Acoustic vowel space in two dialects of Konkani: A comparative study

JOYLINE RAVINA DSILVA

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Degree of Master of Science

(Speech-Language Pathology)

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All India Institute of Speech and Hearing

Manasagangothri, Mysuru- 570006

September, 2023

CERTIFICATE

This is to certify that this dissertation, entitled "**Acoustic vowel space in two dialects of Konkani: A comparative study**" is a Bonafide work submitted in part fulfilment for the degree of Master of Science (Speech Language Pathology) of the student Registration number P01II21S0015. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

September, 2023

Dr. M. Pushpavathi

Director

All India Institute of Speech and Hearing

Manasagangothri, Mysuru- 570006

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Mysuru

September, 2023

Dr R. Rajasudhakar

Guide

Associate Professor in Speech Sciences

Department of Speech-Language Sciences

All India Institute of Speech and Hearing

Manasagangothri, Mysuru- 570006

DECLARATION

This is to certify that this dissertation entitled "**Acoustic vowel space in two dialects of Konkani: A comparative study**" is the result of my own study under the guidance of Dr R. Rajasudhakar**,** Associate professor in Speech Sciences, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for award of any other Diploma or Degree.

Mysuru **Registration Number: P01II21S0015**

September**,** 2023

Dedicated to my Lord Jesus,

my parents, and my sister

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"A Mentor is someone who allows you to see the hope inside yourself."

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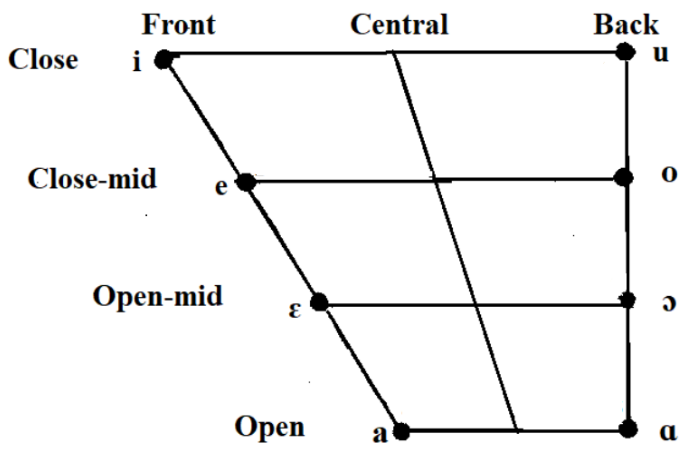
CHAPTER I
INTRODUCTION

"Speech is fundamentally an action, characterized by the production of an acoustic signal by the speaker and its reception and interpretation by the listener" (Redford, 2019). Speech, a complex communication system, is the primary means to convey human language. Speech sounds consist of vowels and consonants. Vowels are a group of sounds produced by the vocal tract that is open and unrestricted above the level of the larynx or without vocal tract constriction. Jones (2003) defined a Vowel as "A sound in speech produced with an unobstructed vocal tract, preventing air pressure accumulation anywhere above the glottis." They are usually described in terms of fundamental frequency, formant frequency, amplitude, and bandwidth. Any vowel sound produced through the lips results from the interaction between vocal fold vibration (source function) and the specific resonances created by the shape and length of the vocal tract (transfer function). Formants (F) emerge as wide spectral peaks produced by the acoustic resonances of the human vocal tract. Each formant aligns with a specific resonance occurring within the vocal tract. According to Ladefoged (2006), each vowel is associated with three formants- namely, F1, F2, and F3- equating to three discernible overtone pitches. In most languages, the vowels can be distinguished by considering the values of the first formant frequency (F1) and the second formant frequency (F2). The first formant (F1) tends to change in relation to the height of the tongue, with an inverse relationship. Meanwhile, the second formant (F2) is directly linked to the forward or backward position of the tongue.

While vowels may exhibit uniformity in sound across languages, subtle variations exist among different languages and dialects. Globally, multiple attempts have been made to study the acoustic properties of vowels in various languages and regional dialects: American English by Hillenbrand et al. (1995); Polish by Majewski and Hollien (1967); Russian by Purcell (1979); Greek by Fourakis et al. (1999); Hindi by Khan et al. (1994); Malayalam by Riyamol (2007); Kashmiri by Tiku (1994); Kannada by Sreedevi (2000). The cardinal vowel space serves as a theoretical model that universally enables the specification of the characteristics and positions of vowels within the speech sounds of various languages. This framework allows us to describe the vowels produced by specific speakers in particular languages at a given moment, using a standardized reference based on tongue position and shape of the oral cavity. Figure 1.1 shows the primary Cardinal vowels (Roach, 2009). Furthermore, many of the world’s languages encompass a vowel repertoire comprising three vowels delineating the extent of the overall vowel space: /a/, /i/, and /u/. These specific vowels are referred to as "corner vowels" or “basic vowels,” holding a distinct significance within the framework of vowel system theories.

