific languages (Maddieson, 2018).

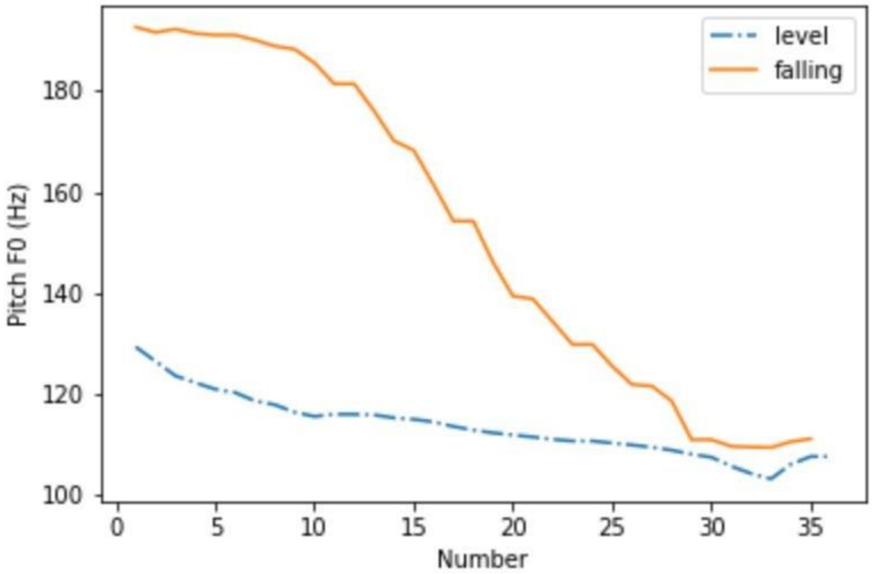
It is important to note that lexical tone formation and usage vary widely across tone languages (Hyman, 2014; Remijsen, 2016). Certain tonemes have pitch trajectories that change over time, known as contour tone languages, whereas others only use level pitches or register tone languages. Some only use pitch parameters to distinguish between tones, while others consider differences in phonation. Some have seven or more contrastive tones, while others have as few as two. While some limit tone values to the accented syllables of particular words, others pertain to tone principles for all syllables. Some only employ tones for stem morphemes; others also mark morphological or grammatical alternations with tones.

Languages also vary in how much they rely on lexical tone distinctions; this may differ from a high functional load, which implies extensive use, to a low functional load with restricted use. The tone results from the interaction between the fundamental frequency and other speech acoustic characteristics (Rose, 1990). According to Fromkin and Rodman (2014), the pitch of each tone in some languages is level or register, and pitch direction is essential in others. Tones that glide are called contour tones, and tones that do not glide are called level or register tones. It is not the absolute pitch of the syllable that is important; it is the relationship between the pitch of different syllables. Tone language has four essential characteristics: lexically significant pitch, i.e., pitch distinguishes the meanings of words; contrastive pitch, where the pitch can differ within a functional system; and relative pitch, which considers the relative height of the toneme. Finally, the significant pitch unit is the most frequently used pitch, a one-to-one correlation between the number of syllables and tonemes-specific utterances and syllables permitted to have more than one toneme (Narasimhan et al., 2020).

The present study will consider the Manipuri language, and based on the literature, there are various classifications of tonal contour. Devi and Das (2021) analysed Manipuri tones in level and falling tones. It is syllabic and follows an onset-nucleus-coda (consonant-vowel-consonant) structure, where the nucleus is the core component for tone, defined by the vowel (Singh et al., 2016). The level tone has a relatively steady-state pitch and is considered a lower tone, while the falling tone begins at a higher pitch level and proceeds to a lower one. In the study by Devi and Das (2021), the vowel in the falling tone bears a higher tone at initiation and lowers to the following coda, and the vowel in the level tone is lower than that of the falling tone, as shown in Figure 1.1.

Figure 1.1

Comparison of male averaged level and falling pitch of the word Sing /sIŋ/ taken from Devi and Das (2021)



Shastri and Kumar (2015) characterised four-pitch contours for monosyllabic words and two for bisyllabic words. Another report on three-way tonal contrast includes falling, rising and level (Singh, 1975). However, Manipuri grammar by the Board of Secondary Education, Manipur (BOSEM, 2012) explains two tones, i.e., rising and falling, and Manipuri Grammar by Singh (2019), Madhubala (2002) and Dolen (2004) reported it as level and falling.

1.4 Need for the Study

The use of contrastive pitch specifications at every level of the phonological hierarchy, in comparison to the latter's use at the segmental level, is the primary distinction between tonal and non-tonal languages. Therefore, segmental and tonal knowledge types must be recognised to distinguish a spoken word accurately. The laryngeal mechanism plays a significant role in the change in tone, and how other articulators move in conjunction with the laryngeal system is indispensable. Multiple studies have been conducted to understand the laryngeal system variation during the production of various tones using acoustical and physiological methods (Shastri & Kumar, 2015; Moisik et al., 2014). However, limited physiological studies have been reported to understand the articulatory dynamics of any articulator, such as the tongue and jaw movement in tonal languages (Erickson et al., 2004).

The present study will assess the tongue dynamics during the production of level and falling tones of the same monosyllable utterance that will provide insight regarding the differentiating characteristics of tongue movements, if any, from the laryngeal features.

CHAPTER 2

REVIEW OF LITERATURE

Speech is a complex process that involves various perceptual, cognitive, and linguistic skills (Lalonde & McCreery, 2020), and accumulating evidence has shown that speech perception is also an audiovisual (AV) process where visual cues such as the speaker's articulatory movements play an essential role in speech perception (Richie & Kewley, 2008; Rosenblum, 2008). When acoustic signals are degraded, listeners dynamically allocate more cognitive resources to the visual channel to assist their speech comprehension (De Gelder & Bertelson, 2003). Various imaging and tracking technologies have measured multiple morphological and physiological correlates of speech production in measuring articulatory gestures. Such studies in the field of speech and language include Magnetic Resonance Imaging (MRI), Lateral Cephalogram (X-ray) (Westbury et al., 1994), Computed Topography (CT-Scan), Ultrasound (Stone & Davis, 1995; Whalen et al., 2005), Electroglottography (EGG), Electromyography (EMG), Electromagnetic Articulography (EMA, Perkell et al., 1992; Wrench, 2000), Electropalatography (EPG, Hardcastle, 1997), Nasometry, Videofluoroscopy, Stroboscope, etc.

These techniques have been used to study the development of the oral mechanism structures throughout the life spans, such as in Cleft lip and palate (Abramson et al., 2015; Perry et al., 2017; Zourmand et al., 2014; Scott et al., 201), various articulators such as tongue contours of children and adult (Irfana & Sreedevi, 2013; Ansu & Sreedevi, 2014), speech sounds such as fricatives (Bresch et al., 2008; Narayanan et al., 1995), speech sound errors (Preston et al., 2016), coarticulation (Kochetov et al., 2011, 2014; Irfana & Sreedevi, 2016), dynamic nature of various articulators (Tilsen et al., 2015), laryngeal system (Hong et al., 2015; Murmura et al., 2021), identification of various structural abnormalities (Abramson et al., 2015), speech production, (Ramanarayanan et al., 2018), analysis of running speech (Harper et al., 2018) and effectiveness of surgical interventions. They also study vocal tract configurations during speech and at rest.

However, the cost of MRI and CT scans and their applications could be better included in routine clinical practices. They are expensive and bulky and also contain radiation exposure. They are mostly limited to research. Nasometry, video fluoroscopy, and Stroboscopy are also invasive techniques. They provide visualisation of the vocal tract, especially the velopharyngeal port and vocal fold vibrations during speech and swallowing. Videofluoroscopy requires the intake of radio-opaque substances. The EMA and EPG instrumentation are complicated, and assessment or testing takes time. Data obtained for articulatory movements, such as tongue movements, are not free articulatory movements. The presence of electrodes affects the actual values. Also, these instruments and their electrode placement are not readily accessible in the Indian context. The EMG and EGG are used to assess laryngeal activities. These studies are discussed in the following section.

