CROSSLINGUISTIC ULTRASOUND STUDY OF TRILLS AND LATERALS

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CERTIFICATE

This is to certify that this dissertation entitled **“A crosslinguistic ultrasound study of laterals and trills”** is a bonafide work submitted in part fulfillment for the Degree of Master of Science (Speech-Language Pathology) of the student (Registration No.: 21SLP018). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the Universities for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled "**A Crosslinguistic Ultrasound Study of Laterals and Trills**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled “**A Crosslinguistic Ultrasound Study of Laterals and Trills**” is the result of my own study under the guidance of Dr. M. Irfana, Assistant Professor in Speech Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier for the award of any Diploma or Degree to any other university.

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CHAPTER I

INTRODUCTION

Speech is a remarkable and unique motor accomplishment (Kent, 2000). Speech production is a complex process that needs coordination between several systems, many muscles, and several millions of neurons. It involves more motor fibers than any other human mechanical activity (Fink, 1986). During the production of speech sounds, the speaker performs a series of complex tasks within the brain before the sound comes out of the mouth. The articulators that are involved in the production of these sounds are the tongue, palate, lips, teeth, etc. The articulatory system is critical in moulding the vocal tract to create various speech sounds and phonetic features. In the process of production of speech sounds, the articulators move together in a coordinated manner. The study of how these articulators move in a coordinated way and with precise movement during speech sound production is called articulatory dynamics. It involves the coordination of different articulatory gestures. These gestures are movements of speech organs that create specific configurations in the vocal tract, leading to the production of distinct speech sounds. For example, the tongue position, whether it's raised or lowered, front or back in the mouth, determines the production of different vowels and consonants.

The speech sounds /r/ and /l/, which were considered for the study, are less studied in Dravidian languages. These two are difficult sounds for many children to master due to their articulatory complexity, which requires the ability to coordinate the tongue, lips, and other articulatory structures for their production. Both sounds are produced in the alveolar region of the mouth, involving the tongue's interaction with the alveolar ridge.

Both are sonorant sounds, which means they are relatively open in terms of the airflow through the mouth. This contributes to their resonant and melodic quality. Studying these sounds is significant primarily because of their importance in phonetics, phonology, and language learning. These sounds have distinctive features in many languages, and studying these sounds will provide information on speech production, perception, and communication.

The articulatory dynamics of the /l/ sound involve the tongue and the mouth in a specific configuration. The speech organs are partially closed, and air rushes over the edges of the tongue (Finch, 1997). The tongue tip makes contact with the alveolar ridge, but it is designed to leave lateral openings on each side of the area of contact (Pickett, 1980). It is classified as a lateral approximant consonant, meaning that the airstream flows along the sides of the tongue without a complete closure, resulting in partial obstruction of the airflow. The /l/ sound is an alveolar consonant, which means it is produced by raising the tongue tip to the alveolar ridge, which is the area back of the upper front teeth. The tongue touches the alveolar ridge, creating a narrow passage on either side of the tongue. It is considered a voiced alveolar lateral approximant (Ladefoged & Johnson, 2010). The sides of the tongue create enough obstruction to cause turbulence in the airflow but not enough to stop it completely.

The trill /r/ sound is a type of consonant sound produced by the rapid vibration or fluttering of the articulators. It is also known as a rolled /r/ sound (Ladefoged & Johnson, 2010). The trill /r/ sound is generated by positioning the tongue loosely in a particular location so that the air current causes the tongue to vibrate. The tongue should be placed just beyond the upper front teeth, slightly touching the alveolar ridge. The sound is classified as a voiced consonant, meaning the vocal cords vibrate during production. Air is pushed out from the lungs through vocal cords and over the vibrating tongue tip, creating a series of brief, rapid bursts of sound. The primary articulators involved in the production of the trill /r/ sound are the tongue and alveolar ridge. The trill /r/ sound can vary in terms of its length and intensity, depending on the language or dialect in which it is used. It may be a long or short trilled [r]. In short [r], the tongue makes only one touch with the roof of the mouth; in long [r], the tongue makes three connections. In both circumstances, tongue contacts during trill generation are driven by an aerodynamic force, just as vocal fold vibration during voicing is caused by airflow. Some southern Indian languages distinguish between alveolar and dental trills (Ladefoged & Johnson, 2010).

The tongue is one of the active articulators listed above; each vowel and consonant will demand precision in the tongue's spatial location and dorsal surface form (Stone & Lundberg, 1996). The tongue quickly changes its shape and location, yet it does so in a well-coordinated and exact way. Along with direct cortical connections to the motor neurons regulating the tongue, they include a specific speech-motor control center in the cerebral cortex (Broca, 1861; Kuypers, 1958). As the tongue plays a significant role in speech production, its study can give some beneficial information about the production of speech sounds.

As technology increased, many new ways emerged to study the nature of tongue shapes during speech sound production. One such advancement of technology is ultrasound, which is easier and safer to administer in comparison to other measures like X-ray, Palatography, Electro Magnetic Midsagittal Articulography (EMMA). Ultrasound can be used for visualization of the tongue during speech production, especially lingual consonants. This provides valuable insights into articulatory processes and how sounds are produced. It is a non-invasive, safe approach for studying tongue forms that interfere very little with speech production and can be used for younger children, newborns, and adults. With this relatively inexpensive and portable equipment, real-time viewing of the tongue is achievable (Ball et al., 2001; Bressmann et al., 2005). Although frame rates are limited to 60 frames per second, spatial and temporal resolutions are relatively good. Other advantages of ultrasound are that it can be observed either dynamically or statically in mid-sagittal or coronal views. Two - dimensional images can be used to understand the movement of the tongue during speech production and swallowing (Ansu & Sreedevi, 2014). Aside from the practical benefits mentioned, an important element of ultrasound that underlines its growth as a therapeutic tool is that it is generally simple to interpret. The tool can provide visual feedback on tongue shape for toddlers and adults with speech difficulties. It had previously been utilized less for therapeutic purposes, but currently, it is being used regularly (Bernhardt et al., 2005; Bernhardt et al., 2003; Shawker et al., 1985). There has been a remarkable increase in studies employing ultrasound for exploring tongue dynamics during swallowing and speech in individuals across different age groups over the last 20 years (Ballet al., 2001; Chi Fishman, 2005; Stone, 1991; 1997; 2005). Over the past 15 years, Stone and colleagues have pioneered ultrasound for tongue imaging during speech. Ultrasound imaging uses sound waves that are in ultra-high frequency to create tissue images that reveal different tongue movements and forms for velar and alveolar articulations, as well as vowels (Lundberg et al., 1999; Sonies et al., 1981; Stone, 2005; Stone et al., 1996) . It offers characteristics that make it a valuable instrument for individuals with speech problems and as a tool for investigating tongue movements in people with hearing loss (Bernhardt et al., 2005; Bernhardt et al.,2003), glossectomy and residual articulation difficulties (Shawker et al.,1985).

Few studies describe tongue shapes during the production of different sounds in various languages. Studies were done in the English lateral /l/, and based on acoustic analysis, the authors reported having consistent production based on acoustic analysis but found greater variability in ultrasound analysis (Charles & Lulich, 2019). There are few studies in Indian languages, which are done majorly in Malayalam and Kannada. In Malayalam, the speech sounds include two rhotics (/r/ and /ɾ/, a trill and a tap), two laterals (/l/ and /ɭ/, an alveolar and a retroflex lateral respectively), and a liquid. The authors discovered the contrast between the tap sound, which occasionally resembles a stop, and the trill, as well as the alveolar and retroflex lateral (Scobbie, Punnoose & Khattab, 2013). In Kannada, the speech sounds included were /r/,/l/,/ḷ/,/t̪/,/ṭ/, /tʃ/, and /k/ on comparison of tongue contours; noticeable differences were found in the tongue contours of native and nonnative speakers though they were similar in pattern (Anjali & Sreedevi, 2014). Another study was conducted in Kannada to compare the tongue contours of children and adults with the sounds taken where lingual stops dental /t/, retroflex /ʈ/, and velar /k/, and the results showed that tongue contours for the three places of articulation of children and adults are of similar patterns. However, the overall height of the tongue contour is more significant in adults, particularly in the anterior tongue body region (Irfana & Sreedevi, 2013).

Need for the study

The present study focused on lateral /l/ and trill /r/ production in three Dravidian languages, which are Telugu, Kannada, and Tamil, and aims to study the articulatory dynamics of these languages using ultrasound. This study aims to define articulatory configurations of trill and lateral speech sounds. There are many techniques that can be used to study the shape of the tongue during articulation. The present study used the ultrasound imaging technique (UIT) because it has the advantage of providing images of the tongue in real time. It is a non-invasive, safe, and cost-effective procedure by which we can obtain images of articulatory gestures. It is possible to obtain ultrasound images by placing the transducer probe below the chin. As the upper surface of the tongue has air and air is a poor conductor of the ultrasound waves, the waves are reflected back. When ultrasound waves encounter a bone, almost all the energy of the waves is reflected, creating a dark shadow of that region. Therefore, the palate and teeth are not seen in the images from ultrasound, and the upper surface of the tongue is clearly visible as a white line. Based on this, the tongue contour can be plotted.

The study focused on lateral /l/ and trill /r/. These are the sounds that have complex articulation and numerous constrictions (both labial and lingual) that vary depending on word position and between speakers (Gick, 2003; Gick & Campbell, 2003; Oh, 2005). /l/ and /r/ sounds are developed later in children in comparison with other speech sounds. According to the speech sound norms by the Goldman Fristoe Test of Articulation (2000), /l/ will be mastered by the age of 5 years in all the word positions. The child may develop the /r/ sound at the age of three years but not master it until five, which is considered a typical development (Hogan et al., 2019).

Liquids and trills are considered to be the most difficult sounds to learn (Shriberg & Kent, 1982), both for children and adult learners. Clinically, cases of "resistant" /l/ and /r/ are regularly seen, translating into significant levels of frustration for patients and therapists. According to some reports, problems with /r/ alone can account for as much as 60% of the typical school-based clinician's caseload (Craighead et al., 1989). Words containing /l/ and /r/ are frequently the source of errors in automatic recognition systems (Espy-Wilson, 1992). Compared to other sounds, /l/ and /r/ have much more complex and more variable articulatory configurations across speakers. Compared to vowels or obstruent consonants, the acoustics and vocal tract models of /l/ and /r/ are less studied, except for some idealized articulation (Stevens, 1998).

Greater airflow over the lateral borders of the tongue than over the mid-line is typically mentioned when lateral speech sounds are articulated (Charles & Lulich, 2019). This type of articulation can be achieved by placing the tongue against the palate in such a way that there will be an occlusion in between, and it flows from the sides, and sound is generated. Acoustic characteristics of laterals are that they have distinct formant positions and lower intensities when compared to vowels. There are many surface realizations of the alveolar lateral approximant (/l/) in American English. It has anterior occlusion in variable length, and behind is a vowel-like gesture of the tongue. In American, English laterals are the sounds that are acquired late (Charles & Lulich, 2019).

In Kannada, /l/ frequently occurs intervocalically, either as singletons or geminates; /l/ also occurs word-initially it won't occur word-finally (Upadhyaya, 1972). The exact place of articulation of /l/ in Kannada is still a conflict some will describe it as "dental" (Bright, 1958; Nayak, 1967; Andronov, 1969; Sridhar, 1990); others as "alveolar" (Upadhyaya, 1972; Schiffman, 1979). Upadhyaya's (1972) description of the sound ("the tip of the tongue against the tooth ridge") suggests that this sound is apical. In Telugu, /l/ is a voiced sound, and the tongue tip will be placed against the alveolar ridge or post-dental. Also, /l/ is considered an alveolar or post-dental lateral consonant in Telugu. However, in Tamil, the tongue tip makes contact with the dental region during the creation of the lateral /l/ sound. A physiological study done by using X-ray reveals that the tongue root will be retracted towards the posterior pharyngeal wall, and the posterior portion of the tongue body will be slightly higher in position. The front surface was level and will have a convex shape. The inward lateral compression typical of the consonant is produced by the curved sides of the posterior tongue (Faber et al., 1992; Narayanan et al., 1997).

Trills are a stricture type (Catford, 1977), produced by the vibration of one speech organ against another, driven by aerodynamic conditions (Ladefoged & Maddieson, 1996). The common trill produced is by the vibration of the tongue tip, which comes in contact with the dental/alveolar region. These are called apical trills (McGowan, 1992; Ladefoged & Maddieson, 1996), which are common trills in Indian languages. The trills in all three languages are produced in the same way. However, there is a dearth of studies to understand the articulatory dynamic nature of trills in Indian languages.

In this study, a comparison was made for the tongue contours of speech sounds in Telugu, Kannada, and Tamil, which belong to the Dravidian language family. There are studies where they have found the place of articulation of these sounds, but physiological studies are less, and still, there is no clarity about the exact place of articulation of these phonemes. Few studies have taken only one utterance into consideration, which will provide scope for large variability. A comparison of lateral sound /l/ and trill /r/ across different languages was not made, so this study can give us an idea about how these speech sound production and place of articulation will be different across languages even though they sound similar.

Aim of the study

The present study aims to find the tongue contours of lateral /l/ and trill /r/ across three Dravidian languages, i.e., Tamil, Telugu, and Kannada.

Objectives of the study

- To understand the tongue contours of lateral /l/ and trill /r/ in Telugu, Tamil, and Kannada.
- To compare the tongue contours of lateral and trill across languages.
- To understand the effect of gender on tongue contour.

CHAPTER ll

REVIEW OF LITERATURE

Articulatory configurations of the tongue have been studied using many methods. It can be analyzed using perceptual, acoustical, and physiological methods. The study of speech sounds using different methods will have implications in different fields, including linguistics, psychology, cognitive science, neuroscience, education, and communication disorders. Each of these methods contributes to our understanding of speech sounds from different angles, and researchers often combine multiple approaches to gain comprehensive insights into the complex nature of human speech production and perception. Perceptual studies help to study how listeners perceive speech sounds and help researchers understand the human auditory system processes that categorize sounds. Acoustic studies focus on studying the sound waves produced during speech. They are also used to investigate how different speech sounds are distinguished acoustically and to identify variations in speech across different speakers and languages. Physiological methods involve examining how speech sounds are physically produced by the articulatory organs (e.g., tongue, lips, vocal cords). It helps in understanding the precise movements involved in speech production.

2.1 Perceptual studies

Perceptual speech studies are a branch of research that focuses on understanding how humans perceive and process speech. These studies aim to uncover the mechanisms and cognitive processes involved in speech perception, including how we interpret speech sounds, recognize words, and comprehend spoken language. The findings from these studies can inform speech and language therapy, improve speech recognition technologies, and enhance our understanding of how the human brain processes language. Perceptual speech studies are crucial for understanding the mechanisms of speech perception, improving speech-related technologies, aiding in language acquisition and rehabilitation, and addressing various communication-related challenges.

Maharani (2006) conducted a study on the perception of Tamil laterals and trills. The study's participants were 40; stimuli of 80 Tamil words containing an equal number of trills and laterals in the middle and end of words were selected and asked participants to discriminate. The findings of the study revealed that native Tamil speakers were discriminated against as substantially superior to non-native Hindi speakers in all four sets and indicated the phoneme-specific characteristics of laterals and trills in Tamil. Liker and Gibbon (2012) conducted another study using palatal and postalveolar affricates (/ʧ/ & /ʤ/; /ʨ/ & /ʥ/) in the Croatian language. The study was conducted with six individuals who are native adult speakers of Croatian. The results showed that listeners identified palatal and postalveolar affricates well above the chance level, with correct responses in 86% of the cases.

Similar results were found in another study which was conducted to study the perception of three separate non-native rhotics (i.e., /r /) by native English speakers compared to non-native sounds from four other modes of articulation (stops, nasals, fricatives, and laterals). Findings revealed that the rhotic segments exhibited similar acoustic-perceptual properties, leading non-native listeners to mistake them for the same sound. All non-native rhotics demonstrated low discriminability, especially when compared to other non-native sounds. This shows that the rhotics investigated in this investigation have acoustic perceptual similarities (Howson & Monahan, 2019).

In another perceptual study done by Lesley (2022), the author explored the perception of tap and trill in Spanish-English bilinguals. The results showed that speakers can detect the sounds but not as well as monolingual Spanish participants. The author also specified that education was a significant factor in distinguishing the tap and trill. Khul (1995) conducted a perceptual study on the Japanese and English languages, the results showed that the underlying perceptual space encompassing /r/ and /l/ varies greatly in American and Japanese listeners, and their perceptual maps are dramatically different.

Japanese and English perceptual study on /l/ and /r/ speech sounds was conducted by Mackain, Best, and Strange (1981), and the results showed classic categorical perception by an American-English control group. The not-experienced Japanese showed near-chance performance on all tasks, with performance no better for stimuli that straddled the /r/-/l/ boundary than for stimuli that fell in either category. The experienced Japanese group, however, perceived /r/ and /l/ categorically. Their identification performance did not differ from the American-English controls, but their overall performance levels on the discrimination tests were somewhat lower than for the Americans. The authors concluded that native Japanese adults learning English as a second language were capable of categorical perception of /r/ and /l/.

The impact of perceptual identification training on the production of /r/ and /l/ in adult Japanese speakers learning English as a second language was examined by Bradlow et al. (1997). The researchers observed that engaging in perceptual training had a beneficial effect on the learners' ability to differentiate between /r/ and /l/. These findings indicate that undergoing perceptual training is essential for enhancing the perception of non-native sound distinctions, such as those involving /r/ and /l/. Similar results were seen in the study conducted by Takagi et al. (1995). The study examines the perception of /r/ and /l/ by adult Japanese learners of English who had prolonged exposure to those sounds. The results of the study revealed that extended exposure may improve /r/-/l/ identification accuracy; it does not ensure perfect perceptual mastery.

The study conducted by Miyawaki et al. (1975) found that the cross-language discrimination difference between English and Japanese speakers was eliminated when listeners heard only isolated F3 stimuli. The findings of the study suggest that perceptual sensitivity to /r/ and /l/ stimuli were influenced by the phonological patterns of one's native language. The difficulty in distinguishing non-native sound contrasts, such as /r/ and /l/, by adult learners can be attributed to the phonological patterns of their native language. Similar results were found in the study done by Ingvalson et al. (2012). The results revealed that significant improvement was shown by some listeners, suggesting some enhancement of /r–l/ identification is possible following training with only F3 onset frequency.

Perception is a subjective experience, and different individuals might perceive the same stimulus in slightly or significantly different ways. This subjectivity makes it challenging to generalize findings across populations. Perceptual studies can be influenced by various biases, such as response bias, selection bias, and confirmation bias. Participants might provide answers they think researchers want to hear, leading to inaccurate results. People vary in terms of their sensory acuity, cognitive abilities, and attention levels. This variability can lead to difficulties in establishing consistent and generalizable results. Perceptual experiences can be influenced by environmental factors like lighting, noise, and distractions. These factors can impact the way individuals perceive stimuli and may introduce confounding variables. Certain perceptual experiences, such as emotions or aesthetic judgments, are challenging to measure objectively and might require additional qualitative or subjective assessment methods. Perceptual experiences can change over time, and some studies might not capture the dynamic nature of perception adequately. Also, the majority of the studies used categorical discrimination, which did not exactly explain the specific features of each phoneme. Hence, the perceptual method is not a suggested way of understanding phoneme characteristics.