Figure 1.1

The Primary Cardinal vowels (Source: Roach, 2009)



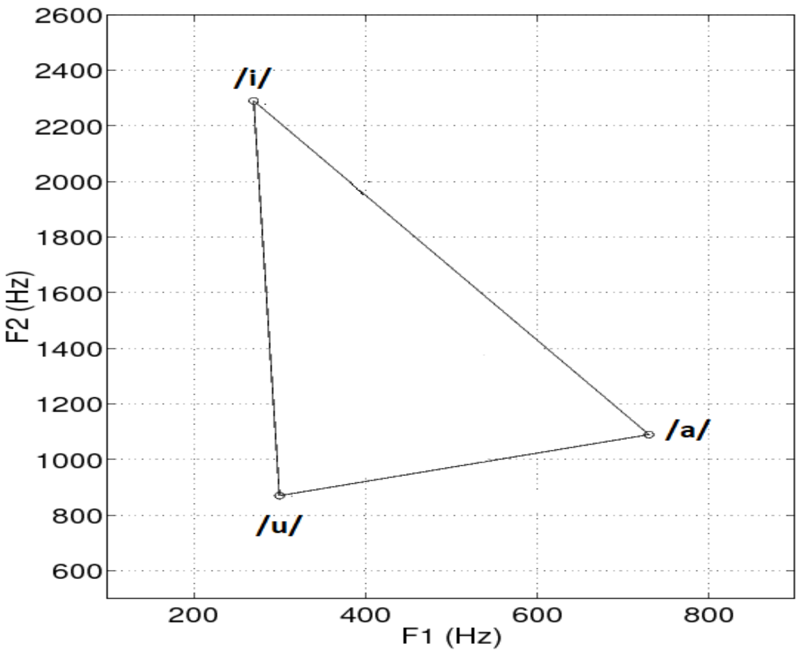
Vowel Space Area

Fant (1973) defined the Vowel Space Area (VSA) as the two-dimensional representation of vowels formed by considering the first two vowel formants. The triangle formed by the three corner vowels is subject to area calculation by using average F1 and F2 values. Berisha (2014) also stated that the area under the quadrilateral formed by marking the first two formants of the four corner vowels (/a/, /i/, /u/, /e/) characterizes speech motor control. VSA is a visual representation of the kinematic shift of the articulator, as the first and second formant frequency closely matches the cavity size and shape created by the jaw opening and tongue position, respectively (Lee & Shaiman, 2012). The vowels (/a/, /i/, and /u/) represent the utmost variations in the articulatory points of the tongue across various languages. Pols et al. (1969) referred to as "voice space," a distinct location in the oral cavity where the range of vowel production is confined. This space acts as an acoustic indicator, frequently employed in clinical research to indirectly assess the normality of vowel enunciation. Generally, research indicates that the Vowel Space Area (VSA) tends to be larger for clear and easily comprehensible speech than speech with a smaller VSA. This phenomenon reflects greater articulatory movements and more pronounced distinctions in acoustic-articulatory vowel targets. Figure 1.2 illustrates a vowel triangle based on F1 and F2 values of the vowels /i/, /u/, and /a/.

As the shape and size of the vocal tract varies across age and gender, subsequently the VSA also shows relative changes across age and gender. These relationships have been studied by various authors (Vorperian & Kent, 2007; Krishna & Rajashekar, 2012; Krishnan, 2015). A decrease in the area defined by the primary corner vowels indicates diminished tongue movement toward the intended vowel targets. This phenomenon is consistently observed in etiologies such as dysarthria, hearing impairment, Down syndrome, neurodegenerative disorders, cleft lip and palate and so on by Choi et al. (2022); Hung et al. (2017); Nunez-Batalla et al. (2019); Carl et al. (2020); Whitfield and Mehta (2019); Sorianello (2021).

Figure 1.2

Diagram illustrating a vowel triangle based on F1 and F2 values of the vowels /i/, /a/ & /u/. (Source: https://www.jobilize.com)



Konkani Language

Konkani, classified as an Indo-Aryan language, is part of the larger Indo-European language family (Chandramouli & General, 2018). It holds the status of being one of the 22 official languages of India, which is mainly spoken in Goa, Karnataka, Kerala and Maharashtra. Modern Konkani has evolved and been influenced by many other Indian Languages like Sanskrit, Kannada, Marathi, and also French, Portuguese and Arabic. Konkani exhibits a remarkable abundance of dialects despite its relatively small speaker population. These dialects can be systematically categorized based on geographical location, religion, caste and influence of other local languages, resulting in a discernible dialectal tree structure (Madhavi, 2004). In India, the various Konkani dialects spoken are influenced by multiple languages. Northern (spoken in Maharashtra), Central (spoken in Goa and North Karnataka) and Southern Konkani (spoken in Dakshina Kannada and Udupi districts of Karnataka) are influenced by Marathi, Portuguese and Kannada, and Tulu and Kannada, respectively. It has a phonetic inventory comprising 16 vowels, 36 consonants, five semivowels, three sibilants, one aspirate and many diphthongs.