2.1 Studies using X-Ray

Words, phrases, and sentences are formed by the meticulously coordinated production of strings of sounds by a number of articulators, including the lips, tongue, jaw, and soft palate. Several of these articulators are challenging to keep track of while speaking. (Nakai et al., 2016). Speech production has been investigated using the X-ray imaging process for the reason that all articulators are visible on X-rays (Stone, 2013). It is the oldest imaging technique for studying speech production's physiology and anatomy. Participants are asked to stop at a particular position for each speech sound, such as tongue tip touching at the alveolar ridge for /t/ for the imaging. It involves harmful radiation and has a reasonable resolution of the image. It can take only a static image at a time, and this instrument cannot capture the dynamic pathway of the tongue. Such studies include Fujimura et al. (1973) and Kent and Moll. (1972).

X-rays have been used to trace the part of the tongue involved in retroflex and dental articulations of Tamil, Telugu and Urdu (Svarney & Zvelibel, 1995). It provided that the retroflexes were produced with the edge of the tongue tip or the underside. A concave shape of the anterior tongue body and sublingual cavity was also observed during the tracings.

The tongue shapes across different languages, such as in Hindi and Telugu, have been obtained using X-rays by Ladefoged and Bhaskararao (1982). They found that the articulatory gestures were similar for dental consonants with tongue tip more curled further up and back in Telugu retroflex consonants than in Hindi.

2.2 Studies using EMG

Using electromyography (EMG), Helle (1994) studied the role of sternohyoid (SH) in the production of mid-rising and high-falling in Modern Standard Chinese. Additional tones, as well as the function of the vocalis and cricothyroid muscles, were also examined to confirm past findings and offer a more complete picture of Chinese tone production. This study found that the SH is consistently utilised to reset F0 to a mid-low value at the onset of tone2 and participated in the F0 fall of tone4, but less consistently.

2.3 Electropalatography (EPG) Studies

Using various palatographic techniques, the anterior portion of the tongue's surface has been studied during speech. These include optical tracking of the tongue's surface (Chuang & Wang, 1978; Fletcher et al., 1981), electropalatography (Fujimura et al., 1973; Hamlet & Stone, 1976, 1978; Fletcher, 2004), and the use of palatally located pressure transducers (McGlone & Proffit, 1971; Leeper & Appl, 1975). These instruments yield data on tongue surface features (e.g., retraction and grooving) and the area of tongue-palate contact. With the light source and sensor located at the midline, optical tracking provides information about the height and shape of the tongue. However, the surface measurements only provide incomplete configuration information.

Butcher (1995) showed that using palatograms and EPG in various Australian languages, retroflexes were produced with the underside of the tongue in post-alveolar or post-palatal. Similar results have been reported by Anderson (2000) using static palatography for Western Arrernte. Retroflexes were produced beneath the tongue's rim, and the constriction was posteriorly located close to the post-alveolar and even alveolar.

Dixit and Hoffman (2004) used electropalatography (EPG) to study the articulatory properties of Hindi fricatives and affricates. The area of tongue-palate contact for the voiced fricative was found to be significantly more significant than that of the voiceless fricative, according to the results. However, for the top portion of the voiceless affricate compared to the voiced affricate, the contact area was significantly more significant in affricates.

2.4 Studies using EMA

Using the electromagnetic articulatograph (EMA), Erickson et al. (2004) examined the articulatory changes of the jaw and tongue in tonal conditions of the syllable in two native Mandarin Chinese speakers producing tones on monosyllabic words comprising the vowel /a/, as in /ba/, /ma/, and /pa/. Measurements of jaw and tongue movements were done by placing one receiver coil attached to the lower incisor representing the jaw and four coils attached to the tongue's surface along the longitudinal sulcus. According to this study, there were significant differences between the two tones' supralaryngeal articulation. For both speakers, the low tone is markedly more retracted than the high tone in terms of the jaw and tongue. It offered helpful information for investigating the interactive control that a tone language speaker needs to generate tones: the control between laryngeal mechanisms and vocal tract shape articulation.

EMG uses variations in skeletal muscle contraction to derive details concerning laryngeal movements. EMG research by Simada and Hirose 1970; Sawashima et al. (1973), Collier (1975), Sagart et al. (1986), Erickson (2011), and Halle (1994) have demonstrated. However, not directly, in Mandarin and Thai, changes in larynx height do occur during tone and production. This method can be used to deduce the function of larynx height in the linguistic use of pitch and tone production.

2.5 Studies Using MRI

MRI has been used to overcome exposure to radiation and study the movements of the tongue during speech. It can offer more details about the vocal tract, soft tissues, and craniofacial structure and has a higher resolution. Additionally, real-time image acquisition using MRI is used to improve speech articulation analysis and visualise tongue movement. It is taken in the supine position of the body, so there will be gravitational influence on the tongue movement. Also, the instrumentation is extensive, costly, and inaccessible to the population. Such studies using MRI on tongue movement include Isaieva et al. (2020), Scoppa et al. (2020), and Chen et al. (2019).

Proctor et al. (2009) reported the subapical production with concave tongue shape for stops and retroflexes with different back cavities for dental and retroflex in Nepali using real-time magnetic resonance imaging (MRI). It was obtained from four native speakers in a word list of vowel-consonant-vowel combinations; each target word was repeated five times in a supine position.

Ramanarayanan et al. (2018) examined numerous techniques for analysing data on human voice production acquired from real-time magnetic resonance imaging (rMRI). MRI is a helpful tool for characterising soft tissues and observing the overall shape of the vocal tract; however, it is not as fast in imaging teeth with low water or fat content. The latter is a limitation of MRI applications in speech research because teeth are necessary for sound production, like [f] and [θ], as in *fin* and *thin*.

Kochetov et al. (2024), using articulatory shapes taken from a large MRI corpus of unchanging vocal tract positions used by Kannada speakers, examined the production of dental and retroflex stops, fricatives, nasals, and laterals in Kannada language. The goal was to capture essential elements of phonemic articulations. Using articulatory modelling, a group of elements in charge of putting place and manner contrasts into practice were identified for (/t̪ s̪ n̪ l̪/ vs. /ʈ ʂ ɳ ɭ/). Both lingual and non-lingual articulatory parameters were included in the study, where the results showed that the speakers made constrictions behind the alveolar ridge and a distinctive convex tongue shape without retracting the posterior part of the tongue for non-fricative retroflexes with a retracted tongue tip.

2.6 Imaging Tongue Contours Using Ultrasound

Ultrasound imaging technology has been used since it came into regular clinical use in the 1960s and 1970s. It captures the dynamic tongue size and shape, enabling the measurement of the lingual features during speech. This tool has been used extensively due to its cost-effectiveness and non-invasiveness. Also, the availability of portable ultrasound allows for the broader use of this tool. Ultrasound has been used in research, clinical diagnosis, monitoring, and therapeutic purposes for various communication disorders such as speech sound. It provides visual as well as tactile feedback for the intervention. Such studies include Yun & Moisik (2019), Roon et al. (2020), Gick (2002), Preston et al. (2014, 2017, 2019), etc.