2.2 Acoustical studies

Acoustical studies of speech involve the scientific investigation of the acoustic properties of spoken language. Acoustic speech studies involve analyzing and measuring various features of speech sounds and patterns. These features are crucial for understanding speech production, perception, and linguistic analysis. Some of the commonly measured features in acoustic speech studies include pitch, intensity, duration, formants, Voice Onset Time (VOT), spectral features, vowel formant transitions, F0 contour, Harmonics-to-Noise Ratio (HNR), and spectral envelope.

Acoustic analysis can be useful since it allows for quantitative analyses that can be used to describe subsystems and determine the correlates of perceptual judgments of intelligibility and quality. As a result, sound analysis can be a useful supplement to perceptual evaluation. Acoustic analysis is intriguing for speech research for a number of reasons. The acoustic signal links the acts of speech creation and the perception of speech. As a result, the acoustic analysis gives information on both the behavior of the speaker and the perception of the generated signal by the listener. It is attractive due to its ease of execution. Digital processing techniques have made significant advancements, resulting in improved speed and capabilities for acoustic analysis. As a result, even with limited funding, it is now possible to conduct advanced investigations in this field. The availability of quantitative theories supports these investigations, enabling the explanation of acoustic data in relation to the production and perception of speech. Acoustic analysis serves as a valuable addition to investigations on speech physiology, as well as studies on speech perception. Moreover, it can aid in enhancing comprehension of communication-related disorders.

Dhananjaya, Yegnanarayana, and Bhaskararao (2012) investigation focused on studying the acoustic properties of apical trills. These trill speech sounds are produced by a periodic vibrating of the tongue apex. In order to examine the source of the excitement and the resonance characteristics in the vocal tract, certain signal processing techniques were used on speech signals. These techniques involve filtering out frequencies at zero Hz and applying liftering operations that have no time delay. The authors of this study have identified auditory cues that can be used to detect trills in continuous speech. By observing the variations in the strength of excitement during specific time periods and the immediate fundamental frequency (F0), trills can be distinguished from other voiced sounds.

In another acoustical study, an acoustic analysis of the difference between single and double consonant sounds in the Kannada language focused on the length characteristics of lateral sounds (Kochetov, 2015). Specifically, the study examined the duration of alveolar laterals /l/-/l/ and retroflex laterals /ɭ/-/ɭː/. The findings indicated that geminate laterals were longer in duration compared to singleton laterals, supporting the expected outcome.

A study was done on English speech sounds (/r/, /w/ & /l/) by Dalston (1975), focused on the duration and rate of the third-formant transition, which consistently distinguished /r/ from /w/ and /l/ in the sonorant productions. The author also mentioned that spectrographic analysis cannot determine the significance of these characteristics in identifying /r/. It is unclear whether these characteristics contribute to the naturalness of the speech sound or if they are coincidental and perceptually unimportant outcomes of differences in third-formant frequency.

Acoustic analysis of Italian [r] and [l] was carried out by Francesca et al. (1995). Speech materials consisting of prestressed VCV syllables produced by three male and three female native speakers of Italian formed the basis of the present study. Each syllable was repeated three times by each speaker. The vowel in the syllable was [i, a, u], and the consonant was [r] or [l] in geminated and nongeminated form, leading to 216 syllables. Results of the analysis showed that the first vowel duration was systematically shortened in the geminated consonants. The data also showed that in the present case, the duration of the consonant, as well as, in most cases, of the VC and CV transitions, were lengthened in the geminated form. Spectral analysis showed that there is little or no effect on the spectral properties of the consonants due to the presence of gemination. However, [r] in geminated form is, in a few cases, devoiced.

There are some key limitations associated with acoustical studies. In some situations, sound waves can exhibit nonlinear behavior, meaning that the relationship between input and output is not proportional. This can lead to unexpected effects and difficulties in modeling and predicting sound behavior accurately. Sound waves can behave differently at different frequencies. Some materials might absorb or reflect certain frequencies more effectively than others. This frequency-dependent behavior can complicate the analysis and design of acoustic systems. Sound waves can interact with surfaces and boundaries, leading to effects like reflection, diffraction, and scattering. The complex interactions between sound and these surfaces can be challenging to model accurately. In many real-world scenarios, there is existing background noise that can interfere with the measurements or analysis of acoustical data. This noise can make it difficult to isolate and analyze specific sound sources. The accuracy and precision of acoustical measurements can be limited by the quality of the measurement equipment, the calibration procedures used, and the physical constraints of the measurement environment. Acoustical studies often involve considering human perception of sound quality and comfort. However, human perception can be subjective and influenced by individual preferences and cultural factors, making it challenging to establish universal standards. While acoustical models can provide valuable insights, they may not always accurately predict real-world outcomes, especially in complex or unusual scenarios. Validation through real-world measurements is essential, but even then, some level of uncertainty might remain. Despite these limitations, acoustical studies remain crucial for understanding and managing sound in various contexts.

2.3 Physiological studies

Researchers and therapists can utilize instrumental techniques to directly observe the movement of articulators during speech. This approach offers several benefits in the clinical linguistics and phonetics field. An advantage of this is that it offers valuable data that contributes to ongoing discussions regarding the role of motor control in both typical and impaired production of speech. In clinical linguistics and phonetics, utilizing direct physiological measures offers an additional benefit. It provides valuable data that contributes to ongoing discussions in the field, particularly regarding the functions of articulators in both normal and impaired production of speech. However, certain procedures may not be suitable for specific clinical populations due to specific requirements. In addition, the analysis of instrumental data can have challenges and demand substantial time, particularly due to the processing of extensive amounts of data.The tools mentioned can be used to measure the tongue, lips, and lower jaw as articulators. These articulators differ when considering the velocity and intricacy of their motion, structural composition, shape, and location. Therefore, specific devices are needed to measure each articulator, as instruments designed for one may not be suitable for another.

The X-ray machine is one such instrument that was developed in the early 1960s, the process involves the utilization of ionizing radiation to capture images. This is achieved by exposing the individual to X-rays and subsequently capturing the shadow on the film. The imaging can reveal various parts of the articulators that are mobile, like the tongue and lips, as well as the stationary organs, like the hard palate. In speech studies, static images of X-rays for a particular posture or vocal tract are typically obtained from a lateral perspective, which provides a side view. For studying the movement of articulators, dynamic events can be recorded using serial or cineradiography. This technique was commonly used until the early 1970s to study how the articulator functions (Hiiemae & Palmer, 2003).

Ladefoged and Bhaskararao (1983) studied retroflex stops using X-rays. The retroflex stops in three languages were compared: Hindi, Tamil, and Telugu. The writers came to the conclusion that the retroflex stops in these languages differ. The tip of the tongue in Hindi retroflex stops is not as far back as it is in Dravidian retroflex stops, but Hindi retroflex stops are not the same as English alveolar stops.

Another study was conducted using x-rays; the speech sounds taken for this study are /l/ and /s/ in three vowels (/o/, /i/ & /ɑ/) contexts. The author studied these sounds on a single female subject who was 26 years old and spoke English in a mid-western dialect.

The results showed that the dorsal segment was the most extended or shifted functional segment for /l/. Furthermore, the central part remained the most compacted. In contrast, the /s/ was formed with a considerable front expansion of the tongue. The tongue had a groove in the middle for producing the sound /s/, which caused it to be less lifted and expanded compared to the sound /l/. When producing the sound /s/, the front part of the tongue stuck out more than when producing the sound /l/, which explains the greater expansion. In the context of the sound /s/, the front part of the tongue was enlarged more for each vowel compared to the context of the sound /l/. In the context of the sound /l/, the back part of the tongue was enlarged for each vowel (Stone, 1990).

Electropalatography (EPG), which is also referred to as photometry and dynamic palatometry, is another instrument developed to document a fundamental aspect of speech articulation. This device is designed to capture and store data regarding the timing and position of the hard palate and tongue contact. A custom-designed plate, specifically shaped to fit the person's hard palate, is an essential part of every EPG system. The electrodes have been placed on the underside of the artificial plate to detect when the tongue meets them. In the field of research and clinical application, three prominent EPG systems have held sway for the past four decades. Numerous research investigations done in Europe and Hong Kong have utilized the EPG3 system, which is a British system established at the University of Reading (Hardcastle et al., 1991; Hardcastle & Gibbon, 1997). Queen Margaret University in Edinburgh has just developed a new Windows® version of the Reading EPG (Wrench et al., 2002). The Kay Palatometer has primarily been utilized in research conducted within the United States (Fletcher, 1983), and the Rion EPG has gained significant popularity and widespread usage in Japan (Fujimura et al., 1973; Hiki & Itoh, 1986). The EPG systems exhibit certain characteristics, although they may vary in specific aspects such as plate structure, number and electrode configuration, and hardware/software specifications (Gibbon et al., 1999; Hardcastle et al., 1997).

Ramsammy (2021) conducted a study on Spanish /l/, which is embedded in carrier phrases with nonsense words using EPG. A total of 40 participants were considered for the study. The findings demonstrated notable patterns of spatial and reduction of temporal aspects of the final /l/ sound in different phonetic settings in Spanish. Generally, the reduction is more pronounced before consonants are produced with the tongue back (dorsal obstruents) compared to those produced with the lips (labial ones). Additionally, when /l/ appears before fricatives, the contact is less between the tongue and the palate, and the duration of the contact is shorter compared to when /l/ appears after a stop sound. Consequently, although all speakers tend to produce varying degrees of reduced /l/ sounds depending on the surrounding sounds, there is a significant variation among speakers in the extent to which /l/ is reduced across different contexts.

Magnetic resonance imaging (MRI) is another instrument that can also be used to measure the articulators. This technique is non-invasive and has the ability to generate images with quality that is higher in tissues of the vocal tract, extending from the lips to the larynx (Baer et al.,1991; Stone, 1991). MRI creates a magnetic field around the body by using radiofrequency radiation and scanners made up of electromagnets. MRI is now being used more frequently to study the movement of speech in typical individuals. Previously, it was primarily used to examine impaired articulation by identifying abnormalities in tongue mass, shape, and position rather than focusing on movement (Cha & Patten, 1989; Wein et al., 1991). The limited application of this method in the field of movement research is mainly attributed to its insufficient temporal resolution, rendering it inappropriate for analyzing the dynamic aspects of speech or speech disorders. Recent advancements in temporal resolution have enabled researchers to explore the dynamic aspects of speech, including segment durations, articulator positions, and interarticular time (Narayanan et al., 2004).

Narayanan et al. (1997) conducted a study using EPG and MRI in which the speech sounds used were light and dark allophones of /l/. The authors discovered that the contact in the front region for /l/ (light allophone) and /ɫ/ (dark allophone) differed among subjects: laminal light /l/ had considerably more anterior-region contacts than laminal dark /l/. Furthermore, for all subjects, /l/ had better lateral contact in the palatal region. The MRI pictures for the light allophone /l/ and the dark allophone /ɫ/ show that the midsagittal tongue shapes differ between subjects. The contact was 1-1.5 cm distant from the opening of the lip, and the length of contact was 0.6-1.5 cm in the alveolar region, with relatively modest apertures on both sides. The main articulatory difference between light /l/ and dark /l/ is the greater retraction of the anterior tongue body in the dark/l/.

Electromagnetic articulography (EMA), also known as electromagnetic midsagittal articulography (EMMA), is a technique used to record the two-dimensional movement trajectories in the midsagittal plane of specific points on the tongue, lips, and jaw. One advantage of using EMA is that the resulting data provides precise information regarding the exact location of these points, thanks to its high sample rate. The disadvantages of Electromagnetic Articulography (EMA) are twofold. Firstly, it is a costly investment to acquire. Additionally, the procedure itself is invasive as it necessitates the adhesive attachment of magnetic coils directly onto the articulators, potentially disrupting normal speech patterns. Moreover, the experimental setup can be restrictive and uncomfortable due to the requirement of wearing a helmet. However, recent advancements in the German EMA system have a detachable helmet from the head, allowing the speaker to have unrestricted movement. Because of the methodological limitations of previous versions of EMA, it has not been employed with young children or newborns.

2.4 Articulatory dynamic measures of ultrasound

Ultrasound can also be used to measure the articulators, mainly the movement and shape of the tongue while swallowing and the production of speech. To conduct a tongue scan, an ultrasound probe is placed below the chin and directed upward. This probe emits ultrasound waves and also receives the echoes produced when these waves encounter the boundary between the tongue's soft tissue and the surrounding air. These echoes are then recorded and displayed in real-time as tongue visual images. The images can be observed from either a longitudinal or cross-sectional viewpoint. While ultrasound typically generates 2D images, it is also possible to create 3D images by combining multiple scans using specialized software in the computer (Bressmann et al., 2005; Lundberg et al., 1999). Due to its portability, ease of data collection, and efficient availability in medical facilities, this method holds promise for regular utilization in clinical environments.

Irfana and Sreedevi (2013) conducted a study to compare the tongue contours of children with adults in Kannada. The speech sounds the authors considered were dental /t/, retroflex /ţ/, and velar /k/. According to the findings of the study, the tongue contours of children and adults have comparable patterns for the three points of articulation, and the total height of the tongue contour is higher in adults, particularly in the anterior tongue body region.

Another study conducted by Campos (2016) to check tongue position during Spanish trill production. Created a word list of Spanish words containing the target sound /r/ with different vowel contexts and positions. Twenty-four participants were recruited for the study. The results revealed that vowels might not have an extreme tongue root positioning, and vowels seem to have a minimal effect on /r/ tongue root positioning; the rhotic segment /r/ maintains what appears to be an intrinsic aspect of its articulatory requirements; a retracted positioning of the root of the tongue. Ultrasound imaging can accurately determine the precise retracted tongue root position during the rhotic sound /r/ production. Another study was conducted to compare an Australian language, Arrernte, with Kannada. The authors found that the tongue back is consistently more back for the lateral manner of articulation and almost always more forward for the nasal manner (Tabain, Kochetov, Beare & Sreedevi, 2016).

Charles and Lulich (2019) studied American lateral /l/ on 14 typical children. The authors have identified variations both within and among speakers and have categorized midsagittal tongue forms into three main groups based on the visual examination. The initial group can be identified by an elevated position of the tongue blade, a lower position of the tongue body, and the tongue root is retracted. The second group can be distinguished by a higher tongue body position, a lower position of the tongue blade, and a retracted tongue root that results in the formation of a posterior arch. In the third group, there is an elevated tongue blade, a higher position of the tongue body, and the tongue root is advanced, which forms an anterior arch. The second group contains the majority of tongue forms, indicating a prevalent pattern.

Nepali retroflex plosives were studied by using ultrasound by Sabin (2020) and the findings of the study indicated that the elevation of the tongue for female speakers was higher at the tongue front region. In contrast, it was higher for the male participants in the posterior tongue body. For females, the unaspirated voiced sound had more tongue height in the tongue front region, and in the aspirated voiced sound, the tongue height was higher in the posterior region. The results were the opposite for males.

All three ways of analyzing speech sounds have their value; instrumental analysis is superior to other methods, such as acoustic or perceptual analysis, as it allows for direct observation of articulator activity through recorded data. These direct measures enable the identification of motor deficits and articulation abnormalities, as well as the objective quantification of behavioral changes resulting from factors such as disease progression or the impacts of intervention during therapy can all play a significant role in influencing various outcomes. In the last two decades, there have been notable advancements in the technologies employed for the examination of articulation. The recording of tongue-palate contact using the EPG method has been enhanced through the creation of a prototype system that can accurately detect the dynamic pressures occurring between the tongue and palate (Murdoch et al., 2004). In addition to instrumental measures, advancements in acoustic analysis have provided numerous opportunities to define the fundamental aspects of speech-language disorders and elucidate the mechanics involved in speech production, both in individuals with typical speech patterns and those experiencing disruptions in their speech patterns.

Ultrasound allows for real-time visualization of the vocal tract during speech production. Researchers can observe the movement and shape of the articulators (e.g., tongue, lips, palate) as speech sounds are produced, providing insights into articulatory coordination. Unlike static imaging methods like MRI or CT scans, ultrasound provides dynamic images, allowing researchers to capture the rapid movements of articulators during speech, which is crucial for understanding articulatory phonetics. It offers high temporal resolution, allowing researchers to capture articulatory gestures with precision in terms of timing. This is essential for studying speech sound production, coarticulation, and timing relationships between articulatory movements. Ultrasound machines are relatively compact and portable, making them suitable for use in both research laboratories and clinical settings. This accessibility facilitates a wide range of studies and applications. It can also be useful to study dialect and language variability in speech. Researchers can examine how different populations produce speech sounds and study the articulatory strategies used in various languages and accents. It is employed in speech therapy and clinical practice to provide visual feedback to individuals with speech disorders. It helps clients and therapists identify and target specific articulatory issues, making it an effective tool for speech therapy. Ultrasound is valuable for studying speech disorders such as apraxia of speech and cleft palate, as it allows for a detailed examination of articulatory abnormalities and the effectiveness of therapeutic interventions. This instrument can be used as an educational tool for students and clinicians learning about speech production and articulatory phonetics. It provides a visual representation of the complex processes involved in speech.

The prominence and difficulty of distinguishing between /l/ and /r/ sounds can vary significantly from one language to another, making it difficult for researchers to understand the exact place of articulation of these sounds. Research on the articulation of the /l/ and /r/ sounds using ultrasound imaging has been relatively limited compared to other areas of speech sound research. There has been some research on /l/ and /r/ using ultrasound, though it may not be as extensive as research on other speech sounds. While there may not be as many ultrasound studies on /l/ and /r/ as there are for other speech sounds, researchers continue to explore ways to use ultrasound and other imaging techniques to gain a better understanding of the articulation of these sounds. Advances in technology and research methodologies may lead to more studies in the future that contribute to our understanding of /l/ and /r/ production.

CHAPTER lll

METHOD

3.1. Participants

A total of 30 subjects from three language groups were taken for the study, with 10 participants from each language, which includes an equal number of males and females. All of them were from 18 to 30 years of age and equitably considered Tamil, Telugu, and Kannada native speakers. The subjects were considered for the study after the screening of speech, language, cognitive, neurological, oral motor, and sensory deficits. A checklist, which was adopted by Johnson-Root (2015), was administered to rule out sensory-motor deficits of the tongue in the participants.

3.2. Materials

Tongue contours for each subject were taken for /l/ and /r/ sounds in the VCV context. The vowels accepted were the low central vowel /a/, the high front vowel /i/, and the high back vowel /u/. The three vowels were taken for the study because they allow testing for divergent tongue positions. The stimuli taken for the study were non-words in all three languages. The material included lateral and trill between vowels, and each target non-word was recorded with a carrier phrase, “Now I am saying TARGET,” in respective languages.