According to Ghatage (1963), there are 14 vowels in Konkani and they can be classified into three groups;

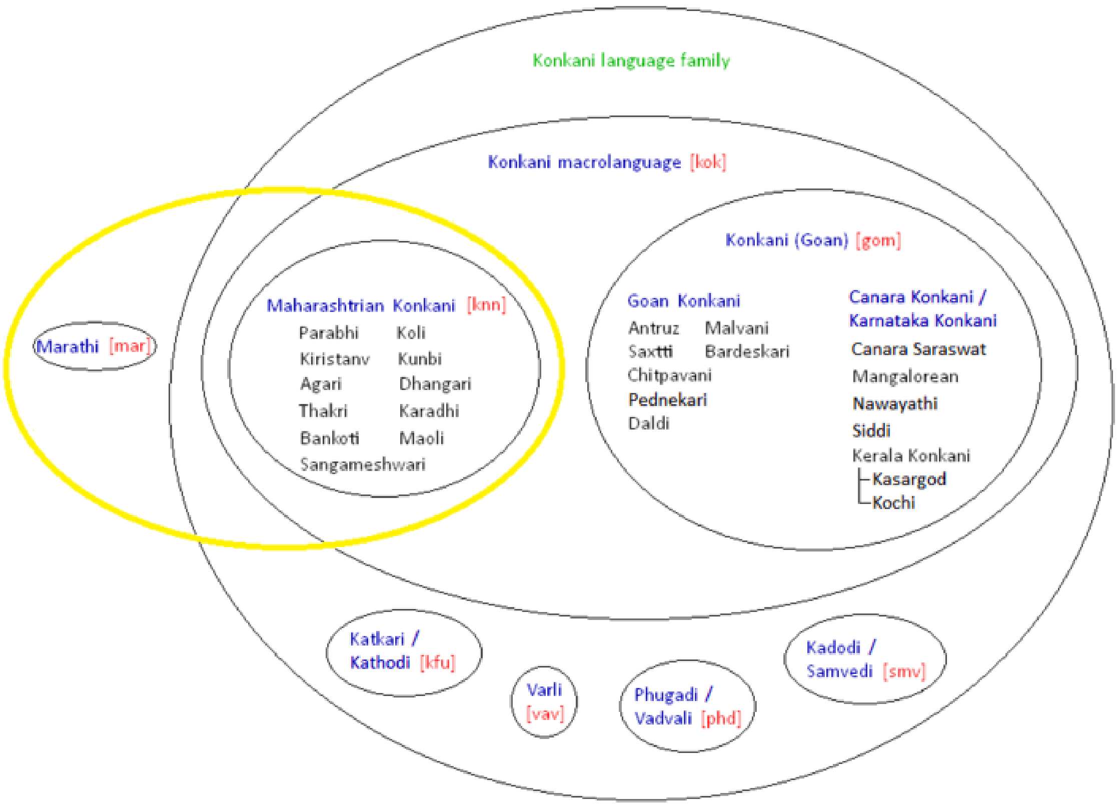
a) Long vowels including /aː/, /iː/, /uː/, /eː/, /oː/ and /əː/
b) Short vowels /a/, /i/, /u/, /e/, /o/ and /ə/
c) The two vowels /ɔ/ and /ɛ/

Much like its Indo-Aryan counterparts, Konkani employs short and long vowels, occasionally lending an impression of stress to syllables with extended vowels. Notably, its distinctiveness lies in incorporating various nasal vowels (Bhat & Bai, 2004). Konkani grammar aligns closely with other Indo-Aryan languages, while also bearing the marks of influence from Dravidian languages. It does not conform to the characteristics of a stress-timed or tonal language (Caroline, 2008).

Figure 1.3 is an illustrative representation using a Venn diagram showcasing the diverse languages and dialects within the Konkani family, categorized in accordance with the ISO 639 classification (ISO 639 is a standardized system employed for categorizing languages using a uniform nomenclature). The ISO 639 codes are indicated within red brackets. Notably, certain linguistic experts perceive the dialects of Maharashtrian Konkani to be linked to Marathi, leading to the inclusion of a yellow demarcation line between the two.

Figure 1.3

Venn diagram showing various languages and dialects of Konkani family (ISO 639). (Source: Retrieved from https://commons.wikimedia.org)



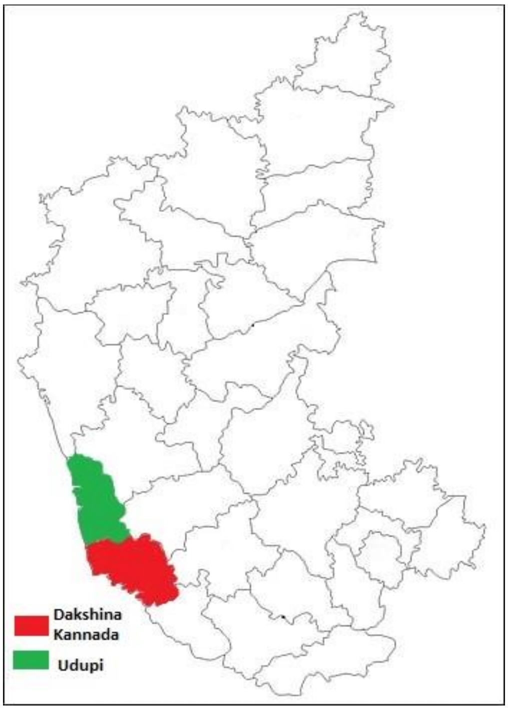
In Dakshina Kannada and Udupi districts of Karnataka, Hindu and Christian communities speak the Southern Konkani. The dialects used in the South Canara region (including Dakshina Kannada, Udupi) of Karnataka and Kasaragod in Kerala exhibit strong linguistic connections with both Tulu and Kannada. In this context, southern Konkani exhibits a notable resemblance to Marathi, incorporating a limited number of loanwords from Tulu and Kannada, along with minor divergences in pronunciation. Konkani spoken by Hindus is termed as 'Saraswat' dialect and the

Konkani spoken by Christians is termed as 'Catholic' dialect. The Saraswat dialect is greatly influenced by Kannada, Tulu and Sanskrit whereas Portuguese and Marathi influence is stronger on the catholic dialect (Lobab, 2016).