Ultrasound tongue imaging (UTI) is widely used to study the actions of the tongue during utterances. UTI takes advantage of the observation that sound waves bounce back at tissue-air boundaries but pass through soft tissue well. As a result, real-time images of the tongue dorsum can be captured while the speaker is speaking by placing a probe beneath their chin that emits and receives ultrahigh frequency sound waves. The tongue tip is often invisible in UTI data because of an air pocket underneath or a shadow cast by the jawbone. With UTI, it is easier to achieve frame rates that are high enough to capture most tongue motions during speech production, with many modern ultrasound machines capable of scanning at around 90 fps (frames per second) (Stone et al., 2013). Compared with MRI, other advantages of UTI include relative ease with which high-quality audio recordings can be obtained during data acquisition, as well as relatively low cost and convenience. The technique images oral and laryngeal articulator movements in the production of each sound category. This resource is envisioned as a teaching tool in pronunciation training, second language acquisition, and speech therapy.

Ultrasound is an increasingly common part of the toolkit for studies of dialect variation (Lawson *et al.*, 2012; De Decker & Nycz, 2012; Mielke, 2015) because data collection is convenient and affordable compared to other lingual imaging techniques.

Using ultrasound, Stone and Lundberg (1996) obtained four tongue shapes of front raising, complete groove, back rising and two-point displacement from 18 American English sounds. Using ultrasound imaging techniques, Davidson (2006) studied the tongue shapes for /k/, /g/, and /z/ in American English.

Mielke et al. (2017) explored the articulatory basis of /æ/-raising across North American English dialects and related them to their apparent phonetic motivations (nasalisation, voicing, and tongue position). They found that /æ/ raising before anterior /m/ and /n/ (before anterior fricatives in Philadelphia) is produced with a tongue-raising gesture aligned near the midpoint of the vowel interval and independent of the following consonant gesture. Raising before /ŋ/ is as significant and widespread as raising before other nasals. However, it involved a tongue gesture with a rising trajectory that peaks near the end of the vowel, where the velar closure started. While it remained plausible that the acoustic consequences of nasalisation constitute the original phonetic motivation for all pre-nasal raising, the raised variants of /æ/ that they observed appear to be too high (due to tongue raising) for nasalisation to have the effect of lowering F1 frequency and making the vowels sound higher. Further, they stated that /æ/ raising before /ɡ/, as observed in the North and Northwest of the United States and parts of Canada, involved a tongue gesture similar to raising before /ŋ/. However, the magnitude of the tongue gesture involved in /æɡ/ raising is consistently less than for /æŋ/ raising. Tongue root advancement was observed for both voiced velars for nearly all speakers in the sample. However, only a tiny group of Midwestern speakers showed a more anterior constriction location for /ɡ/ and /ŋ/. Anterior /ɡ/ might have led to the development of /æɡ/ raising in the Midwest, and this phonological raising pattern may then have spread independently to other regions, such as the Pacific Northwest and Canada.

Tabain et al. (2017) investigated the generation of alveolar and retroflex consonants with ultrasound. The results revealed few variations between the retroflex and the alveolar at stop offset; however, during stop onset, the retroflex had a higher front region of the tongue and a more front posterior portion. The contrast between the alveolar and retroflex is most evident in unstressed prosodic settings. This finding was consistent with their prior research on EPG and EMA, which revealed that the most archetypal retroflex consonant occurs in the unstressed prosodic position.

Tabain et al. (2018) used ultrasound to present tongue contours for stop, nasal, and lateral productions of four coronal places: dental, alveolar, retroflex, and (alveo-)palatal- /t̪ t ʈ c/, /n̪ n ɳ ɲ/, and /l̪ l ɭ ʎ/, as well as the two contrastive rhotics of Arrernte, the alveolar trill /r/ and the retroflex glide /ɻ/. The results revealed that the palatal has a high and front tongue position, whereas the dental has a relatively low and flat tongue in the mid-to-front part. Consistent with prior research, the alveolar and retroflex are challenging to distinguish, and possible differences are examined. Rhotics were distinguished by a low front section of the tongue and a retracted back portion of the tongue. The alveolar trill had a lower front section of the tongue than the retroflex glide, but the back of the tongue was more retracted. The back of the tongue was more retracted for the rhotics than for the comparable stops and nasals. However, there was evidence that this section of the tongue patterns was similar to the laterals and the rhotics. It was proposed that posterior constriction for the various liquid sounds resulted from an interplay between the tongue's biomechanical qualities and the style of articulation required.

Zhu et al. (2019) used a convolutional neural network to extract the brightest edge from a noisy ultrasound image, which corresponded to the tongue tissue air interface. Following the segmentation of the image, they calculated a tongue surface curve. Extracting tongue contours from ultrasound pictures is an essential step in ultrasound data analysis. However, this operation frequently necessitates non-trivial manual annotation. This study used neural network-based algorithms to propose an open-source application for automatically tracking tongue contours in ultrasound footage. Under various settings, they developed and thoroughly compared two convolutional neural networks, U-Net and Dense U-Net. Though both models could execute automatic contour tracking with equivalent accuracy, the Dense U-Net architecture was more generalisable across test datasets, while U-Net had a faster extraction time. Their analysis also revealed that the loss function and data augmentation had a more significant impact on tracking performance on the job. This freely available segmentation method demonstrated the potential for automatic tongue contour annotation of ultrasound images in speech research.

2.7 Use of ultrasound to study articulatory development

Smith et al. (2023) compared the tongue shapes during multiple repetitions of various consonants in typically developing (TD) children across different ages and children with SSD, using mean Nearest Neighbour Distance (NND). Results suggested no significant effect of age in the TD group, while Children with SSD had significantly higher tongue shape variability than TD children. Cleland and Scobbie (2021) obtained the articulatory norms for dorsal differentiation using KTMax and KT crescent area measurements in typically developing children's alveolar and velar stops, which were then compared to dorsal productions by the children with speech disorders before, during, and after the intervention. The children with persistent velar fronting showed KTmax values near zero before the intervention, showing a complete merger between /k/ and /t/. During the intervention, they showed variable KTmax values. Post-intervention, they showed values within the range of typical children.

Ribeiro et al. (2021) trained the systems on usually developing kid speech and supplemented them with an adult speech database utilising ultrasound to detect speech articulation problems. Evaluation of usually developing speech shows that pre-training on adult speech and employing ultrasound and audio together produces the most significant outcomes (86.9% accuracy). To assess disordered speech, they gathered pronunciation scores from expert speech and language therapists, concentrating on cases of velar fronting and gliding of /r/. The ratings indicated strong inter-annotator agreement for velar fronting but not for gliding mistakes. The best results for automatic velar fronting fault identification come from utilising ultrasound and audio together. The ratings indicated strong inter-annotator agreement for velar fronting but not for gliding mistakes. The best results for automatic velar fronting fault identification come from utilising ultrasound and audio together. The top algorithm correctly detects 86.6% of the problems reported by qualified doctors. Of all the segments recognised as errors by the best system, 73.2% match errors found by physicians.

2.8 Ultrasound studies in communication disorder

Increasing data suggests that ultrasound visual biofeedback (U-VBF) can benefit patients, therapists, and annotators (Bernhardt et al., 2005; Cleland et al., 2019; Cleland et al., 2020). U-VBF is effective in treating a variety of speech sound problems, particularly in the early phases of motor learning (Sugden et al., 2019; Bryfonski, 2023). Related research implies that U-VBF can be used as an objective measure of intervention progress (Cleland & Scobbie, 2020) or as a supplement to audio feedback and positive reinforcement (Roxburgh et al., 2015). U-VBF can also help annotators detect covert errors and improve inter-annotator agreement ratings (Cleland et al., 2020). Additionally, U-VBF can help with the automatic processing of speech therapy recordings. Recent work has employed ultrasound data to construct tongue contour extractors (Fabre et al., 2015), animate a tongue model (Fabre et al., 2017), automatically synchronise therapy recordings (Eshky et al., 2019), and for speaker diarisation and therapy session alignment (Ribeiro et al., 2019a). However, there are significant obstacles involved with automatically processing ultrasound tongue pictures (Stone, 2005; Ribeiro et al., 2019b).