Table 3.2.1

Stimuli used for the study

Vowels	/r/	/l/
Low	/ara/	/ala/
High front	/iri/	/ili/
high back	/uru/	/ulu/

3.3. Principle

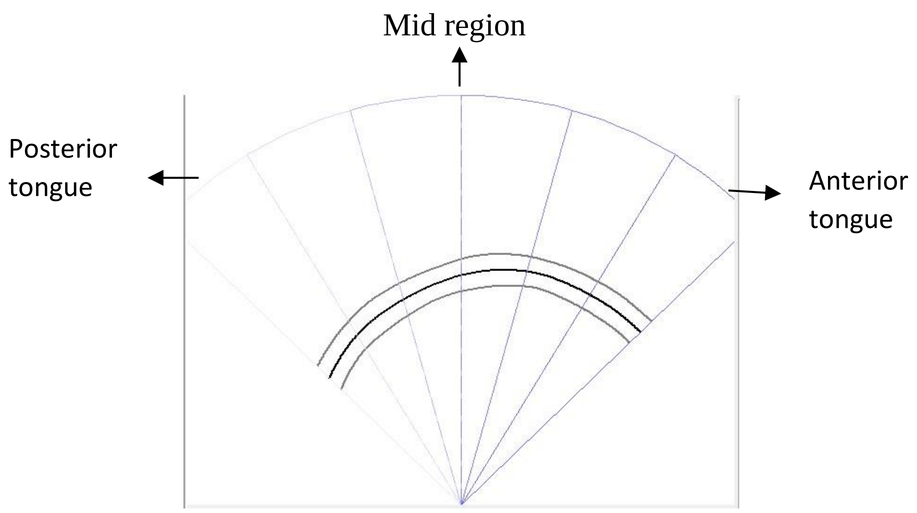
The contours were analyzed using an ultrasound instrument, which works on the reflective principle of sound waves. In the ultrasound imaging technique, the sound wave was reflected downward from the upper surface of the tongue after being projected from the probe through the tongue body. Above the upper surface of the tongue and palatal bone, an airway is present, which is different in density from the tongue. As a result, there was a strong echo. The sound wave is lost when the signal travels through air or bone, and no echo is returned to the transducer because the conductivity for sound is either too low or too high.

3.4. Instrumentation

The micro-ultrasound system was used to obtain the tongue images, and the Articulate Assistant Advanced (AAA) ultrasonography module Version 2.17.07 was used for analysis with 60 frames per. It had a 22000Hz sample rate and was synced to the audio input. With the aid of a stabilizing headset, the participant's chin was positioned, and beneath a micro convex (MCA-2R205-3) transducer probe was placed (Articulate instrument, Scobbie, Wrench & van der Linden, 2008). The AAA system saved each ultrasound frame as a collection of raw echo pulses with a depth of 7 mm from which a typical two-dimensional midsagittal image was produced. The three recording modes for the ultrasound system were "Amplitude (A-Mode), Brightness (B-Mode), and Motion (M-Mode)." The current investigation was recorded in Motion (M-mode). The tongue contour was also divided into three parts for analysis, which are the anterior region, mid-region, and posterior region.

Figure 3.4.1

Tongue contour for representation of different regions of the tongue



3.5. Procedure

Data collection was done individually. The patients were made to sit in a comfortable position. Before data collection, the procedure was explained to the participants briefly, and they were asked to have some water before starting the procedure so that the oral cavity was moisturized for better images from the ultrasound. The ultrasound transmission gel (Aquasonic 100) was applied to the transducer probe, and it was placed below the chin for recording images. The multimedia microphone was used for recording the synchronized speech samples. The list of the stimuli was presented visually on the screen of the computer to the participant. Ten repetitions were collected from each subject. A total of 60 utterances were recorded from each participant, including ten (10) repetitions of 6 target stimuli [2 consonants * 3 vowel contexts (V1CV1); 6*10 repetitions=60]. A grand total of 1800 utterances (30*60=1800) were recorded for the purpose of this study.

3.6. Data analysis

For the analysis of collected data, AAA software was used with fan spline technology, which has 42 points or axes. Fan spline was set up for each place of articulation. Splines are mathematically defined curves that pass through predetermined points. The placement of the fan spline depends on the place of articulation of the sounds. For laterals and trills, the fan spline was set in the anterior position. Semiautomatic contour plotting of the midsagittal view was used for the study on average; ten tongue contour repetitions were taken for each phoneme, and average consonant splice and V1/V2 splice were considered for analysis.

3.7 Intra-judge reliability: A randomly selected 20% of the data was subjected to intra-judge reliability. Cronbach's Alpha was administered to check the agreement, and results showed 78.5% agreement between repeated measures.

CHAPTER lV

RESULTS

The present study aimed to understand the articulatory dynamics of lateral /l/ and trill /r/ in Telugu, Kannada, and Tamil. The tongue contours of these consonants were in the VCV context. The total number of participants were 30, with 10 in each language, and an equal number of males and females were considered under each language group. The objectives of the study were:

- To understand the tongue contours of lateral /l/ and trill /r/ in Telugu, Tamil, and Kannada.
- To compare the tongue contours of lateral and trill across languages.
- To understand the effect of gender on tongue contour.

4.1. The tongue contours of /l/ and /r/ within the language

The tongue contour was divided into three parts, namely anterior, mid, and posterior. Tongue contours of /l/ and /r/ were analyzed within each language. There were slight variations of tongue contours across different vowel contexts.

4.1.1. Tongue contours for /l/ and /r/ in Telugu

Figure 4.1.1 and 4.1.2 depicts the comparison of /l/ and /r/ in Telugu. On observation of the tongue contours in the /a/ context, the overall height for /l/ was more than /r/, and the standard deviation decreased as it moved to the anterior side of the tongue contour for both sounds. In the /i/ context, the overall tongue height is more for /l/, and the standard deviation is the same across the tongue contour, but for /r/, the standard deviation decreases as it moves towards the anterior side of the tongue. For /u/, the overall tongue height is higher for /l/, and the standard deviation decreases for both as it moves toward the anterior side of the tongue contours. For statistical analysis, the Wilcoxon signed-rank test was used. It is a non-parametric test that can be used if the data doesn't meet the normality assumption and with a small sample size. The results of the statistical comparison of the tongue contours of /l/ and /r/ in the non-words /ala/ and /ara/ revealed that the tongue advancement was more for /l/ when compared to /r/. The tongue height in the anterior region was more for /l/. On comparison of the tongue contours of /l/ and /r/ in the non-words /ili/ and /iri/, the results revealed that there was no significant difference in the tongue height and tongue advancement for both sounds. On comparing the tongue contours of /l/ and /r/ in the non-words /ulu/ and /uru/, the results revealed that the tongue advancement was higher for /l/ and the tongue height in the anterior region was higher for /l/ when compared to /r/.

Figure 4.1.1

Tongue Contours of /l/ in Telugu in /a/, /i/, and /u/ Contexts

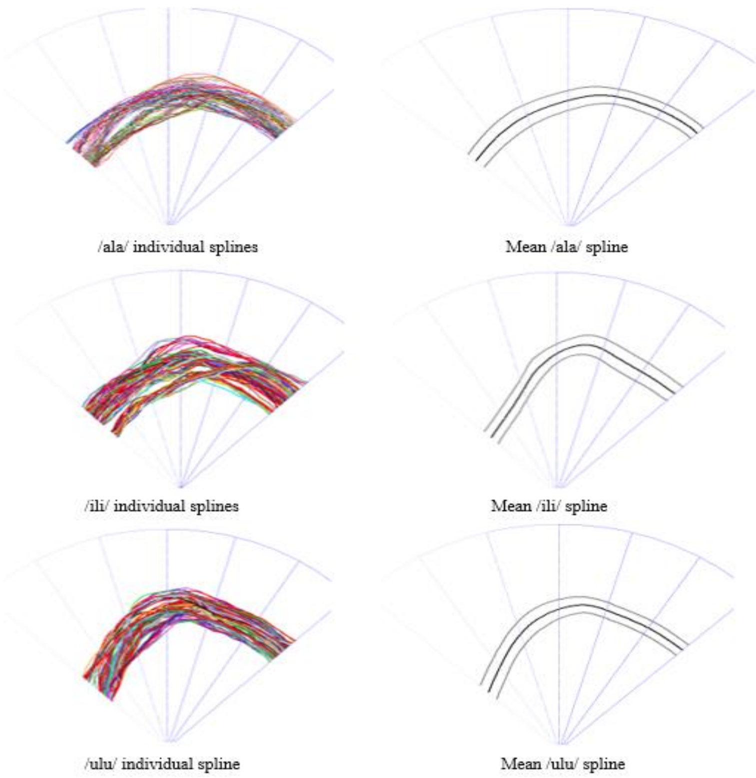


Figure 4.1.2

Tongue Contours of /r/ in Telugu in /a/, /i/, and /u/ Contexts

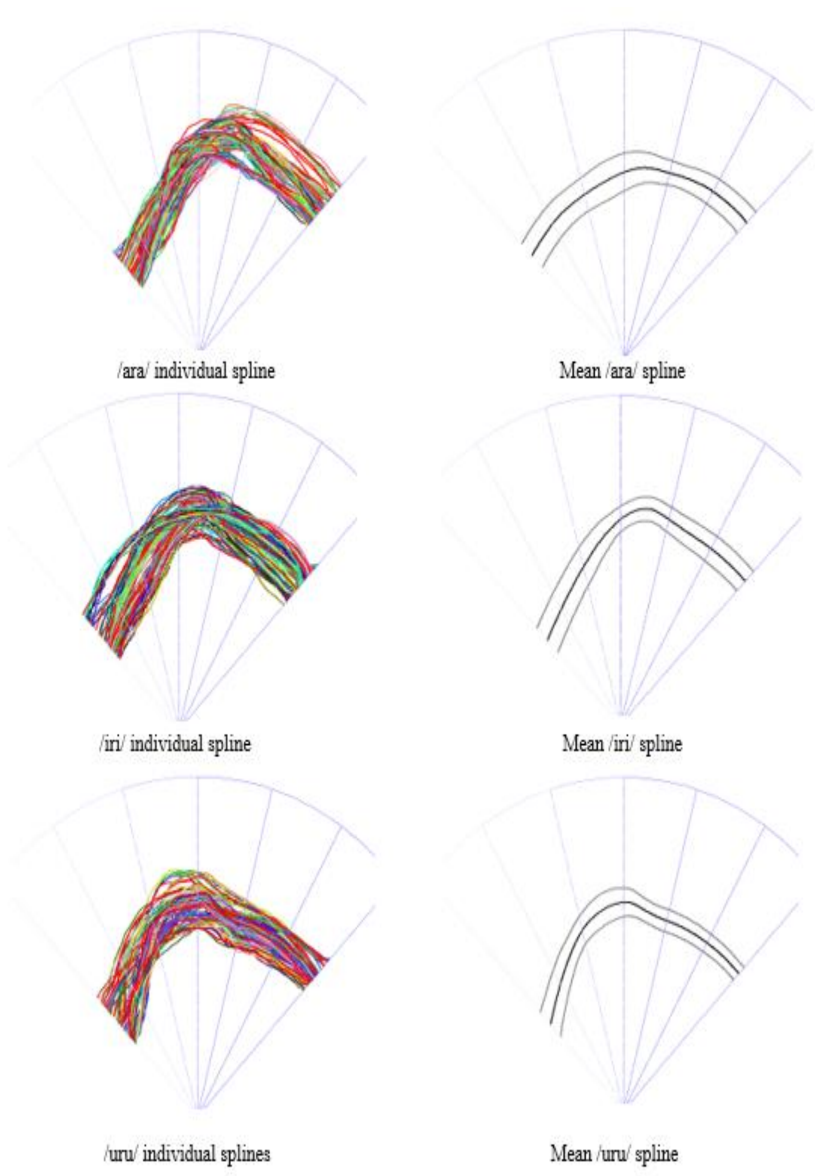


Table 4.1.1

Descriptive statistics of (x, y) coordinates at anterior, mid, and posterior sections of /l/ and /r/ in Telugu

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.39	8.36	0.16	0.31	8.21	8.21	0.25	0.28
aCa anterior y	3.27	3.24	0.16	0.31	3.08	3.08	0.24	0.26
aCa mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.38	4.41	0.33	0.51	4.24	4.28	0.44	0.63
aCa posterior x	2.57	2.63	0.22	0.40	2.57	2.50	0.28	0.39
aCa posterior y	2.30	2.28	0.27	0.37	2.33	2.38	0.26	0.36
iCi anterior x	8.49	8.53	0.24	0.37	8.38	8.42	0.22	0.41
iCi anterior y	3.36	3.39	0.22	0.35	3.24	3.28	0.02	0.41
iCi mid x	5.00	5.00	0.00	0.00	4.99	5.00	0.00	0.00
iCi mid y	4.73	4.81	0.32	0.59	4.99	4.75	0.28	0.47
iCi posterior x	3.05	3.13	0.22	0.30	3.02	3.13	0.29	0.39
iCi posterior y	1.87	1.79	0.21	0.29	1.90	1.80	0.27	0.37
uCu anterior x	8.43	8.49	0.17	0.31	8.19	8.18	0.14	0.12
uCu anterior y	3.30	3.36	0.17	0.30	3.07	3.06	0.13	0.11
uCu mid x	4.99	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.66	4.68	0.32	0.46	4.67	4.72	0.33	0.51
uCu posterior x	3.02	3.12	0.23	0.27	2.98	3.04	0.28	0.52
uCu posterior y	1.89	1.82	0.22	0.27	1.94	1.90	0.27	0.50

*SD = Standard deviation, IQR= Interquartile range

Table 4.1.2

/Z/ and p values of pairwise comparisons *at anterior, mid, and posterior sections of /l/ and /r/ in Telugu*

	/Z/	**p**
ara anterior x - ala anterior x	2.705	0.007*
ara anterior y - ala anterior y	2.710	0.007*
ara mid x - ala mid x	1.000	0.317
ara mid y – ala mid y	1.428	0.153
ara posterior x – ala posterior x	0.357	0.721
Ara posterior y – ala posterior y	0.357	0.721
iri anterior x – ili anterior x	1.718	0.086
Iri anterior y – ili anterior y	1.718	0.086
Iri mid x – ili mid x	1.000	0.317
Iri mid y – ili mid y	0.968	0.333
Iri posterior x – ili posterior x	0.051	0.959
Iri posterior y – ili posterior y	0.072	0.521
Uru anterior x – ulu anterior x	2.803	0.005*
Uru anterior y – ulu anterior y	2.803	0.005*
Uru mid x – ulu mid x	1.000	0.317
Uru mid y – ulu mid y	0.359	0.317
Uru posterior x – ulu posterior x	0.153	0.878
Uru posterior y – ulu posterior y	0.153	0.878

*Significantly different

4.1.2. Tongue contours for /l/ and /r/ in Kannada

On observation of Figures 4.1.3 and 4.1.4, the posterior tongue height was more for /l/, and height in the mid-region was more for /r/. The standard deviation was the same across the tongue contours for both the sounds in the /a/ context. In the /i/ context, the posterior height was higher for /r/; the height in the mid-region and the anterior region were the same for both. The standard deviation was the same across the tongue contours for both sounds. In the /u/ context, the posterior tongue height was higher for /r/, and the height in the mid-region and the anterior region were the same for both. The standard deviation was the same across the tongue contour of /l/ and decreased for /r/

as it moved to the anterior side. For statistical analysis, the Wilcoxon signed-rank test was done. The comparison of /l/ and /r/ in Kannada reveals a significant difference in the tongue advancement between the two sounds only in the /a/ context. The advancement of /l/ was greater when compared to /r/ during the production of the non-words /ala/ and /ara/, and the tongue height in the anterior region was higher for /l/ than /r/. For both the sounds in the /i/ and /u/ contexts, the results revealed that there was no significant difference in tongue advancement and tongue height during their production.