Figure 1.4

Map of Karnataka showing Dakshina Kannada and Udupi district

(Retrieved and adapted from https://www.pxfuel.com/en/desktop-wallpaper-hoqvo)



Need for the study

Formant frequencies play a crucial role in assessing the clarity and authenticity of speech. The Vowel Space Area is an extensively employed acoustic metric for quantifying vowel articulation (Narasimhan & Karunarathne, 2021). There are subtle differences in vowels across dialects and languages, so it is important to analyze the formant frequencies and create a database. There is a dearth of studies on the acoustics of vowels in the Konkani language.

Fadte et al. (2022) acoustically analyzed nine vowels spoken by 28 native Goan Konkani speakers (15 males and 13 females). The participants were asked to read the prepared speech reading material composed of the vowels (in isolation and word level (28 words)) while being recorded using a Zoom H6 Handy recorder. Following data validation, every recording file underwent manual phoneme-level annotation utilizing PRAAT software. The vowel formant values were extracted using the Burge algorithm. The data and vowel charts were visualized using R script and phonR package, respectively. The vowel /a/ revealed maximum variance for the first two formants whereas for the vowel /e/, variance was observed to be maximal only for F2. Additionally, the analysis demonstrated that the variance of F2 was minimal for back vowels /o/, /u/ and /O/, while being maximal for front vowels /e/ and /E/. Females exhibited a larger vowel space as compared to males. Thus, this study accurately classified Konkani vowels and proposed a vowel chart for the same. However, the author did not provide any details regarding the dialects of Konkani language considered for the study. Also, acoustic analysis was restricted to the extraction of formants. Further analysis such as plotting of Isovowel lines or Acoustic vowel space was not carried out.

Spectral and temporal attributes of 10 vowels within the Catholic dialect of Konkani spoken in Mangalore were examined by Gunjawte et al. (2021). 30 native Konkani speakers (11 males and 19 females in the age range of 18-55 years) residing in Mangalore were asked to produce 30 target words consisting of 10 Konkani vowels (/i, iː, e, ɵ, ə, u, o, ɐ, ä, ɔ/). The spectral characteristics- fundamental frequency (F0), formants (F1, F2, F3), and temporal characteristics- vowel duration- were obtained using PRAAT software. Among both males and females, the back vowel /u/ exhibited the highest fundamental frequency, measuring at 163 Hz and 242 Hz, respectively. Conversely, the lowest fundamental frequency was observed in males for the front mid vowel /e/ (143 Hz), while in females, it was in the central low vowel /a/ (210Hz). Notably, short and high vowels displayed greater fundamental frequency values in comparison to their long and back vowel counterparts. In terms of duration, long vowels such as /i:/, /e/, /a/ and /ɔ/ were lengthier than short vowels, with females exhibiting longer durations than males. In this study, the authors have included only thirty participants in a wide age range (18-55 years), and the number of male and female participants included were not equal (11 males and 19 females). Also, the authors have considered only one dialect of Konkani spoken in Mangalore. Further acoustic analysis such as determination of Vowel Space Area was not carried out in the above study.

Both the above-mentioned studies have analyzed the acoustic features of Konkani vowels in different dialects spoken in two states of India (Goa and Karnataka). Measurement of Vowel Space Area and comparison across different dialects of Konkani has not been studied. Also, no research has been conducted on the acoustic properties of vowels in the ‘Saraswat’ dialect of Konkani. Hence, the current study aimed to explore the vowel space areas in two dialects of Konkani mostly spoken in Dakshina Kannada and Udupi districts of Karnataka.

Most of the studies in the past, have analyzed the vowel space areas in CVC context where the vowel is in the medial position: Fox & Jacewicz, (2008); Lyngkhoi, (2020) and also in isolation (Narasimhan & Nataraja, 2019). The examiner of this study hypothesizes that the vowel position may influence the formant frequencies. No attempts have been made in the past to analyze the effect of vowel position on the

VSA. Hence, this study also seeks to assess how vowel position influences formant frequencies and VSA in both the dialects of Konkani.

Aim of the study

To compare the acoustic Vowel Space Area between two dialects of Konkani (Saraswat and Catholic dialects) spoken in Dakshina Kannada and Udupi districts of Karnataka.

Objectives of the study

1) To determine the first two formant frequencies in Saraswat and Catholic dialects of Konkani language.
2) To determine the effect of vowel position (Initial, Medial and Final) on the formant frequencies (first two) in two dialects of Konkani.
3) To compare the vowel space area (VSA) between Saraswat and Catholic dialects of Konkani.
4) To compare the gender difference on Acoustic Vowel Space Area (VSA) in two dialects of Konkani.

CHAPTER II
REVIEW OF LITERATURE

Vowels can be categorized based on the tongue height and advancement in the oral cavity. The articulators can manipulate formant frequencies by bringing about a variation in the configuration of the vocal tract, including the length of the vocal tract, place of constriction and degree of constriction. As the formant values depend on the Vocal tract's size and dimensions, they increase from men's to women's to children's values. Formants are also related to tongue height and tongue advancement because it is one of the major articulators which moves in the oral cavity, thereby the shape of the oral cavity changes. According to Kent and Rountrey (2020), "Vowels are an important aspect of developing speech which contributes to speech intelligibility, are dynamic, influenced by language and dialect, contribute to speech rhythm and prosody and affected by various speech and language disorders."