Dugan et al. (2023) investigated the perspectives of speech-language pathologists (SLPs) who have used ultrasound biofeedback in speech sound therapy programs. While SLPs were optimistic about using UBT for speech sound disorder treatment, they acknowledged institutional barriers and limitations at the organisational and social levels. Sugden et al. (2019) examined the research evidence for U-VBF (Ultrasound-Visual Biofeedback) in the treatment of developmental SSD, finding that the majority of studies reported that U-VBF facilitated target acquisition, with effect sizes ranging from no effect to a significant impact. Furthermore, most research was classified as efficacy rather than effectiveness studies, resulting in lower levels of evidence. Overall, the evaluated studies scored higher on criteria of external validity than internal validity.

Mara de Oliveira et al. (2022) used ultrasound to compare the tongue contours of children with phonological disorders (PD) and children with childhood apraxia of speech (CAS), and the results revealed differences in tongue contours for correct plosive productions. Children with PD used different articulation methods with inaccurate and faulty output than children with CAS.

The previous study (Kocjancic, 2010) examined ultrasound data of Scottish adolescents with Childhood Apraxia of Speech (CAS) producing simple syllables (consonant-vowel) and complex syllables (consonant, consonant, and vowel) and discovered minor tongue movement in the vertical and horizontal directions when compared to data from children without speech disorders. Bernhardt et al. (2005) used ultrasonography in speech therapy, and the results demonstrated that ultrasound is a promising technique to expedite positive change in speech output in adolescents and adults with different backgrounds (hearing impairment, chronic speech impairment, accented English).

Preston et al. (2013) employed real-time ultrasound images as biofeedback to treat persistent CAS, and posttreatment probes remained very accurate. The two-month follow-up demonstrated excellent performance across all target sequences. Cleland et al. (2019) tested ultrasound visual biofeedback treatment for teaching new articulations to children with various speech sound disorders. The treatment included velar fronting, postalveolar fronting, and backing alveolars to pharyngeal or glottal place, delocalisation (production of all onsets as [h]), vowel merger, and lateralised sibilants.

Cleland et al. (2022) studied a comparison between ultrasound visual biofeedback (U-VBF) and traditional articulatory intervention for children with cleft lip and palate and showed improvement utilising the former technique.

2.9 Ultrasound Studies in Indian Languages

It has been extensively studied in Indian languages such as Malayalam (Scobbie et al., 2013), Hindi, Kannada (Irfana & Sreedevi, 2017), Nepali language (Sabin, 2020), and cross-linguistically (Irfana & Sreedevi, 2019). Tongue contours of children and adults (Irfana & Sreedevi, 2013; Ansu & Sreedevi, 2014) and speech sounds such as lingual consonants (Kochetov et al., 2011), retroflexes (Sabin, 2020; Kochetov et al., 2014)) have been studied using ultrasound. It has also been studied in the hearing-impaired population (Neethu Thoduvayil, 2014) and coarticulation (Irfana & Sreedevi, 2014, 2016, 2017).

Kochetov et al. (2012) compared tongue contours of the lingual articulations of Kannada words /aʈʈ/, /atta/, /aʧʧa/ and /akka/. A more significant vertical and horizontal displacement of the tongue was obtained for retroflex /ʈ/ and alveopalatal /ʧ/relative to dental/t/ and velar /k/consonants with significant fronting of the tongue body for retroflex.

Using ultrasound, Kochetov et al. (2013) obtained the tongue contours for the Nepali language in a single speaker for lingual consonants. They reported a significant rise of tongue front and tip for apical stops and different tongue shapes for voiced stops.

Anjali and Sreedevi (2014) compared the tongue contours in native and non-native speakers of Kannada using ultrasound imaging, and the result revealed that there were differences in tongue contours in native and non-native speakers with a higher positioning of the tongue compared to non-native Kannada speakers. The difference in tongue height was mainly in the anterior region of the tongue.

Kochetov et al. (2014) investigated the production of geminate retroflex stops in Kannada using a combination of ultrasound and articulography. The results showed that the constriction for the Kannada retroflex stop /ʈ/, as inferred from ultrasound images and the EMA trajectories of the tongue tip, was considerably more back and higher than the corresponding constriction for the dental /t/.

Irfana and Sreedevi (2015) found that in the productions of children with CAS, speakers of Kannada restricted tongue movements in the vertical and horizontal axes of the vocal tract compared to a control group. The motor restrictions may cause imprecisions and variabilities between articulators, and variations of articulators were more evident in the posterior regions of the tongue than in the anterior region.

Kochetov and Sreedevi (2016) studied the articulatory of voiceless geminate affricate /ʧ/ using ultrasound, and the study revealed that /ʧ/ is produced with the tongue shape intermediate between the palatal glide and the dental stop and with the laminal constriction at the alveolar ridge. The observed articulatory differences were reflected in acoustic formant patterns of vowel transitions and stop/affricate bursts. Altogether, the results showed that the Kannada consonant in question is an alveolopalatal affricate, supporting some of the previous descriptive phonetic accounts of the language and raising questions for further research on normal and disordered speech. The results also suggested that affricates in South Asian languages tend to be phonetically variable and historically unstable compared to other consonant articulations.

Irfana and Sreedevi (2017) studied tongue contours to investigate coarticulation using ultrasound in Kannada, Malayalam, and Hindi. Ninety adult native speakers of equal male and females, 30 each for each language, were included in the study where V1CV2 sequences with C corresponding to voiced/unvoiced counterparts of dental (/t/, /d/) or retroflex (/ʈ/, /ɖ/) or velar stops (/k/, /g/) in the context of /a/, /i/, and u/ were the stimuli. The result revealed different patterns of the extent of coarticulation across the languages, with significant anticipatory direction in all the languages and significant coarticulation resistance for retroflexes compared to dental and velars.

Sabin and Yeshoda (2020) explored the tongue contours for retroflex plosive consonants of the Nepali language: /ʈ/, /ʈ^h/, /ɖ/ and /ɖ^h/ embedded in between vowels in a geminate form. The mean of ten tongue contours for each target phoneme was obtained from seven native speakers, four males and three females. The tongue contours showed a similar pattern for retroflex with higher tongue front regions in females and posterior tongue body in males. The results also showed that the tongue front was more advanced for /ʈ^h/ and tongue height was more significant for /ʈ/ in males, whereas both the unvoiced (/ʈ/, /ʈ^h/) have similar tongue contours for females. For voiced sounds, tongue height and curling in the tongue front in male participants were observed for /ɖ^h/, which was contrary for females. In between the /ʈ/ and /ɖ/, males have more tongue height for /ʈ/ while females have the tongue front higher for /ɖ/. For /ʈ^h/ and /ɖ^h/, the anterior advancement was higher for /ʈh/ and the tongue height was higher in the anterior tongue body in male participants. In contrast, there was a significant difference only in tongue height in the posterior tongue body in cases of females.

2.10 Ultrasound studies in tonal languages

Moisik et al. (2014) examined tonal production using laryngoscopy and laryngeal ultrasound for five Mandarin tones of high level, mid-rising, falling rising, and high falling with tone sandhi rules in monosyllabic. Three participants were included in the study, two native and one non-native, whose speech was judged by several native speakers to be highly natural. The vowel /i/ was used for an optimal laryngoscopic view of the larynx, repeating each target word three times. They found that the extra-glottal laryngeal mechanisms play essential roles in facilitating the production of tone targets.

2.11 Aim of the Study

The study aims to understand the tongue contours of monosyllabic level and falling tonal counterparts in Manipuri.

2.12 Objectives and Hypothesis

The following are the objectives of the study and the hypothesis:

1. To obtain tongue contours during the production of monosyllabic level and falling tonal counterparts in Manipuri.

   Hypothesis: No significant differences exist in the tongue contours of monosyllable level and falling counterparts.