Figure 4.1.3

Tongue Contours of /l/ in Kannada in /a/, /i/, and /u/ Contexts

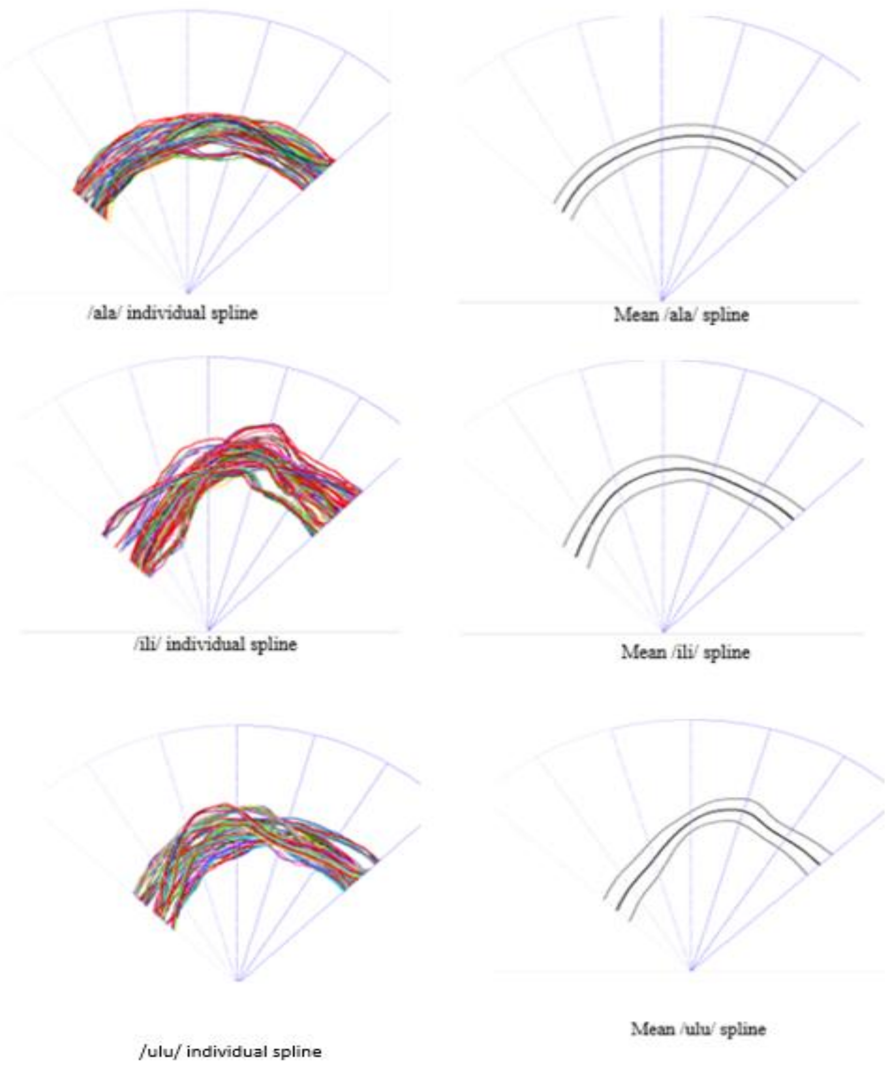


Figure 4.1.4

Tongue Contours of /r/ in Kannada in /a/, /i/, and /u/ Contexts

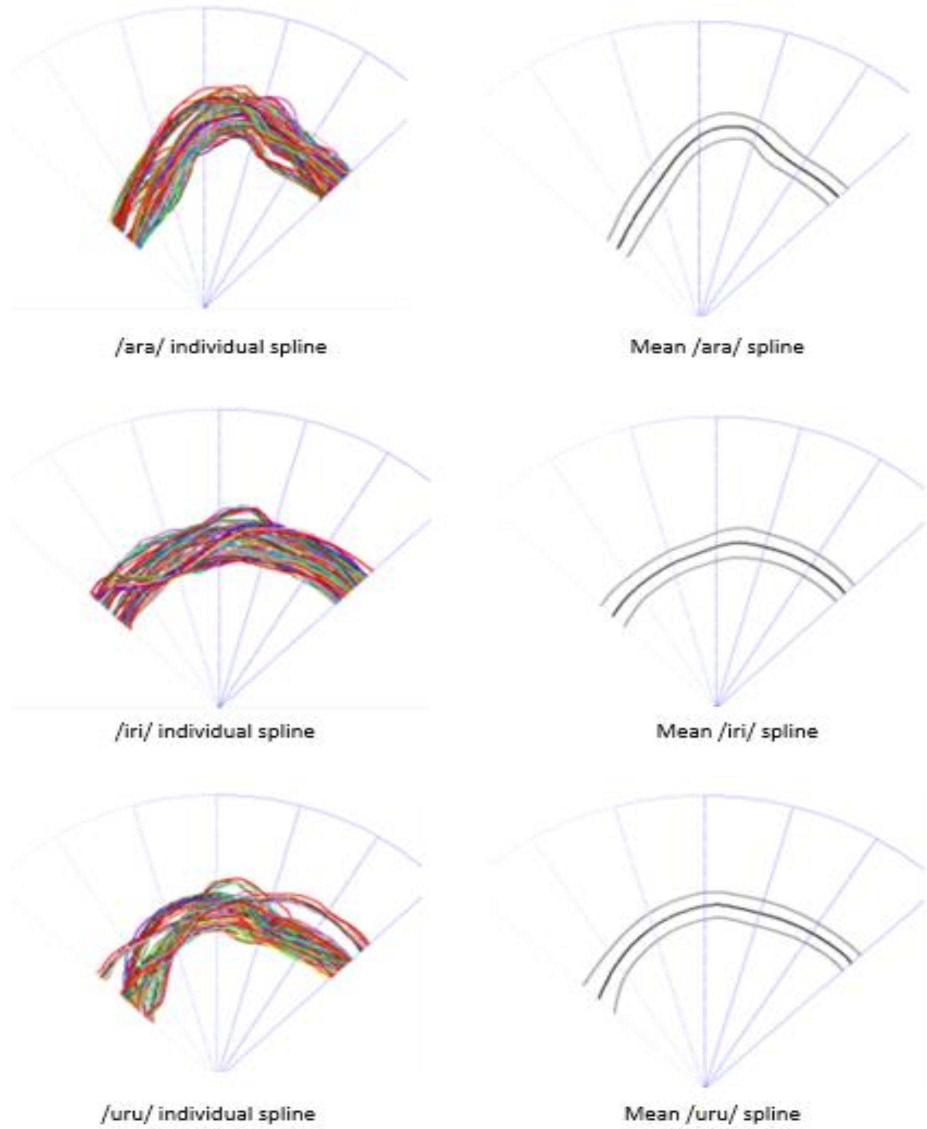


Table 4.1.3

Descriptive statistics of (x, y) coordinates at anterior, mid, and posterior sections of /l/ and /r/ in Kannada

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.27	8.27	0.21	0.37	8.06	8.10	0.21	0.38
aCa anterior y	3.15	3.14	0.19	0.30	2.30	2.96	0.21	0.38
aCa mid x	5.00	5.00	0.00	0.00	4.99	5.00	0.00	0.00
aCa mid y	4.19	4.23	0.29	0.52	4.09	4.12	0.40	0.79
aCa posterior x	2.59	2.69	0.22	0.42	2.56	2.64	0.30	0.59
aCa posterior y	2.32	2.23	0.20	0.38	2.33	2.26	0.29	0.55
iCi anterior x	8.28	8.23	0.32	0.46	8.21	8.23	0.22	0.41
iCi anterior y	3.17	3.13	0.30	0.44	3.08	3.10	0.21	0.40
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	4.44	4.40	0.26	0.36	4.50	4.47	0.28	0.47
iCi posterior x	3.11	3.19	0.33	0.33	3.11	3.21	0.21	0.35
iCi posterior y	1.80	1.73	0.33	0.32	1.80	1.72	0.20	0.33
uCu anterior x	8.21	8.20	0.26	0.46	8.10	8.11	0.23	0.33
uCu anterior y	3.08	3.07	0.25	0.42	2.96	2.95	0.22	0.31
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.31	4.39	0.37	0.66	4.51	4.56	0.26	0.36
uCu posterior x	2.90	2.97	0.31	0.52	2.93	3.00	0.30	0.26
uCu posterior y	2.01	1.95	0.29	0.49	1.99	1.92	0.29	0.24

*SD = Standard deviation, IQR= Interquartile range

Table 4.1.4

/Z/ and p values of pairwise comparisons *at anterior, mid, and posterior sections of /l/ and /r/ in Kannada*

	/Z	p
ara anterior x - ala anterior x	2.805	0.005*
ara anterior y - ala anterior y	2.805	0.005*
ara mid x - ala mid x	1.414	0.157
ara mid y – ala mid y	1.172	0.241
ara posterior x – ala posterior x	0.051	0.241
Ara posterior y – ala posterior y	0.153	0.878
iri anterior x – ili anterior x	1.173	0.241
Iri anterior y – ili anterior y	1.326	0.185
Iri mid x – ili mid x	0.000	1.000
Iri mid y – ili mid y	0.830	0.407
Iri posterior x – ili posterior x	0.459	0.646
Iri posterior y – ili posterior y	0.564	0.531
Uru anterior x – ulu anterior x	1.478	0.139
Uru anterior y – ulu anterior y	1.530	0.126
Uru mid x – ulu mid x	0.000	1.000
Uru mid y – ulu mid y	1.734	0.083
Uru posterior x – ulu posterior x	0.051	0.959
Uru posterior y – ulu posterior y	0.102	0.919

*Significantly different

4.1.3. Tongue contours for /l/ and /r/ in Tamil

Figures 4.1.5 and 4.1.6 depict the tongue contours of /l/ and /r/ in Tamil. On observation in the /a/ context, the posterior tongue height was more for /r/, and there was no difference in height in the mid-region and anterior region. The standard deviation decreased for /l/ as it moved towards the anterior region. The standard deviation was high in the mid-region for /r/. In the /i/ context, the posterior tongue height was more for /r/, and there was no difference in the height of the mid and anterior regions. The standard deviation for /l/ was less in the mid-region, and for /r/, it decreased as it moved towards the anterior side. In the /u/ context, the tongue height was more for /l/, and the standard increased as it moved to the anterior region. For /r/, the standard deviation decreased as it moved towards the anterior region. For statistical analysis, the Wilcoxon signed-rank test was used. The /l/ and /r/ sounds were compared in three vowel contexts in Tamil, the results revealed that in the /a/ context, there was no significant difference in tongue advancement and tongue height. The tongue height for /l/ was more in the anterior region when compared to the /r The tongue advancement was more for /l/ in /u/ context, and the tongue height for /l/ was more in the anterior and mid-regions when compared to /r/.

Figure 4.1.5

Tongue Contours of /l/ in Tamil in /a/, /i/, and /u/ Contexts

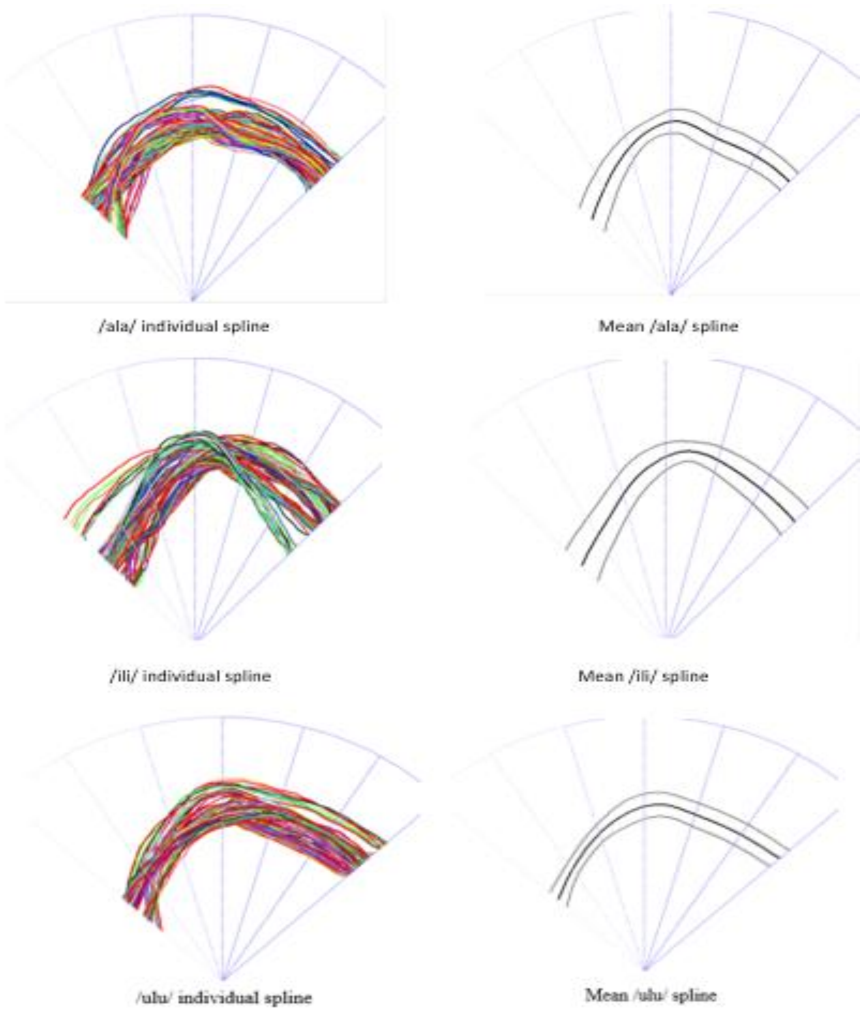


Figure 4.1.6

Tongue Contours of /r/ in Tamil in /a/, /i/, and /u/ Contexts

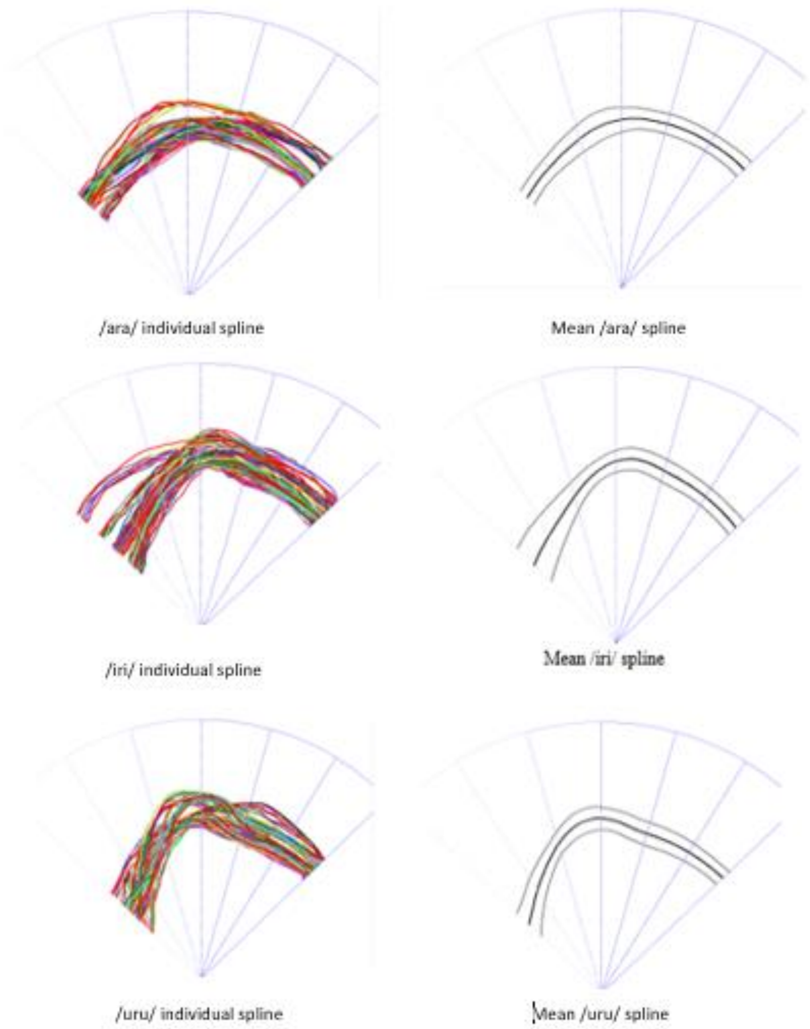


Table 4.1.5

Descriptive statistics of (x, y) coordinates at anterior, mid, and posterior sections of /l/ and /r/ in Tamil

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.37	8.35	0.19	0.23	8.26	8.22	0.19	0.23
aCa anterior y	3.23	3.22	0.18	0.22	3.13	3.09	0.17	0.20
aCa mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.60	4.52	0.43	0.60	4.44	4.35	0.33	0.51
aCa posterior x	2.59	2.58	0.32	0.48	2.49	2.45	0.19	0.32
aCa posterior y	2.32	2.33	0.31	0.48	2.39	2.44	0.18	0.32
iCi anterior x	8.06	8.30	1.09	0.38	8.28	8.23	0.21	0.41
iCi anterior y	3.27	3.27	0.20	0.36	3.17	3.19	0.20	0.41
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	4.92	4.92	0.29	0.55	4.89	4.82	0.20	0.36
iCi posterior x	2.85	2.87	0.42	0.61	2.72	2.76	0.45	0.71
iCi posterior y	2.06	2.05	0.41	0.60	2.17	2.14	0.44	0.68
uCu anterior x	8.46	8.43	0.25	0.40	8.24	8.17	0.17	0.22
uCu anterior y	3.31	3.27	0.24	0.40	3.11	3.04	0.17	0.21
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.84	4.75	0.37	0.55	4.69	4.59	0.30	0.36
uCu posterior x	2.81	2.71	0.22	0.21	2.95	3.01	0.45	0.69
uCu posterior y	2.09	2.19	0.21	0.22	1.96	1.89	0.43	0.68

*SD = Standard deviation, IQR= Interquartile range

Table 4.1.6

/Z/ and p values of pairwise comparisons *at anterior, mid, and posterior sections of /l/ and /r/ in Tamil*

	/Z/	**p**
ara anterior x - ala anterior x	1.786	0.074
ara anterior y - ala anterior y	1.784	0.074
ara mid x - ala mid x	0.000	1.000
ara mid y – ala mid y	1.479	0.139
ara posterior x – ala posterior x	0.561	0.575
Ara posterior y – ala posterior y	0.562	0.574
iri anterior x – ili anterior x	0.866	0.386
Iri anterior y – ili anterior y	2.143	0.032*
Iri mid x – ili mid x	0.000	1.000
Iri mid y – ili mid y	0.664	0.507
Iri posterior x – ili posterior x	1.378	0.168
Iri posterior y – ili posterior y	1.356	0.386
Uru anterior x – ulu anterior x	2.497	0.013*
Uru anterior y – ulu anterior y	2.499	0.120
Uru mid x – ulu mid x	0.000	1.000
Uru mid y – ulu mid y	2.295	0.022*
Uru posterior x – ulu posterior x	0.764	0.445
Uru posterior y – ulu posterior y	0.816	0.415

*Significantly different

4.1.4. Tongue contour across vowel contexts

A comparison was made for the tongue advancement and height of /l/ and /r/ across three vowels. Friedman test was administered within each consonant, and as shown in Table 4.1.7, there was no significant difference in the anterior region. However, a significant difference was found for the mid and posterior regions for both consonants. This trend was observed in all three languages. Hence, the Wilcoxon Signed Rank test was administered further to do pairwise comparisons, and Table 4.1.8 shows the same. When a comparison was made between /ili/ and /ala/, the results revealed that the tongue height in the mid-region was more for /l/, and it was produced with more advancement in the /i/ context, the tongue height in the posterior region was higher in the /a/ context for the three languages. Comparison between /ulu/ and /ala/ revealed that the tongue height in the mid-region was higher and produced with more advancement in the /u/ context, the posterior tongue height was more in the /a/ context for three languages. For /ulu/ and /ili/, there was no significant difference in height and advancement in Telugu and Tamil. In Kannada, for /ulu/ and /ili/, there was no difference in the tongue height in the mid-region, and it was produced with more advancement in the /i/ context. The tongue height in the posterior region was more for the /u/ context.

When a comparison was made for /ara/ and /iri/, the tongue height was more in the mid-region and produced with more advancement in the /i/ context, the tongue height in the posterior region was more in the /a/ context for the three languages. On comparison of /uru/ and /ara/, the tongue height was more in the mid-region and produced with more advancement in the /u/ context, the tongue height in the posterior region was more in the /a/ context for the three languages. For /uru/ and /iri/, there was no significant difference in height and advancement in Telugu. For /uru/ and /iri/ in Kannada, there was no significant difference in height in the mid-region of the tongue, and it was produced with more advancement in the /i/ context. The height in the posterior was more for /u/. In Tamil, /uru/ and /iri/, the tongue height in the mid-region was more in the /i/ context.