Acoustic Vowel space

Formant frequency is considered the most preferred resonating frequency of the vocal tract and is inversely proportional to its length. As the length increases, the formant values decrease. Due to this, as a child grows the vocal tract's resonance changes, and gender differences in growth rates start to emerge.

Stehr et al. (2021) examined the vocal attractiveness through Vowel Space Area (VSA). As females produce speech that is clearer and more distinct when compared to males, the authors aimed to establish a relationship between clear speech and subjective evaluation of vocal attractiveness. They recorded four corner vowels within the context of /bVd/ and at the sentence level. Various acoustic measures were elicited including formants, measures of vowel space, shape and size, fundamental frequency and spectral change and also temporal measures such as speaking rate, word duration and speech to pause ratio. A listening experiment was conducted where 124 participants rated the speech for vocal attractiveness through paired comparisons. The females produce clearer and more distinct speech, leading to larger VSA, and is related to higher attractiveness. They also attributed the higher attractiveness to the role of social interest. For example, females tend to smile more often while talking, which retracts the corners of the mouth, shortening the vocal tract length in turn raising the resonances, particularly F2.

VSA across age and gender

The study of vowels is essential in understanding the acoustic characteristics of speech because they emerge early in speech development. Vorperian and Kent (2007) noted a continuous reduction in VSA size till adulthood, in which formants gradually decreased through childhood and adolescence and an increase in the stability of formant values. Children and those in the pre-pubertal stage of development have greater formant and fundamental frequency (F0) values due to the small size of their vocal tracts and shorter length of vocal folds. Children's vowel acoustic signatures differ from adults in that they are longer, more variable, and have a larger VSA. According to Logan et al. (2011), During the initial decade of life, children exhibit slower articulation rates compared to adults, which then progressively rise to reach adult-level rates.

Krishna and Rajashekhar (2012) studied VSA across age, gender and dialects of Telugu language. 72 participants were classified into 3 age groups (6-9 years, 13-15 years and 19-30 years). Three regional dialects were considered (Coastal, Rayalaseema and Telangana). Words with different vowels in various phonetic contexts were recorded and VSA was calculated. A decreasing trend of VSA was seen with increasing age. In comparison to males, females exhibited a larger VSA. When examining the dialects, Coastal dialects displayed the highest VSA followed by Telangana, while the Rayalaseema dialect of Telugu demonstrated the smallest VSA.

Similar results were found in a study done by Krishnan (2015) which aimed to investigate how VSA varied across age and gender in native Malayalam-speaking individuals. 72 participants were distributed among three age categories: (a) 3-4 years, (b) 7-8 years, (c) 20-25 years. Each of these groups consisted of 24 individuals, evenly split between males and females, with 12 of each gender. Nine non-words consisting of vowels (/a/, /i/, /u/) in CVCV combination were used as stimuli. Consonants like /p/, /t/ and /k/ were selected to vary the phonetic context. The participants were asked to repeat each non-word three times. The formants were extracted using PRAAT software and VSA was calculated using MATLAB. Results revealed a decline in the VSA with age. VSA in children, i.e., Group a and b had significantly higher VSA when compared to adults (Group c), but group a and group b did not show any significant differences. When comparing the genders, females had a higher VSA and the same is observed only in the adult group. No gender-wise difference was seen in VSA for the children’s group, indicating that the gender differentiation takes place after 8 years of age. In terms of phonetic environment, VSA was largest for /k/ followed by /p/ and least for /t/. This study did not include an adolescent and geriatric age group. This study could be replicated in a larger population using more natural speech material as stimuli.

Narasimhan and Karunarathne (2021) explored the effect of both age and gender on VSA within the Sinhala language. Three cohorts, each comprising 20 participants, encompassed children (aged 7-11 years), adults (aged 25-30 years), and elderly individuals (aged 65-79 years). Every group comprised 10 male and 10 female participants. The authors examined three short vowels, namely /a/, /i/ and /u/, which were embedded in meaningful words within VCV, CVC, VCCV and CVCV contexts. A total of 27 words with visual representations were carefully chosen and displayed to the participants using flashcards. The researchers used PRAAT software to record the participants' utterances and extract formant values from the spoken words. Subsequently, a VSA was established based on the F1/F2 plane. The findings of this investigation supported those from earlier research by Krishna and Rajashekhar (2012) that the VSA was greater for children when compared to adults and also, females had higher formant values when compared to males. Although the findings of this study have added to the database of acoustics of Sinhala speakers, participants from only one dialect (central province) were considered in this study. Also, the authors focused on picture-naming task rather than analyzing spontaneous speech. They also suggested that future research could explore VSA as a function of age.