2. To compare the horizontal tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.

   Hypothesis: There is no significant difference in the horizontal tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.

3. To compare the vertical tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.

   Hypothesis: There is no significant difference in the vertical tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.

4. To see the effect of gender on the horizontal and vertical tongue dynamics of monosyllabic level and falling tonal words.

   Hypothesis: There is no significant gender effect on the horizontal and vertical tongue dynamics of monosyllabic level and falling tonal words.

CHAPTER 3

METHOD

3.1 Research design

A comparative study was carried out to compare the tongue contours of level and falling tonal words and to find the difference in tongue contours across the genders.

3.2 Participants

A total of 10 native speakers of the Manipuri language, with an equal number of males and females, were selected for the study. All the subjects were above 18 years of age.

3.2.1 The inclusion criteria for the study were as follows:

- The participants were native speakers of Manipuri language (L1).
- The participants have no history of cognitive, hearing, or speech-language impairment.
- The subjects have no structural abnormalities such as ankyloglossia, macroglossia, or cleft lip and palate and have not undergone glossectomy.
- They were not using any dental/oral prostheses.

3.3 Materials

As seen in Table 3.1, 10 minimal pairs of monosyllabic words contrasting in tone were considered for the study (Singh, 2019; Devi & Das, 2021). These words were presented in phrases or sentences to produce various tones more naturally. An agreement test was used to choose these sentences across five judges. These judges were native speakers of Manipuri who knew how to read and write the language and were not considered participants. Four phrases/sentences were prepared for each word with both tones, and the judges rated the appropriateness of tonal variation. Forty phrases/sentences were prepared based on books and magazines, among which twenty phrases/ sentences were chosen for the final study based on 75% agreement criteria.

Table 3.1

Manipuri monosyllabic words having both level and falling tones.

Tonal words	Level tone	Falling tone
1. Ee /i/	Blood	Thatch
2. Mee /mI/	People	Spider
3. Kang /kaŋ/	Mosquito	A kind of game
4. Thong /t^hoŋ/	Door	Bridge
5. Khong /k^hoŋ/	Leg	Canal
6. Sing /sIŋ/	Ginger	Firewood
7. Sam /sam/	A basket made of bamboo	Hair
8. Tai /taɪ/	Listen/hear	Fall
9. Ki /kI/	Fear	Tie
10. Lei /laɪ/	Flowers	Tongue

3.4 Instrumentation

The Articulate Assistant Advanced (AAA) software and the Mindray Ultrasound 6600 were used to record and analyse the sample. Before the subject started the task, the transducer, a long-handled, 6.5MHz micro-convex probe, was positioned under the chin. To minimise artefacts and enhance the imaging clarity, the probe was covered with ultrasound transmission gel. The spoken phrases/sentences were recorded by a headset microphone with the ultrasound image signal. The AAA analysed the acquired images and audio samples at a processing rate of 60 frames per second. The instrument setup is shown in Figure 3.1.

Figure 3.1

Ultrasound instrument setup: 1. Ultrasound displayed in AAA software, 2. Focusrite, 3. Transducer Micro-convex probe, 4. Headphones, and 5. Ultrasonic transmission gel

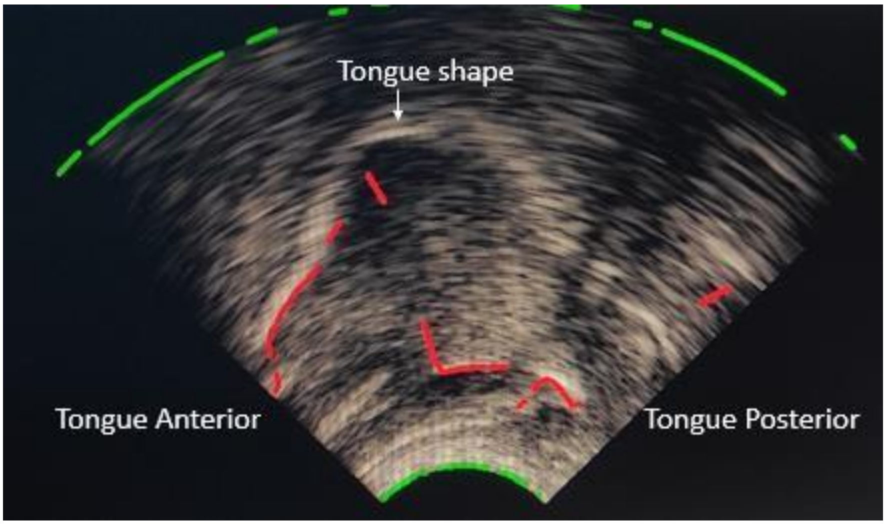
Note: Instruments in the Ultrasound Lab, Department of Speech-Language Sciences, Centre of Excellence (COE), All India Institute of Speech and Hearing, Mysore, Karnataka

3.5 Principle

The ultrasound works on the reflection principle of sound in which the air and the bony palate act as the medium of reflecting the ultrasound wave from the transducer probe. Ultrasound waves reach the air space between the tongue and the palate, creating a dark shadow since air is a poor conductor due to the density difference between them. The tongue's upper surface appears white, as shown in Figure 3.2, which can be traced and plotted for various samples. Thus, the tongue contours were obtained and compared.

Figure 3.2

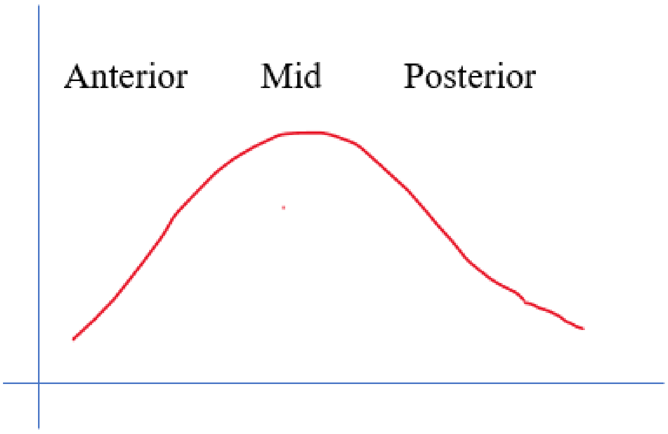
Imaging of the tongue using ultrasound



The tongue contour is visually divided into the anterior, mid and posterior regions, as shown below in Figure 3.3.

Figure 3.3.

The Anterior, Mid and Posterior regions of the tongue.



3.6 Procedure

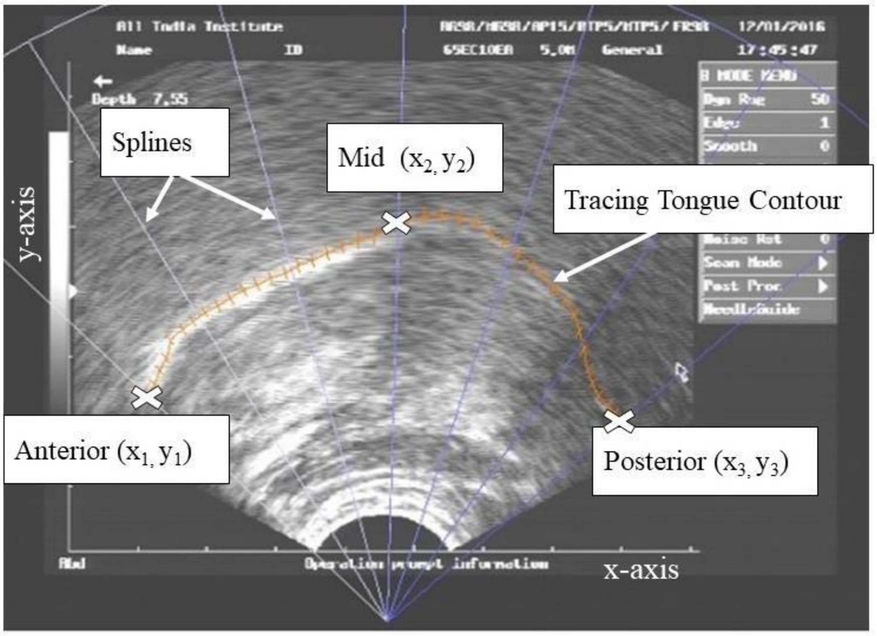
The headphone with the microphone was placed securely on the participant's head to record the utterances. The ultrasonic conduction gel was applied to the transducer probe and was placed under the participant's chin. The 20 sentences were presented in text, and picture representations of the target word were provided during the ultrasound recording. Participants repeated each stimulus ten times; a total of 200 recordings (20 sentences x 10 repetitions) were collected per participant. The recording was later analysed offline.