Table 4.1.7

Non-parametric test results on the effect of vowel on tongue contour of /l/ and /r/

	Telugu		Kannada		Tamil	
	χ^2	p	χ^2	p	χ^2	p
vlv anterior x	2.000	0.368	2.513	0.285	2.000	0.368
vlv anterior y	1.077	0.584	2.600	0.273	0.053	0.974
vlv mid x	3.000	0.223	2.000	0.368	0.200	0.905
vlv mid y	12.200	0.002*	2.205	0.332	9.800	0.007*
vlv posterior x	14.000	0.001*	12.800	0.002*	8.667	0.013*
vlv posterior y	11.231	0.004*	12.800	0.002*	6.513	0.039*
vrv anterior x	4.200	0.122	4.769	0.092	0.632	0.729
vrv anterior y	4.200	0.122	5.105	0.078	0.154	0.926
vrv mid x	2.000	0.368	2.000	0.368	2.000	0.368
vrv mid y	12.200	0.002*	9.800	0.007*	12.359	0.002*
vrv posterior x	9.800	0.007*	15.800	0.000*	7.200	0.027*
vrv posterior y	9.800	0.007*	15.800	0.000*	6.821	0.033*

*Significantly different

Table 4.1.8

/Z/ and p values of pairwise comparisons of /l/ and /r/ across vowel contexts

	Telugu		Kannada		Tamil	
	/Z/	p	/Z/	p	/Z/	p
Ili vs ala mid y	2.803	0.005*	1.989	0.047	2.601	0.009*
ulu vs ala mid y	2.599	0.009*	1.660	0.097	2.599	0.009*
ulu vs ili mid y	0.866	0.386	0.969	0.333	1.070	0.285
ili vs ala posterior x	2.666	0.008*	2.606	0.009*	2.194	0.028
ulu vs ala posterior x	2.803	0.005*	2.601	0.009*	2.805	0.005*
ulu vs ili posterior x	0.051	0.950	2.244	0.025	0.764	0.445
Iii vs ala posterior y	2.599	0.009*	2.550	0.011	2.194	0.028
ulu vs ala posterior y	2.666	0.008*	2.599	0.009*	2.652	0.008*
ulu vs ili posterior y	0.051	0.959	2.091	0.037	0.663	0.508
ara vs iri mid y	2.599	0.009*	2.295	0.022	2.701	0.007*
uru vs ara mid y	2.803	0.005*	2.701	0.007*	2.374	0.018
uru vs Iri mid y	0.408	0.683	0.153	0.878	2.193	0.028
iri vs ara posterior x	2.701	0.007*	2.805	0.005*	1.530	0.126
uru vs ara posterior x	2.599	0.009*	2.805	0.005*	2.395	0.017
uru vs iri posterior x	0.764	0.445	2.191	0.028	1.478	0.139
iri vs ara posterior y	2.652	0.008*	2.803	0.005*	1.478	0.139
uru vs ara posterior y	2.599	0.009*	2.803	0.005*	2.395	0.017
uru vs iri posterior y	0.764	0.445	2.193	0.028	1.481	0.139

*Significantly different

4.2. Tongue contours across languages

Descriptive statistics of Telugu, Kannada and Tamil are given in Table 4.1.1, 4.1.3 and 4.1.5 respectively. On observation of /l/ across Telugu and Kannada, the tongue height was higher in Telugu in comparison to Kannada in the /a/ context. For /r/, the posterior tongue height was higher in Telugu, and no difference in height in the mid and anterior regions. In the /i/ context, the posterior tongue height was more in Kannada, and the height in the mid and anterior regions was more in Telugu for /l/. For /r/, the posterior tongue height was higher in Kannada, the mid-region was higher in Telugu, and there was no difference in the anterior region. In the /u/ context, the posterior tongue height was higher in Telugu and Kannada for /l/ and /r/, respectively, and there was no difference in the mid and anterior regions for both sounds. On observation of /l/ and /r/ in Telugu and Tamil, the tongue height was more for /l/ in Telugu, and for /r/, it was more in Tamil in the /a/ context. In the /i/ context, posterior tongue height was higher in Tamil, and anterior height was higher in Telugu. For mid-region, no difference was found for /l/. For /r/, posterior tongue height was more elevated in Tamil, and no difference was found for the mid and anterior regions. In the /u/ context, posterior tongue height was higher in Tamil, and no difference was found for the mid and anterior regions for /l/. The tongue height was higher in Tamil for /r/. Across Kannada and Tamil, the tongue height was higher in Kannada for /l/, and posterior tongue height was higher in Tamil for /r/ in /a/ context. No difference was found for the mid and anterior regions of /r/ in terms of height. In the /i/ context, the tongue height was similar for /l/ in both languages. For /r/, posterior tongue height was higher in Kannada, and no difference was found for the mid and anterior regions. In the /u/ context, for /l/, the tongue height was higher in the posterior and mid regions in Tamil, and there was no difference in the anterior part. For /r/, posterior tongue height was higher in Kannada, and no difference was found for the mid and anterior regions.

For statistical analysis, the Kruskal-Walli H test was administered. The results revealed that a significant difference was found only for three parameters among 36 parameters which were /ili/ mid-tongue y- axis (/Z/= 9.733, p=0.008), /ulu/ mid-tongue y-axis (/Z/= 6.397, p=0.041) and /iri/ mid tongue y-axis (/Z/= 7.855, p= 0.020). Further, Pairwise language comparisons were done using the Mann-Whitney U test. As shown in Table 4.2.1, the tongue height for /l/ in the /i/ context was more in Telugu when compared to Kannada. Similarly, the tongue height was higher in Telugu for /l/ in /u/ context. For all these parameters were significantly different across Kannada and Tamil, no difference was found between Telugu and Tamil. /ili mid y was different between Telugu and Kannada. However, mid-tongue vertical distance was more for Tamil than Kannada for all three parameters.

Table 4.2.1

/Z/ and p values of pairwise comparison across languages

	Telugu and Kannada		**Telugu and Tamil**		**Kannada and Tamil**	
	/Z/	**P**	**/Z/**	**P**	**/Z/**	**P**
ili mid y	2.00	0.045*	1.097	0.273	3.026	0.002*
ulu mid y	1.81	0.070	0.832	0.406	2.343	0.019*
iri mid y	1.17	0.247	1.741	0.082	2.685	0.007*

* Significant difference

4.3. To understand gender effect

On observation of the tongue contours of /l/ in females and males in the Telugu language in /a/ context, the posterior tongue height was higher in males when compared to females, and the standard deviation increased in females as it moved towards the anterior side and decreased in males. In the /i/ context, the tongue seemed to be similar in both genders. The standard deviation in females decreased as it moved towards the anterior side, and for males, the standard deviation was more in the mid-region of the tongue. In the /u/ context, the height in the posterior and mid-region was higher for males. The standard deviation increased and decreased as it moved towards the anterior side in females and males, respectively. For /r/ in the /a/ context, the tongue was similar for both genders. The standard deviation increased as it moved towards the anterior side in females, and for males, the standard deviation was more in the mid-region of the tongue. In the /i/ context, posterior tongue height was higher in females. The standard deviation increased and decreased as it moved towards the anterior side in females and males, respectively. In the /u/ context, tongue height was similar for both females and males. The standard deviation was more in the middle for females, and for males, it decreased as it moved towards the anterior side. Mann-Whitney Test was used for statistical analysis. On statistical comparison of /l/ and /r/ in Telugu between the genders, /l/ was more retracted in females in the /a/ context than in males, and the posterior tongue height was more in females than males during the production of /l/. Similarly, in the /i/ context, the tongue height was higher for females in the anterior region, and /l/ was produced more anteriorly by males. In the /u/ context, there was no significant difference for /l/. For /r/, in the /i/ context, the tongue height was more for females in the posterior region and more anteriorly produced by males. There was no significant difference in the /a/ and /u/ context for /r/.

Figure 4.3.1

Individual and mean tongue contour of /ala/ for females and males in Telugu

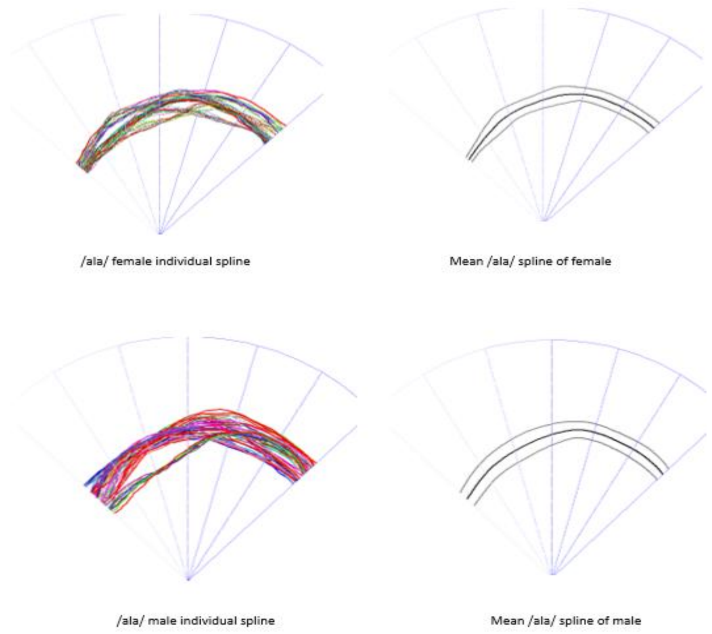


Figure 4.3.2

Individual and mean tongue contour of /ili/ for females and males in Telugu

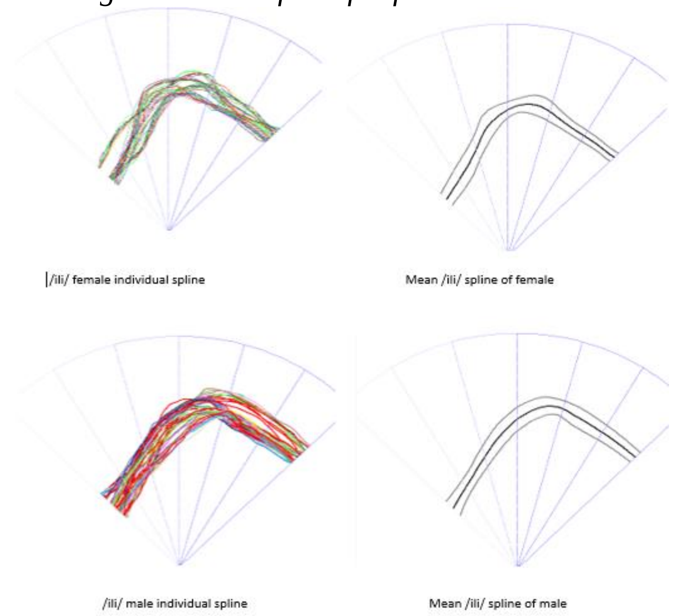


Figure 4.3.3

Individual and mean tongue contour of /ulu/ for females and males in Telugu

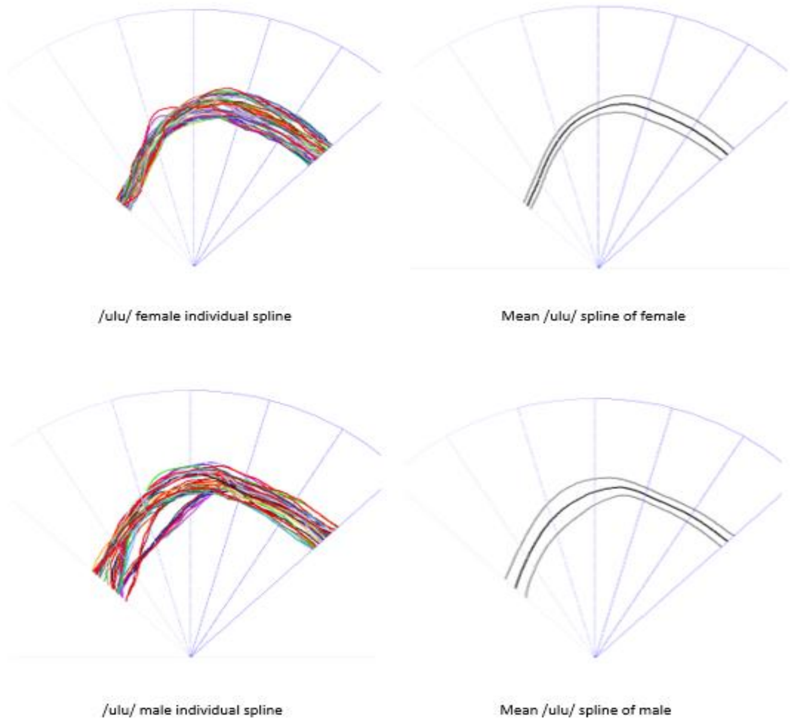


Figure 4.3.4

Individual and mean tongue contour of /ara/ for females and males in Telugu

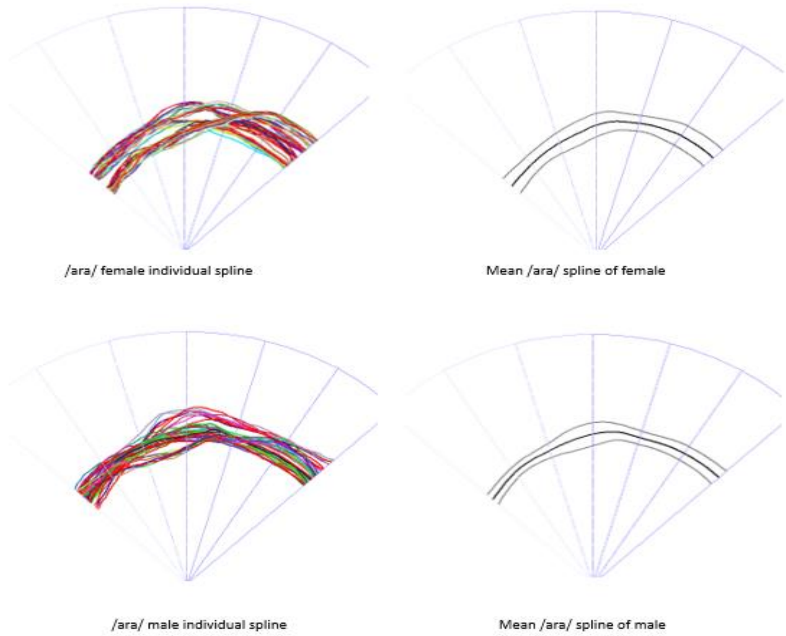


Figure 4.3.5

Individual and mean tongue contour of iri/ for females and males in Telugu

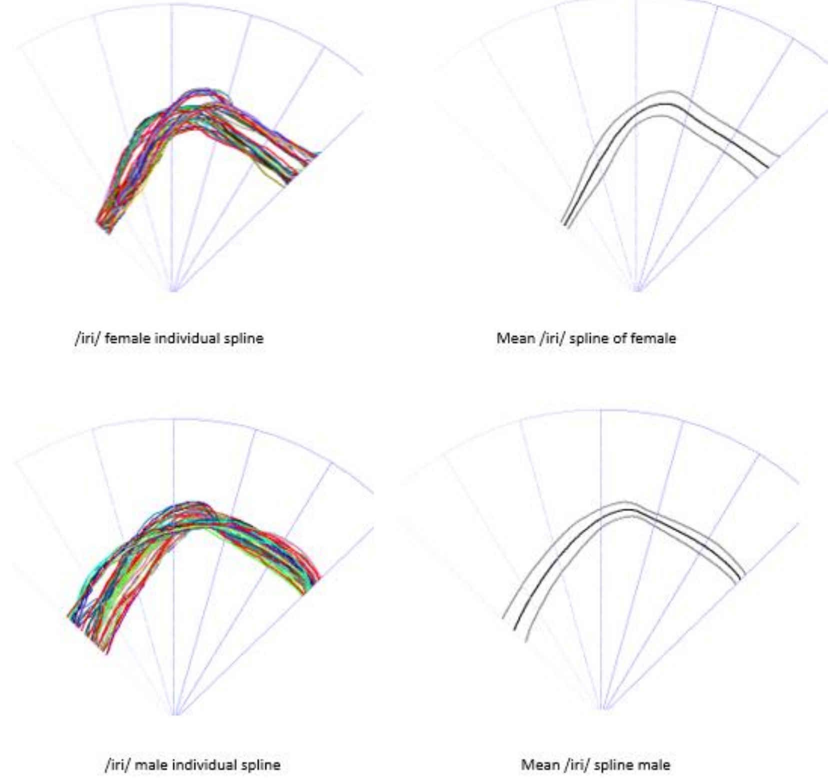


Figure 4.3.6

Individual and mean tongue contour of /uru/ for females and males in Telugu

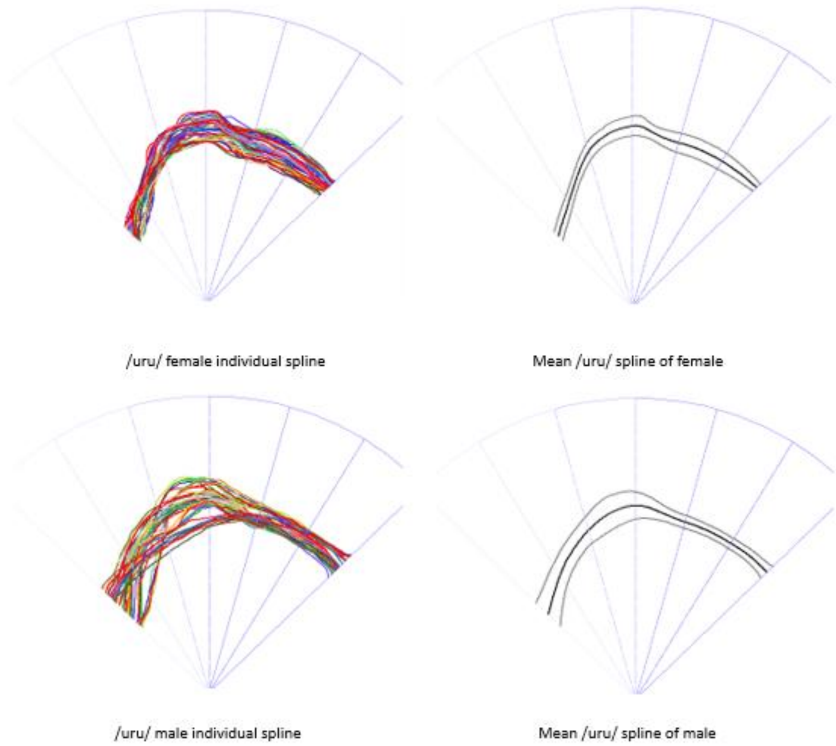


Table 4.3.1

Descriptive statistics of (x, y) coordinates at anterior, mid, and posterior sections of /l/ and /r/ x females in Telugu

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.38	8.42	0.17	0.32	8.32	8.30	0.20	0.34
aCa anterior y	3.25	3.29	0.16	0.30	3.18	3.15	0.19	0.31
aCa mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.50	4.58	0.34	0.61	4.49	4.44	0.37	0.65
aCa posterior x	2.42	2.36	0.22	0.39	2.37	2.37	0.12	0.24
aCa posterior y	2.47	2.54	0.20	0.38	2.51	2.51	0.12	0.25
iCi anterior x	8.68	8.61	0.16	0.29	8.46	8.46	0.09	0.18
iCi anterior y	3.54	3.47	0.15	0.28	3.32	3.32	0.10	0.20
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	4.75	4.91	0.39	0.69	4.82	4.78	0.22	0.37
iCi posterior x	3.01	3.08	0.24	0.42	2.83	2.92	0.31	0.61
iCi posterior y	1.91	1.86	0.23	0.41	2.07	2.00	0.29	0.56
uCu anterior x	8.50	8.56	0.15	0.24	8.28	8.19	0.15	0.25
uCu anterior y	3.36	3.41	0.16	0.24	3.15	3.07	0.13	0.21
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.79	4.71	0.39	0.72	4.82	4.81	0.36	0.61
uCu posterior x	2.90	3.01	0.28	0.55	2.82	2.79	0.31	0.62
uCu posterior y	2.01	1.91	0.27	0.53	2.08	2.12	0.31	0.60