Albuquerque et al. (2023) investigated how age and gender affect the European Portuguese (EP) vowels. To test the claim that as one ages, numerous changes in the physical and physiological systems take place, and as a result, various acoustic parameters also change accordingly. With respect to gender, females tend to have clearer speech and hence have a greater VSA. 113 adults aged between 35 and 97 years (56 males and 57 females) participated in the study and produced the EP oral vowels. The stimuli consisted of 36 words, which included [i], [e], [ɛ], [a], [o], [ɔ], and [u] vowels. All the vowels were included in a disyllabic sequence (CVCV) embedded in a carrier sentence. The participants were asked to repeat each sentence three times and the samples were analysed using PRAAT software. Various acoustic parameters were extracted including duration, fundamental frequency, formant frequencies, Vowel Space Area, Vowel Articulation Index (VAI), and Formant centralization ratio (FCR). Vowel formant centralization is a phenomenon that is seen in speech disorders such as dysarthria. This phenomenon arises from articulatory undershoot, which occurs when the range of motion of the speech articulators is diminished. Vowel formant centralization results in reduced Vowel space area (Kent & Kim, 2003). Sapir et al. (2010) introduced an acoustic measurement known as Formant Centralization Ratio (FCR) designed to enhance the ability to detect vowel centralization while reducing its sensitivity to differences between speakers. FCR is represented by the formula "(F2u+F2ɑ+F1i+F1u)/(F2i+F1ɑ)", where F2u corresponds to the second formant frequency of the vowel /u/, F1i denotes the first formant of the vowel /i/, and so forth". A higher FCR value indicates greater centralization. Vowel Articulation Index (VAI) is the inverse of FCR, i.e., (F2i+F1a)/(F2u+F2a+F1u+F1i). VAI should be close to 1.0, as it is considered a tool that normalizes vowel connections between speakers. Results showed that with aging, there is (a) an increase in vowel duration in both genders, (b) a decrease in formant frequencies in females, (c) The vowel space acoustic indices showed alterations in males that were compatible with vowel centralization (d) No changes in F3 in both the genders. The results substantiated the idea that the acoustic features of speech alter with age and exhibit distinct patterns depending on gender. The study's limitations were that the external factors such as physiological condition, occupations and lifestyle that could have affected the samples were not considered. Also, the vowel duration was not controlled and the authors suggested that a better task that would place greater demands on the movement of speakers' vocal tracts could be used. The authors also recommend using instrumental techniques such as ultrasonography in future studies to know if the changes in acoustic features are due to physiological variations in the vocal tract alone or the active modification of speech as one ages.

Chung et al. (2021) studied how listener language and speaker age influence the cross-linguistic perception of the three corner vowels. The objective was to analyze the dimensions and positioning of the vowel perceptual space (VPS) in relation to talker age (TA) and listener language (LL). Adult listeners between the age of 18-30 years of three distinct first languages, Korean, Greek, and American English (20 listeners in each group), were asked to categorize and grade the quality of various vowels produced by speakers of those languages at ages 2, 5, and adulthood, as well as Cantonese and Japanese speakers. The stimuli were chosen from the 'paidologos corpus' comprising real words and nonwords with five vowels (/i/, /a/, /e/, /o/, /u/) produced by three distinct groups, 2-year-olds, 5- year-olds, and adults. The consonant-vowel (CV) sequence was excised from those words to be used as the stimuli for the study. For the perception experiment, E-prime 1.0 software was used. Every participant was required to perform two tasks: vowel categorization and rating the goodness of the vowels. After listening to each CV sequence, the listeners were instructed to categorize the vowel into one of their native vowels presented on a screen. For the goodness rating task, the listeners rated each Vowel on a visual analog scale labelled "very good example" on one end and "very bad example" on the other. F1 and F2 were determined for each talker age group using the PRAAT software. Categorization results of vowels by three listener groups were represented on an F1-F2 plane, giving the Vowel Perceptual Space (VPS). The central point of each listener's VPS was calculated by dividing the sum of the z-transformed formant values for all stimuli within a specific category by the sum of the goodness rating for that category, expressed as the formula. The vowel category (VC) centres' F1 and F2 values varied significantly by LL and TA. The three types of vowels showed qualitatively distinct effects: Greek and Korean listeners' /a/ and /u/ centres differed from those of English speakers. The size of VPSs varied by TA but not by LL significantly. Greek and Korean listeners perceived vowels uttered by 2-year-olds as having a more expanded vowel space than those produced by 5-year-olds or adults. In contrast, English listeners exhibited larger vowel spaces for /a/ as opposed to /i/ or /u/. These findings support that the perception of vowel categories by listeners varies according to their native vowel system (LL) and is influenced by the age of the speaker (TA). The authors used naturally produced vowels but were edited to generate CV sequences, which could have altered the temporal and spectral properties of the vowels, thereby influencing the perception of the vowels. The authors propose that future studies could incorporate entire words or brief phrases and consider including vowels produced by 3- and 4-year-olds to examine how listeners' VPSs evolve gradually as children refine the phonetic characteristics of each vowel-consonant combination with age. Additionally, one of the study's limitations was the variation in the number of choices provided to listeners in the vowel categorization task, which was influenced by the characteristics of their native vowel systems (English listeners- 11 alternatives, Greek listeners- 5 alternatives and Korean listeners- 7 alternatives) which could have affected the categorization performance.

VSA and Loudness

Whitfield et al. (2018) examined how speech intensity affected articulatory working space measurements in terms of both kinematics and acoustics in speakers of American English. 20 young adults, consisting of 10 males and 10 females aged between 20-35 years, were instructed to repeat two sentences at three different loudness levels. The two sentences consisted of three corner vowels (/a/, /i/, /u/). The participants were asked to repeat each sentence thrice at three loudness levels (soft, comfortable and loud), monitored using a sound level meter. NDI WaveFront software was used to measure the kinematic signals. Three sensor coils were placed on the tongue. The first sensor (TF) was positioned 1 cm behind the tip of the tongue, the second (TM) was located 3 cm away from the tip along the midline and the third sensor (J) was placed at the midpoint of the lower incisor. Formants were then extracted from the acoustic signals using PRAAT software, and various metrics related to vowel space (both acoustic and kinematic) were assessed.