3.7 Analysis

The Articulate Assistant Advanced (AAA) software analysed the acquired tongue images. Tongue contours were obtained based on the (x-y) coordinates of the tongue's anterior, mid, and posterior regions based on 7 splines. As shown in Figure 3.4, the anterior tongue (x_1, y_1) was measured where the first spline crossed the tongue contour, the mid portion of the tongue (x_2, y_2) was the point where the fourth spline crossed the tongue contour and finally, posterior tongue (x_3, y_3) was considered where the seventh spline crossed the tongue contour. The seven splines were kept constant for both level and falling tones to reduce the variability.

Figure 3.4

Tracing Tongue Contour across (x-y) coordinates.



Note: The anterior tongue is towards the right side, with the x-axis showing tongue advancement and the y-axis showing tongue height.

3.8 Statistical analysis

Gender and tone were considered the independent variables, while the horizontal and vertical values of anterior, mid and posterior (x, y) tongue regions were the dependent variables. Shapiro-Wilk Normality Test was administered to verify normality, and data followed normality. Paired t-test was administered to compare the level and falling tones across the tongue anterior, mid and posterior regions. Non-parametric Mann-Whitney U-test was administered to compare the vertical and horizontal tongue dynamics across the genders. Intrajudge reliability was tested using Cronbach's alpha.

CHAPTER 4

RESULTS AND DISCUSSIONS

The study aimed to investigate the tongue contours of Manipuri's monosyllabic level and falling tonal counterparts with the following objectives:

1) To obtain tongue contours during the production of monosyllabic level and falling tonal counterparts in Manipuri.
2) To compare the horizontal tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.
3) To compare the vertical tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.
4) To find any effect of gender on the horizontal and vertical tongue dynamics of monosyllabic level and falling tonal words.

Ten participants, 5 males and 5 females were enrolled in the study. The stimulus consisted of 20 sentences of 10 tonal words, in level and falling tone (Table 2.1). Each sentence was repeated 10 times, and the mean of the 10 repetitions was obtained. The tongue contours were plotted for the vowels of /i/, /I/, /a/, /o/ and a diphthong /aɪ/ in the context of V, CV and CVC, where C represents the consonants, and V represents the vowels/ diphthongs (Table 2.2). The target vowels were the nucleus of the tonal production, making it easier to visualise ultrasound images. The tongue contours were visually analysed using the constant 7 splines throughout the repetitions. At the intersection of tongue contour with the 1st, 4th and 7th splines, the mean x and y values were obtained for the anterior, mid and posterior tongue. The x and y values were the horizontal and vertical tongue dynamics, respectively, across the anterior, mid and posterior tongue. The horizontal tongue dynamics is the tongue advancement plotted on the x-axis, and the vertical tongue dynamic is the height of the tongue against the y-axis for the anterior, mid and posterior regions of the tongue.

Descriptive statistics of each parameter with ultrasound-averaged tongue images of each word are discussed according to the objective of the study.

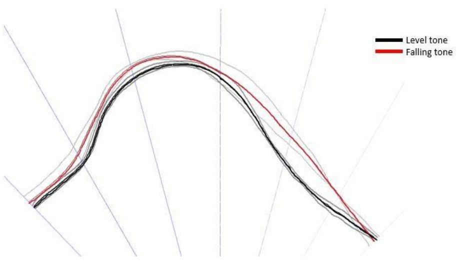
4.1 Tongue contours during the production of monosyllabic level and falling tonal counterparts in Manipuri.

Figure 4.1 shows the images of tongue mean contours obtained for the level tone in the red line and the falling tone in the black line for 10 repetitions of 10 words for 10 participants.