*SD = Standard deviation, IQR= Interquartile range

Table 4.3.2

Descriptive statistics of (x, y) coordinates at the anterior, mid, and posterior sections of /l/ and /r/ of males in Telugu

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.41	8.30	0.17	0.32	8.10	8.19	0.27	0.50
aCa anterior y	3.29	3.19	0.17	0.32	2.98	3.07	0.26	0.49
aCa mid x	5.00	5.000	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.25	4.30	0.30	0.54	3.99	3.99	0.38	0.73
aCa posterior x	2.72	2.76	0.90	0.16	2.77	2.66	0.25	0.48
aCa posterior y	2.12	2.17	0.23	0.34	2.15	2.26	0.24	0.46
iCi anterior x	8.30	8.30	0.13	0.23	8.29	8.16	0.28	0.54
iCi anterior y	3.18	3.18	0.13	0.24	3.17	3.03	0.28	0.52
iCi mid x	5.00	5.00	0.00	0.00	4.99	5.00	0.00	0.00
iCi mid y	4.71	4.74	0.27	0.54	4.50	4.36	0.25	0.47
iCi posterior x	3.10	3.14	0.21	0.31	3.21	3.22	0.08	0.15
iCi posterior y	1.82	1.79	0.20	0.29	1.72	1.72	0.08	0.15
uCu anterior x	8.36	8.34	0.17	0.31	8.11	8.12	0.08	0.15
uCu anterior y	3.24	3.21	0.17	0.32	2.99	3.01	0.08	0.15
uCu mid x	4.99	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.54	4.58	0.18	0.35	4.53	4.64	0.25	0.48
uCu posterior x	3.15	3.12	0.92	0.17	3.15	3.15	0.11	0.22
uCu posterior y	1.78	1.82	0.09	0.17	1.79	1.77	0.11	0.24

*SD = Standard deviation, IQR= Interquartile range

Table 4.3.3

/Z/ and p values of pairwise comparisons *at the anterior, mid, and posterior sections of /l/ and /r/ in Telugu*

	/Z/	p		/z/	p
ala anterior x	0.420	0.674	ara anterior x	0.940	0.347
ala anterior y	0.419	0.675	ara anterior y	1.048	0.295
ala mid x	1.000	0.317	ara mid x	0.000	1.000
ala mid y	1.149	0.251	ara mid y	1.776	0.760
ala posterior x	2.200	0.028*	ara posterior x	2.402	0.160
ala posterior y	2.200	0.028*	ara posterior y	2.402	0.160
ili anterior x	2.611	0.009*	iri anterior x	0.940	0.347
ili anterior y	2.611	0.009*	iri anterior y	0.940	0.347
ili mid x	0.000	1.000	iri mid x	1.000	0.317
ili mid y	0.522	0.602	iri mid y	1.676	0.094
ili posterior x	0.522	0.602	iri posterior x	2.193	0.028*
ili posterior y	0.522	0.602	iri posterior y	2.095	0.036*
ulu anterior x	1.358	0.175	uru anterior x	1.892	0.059
ulu anterior y	1.149	0.251	uru anterior y	1.892	0.059
ulu mid x	1.000	0.317	uru mid x	0.000	1.000
ulu mid y	1.149	0.251	uru mid y	1.567	0.117
ulu posterior x	1.362	0.173	uru posterior x	1.798	0.072
ulu posterior y	1.358	0.175	uru posterior y	1.257	0.209

*Significantly different

On observation of the tongue contours of females and males of /l/ in the Kannada language in the /a/ context, the tongue height was more in the posterior region for females. The standard deviation increased as it moved towards the anterior in females and was the same across the tongue contour for males. In the /i/ context, the tongue was similar for both genders, and the standard deviation was less in the mid-region of the tongue for both females and males. In the /u/ context, the tongue was similar for both genders. The standard deviation was similar across the tongue contour for females and decreased as it moved towards the anterior side in males. For /r/ in the /a/ context, the tongue was similar for both genders. The standard deviation was more in the mid-region for females and decreased as it moved towards the anterior side in males. In the /i/ context, the tongue height in the posterior and mid-regions was higher for females. The standard deviation decreased as it moved towards the anterior side in females and was less in the mid-region for males. In the /u/ context, the posterior tongue height was higher in females. The standard deviation was less in the mid-region for females and decreased as it moved towards the anterior side in males. Mann-Whitney Test was used for statistical analysis. The results of the statistical analysis revealed that there was no significant gender difference in Kannada during the production of /l/, but the tongue height for /r/ was higher in females in the mid-region of the tongue in /i/ and /u/ contexts when compared to males. There was no significant difference in terms of advancement of the tongue during /r/ production between both genders.

Figure 4.3.7

Individual and mean tongue contour of /ala/ for females and males in Kannada

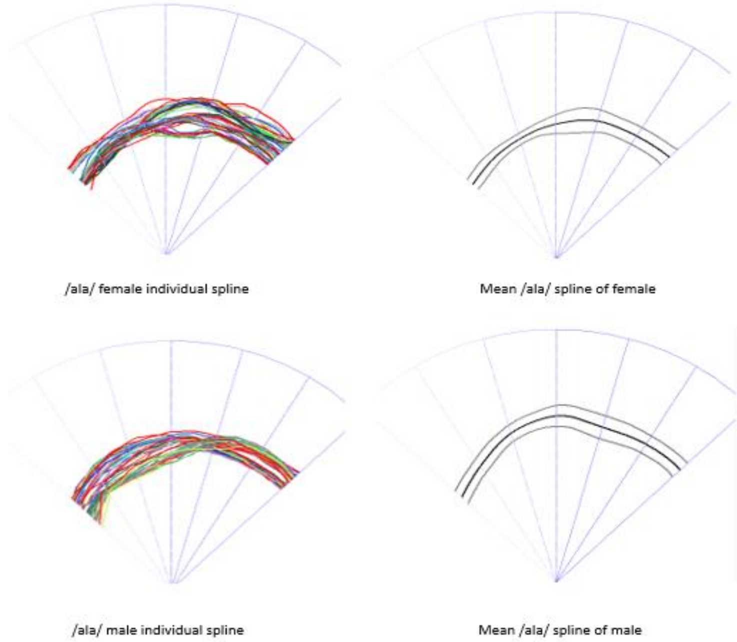


Figure 4.3.8

Individual and mean tongue contour of /ili/ for females and males in Kannada

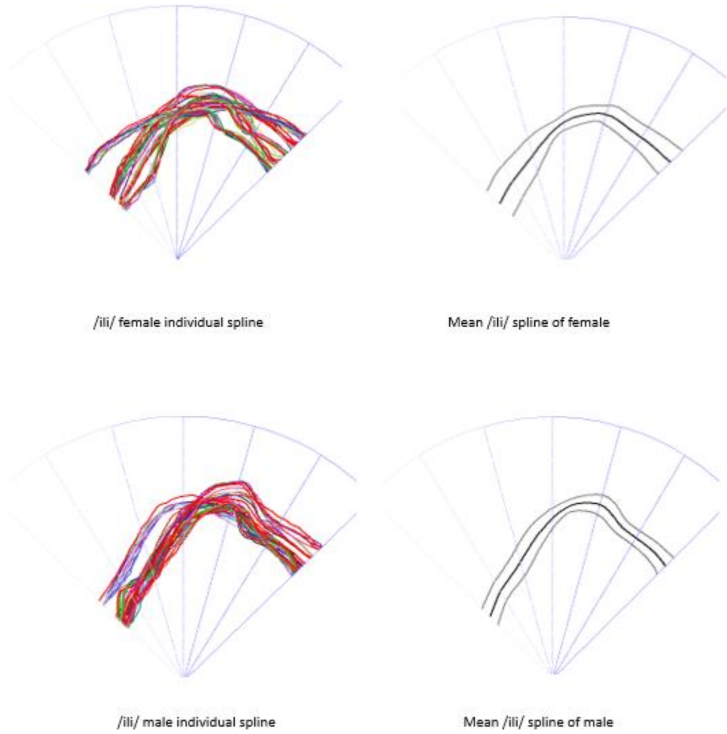


Figure 4.3.9

Individual and mean tongue contour of /ulu/ for females and males in Kannada

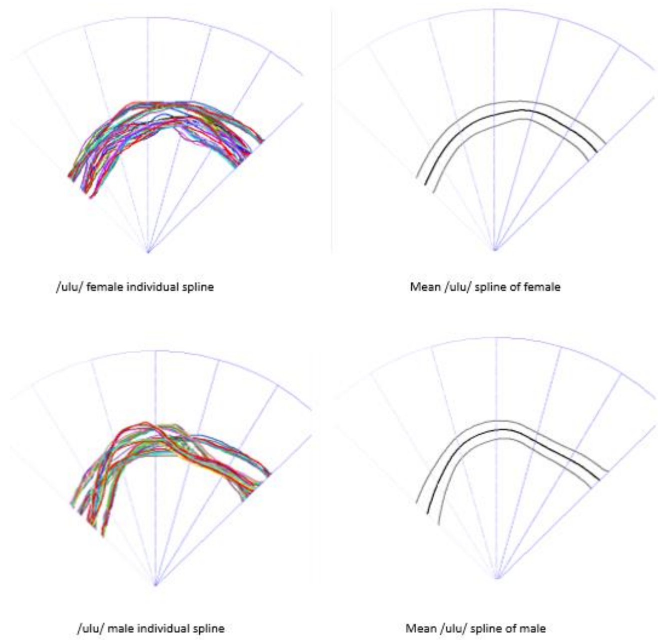


Figure 4.3.10

Individual and mean tongue contour of /ara/ for females and males in Kannada

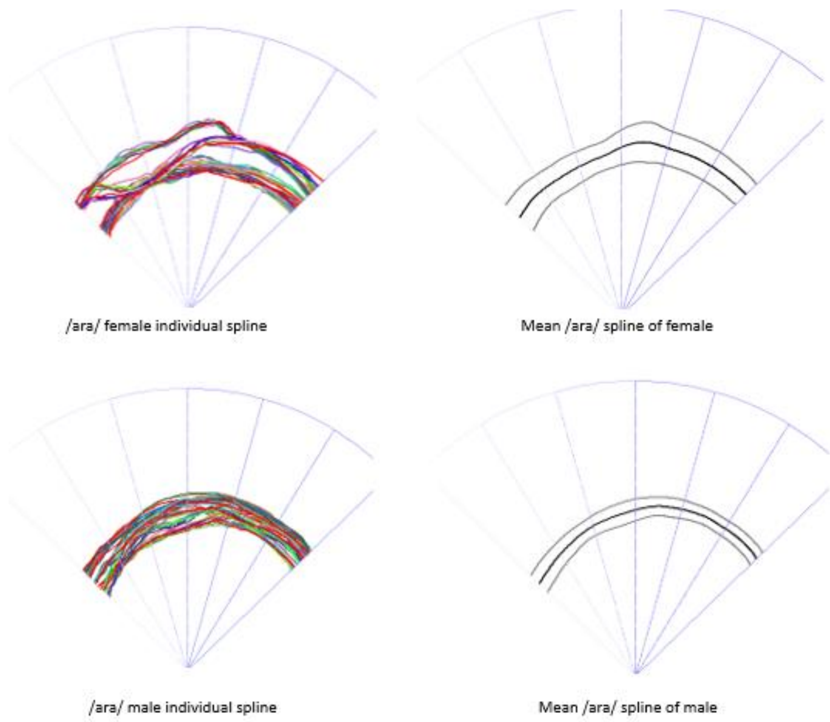


Figure 4.3.11

Individual and mean tongue contour of /iri/ for females and males in Kannada

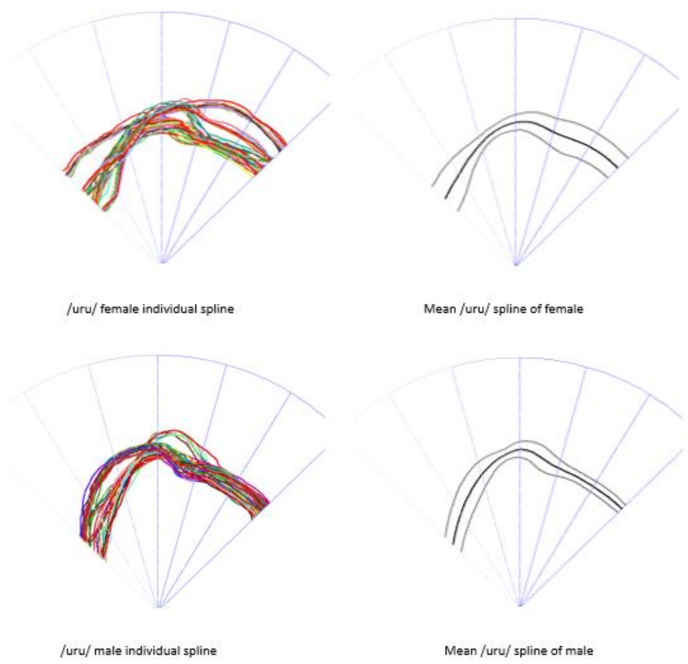


Figure 4.3.12

Individual and mean tongue contour of /uru/ for females and males in Kannada

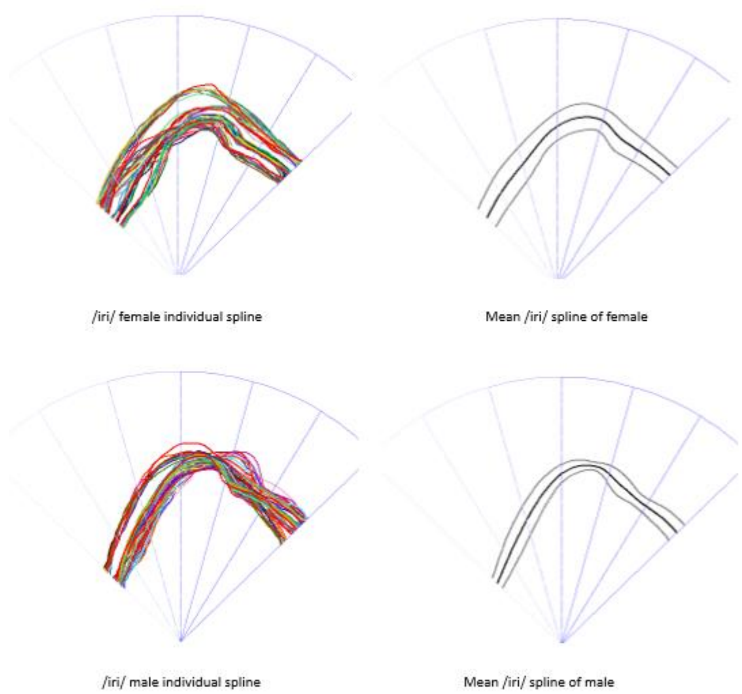


Table 4.3.4

Descriptive statistics of (x, y) coordinates at the anterior, mid, and posterior sections of /l/ and /r/ of females in Kannada

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.33	8.34	0.17	0.33	8.10	8.13	0.16	0.28
aCa anterior y	3.21	3.22	0.14	0.28	2.96	2.99	0.16	0.27
aCa mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.29	4.44	0.28	0.53	4.20	4.22	0.29	0.57
aCa posterior x	2.54	2.54	0.28	0.56	2.56	2.57	0.23	0.46
aCa posterior y	2.37	2.38	0.26	0.51	2.33	`2.32	0.22	0.43
iCi anterior x	8.34	8.23	0.25	0.41	8.24	8.29	0.22	0.41
iCi anterior y	3.23	3.15	0.24	0.40	3.12	3.16	0.22	0.40
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	4.57	4.47	0.23	0.39	4.73	4.68	0.18	0.36
iCi posterior x	3.16	3.21	0.26	0.41	3.21	3.27	0.15	0.24
iCi posterior y	1.75	1.72	0.24	0.39	1.71	1.67	0.14	0.24
uCu anterior x	8.22	8.18	0.27	0.51	8.08	8.10	0.10	0.19
uCu anterior y	3.09	3.06	0.25	0.49	2.94	2.93	0.10	0.18
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.40	4.53	0.39	0.68	4.67	4.64	0.14	0.28
uCu posterior x	2.94	3.01	0.37	0.57	3.03	2.98	0.22	0.36
uCu posterior y	1.96	1.90	0.34	0.53	1.89	1.93	0.20	0.34

*SD = Standard deviation, IQR= Interquartile range

Table 4.3.5

Descriptive statistics of (x, y) coordinates at the anterior, mid, and posterior sections of /l/ and /r for males in Kannada

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.21	8.17	0.26	0.50	8.03	7.95	0.27	0.52
aCa anterior y	3.09	3.06	0.24	0.47	2.91	2.82	0.27	0.52
aCa mid x	5.00	5.00	0.00	0.00	4.99	5.00	0.00	0.00
aCa mid y	4.09	4.02	0.30	0.58	3.99	3.69	0.49	0.84
aCa posterior x	2.64	2.73	0.16	0.25	2.57	2.72	0.38	0.75
aCa posterior y	2.27	2.20	1.51	0.22	2.33	2.17	0.37	0.73
iCi anterior x	8.22	8.23	0.40	0.76	8.18	8.07	0.23	0.45
iCi anterior y	3.11	3.12	0.38	0.73	3.05	2.96	0.22	0.43
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	4.31	4.30	0.25	0.42	4.27	4.28	0.11	0.23
iCi posterior x	3.07	3.13	0.42	0.65	3.02	2.98	0.23	0.47
iCi posterior y	1.86	1.81	0.42	0.65	1.89	1.94	0.22	0.44
uCu anterior x	8.19	8.22	0.29	0.51	8.11	8.12	0.33	0.62
uCu anterior y	3.07	3.08	0.27	0.48	2.99	3.01	0.31	0.59
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.23	4.07	0.37	0.71	4.34	4.37	0.25	0.49
uCu posterior x	2.86	2.94	0.28	0.54	2.82	3.03	0.37	0.59
uCu posterior y	2.05	1.98	0.26	0.51	2.09	1.92	0.35	0.56

*SD = Standard deviation, IQR= Interquartile range

Table 4.3.6

/Z/ and p values of pairwise comparisons *at the anterior, mid, and posterior sections of /l/ and /r/ for gender in Kannada*

	/Z/	p		/Z/	p
ala anterior x	1.576	0.463	ara anterior x	1.362	0.600
ala anterior y	1.485	0.346	ara anterior y	1.149	0.600
ala mid x	0.000	0.317	ara mid x	0.000	0.317
ala mid y	2.611	0.175	ara mid y	1.358	0.251
ala posterior x	2.200	0.753	ara posterior x	1.149	0.917
ala posterior y	1.991	0.754	ara posterior y	1.048	0.917
ili anterior x	0.524	0.675	iri anterior x	0.629	0.675
ili anterior y	0.631	0.602	iri anterior y	0.000	0.597
ili mid x	0.000	1.000	iri mid x	0.000	1.000
ili mid y	1.984	0.117	iri mid y	2.402	0.009*
ili posterior x	2.193	0.754	iri posterior x	1.571	0.249
ili posterior y	2.193	0.753	iri posterior y	1.567	0.251
ulu anterior x	1.567	0.917	uru anterior x	0.943	0.834
ulu anterior y	1.567	0.917	uru anterior y	0.529	0.754
ulu mid x	0.000	1.000	uru mid x	0.000	1.000
ulu mid y	2.611	0.602	uru mid y	1.571	0.047*
ulu posterior x	1.156	0.599	uru posterior x	1.149	0.602
ulu posterior y	0.731	0.530	uru posterior y	1.149	0.602

*Significantly different

On observation of the tongue contours of females and males of /l/ in Tamil in the /a/ context, the tongue height was higher for males. The standard deviation decreased and increased as it moved towards the anterior side in females and males, respectively. In the /i/ context, the tongue height was similar for both genders, and the standard deviation was less in the mid-region for both females and males. In the /u/ context, the tongue height was more in the mid-region for males. The standard deviation was less in the mid-region for females and increased as it moved towards the anterior side in males. For /r/ in the /a/ context, the tongue height was more in the mid-region for males. The standard deviation decreased as it moved towards the anterior side in females and increased in males as it moved towards the anterior side. In the /i/ context, posterior tongue height was higher in males. The standard deviation was similar across the tongue contours for females and males less in the mid-region. In the /u/ context, the tongue height was higher in the mid and anterior regions for males. The standard deviation was less in the mid-region for females and the same across the tongue contour in males. Mann-Whitney Test was used for statistical analysis. The results of the statistical analysis revealed that the production of /l/ was more anterior in males than females, and the height of the tongue in the posterior and mid-regions in the /a/ context was higher for females. In the case of the /i/ context, the results were the same as /a/. In the /u/ context, the tongue height was higher for females in the mid-region. For /r/ in the /i/ context, the tongue height was higher for females in the mid-region, and there was no significant difference in the tongue advancement. There was no significant difference in the tongue advancement and height in the /a/ and /u/contexts.