Acoustic metrics encompassed a) Vowel- level measurements (Vowel space area and Vowel Articulation Index), b) Sentence- level measurements (Acoustic Vowel Space hull area- AVS $_{hull}$) and Kinematic metrics comprised: a) Vowel- level measurements (Kinematic VSA- KVSA and Kinematic VAI- KVAI). The findings demonstrated that elevating loudness resulted in an increase in sentence-level metrics. These traditional measurements, specifically Acoustic VSA and VAI, were employed in the analysis. However, they did not show a statistically significant difference across three loudness conditions. Also, the auditory and kinematic variations of sentence level measurements showed a moderate to strong association within the subjects for most participants. They concluded that the acoustic vowel space metrics, such as speech intensity, were sensitive to intra-speaker variation. The authors could not extract valid formants from the soft loudness level samples due to inadequate acoustic energy in the signal. The authors also suggest that a quadrilateral VSA could have exhibited higher sensitivity to variations in speech intensity compared to a triangular VSA. Future investigations should aim to delineate the relationship among the acoustic, kinematic, and perceptual measures of speech articulation.

Contradicting results were found in a similar study by Koenig and Fuchs (2019). The study's objective was to investigate how loudness influences formant frequencies. It involved the participation of 11 female German speakers aged 20 to 37 years. The participants were made to produce normal and loud speech in 3 tasks. The tasks included reading sentences consisting of the three corner vowels of longer duration, responding to questions that included the target words, and a recipe recall task. By changing the interlocutor distance, i.e., the distance between the speaker and the examiner, loudness was varied naturally. Average Sound pressure level and formants (F1 and F2) were extracted using PRAAT software, which was then used to determine the VSA for the three corner vowels. Results showed a limited variation in the formants as a function of loudness. Among the three tasks, the recipe recall task had the least VSA when compared to the other two tasks. With increased loudness, only F1 changed positively with varied magnitude and no significant effect was seen on F2. Hence, the authors concluded that increasing the loudness does not necessarily change the VSA. The authors assert that languages having small vowel inventories would have different effects of loudness variation on the formants. Also, increasing the loudness alone would not affect the formants, but it appears specific to the speaker, vowel and the task. Hence, future studies should evaluate different types of tasks and check if the results can be generalized cross-linguistically.

VSA in Disordered population

Carl et al. (2020) studied the relationship between vowel acoustics and speech clarity in adults with Down syndrome. A total of 16 participants (8 typically developed controls (TD) and 8 with Down syndrome (DS)) in the age range of 19 to 27 years (Mean age: 21 years for the DS group and 22 years for the control group) were recruited for the study. All the participants were native speakers of American English. The stimuli in the study consisted of single-syllable words containing four corner vowels (/ɑ/, /æ/, /i/, /u/) in CV, CVC or VC contexts. These stimuli were presented both in picture and written formats. Each stimulus was presented 10 times to the participants. A comparison between the perceptual analysis of speech intelligibility and acoustics was made. Formants were extracted using the PRAAT software and various acoustic metrics such as VSA and FCR were calculated. The second part of the study included the intelligibility testing for the DS group only. Test of children's speech (TOCS), a computer-based assessment, was used for the intelligibility judgment by 14 adult listeners who were native speakers of the English language. The listener group comprised 11 females and 3 males (mean age= 28 years). Three different listeners transcribed the speech samples produced by each DS speaker. Lindblom (1963) reported that the most significant impact of variability and vowel centralization, specifically the failure of a peripheral vowel to attain the 'canonical' target position for the respective segment, was observed in the case of low vowels within both groups. The authors concluded that the VSA is differentially affected in individuals with Down syndrome and the speech intelligibility impairments are attributed to the motor control deficits in these individuals. This data can be used for effective treatment planning for deficits in speech production, where the treatment approach would depend on the disorder's characteristics, but most of them follow the principles of motor learning, as explained by Maas et al. (2008). Even though vowels are not targeted separately during the intervention, certain therapy approaches such as interventions specific to clear speech and prosody training, indirectly improve vowel distinctiveness, which adds to the overall speech intelligibility of the individual. The authors delineate a few limitations of the study, such as a small sample size, lack of information regarding the DS group's language level and cognitive skills, and error analysis for intelligibility testing was not carried out. Future studies could overcome these limitations, including how vowel-based or motor-based interventions affect speech intelligibility.