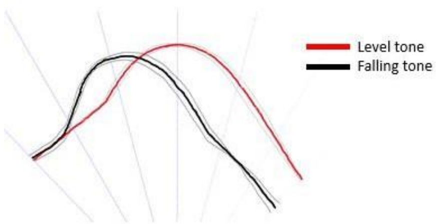
Figure 4.1

Images of averaged tongue contours for the 10 words in level and falling tones

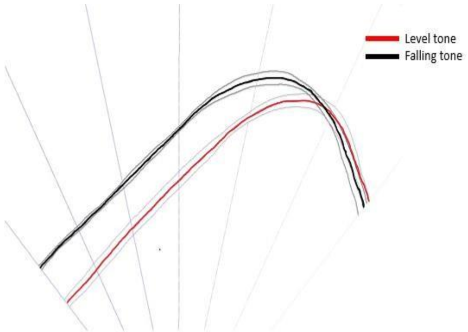
1. Ee /i/



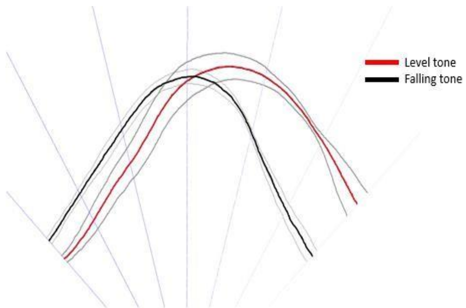
2. Mee /mI/



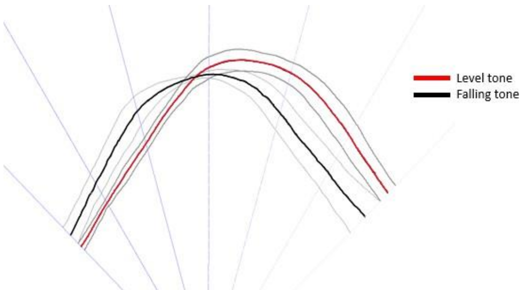
3. Kang /kaŋ/



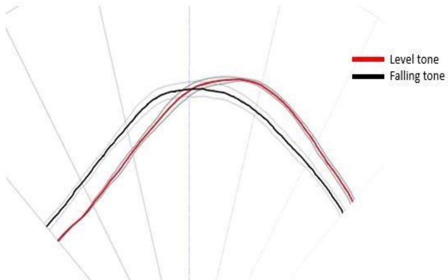
4. Thong /tʰoŋ/



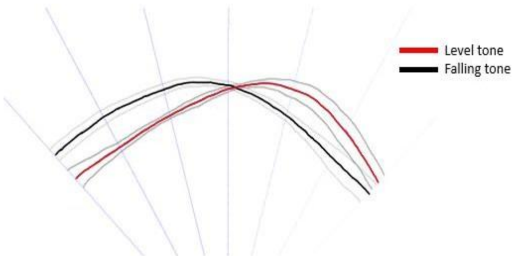
5. Khong /kʰoŋ/



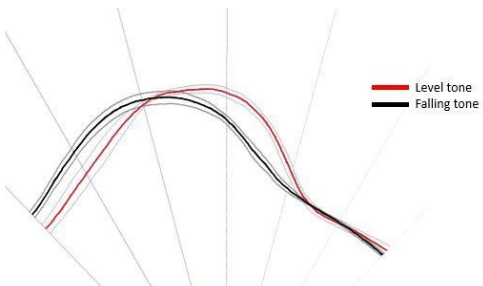
6. Sing /sIŋ/



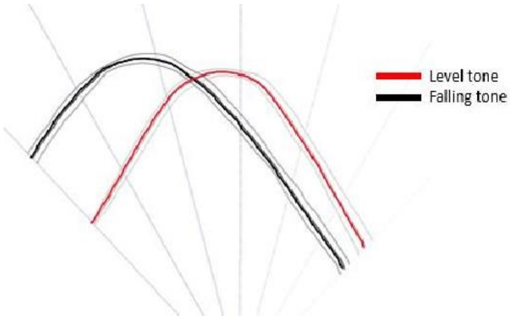
7. Sam /sam/



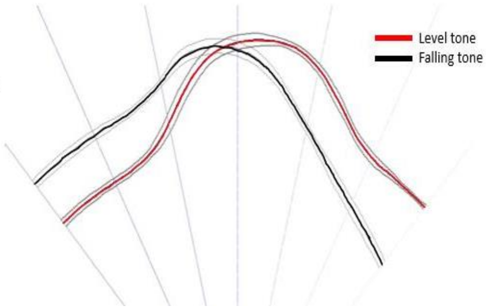
8. Tai / taɪ/



9. Ki /kI/



10. Lei /laɪ/



Note. The anterior tongue region is towards the right side, while the posterior region is towards the left.

Figure 4.1 shows that the tongue contours were visually found to be minimally distinct for the different tones, level and the falling tone. The height of the tongue contour was similar for the two tones in all stimuli; however, the tongue was retracted for level tone compared to the falling tone in all stimuli except for /i/. Hence, the first hypothesis is rejected, and there is a difference in tongue contours for level and falling tones.

Erickson et al. (2004) used an Electromagnetic Articulograph (EMA) to study supralaryngeal (jaw, tongue and larynx) variations in high and low tones in two Mandarin speakers. The study found that supralaryngeal articulation differed significantly for the low and high tones. The study showed that the tongue mid (T2) and dorsum (T3) were significantly more retracted in participant 2 (Figure 4.4). However, the tongue tip (T1) and tongue mid (T2) were significantly more retracted in participant 1 (Figure 4.4). T2 was noticeably more retracted for the low tone than the high tone for both participants, indicating that the tongue was significantly more retracted for the low tone than for the high tone.

Figure 4.2

Placement of coils on the jaw and tongue taken from Erickson et al. (2004)

Moisik et al. (2014) examined tonal production in Mandarin using laryngoscopy and laryngeal ultrasound. Tongue dynamics was not studied since it was not their study objective. They found that the extra-glottal laryngeal mechanisms, such as movements of the jaw and tongue, played a crucial role in facilitating the production of tone targets. The larynx is not the sole mechanism for tonal production. The extra laryngeal structural movement, such as the tongue, also plays a crucial role in tonal language production in addition to the larynx. This study indirectly supports the findings of the current study, where tongue movements were distinct for different tones.

4.2. The horizontal tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.

The horizontal tongue dynamics were plotted on the x-axis, representing the tongue advancement during the production of the tonal words. Paired t-test was administered to compare the horizontal tongue dynamics across different tongue regions. The result revealed no significant difference between the tonal counterparts at the anterior [t (9) = -0.06, p>0.005] and posterior tongue region [t (9) = -0.98, p>0.005], as shown in Table 4.1. Thus, the null hypothesis was accepted as there were no significant differences between the level and falling tones at the anterior and posterior tongue regions.

However, there was a significant difference obtained for the tongue mid of the tongue [t (9) = 450.83, p<0.001] as shown in Table 4.1. Hence, the hypothesis was rejected, and there is a significant difference in the tongue mid-region for the level and falling tones. The level tone has a higher mean value than the falling tone, as shown in Table 4.1. The greater the value along the horizontal x-axis, the more posterior the tongue was, and this indicated the advancement of the tongue toward backwards. This implied that the tongue mid was more retracted for the level tone than for the falling tone.

Table 4.1.

Pair-wise comparison of level and falling tones across the horizontal tongue dynamics

Tongue region	Tone	Mean	Std. Deviation	Sig. (2-tailed)
Anterior	Level	34.11	2.58	0.952
	Falling	34.15	2.79	
Mid	Level	79.27	0.02	**0.000**
	Falling	72.02	0.55	
Posterior	Level	108.94	6.71	0.352
	Falling	110.05	5.45	

The study by Lundmark et al. (2021) revealed a more extended and prolonged tongue body movement in changing tones. A similar finding is seen in this study where the tongue mid, which is the tongue body, is more involved in tonal differentiation of low and high tones.

Erickson et al. (2004) showed significant differences in supralaryngeal articulation in which the tongue was significantly retracted for the low tone compared to the high tone.

Moisik et al. (2014) found the involvement of the extra laryngeal structures, including the tongue, in conjunction with the laryngeal system for tone differentiation. They noted that low tones were attended by laryngeal elevation with constrictions in the supralaryngeal structures, such as the jaw and the tongue.

Hence, the present study found that mid-tongue retraction was seen in the level tone compared to the falling tone, which is supported by the literature using EMA. There were no ultrasound tongue imaging studies done to compare different tones in tonal languages.

4.3. To compare the vertical tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts.

The vertical tongue dynamics are plotted on the y-axis, representing the tongue height during the production of the tonal words. Paired t-test was administered to compare the vertical tongue dynamics. The result revealed no significant difference between the tonal counterparts at the anterior [$t(9) = 0.87$, $p>0.005$], mid dorsum [$t(9) = -0.88$, $p>0.005$] and posterior tongue [$t(9) = -0.60$, $p>0.005$] as shown in Table 4.2. This indicates no tongue height differences between the level and falling tones.

Table 4.2

Pair-wise comparison of level and falling tones across the vertical y-axis.

Tongue region	Tone	Mean	Std. Deviation	Sig. (2-tailed)
Anterior	Level	39.69	2.65	0.407
	Falling	39.23	2.42	
Mid	Level	69.99	4.90	0.403
	Falling	70.66	5.85	
Posterior	Level	39.00	5.83	0.563
	Falling	39.41	5.57	

The height of the tongue is different for different vowels in the stimuli. Studies have shown that tone effects are different for different vowels, as opposed to /a/ and /i/ vowels, which are in the opposite direction as predicted by physiological considerations by Shaw et al. (2016).

The different vowels also have different coarticulation effects, as studied by Irfana and Sreedevi (2017), and hence, the tongue contour changes as the direction of coarticulation differs for different vowels. Foley (2022) also found that apical vowels have more resistance to coarticulation, whereas vowels /a/, /i/, and /u/ are less resistant.

Erickson et al. (2004) studied the /a/ vowel in the context of /ba/, /ma/, and /pa/ for high and low tones, and there was no significant result at the tongue tip and tongue posterior (Figure 4.4) between the low and the high tone.

In this study, the different vowels were not considered separately, and the mean of all vowels was considered, which could normalise the result. The effect of coarticulation for different vowels was also a factor that was not taken into consideration in the present study and could have influenced the result.

Lundmark et al. (2021) revealed only slight differences in tongue body height, which was also insignificant in this study. The previous studies in tonal languages, such as in Mandarin (Erickson et al., 2004), Thai (Moisik et al., 2014) and Swedish (Lundmark et al., 2021), were done between the contrasting tones as high versus low tone, rising versus falling tone. These counterparts are very distinctive and prominent in identifying their differences. This was not the case for the present study, where low level and falling tone were used, which could have diminutive to the findings.