Figure 4.3.13

Individual and mean tongue contour of /ala/ for females and males in Tamil

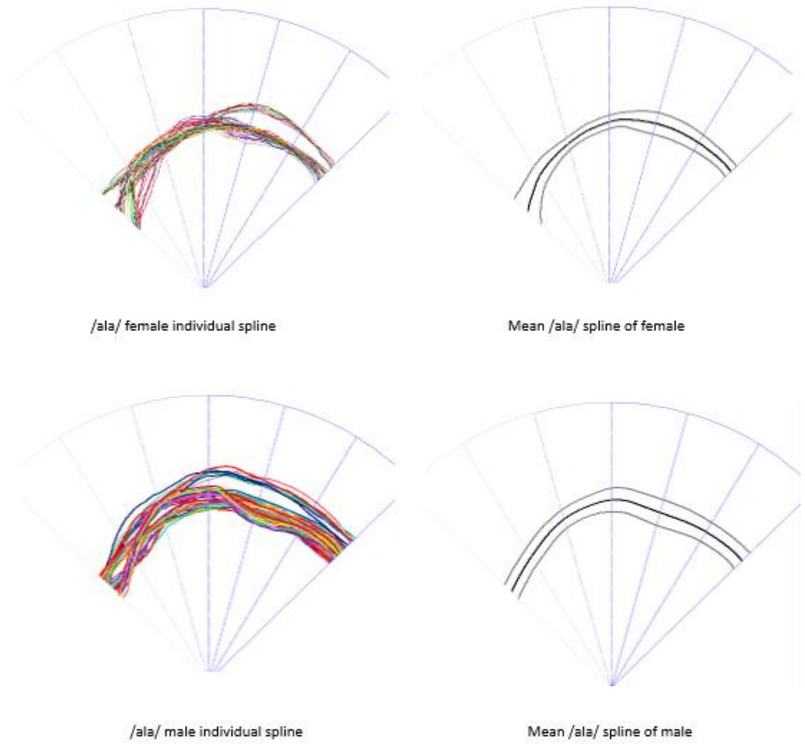


Figure 4.3.14

Individual and mean tongue contour of /ili/ for females and males in Tamil

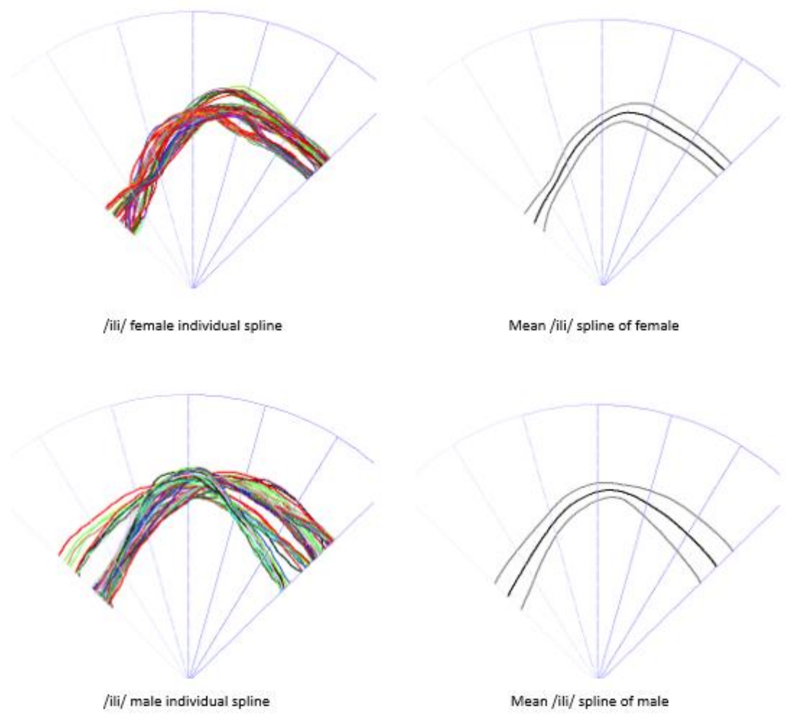


Figure 4.3.15

Individual and mean tongue contour of /ulu/ for females and males in Tamil

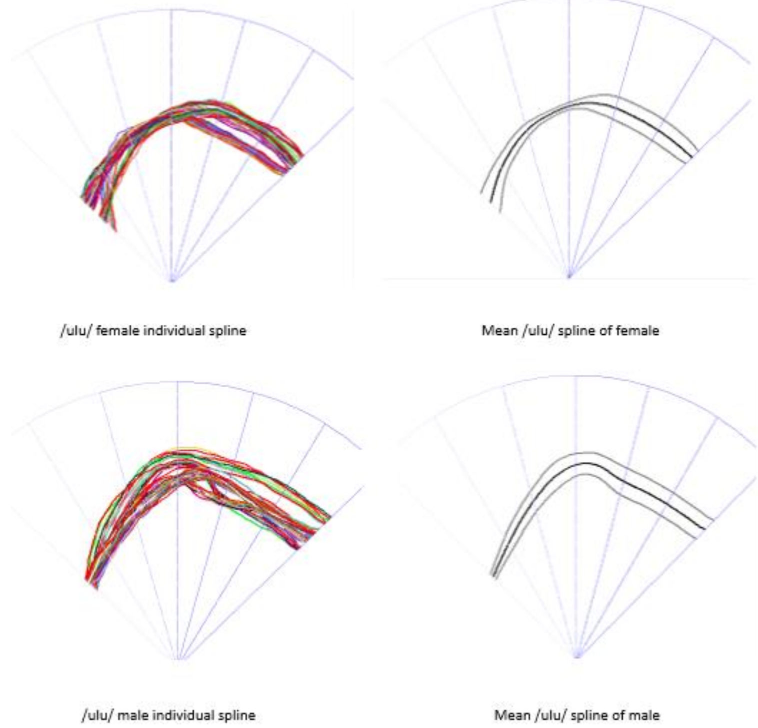


Figure 4.3.16

Individual and mean tongue contour of /ara/ for females and males in Tamil

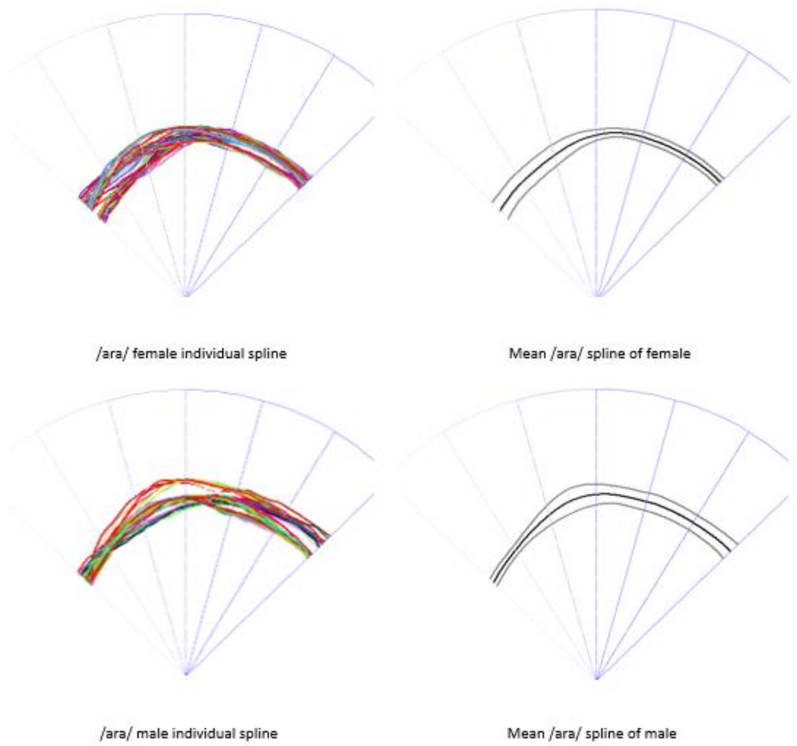


Figure 4.3.17

Individual and mean tongue contour of /iri/ for females and males in Tamil

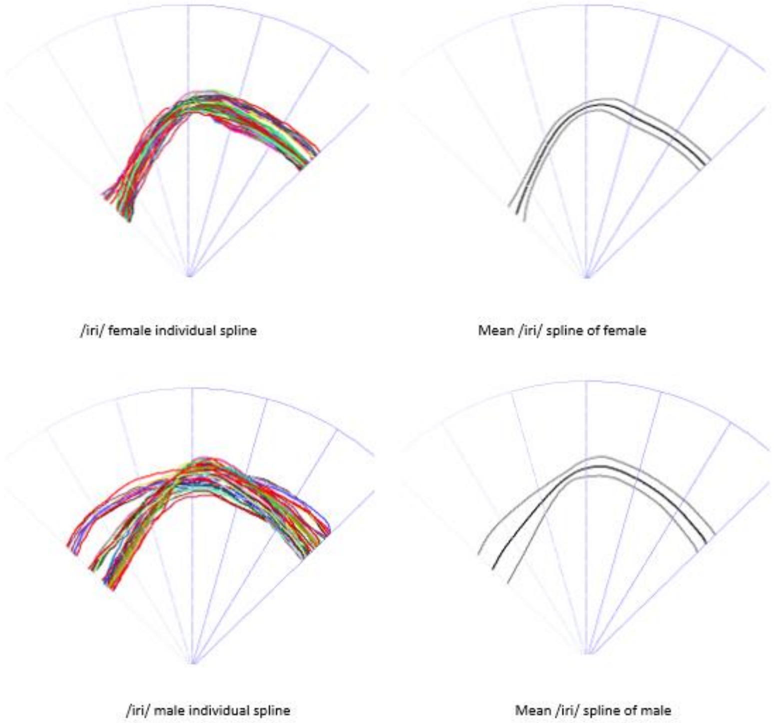


Figure 4.3.18

Individual and mean tongue contour of uru/ for females and males in Tamil

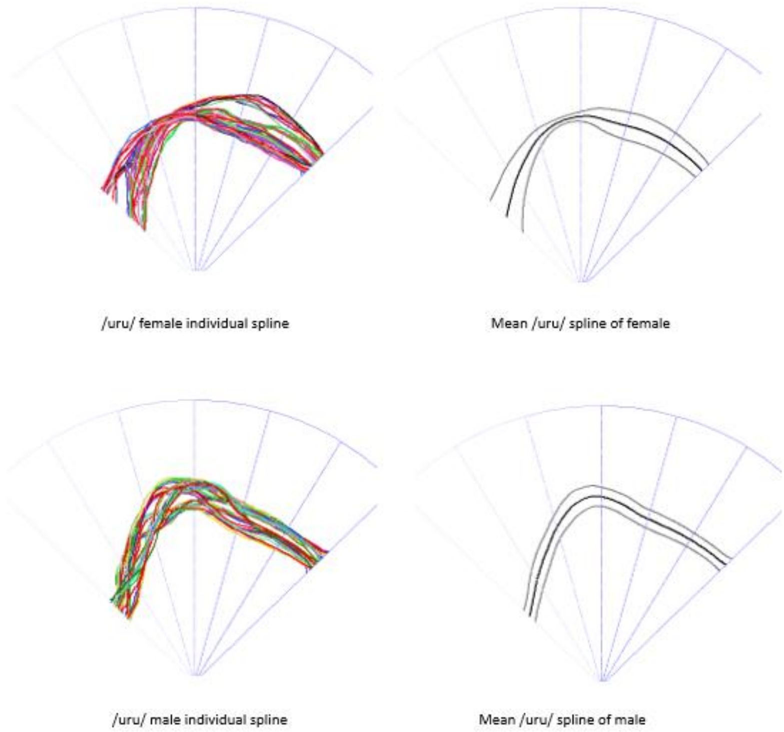


Table 4.3.7

Descriptive statistics of (x, y) coordinates at the anterior, mid, and posterior sections of /l/ and /r/ of females in Tamil

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.46	8.39	0.22	0.39	8.35	8.26	0.23	0.45
aCa anterior y	3.32	3.24	0.21	0.37	3.21	3.11	0.22	0.42
aCa mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.92	4.92	0.33	0.57	4.62	4.63	0.38	0.71
aCa posterior x	2.40	2.32	0.18	0.32	2.42	2.40	0.15	0.26
aCa posterior y	2.50	2.62	0.18	0.32	2.46	2.48	0.14	0.25
iCi anterior x	7.78	8.36	1.56	2.04	8.25	8.10	0.25	0.42
iCi anterior y	3.32	3.40	2.40	0.42	3.17	3.24	0.23	0.44
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	5.12	5.23	0.20	0.39	5.04	5.07	0.15	0.29
iCi posterior x	2.58	2.69	0.39	0.64	2.47	2.68	0.43	0.75
iCi posterior y	2.32	2.22	0.37	0.60	2.42	2.23	0.42	0.73
uCu anterior x	8.58	8.59	0.27	0.48	8.20	8.20	0.23	0.38
uCu anterior y	3.42	3.43	0.26	0.46	3.16	3.06	0.22	0.37
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	5.13	4.97	0.30	0.56	4.85	4.72	0.38	0.70
uCu posterior x	2.71	2.70	0.06	0.09	2.75	2.76	0.47	0.77
uCu posterior y	2.18	2.20	0.06	0.10	2.14	2.14	0.45	0.76

*SD = Standard deviation, IQR= Interquartile range

Table 4.3.8

Descriptive statistics of (x, y) coordinates at the anterior, mid, and posterior sections of /l/ and /r/ of males in Tamil

	/l/				/r/			
	Mean	**Median**	**SD**	**IQR**	**Mean**	**Median**	**SD**	**IQR**
aCa anterior x	8.28	8.23	0.10	0.20	8.18	8.17	0.08	0.15
aCa anterior y	3.15	3.10	0.10	0.19	3.06	3.07	0.07	0.13
aCa mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
aCa mid y	4.28	4.35	0.23	0.37	4.25	4.20	0.12	0.21
aCa posterior x	2.78	2.76	0.33	0.55	2.57	2.54	0.21	0.42
aCa posterior y	2.13	2.16	0.32	0.53	2.33	2.37	0.22	0.43
iCi anterior x	8.34	8.21	0.19	0.35	8.31	8.29	0.19	0.38
iCi anterior y	3.23	3.21	0.17	0.34	3.16	3.15	0.19	0.37
iCi mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
iCi mid y	4.72	4.70	0.21	0.39	4.73	4.75	0.09	0.17
iCi posterior x	3.12	3.26	0.27	0.51	2.98	3.15	0.35	0.63
iCi posterior y	1.81	1.67	0.28	0.52	1.93	1.78	0.34	0.63
uCu anterior x	8.33	8.31	0.18	0.33	8.19	8.14	0.10	0.18
uCu anterior y	3.20	3.17	0.17	0.32	3.07	3.02	0.10	0.17
uCu mid x	5.00	5.00	0.00	0.00	5.00	5.00	0.00	0.00
uCu mid y	4.55	4.51	0.06	0.13	4.53	4.55	0.06	0.12
uCu posterior x	2.92	2.82	0.28	0.54	3.15	3.19	0.06	0.57
uCu posterior y	2.00	2.09	0.27	0.51	1.77	1.74	0.35	0.54

*SD = Standard deviation, IQR= Interquartile range

Table 4.3.9

/Z/ and p values of pairwise comparisons *at the anterior, mid, and posterior sections of /l/ and /r/ for gender in Tamil*

	/Z/	p		/Z/	p
ala anterior x	1.576	0.115	ara anterior x	1.362	0.173
ala anterior y	1.485	0.138	ara anterior y	1.149	0.251
ala mid x	0.000	1.000	ara mid x	0.000	1.000
ala mid y	2.611	0.009*	ara mid y	1.358	0.175
ala posterior x	2.200	0.028*	ara posterior x	1.149	0.251
ala posterior y	1.991	0.047*	ara posterior y	1.048	0.295
ili anterior x	0.524	0.600	iri anterior x	0.629	0.530
ili anterior y	0.631	0.528	iri anterior y	0.000	1.000
ili mid x	0.000	1.000	iri mid x	0.000	1.000
ili mid y	1.984	0.047*	iri mid y	2.402	0.016
ili posterior x	2.193	0.028*	iri posterior x	1.571	0.116
ili posterior y	2.193	0.028*	iri posterior y	1.567	0.117
ulu anterior x	1.567	0.117	uru anterior x	0.943	0.346
ulu anterior y	1.567	0.117	uru anterior y	0.529	0.597
ulu mid x	0.000	1.100	uru mid x	0.000	1.000
ulu mid y	2.611	0.009*	uru mid y	1.571	0.116
ulu posterior x	1.156	0.248	uru posterior x	1.149	0.251
ulu posterior y	0.731	0.465	uru posterior y	1.149	0.251

*Significantly different

CHAPTER V

DISCUSSION

The present study aimed to investigate the tongue contours of /l/ and /r/ in Telugu, Kannada, and Tamil, which are Dravidian languages. The contours were recorded using the Articulate Assistant Advanced (AAA) ultrasonography module Version 2.17.07. Ten repetitions were collected, and a total of 60 utterances were recorded from each participant. After the recording was done, the data was subjected to statistical analysis. The present study had three objectives, which include understanding the tongue contours of lateral /l/ and trill /r/ in Telugu, Tamil, and Kannada, comparing the tongue contours of lateral and trill across languages, and understanding the effect of gender on tongue contours.