Also, Singh (2019) noted that the tones in Manipuri are not as distinctive as in Chinese and Burmese, with its tonal features being lost gradually. This decrease in tonal contrast and lesser distinctiveness could have diminished the findings between the tones.

4.4. Effect of gender on the horizontal and vertical tongue dynamics of monosyllabic level and falling tonal words.

Non-parametric Mann-Whitney Test was administered to check the effect of gender on the horizontal and vertical tongue dynamics of monosyllabic level and falling tonal words. The result revealed no significant difference between males and females, as shown in Table 4.3. This means there is no gender effect on the tongue dynamics across the tones horizontally and vertically, indicating that both genders produced similar horizontal and vertical tongue movements while producing level and falling words. Hence, the hypothesis is accepted: there is no gender effect in tone production in Manipuri.

In the study by Moisik et al. (2014), both males and females used creakiness equally to produce and realise low tones in Mandarin. The findings of the present study indicated that both genders used the extra laryngeal mechanism in addition to the laryngeal mechanism for tonal differentiation.

Table 4.3

Gender-wise comparison of level and falling tones across the horizontal-axis and vertical y-axis.

Tongue Region		Gender	Mean	Median	Std. Deviation	Asymp. Sig. (2-tailed)
LEVEL TONE						
Anterior	Horizontal	F	33.50	34.02	2.49	0.35
		M	34.72	35.36	2.78	
	Vertical	F	40.38	39.55	2.33	0.35
		M	38.99	37.88	3.03	
Mid	Horizontal	F	79.28	79.28	.029	1.0
		M	79.27	79.28	.012	
	Vertical	F	69.56	68.11	4.62	0.75
		M	70.42	72.01	5.67	
Posterior	Horizontal	F	104.99	105.34	6.96	0.08
		M	112.88	113.80	3.71	
	Vertical	F	35.57	34.53	5.78	0.05
		M	42.44	43.35	3.68	
FALLING TONE						
Anterior	Horizontal	F	34.39	32.73	3.79	0.92
		M	33.91	33.49	1.7	
	Vertical	F	39.42	40.48	2.55	0.75
		M	39.04	39.93	2.55	
Mid	Horizontal	F	71.98	71.95	.052	0.06
		M	72.06	72.04	.02	
	Vertical	F	69.58	71.92	4.43	0.60
		M	71.73	73.06	7.38	
Posterior	Horizontal	F	107.91	106.42	5.79	0.35
		M	112.19	114.14	4.68	
	Vertical	F	37.28	34.76	5.72	0.35
		M	41.53	43.70	5.09	

Note: Gender F-Female, M-Male

The current study did not find significant gender-related effects on tongue dynamics, indicating that both male and female participants positioned their tongues similarly for the level and falling tones. This suggests that the production of tonal differences in Manipuri is not significantly influenced by gender, aligning with the findings of Devi and Das (2021).

Intra-judge Reliability:

The investigator reanalyzed 50% of the sample to check the intra-judge reliability of the analysis. Cronbach's alpha was used to check the same, and the findings indicated that Cronbach's alpha α to be 0.8-0.9 is good.

CHAPTER 5

SUMMARY AND CONCLUSION

Tonal language has an additional phonetic unit of accompanying elements, the tone element, apart from the vowels and consonants. In a tonal language like Manipuri, a lexical word has two or more semantic meanings for different tones characterised by pitch variations. This characteristic feature is a crucial component for effective communication when using a tonal language. Tonal language comprises 60–70% of all languages worldwide (Yip, 2002), and more than half of people worldwide speak a tonal language (Fromkin, 1978). However, the tonal languages in India are under-explored, and there exists disagreement in labelling the various aspects of tonality in Indian tonal languages, especially Manipuri.

The pitch variation for different tones by the laryngeal system is greatly appreciable with the elevation of the larynx. The extra laryngeal system, such as the head, jaw and tongue movement in conjunction with the larynx, has also been found to vary in other tonal languages like Mandarin (Erickson et al., 2004; Moisik et al., 2014). However, there is no literature study to understand the tongue dynamics in the Manipuri language. Hence, the current study aimed to investigate some physiological parameters of the tongue involved in tonal production in Manipuri.

The variables in this study are tongue advancement and tongue height obtained in (x-y) coordinates where the horizontal x-axis represents the tongue advancement, and the vertical y-axis represents the tongue height. These values were compared between the level tone and falling across the tongue anterior, mid and posterior. The effect of gender on these parameters was also studied.

A total of 10 healthy native speakers of Manipuri, 5 males and 5 females between the age ranges of 20-35 years were enrolled in the study. They neither had any history of oro-facial structural abnormalities such as ankyloglossia, glossectomy, cleft palate, or other cognitive, hearing, or speech disorders nor communication disorders.

The study material consisted of 20 sentences of 10 tonal words in level and falling tone. The level tone is low, while the falling tone falls from high to low pitch (Devi & Das, 2021). The stimuli words contained vowels: /i/, /I/, /a/, /o/ and a diphthong: /aɪ/ and they were the tone-bearing nuclei for this tonal language. They were used in the context of V, CV and CVC, where C represents the consonants, and V represents the vowels/diphthongs.

The ultrasound tongue image was recorded and analysed using AAA software with a fan spline technique. The tongue contours were plotted on the seven splines, which were kept constant for all the analyses to minimise variabilities. The average tongue contour and means values of (x-y) coordinates for 10 repetitions were obtained by exporting to the workspace, and the average tongue contour was compared between the level and falling tones for each word.

The average tongue contours were obtained for the tonal counterparts. The findings showed differences in the tongue contours for level and falling tones on visual analysis. Hence, there were differences in the tongue contours of monosyllable level and falling. The tongue contours for falling tones were more shifted towards the posterior side than the tongue contours of the falling tones. This indicated that the tongue is more retracted for low tone than for high tone in Manipuri.

To compare the horizontal tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts, the horizontal tongue dynamics were plotted along the x-axis. The findings revealed that the tongue mid region was significantly different in level tone compared to the falling tone in Manipuri.

The findings indicated that there were no significant differences between the anterior and posterior regions.

To compare the vertical tongue dynamics across anterior, mid and posterior tongue regions between level and falling tonal counterparts, the vertical tongue dynamics on the y-axis were obtained. The results showed no significant difference between the tonal counterparts at the anterior, mid and posterior tongue. This suggests that there are no variations in tongue height between falling and level tones found in Manipuri.

The study did not find any significant gender-related effects on horizontal and vertical tongue dynamics in level and falling tones. Both male and female participants demonstrated similar patterns in tongue positioning for the level and falling tones. This suggests that the production of tonal differences in Manipuri is not significantly influenced by gender.

However, the study has few limitations. The sample size considered for the study was smaller. Hence, the findings cannot be generalisation to the broader population. The tone of the monosyllable words of Manipuri was considered to restrict to small data for analysis. However, the tone in bisyllabic words or multisyllabic words could have been studied. The study enrolled only Manipuri speakers of the Meitei group, excluding the Naga and Kuki groups, to maintain uniformity of the participants. The study did not include or study the tones of the Naga and Kuki group speakers, which can be explored in future studies.

5.2 The clinical implications of the present study:

1. It is one of the first physiological studies on Manipuri.
2. The study has provided visualisation of ultrasound tongue contours of tonal words in Manipuri.
3. It will enhance the understanding of Manipuri and help the new language learners in Manipuri.
4. The present study will help in the assessment of tonal aspects in native Manipuri speakers with communication disorders.
5. The current study will aid in phonetic intervention. Phonetic training can enhance the understanding of the tongue dynamics associated with different tones in both native speakers and language learners.
6. The present study can help individuals with communication disorders where targeted interventions can be developed to improve the production of specific tones in Manipuri.
7. This study's findings contribute to a broader understanding of tonal languages and the physiological mechanisms underlying tone production in linguistic and phonetic research

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