The first objective of the study was to compare the tongue contours within the three languages. The results revealed that in Telugu, tongue advancement was slightly more for /l/ when compared to /r/ in /a/ context. The tongue height in the anterior region was slightly more for /l/. On comparison of the tongue contours of /l/ and /r/ in the /i/ context, the results revealed that there was no significant difference in the tongue height and tongue advancement for both sounds. However, in the /u/ context, the results revealed that the tongue advancement and the tongue height in the anterior region were higher for /l/ than /r/. For Kannada, the results revealed that the advancement of /l/ was greater when compared to /r/, and the tongue height in the anterior region was higher for /l/ than /r/ in the /a/ context. For both the sounds in the contexts of /i/ and /u/, there were no significant differences in tongue advancement and height.

In Tamil, the results revealed no significant difference in tongue advancement and tongue height in the /a/ context. There was no significant difference in tongue advancement, but the tongue height for /l/ was more in the anterior region when compared to the /r/ in the /i/ context. The tongue advancement was more for /l/ in /u/ context, and the tongue height for /l/ was more in the anterior and mid-regions when compared to /r/.

The results for Telugu in the /a/ and /u/ contexts, in Kannada for the /a/ context, and /u/ context in Tamil for tongue advancement were supported by the previous studies (Espy et al. 2001 and Stone et al.,1996), which revealed that the /l/ was produced with a more forward position when compared to /r/. However, Recasens (2011) contradicted these findings and stated that /l/ was produced with a lowered and retracted tongue dorsum in Mallorcan Catalan. The difference between the production of /l/ and /r/ might be due to specific articulatory demands and constraints of language specificity. /l/ is produced with the tongue tip touching the bottom of their front teeth, protruding slightly. In contrast, the trill /r/ sound is articulated by a rapid tapping or flapping of the tip of the tongue against the alveolar ridge. It is impossible to produce the English /r/; if the tongue tip is touching the teeth, air cannot pass over the tip (Raver-Lampman, 2015), so this might also be a reason for more advancement during the production of /l/.

The tongue height was higher for /l/ in the anterior region of the tongue for /a/ and /u/ contexts in Telugu, /a/ context for Kannada, and /i/ and /u/ context for Tamil which was supported by a study done by Lawson, 2019, that stated the tongue tip gestures were higher for /l/ than /r/. Genioglossus activity was found to position the tongue tip against the palate (Smith, 1971), which may cause the anterior elevation of the tongue.

A comparison was made for the tongue advancement and height of /l/ and /r/ across three vowels. However, a significant difference was found for the mid and posterior regions for both consonants. This trend was observed in all three languages. But significant difference was found for the mid and posterior regions. When a comparison was made between /ili/ and /ala/, the results revealed that the tongue height in the mid-region was more for /l/, and it was produced with more advancement in the /i/ context, the tongue height in the posterior region was higher in the /a/ context for the three languages. Comparison between /ulu/ and /ala/ revealed that the tongue height in the mid-region was higher and produced with more advancement in the /u/ context, the posterior tongue height was more in the /a/ context for three languages. For /ulu/ and /ili/, there was no significant difference in height and advancement in Telugu and Tamil. In Kannada, for /ulu/ and /ili/, there was no difference in the tongue height in the mid-region, and it was produced with more advancement in the /i/ context. The tongue height in the posterior region was more for the /u/ context.

When a comparison was made for /ara/ and /iri/, the tongue height was more in the mid-region and produced with more advancement in the /i/ context, the tongue height in the posterior region was more in the /a/ context for the three languages. On comparison of /uru/ and /ara/, the tongue height was more in the mid-region and produced with more advancement in the /u/ context, the tongue height in the posterior region was more in the /a/ context for the three languages. For /uru/ and /iri/, there was no significant difference in height and advancement in Telugu. For /uru/ and /iri/ in Kannada, there was no significant difference in height in the mid-region of the tongue, and it was produced with more advancement in the /i/ context. The height in the posterior was more for /u/. In Tamil, /uru/ and /iri/, the tongue height in the mid-region was more in the /i/ context.

Recasens and Espinosa (2011) conducted research on the Catalan /l/ and found that the tongue tip position showed less variation between vowel contexts at the midpoint of the

/l/ consonant, indicating that the tongue tip position is a primary articulatory dimension for /l/. As /a/ is a uetral vowel and influence of /a/ on neighbouring phoneme is comparatively less than other vowel /u/ (Irfana & Sreedevi, 2018). Both /a/ and /u/ are back vowels, although /a/ is low and /u/ is high. Differences in variability may be due to the difference in production height. This may be because /a/ is a low vowel, and the tongue was required to travel greater distances between the consonant contact and the low vowel than with the high vowel. When coarticulated with the high vowels, the tongue-to-palate contact increases, and that may provide additional stability, which influences the amount of variability a phoneme may have. The other high vowel, /i/, also resulted in more variable consonant articulation than /a/, just not significantly so.

The second objective of the study was to compare /l/ and /r/ across three languages. When comparing Telugu and Kannada, the results revealed that a significant difference was found for /l/ in /i/ vowel context for tongue height. The tongue height for /l/ in the /i/ context was more in Telugu when compared to Kannada. Similarly, the tongue height was higher in Telugu for /l/ in /u/ context. There was no significant difference for /r/. Based on the analysis, there was no significant difference in tongue height and tongue advancement when compared across the Kannada and Tamil languages. Tamil had greater tongue height than Kannda.

The tongue advancement was more for /l/ in the Telugu language, which is supported by the study done in English and contradicts for Kannada and Tamil. Results of the study revealed that there is a significant difference in the production of /l/ with tongue tip fronting in English (Gick, 2002; Giles & Moll, 1975; Ash, 1982; Hardcastle & Barry, 1989; Sproat & Fujimura, 1993), /l/ was produced more apically in Cantonese language (Kwok et al., 1997) and forward contact was seen in English (Cheng et al., 2007).

The results of the present study for /r/contradict with the previous studies, which state that /r/ is produced with the anterior raising of tongue and tongue root retraction (Delattre & Freeman, 1968; Hagiwara, 1995; Hwang, 2019) in the English language. The results of the present study are also contradicted by another study done by Campos et al. (2023), which shows the raising of the anterior portion of the tongue for trilling, and in Spanish speakers, there was a retraction of the back part of the tongue (i.e., the tongue root). It can be characteristics of language specificity. It may be due to the tongue shape and the part of the tongue being used during the articulation of the /l/ and /r/ in the vowel contexts. The difference in the production of these sounds might be due to /u/ being a low vowel, and the tongue was required to travel greater distances between the consonant contact for the low vowel than with the high vowel. When coarticulated with the high vowels, the tongue-to-palate contact increases and that may provide additional stability, which influences the amount of variability a phoneme may have (Dromey, 2009).

The third objective of the study is to check for gender effects for /l/ and /r/. On statistical comparison of /l/ and /r/ in Telugu between the genders, /l/ was more retracted in females in the /a/ context than in males, and the posterior tongue height was more in females than males during the production of /l/. Similarly, in the /i/ context, the tongue height was higher for females in the anterior region, and /l/ was produced more anteriorly by males. In the /u/ context, there was no significant difference for /l/. For /r/, in the /i/ context, the tongue height was more for females in the posterior region and more anteriorly produced by males. There was no significant difference in the /a/ and /u/ context for /r/.

The results revealed that there was no significant gender difference in Kannada during the production of /l/, but the tongue height for /r/ was higher in females in the mid-region of the tongue in /i/ and /u/ contexts when compared to males. There was no significant difference in terms of advancement of the tongue during /r/ production between both genders. Similarly, in Tamil, production of /l/ was more anterior in males than females, and the height of the tongue in the posterior and mid-regions in the /a/ context was higher for females. In the case of the /i/ context, the results were the same as /a/. In /u/ context, the tongue height was higher for females in the mid-region. For /r/ in the /i/ context, the tongue height was higher for females in the mid-region, and there was no significant difference in the tongue advancement. There was no significant difference in the tongue advancement and height in the /a/ and /u/contexts.

The present study's results revealed that, there were few differences during the production of /l/ and /r/ in a few regions of the tongue between both genders. There was no statistically significant gender difference for these sounds in the three languages. The results of the present study contradict the study done in the German language by Koos et al. (2013) and the Welsh-English Bilinguals by Morris (2021), which states that there was a significant gender difference. The study done in Dutch supports the results of the present study; the results revealed no gender difference (Kloots et al., 2004). Research has shown that male and female tongues exhibit distinct morphological characteristics, which may contribute to differences in tongue height. For instance, studies have found that male and female tongues differ in tongue morphology.

CHAPTER VI

SUMMARY AND CONCLUSION

Articulatory dynamics of /l/ and /r/ in Dravidian languages were less studied. The present study aimed to investigate the articulatory dynamics of these two sounds in Telugu, Kannada, and Tamil. A total of 1800 utterances were recorded in the VCV context. The total number of participants were 30, 10 in each language group, with an equal number of males and females. Articulate Assistant Advanced (AAA) ultrasonography module Version 2.17.07 was used for the study. The results of the present study are discussed with following objectives:

- To understand the tongue contours of lateral /l/ and trill /r/ in Telugu, Tamil, and Kannada.
- To compare the tongue contours of lateral and trill across languages.
- To understand the effect of gender on tongue contour.

In Telugu, the overall height for /l/ was more than /r/. The standard deviation was the same only for /r/ in the /i/ context and changed for both the sounds in the three vowel contexts. A statistical analysis of the tongue contours of /l/ and /r/ in the /a/ and /u/ contexts revealed that the tongue advancement and the tongue height in the anterior region were higher for /l/. On comparison of the tongue contours of /l/ and /r/ in the /i/ context, the results revealed that there was no significant difference.

In Kannada, the posterior tongue height was more for /l/, and height in the mid-region was more for /r/ in the /a/ context. In the /i/ and /u/ contexts, the posterior height was higher for /r/; the height in the mid-region and the anterior region were the same for both. The standard deviation was the same for both the sounds across the tongue contours in the /a/ and /i/ contexts. But it was different in the /u/ context. The statistical comparison of /l/ and /r/ in Kannada in the /a/ context revealed that the advancement of /l/ was greater when compared to /r /, and the tongue height in the anterior region was higher for /l/ than /r/. For both the sounds during their production in the /i/ and /u/ contexts, no significant difference was observed in terms of tongue advancement and height.

In the /a/ and /i/ contexts, the posterior tongue height was more for /r/ in Tamil. In the /u/ context, tongue height was more for /l/. The standard deviation for both the sounds was different across the tongue contours. The statistical analysis of /l/ and /r/ in Tamil revealed that in the /a/ context, there was no significant difference in tongue advancement and tongue height. The tongue height for /l/ was more in the anterior region when compared to the /r/, but there was no significant difference in tongue advancement in the /i/context. The tongue advancement was more for /l/ in /u/ context, and the tongue height for /l/ was more in the anterior and mid-regions when compared to /r/.

A comparison was made for the tongue advancement and height of /l/ and /r/ across three vowels. There was no significant difference in the anterior region. But significant difference was found for the mid and posterior regions. When a comparison was made between /ili/ and /ala/, the results revealed that the tongue height in the mid-region was more for /l/, and it was produced with more advancement in the /i/ context, the tongue height in the posterior region was higher in the /a/ context for the three languages. Comparison between /ulu/ and /ala/ revealed that the tongue height in the mid-region was higher and produced with more advancement in the /u/ context, the posterior tongue height was more in the /a/ context for three languages. For /ulu/ and /ili/, there was no significant difference in height and advancement in Telugu and Tamil. In Kannada, for /ulu/ and /ili/, there was no difference in the tongue height in the mid-region, and it was produced with more advancement in the /i/ context. The tongue height in the posterior region was more for the /u/ context.

When compared across /ara/ and /iri/, the tongue height was more in the mid-region and produced with more advancement in the /i/ context, the tongue height in the posterior region was more in the /a/ context for the three languages. While comparing /uru/ and /ara/, the tongue height was more in the mid-region and produced with more advancement in the /u/ context, the tongue height in the posterior region was more in the /a/ context for the three languages. For /uru/ and /iri/, there was no significant difference in height and advancement in Telugu. For /uru/ and /iri/ in Kannada, there was no significant difference in height in the mid-region of the tongue, and it was produced with more advancement in the /i/ context. The height in the posterior was more for /u/. In Tamil, /uru/ and /iri/, the tongue height in the mid-region was more in the /i/ context.

In Telugu and Kannada, the tongue height was higher in Telugu when compared to Kannada in the /a/ context. For /r/, the posterior tongue height was higher in Telugu. In the /i/ context, the posterior tongue height was more in Kannada, and the height in the middle and anterior regions was more in Telugu for /l/. For /r/, the posterior tongue height was higher in Kannada, the mid-region was higher in Telugu. In the /u/ context, the posterior tongue height was higher in Telugu for /l/ and Kannada /r/. On statistical analysis, the tongue height for /l/ in the /i/ and contexts was higher in Telugu when compared to Kannada. There was no significant difference for /r/.

In a comparison of /l/ and /r/ in Telugu and Tamil, the tongue height was higher for /l/ in Telugu, and for /r/, it was more in Tamil in the /a/ context. In the /i/ context, posterior tongue height was higher in Tamil, and anterior height was higher in Telugu. For /r/, posterior tongue height was more elevated in Tamil. In the /u/ context, posterior tongue height was higher in Tamil, and no difference was found for the mid and anterior regions for /l/. The tongue height was higher in Tamil for /r/.

The tongue height was higher in Kannada for /l/, and posterior tongue height was higher in Tamil for /r/ in /a/ context when a comparison was made between Kannada and Tamil. In the /i/ context, the tongue height was similar for /l/ in both languages. For /r/, posterior tongue height was higher in Kannada. In the /u/ context, for /l/, the tongue height was higher in the posterior and mid regions in Tamil. For /r/, posterior tongue height was higher in Kannada. When a statistical comparison was made for /l/ and /r/, the tongue height was higher for /l/ in both /i/ and /u/ contexts for Tamil than in Kannada, but there was no difference in advancement.

The tongue contours of /l/ in females and males in the Telugu language in the /a/ context, the posterior tongue height was higher in males when compared to females. In the /i/ context, the tongue height seemed to be similar in both genders. In the /u/ context, the height in the posterior and mid-region was higher for males. For /r/, in the /a/ and /u/ contexts, the tongue was similar for both genders. In the /i/ context, posterior tongue height was higher in females. There were changes in the standard deviation across the tongue contours in both genders for both sounds. On statistical comparison, the results revealed that /l/ was more retracted in females in the /a/ context than in males, and the posterior tongue height was higher in females than males during the production. Similarly, in the /i/ context, the tongue height was higher for females in the anterior region, and /l/ was produced more anteriorly by males. For /r/, in the /i/ context, the tongue height was more for females and more anteriorly produced by males.

On comparison of the tongue contours of females and males of /l/ in the Kannada language in the /a/ context, the tongue height was more in the posterior region for females. In the /i/ and /u/ contexts, the tongue was similar for both genders. For /r/ in the /a/ context, the tongue height was similar for both genders. In the /i/ context, the tongue height in the posterior and mid-regions was higher for females. In the /u/ context, the posterior tongue height was higher in females. The standard deviation was the same for /l/ in the /a/ and /u/ contexts for males and females, respectively, and was changing for both sounds in the remaining vowel contexts in both genders. The statistical analysis results revealed no significant gender difference during the production of /l/, but the tongue height for /r/ was higher in females in the mid-region of the tongue in /i/ and /u/ contexts when compared to males.

The tongue contours of females and males of /l/ in Tamil in the /a/ context, the tongue height was higher for males. In the /i/ context, the tongue height was similar for both genders. In the /u/ context, the tongue height was more in the mid-region for males. For /r/ in the /a/ context, the tongue height was more in the mid-region for males. In the /i/ context, posterior tongue height was higher in males. In the /u/ context, the tongue height was higher for males in the mid and anterior regions. The standard deviation was similar across the tongue contours of /r/ in the /i/ context for females and in the /u/ context for males. It was different for both the sounds in the other contexts for both males and females. On statistical comparison between genders, in Tamil, the results revealed that the production of /l/ was more anterior in males than females, and the height of the tongue in the posterior and mid-regions in the /a/ and /i/ contexts was higher for females. In the /u/ context, the tongue height was higher for females in the mid-region. For /r/ in the /i/ context, the tongue height was higher for females in the mid-region, and there was no significant difference in the tongue advancement.

To conclude, the major points of the present study are explained as follows:

- In Telugu, the tongue height and advancement were more for /l/ than /r/ in /a/ and /u/ contexts. In Kannada, tongue height and advancement were more for /l/ in /a/ context. In Tamil, the tongue height in the anterior region was more for /l/ in /i/ context, and tongue height and advancement were more for /l/ in /u/ context.
- Tongue contours across languages were compared the results showed that there was no significant difference. But few differences were found in terms of height and advancement of tongue. The tongue height was more for /l/ in Telugu in /i/ and /u/ contexts when compared with Kannada. The tongue height was more for /l/ in /i/ and /u/ context in Tamil when compared to Kannada.
- On comparison of /l/ and /r/ across gender, no significant difference was seen, but few parts of the tongue had differences in height and advancement. In Telugu, posterior tongue height and anterior tongue were more for females in /a/ and /i/ contexts, respectively, and /l/ and /r/ were produced more anteriorly by males. In Kannada, tongue height was more for females in the mid-region in the /i/ and /u/ contexts. In Tamil, the tongue height was more in the mid and posterior regions of /l/ for females and produced more anteriorly by males in /a/ and /i/ contexts. For /r/, the tongue height is more in the mid-region for females.

Clinical implications

- The present study findings will provide information regarding the tongue dynamics of trills and laterals in normal individuals across different languages.
- It can be used during the assessment of speech sound errors to verify the appropriateness of articulatory dynamics, specifically for /r/ and /l/, which are two common erroneous sounds.
- Similarly, this can be used in management by showing the typical tongue contours as references for patients with speech sound disorders.
- Even second language learners can use this information to differentiate the differences and similarities of these sounds across languages.

Limitations:

- The sample size in each group is less.

Future recommendations:

- As there is a dearth of studies on /l/ and /r/, more studies should be done to understand these speech sounds in other language families.
- Can be studied these sounds in meaningful words.

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APPENDIX I

ORO MOTOR SENSORY EXAMINATION

Structure

Tongue size

Lingual frenulum length

Tongue tip shape

Tongue surface texture

Overall tongue shape

Motor

Protrusion

Elevation

Lateralization

Wiggle to the left and to the right side

Rotation

DDK- AMR: SMR:

Tongue resistance

- Front
- Side

Sensory

Sensation of:

- Presence of an object
- Size and shape of an object
- Hot
- Cold
- Taste