Hung et al. (2017) studied the vowels produced by hearing aid users with various types of hearing loss. Speech performance was examined in 28 Mandarin speakers. Based on the type of hearing loss, three sub-groups were created. 1) Conductive Hearing loss (HL)= 11 (mean age=9 years; 2) Mixed HL=10 (mean age= 13 years); 3) Sensorineural HL= 7 (mean age= 14 years). A control group (mean age= 28 years) consisting of 26 participants with normal hearing also participated in the study. The stimuli included the 3 corner vowels (/a/, /i/, /u//), and the participants were asked to repeat each vowel thrice in isolation at a normal speech rate. Formants were recorded and extracted using the PRAAT software, and VSA was also obtained. Euclidian distance (ED) was measured in the F1-F2 plane of the vowels. ED is a distance measure calculated between the two points in Euclidian space, a speaker similarity metric. Results showed a reduced VSA in conductive and mixed HL groups, whereas the sensorineural group had similar VSA compared to typically developed individuals. Because the F2 of the /i/ vowel was lowered, analysis of Euclidian distance revealed a compressed VSA in conductive HL. The authors have made an attempt to study speech intelligibility objectively using Euclidian distance and Vowel Space Area in different types of hearing losses. A few drawbacks include a small sample size and using single vowel production in isolation as stimuli. The authors suggest that the use of spontaneous speech as the stimulus in future studies would be more natural and also would address the coarticulatory effects that would affect vowel production.

Choi et al. (2022) correlated the severity of dysphagia with VSA and formant centralization ratio (FCR). They retrospectively studied 74 individuals (45 male and 29 female) with a mean age of 67.38 years with dysphagia and dysarthria post-stroke. While 47 participants had an ischemic stroke, 27 had a hemorrhagic stroke. The PRAAT software was used to analyze the speech samples of the participants in which the participants had phonated the four vowels (/a/, /i/, /u/, / æ /) thrice for a duration of 3 seconds. From the acoustic data, VSA and FCR were obtained. To measure the severity of dysphagia, the Video-fluoroscopic Dysphagia Scale (VDS) was used, and two rehabilitation physicians calculated VDS scores. Results showed a higher FCR and reduced VSA as the VDS scores increased. Also, a broken vowel quadrilateral shape was linked to mild to moderate dysphagia. The results were related to the tongue and jaw movement limitations. The authors concluded that VSA and FCR can be useful parameters to assess the severity of dysphagia. The major drawbacks of the study, as delineated by the authors, include a small sample size and the study being a retrospective analysis, the authors had limited control over the samples collected. In addition, the test group was heterogeneous, i.e., both patients with ischemic and haemorrhagic stroke were mixed together. Future studies are warranted by considering homogenous groups on a larger scale.

Nunez-Batalla et al. (2019) investigated the vowels produced by Spanish hearing-impaired children. A study compared vowel production among three groups: children with hearing impairment who use cochlear implants, those who use hearing aids, and typically developing children. This comparison was made by analyzing the formant frequencies and VSA. 56 children were prelingually deaf, including 31 with hearing aids (2-15 years) and 25 with cochlear implants (4-19 years), as well as 47 controls (23 boys and 24 girls between the ages 5- 7 years) with normal hearing sensitivity. All the children were asked to repeat the five vowels (/a/, /i/, /u/, /e/, /o/) at the comfortable pitch and loudness. PRAAT software was used to extract the formants, and VSA was also calculated. The three groups did not significantly differ in the mean value of F1 across all vowels. A statistically significant difference in the mean F2 values for the vowels /i/, /o/, and /u/ was observed between the two groups of children with hearing impairment and their peers with normal hearing. Children using cochlear implants had slightly higher F2 values when compared to hearing aid users. Regarding VSA, the cochlear implant group had the highest VSA, more than the control group. This was because the children with cochlear implants try to imitate the adults' models and produce exaggerated articulatory movements. All the children considered in the study had undergone newborn hearing screening and were intervened at a very young age. The authors concluded that an objective acoustic analysis program would be able to detect small variations in the articulation of vowels in both prelingually hearing-impaired groups.

It is known that the vowel space reduces progressively with degenerative diseases due to deterioration in the fine motor skills. One such study was carried out by Shamei et al. (2023) to compare the VSA across the two datasets obtained from individuals with Alzheimer’s disease (AD). The data for the study was obtained from the publicly available corpora of two different languages. The datasets consisted of two tasks in two languages, i.e., spontaneous speech in English and reading task in Spanish. English corpus included data from 178 (Males=64, Females= 114) AD participants and 79 (Males=36, Females=43) healthy controls (HC). Similarly, the Spanish corpus consisted of speech samples of 47 (Males= 15, Females=32) AD participants and 154 (Males=49, Females=105) HCs. The participants ranged from ages 49 to 96 years. Euclidean distance and VSA were calculated using the K-means algorithm. Results showed reduced Euclidean distance and VSA for both males and females in the English speakers, but no effect was seen on the Spanish speakers. The findings of this study align with those reported in the research conducted by Xiu et al. (2022), where no difference in VSA was found between the Alzheimer’s disease group and the control group. The authors have tried to explain the possible reason why patients with AD show different results in the reduction of VSA. The tasks through which the corpus was obtained differed across the two language speakers. English speaker’s corpus was spontaneous speech, whereas Spanish speaker’s corpus consisted of read speech. According to the authors, naturally produced speech is more susceptible to reducing VSA. However, future studies are recommended to study the effects of AD on VSA across languages or tasks.

Whitfield and Mehta (2019) employed several vowel space measurements to evaluate the comprehensibility of speech in individuals with Parkinson's disease, which was derived from formant frequencies in different speech tasks that were produced in both clear and habitual speaking styles. A comparative analysis involved 15 individuals (11 males and 4 females, with a mean age of 65.87 years) diagnosed with Parkinson’s disease and 15 controls (7 males and 8 females, with a mean age of 66.47 years). The participants were instructed to repeat the four corner vowels (/i/, /a/, /u/, /æ/) of American English in the “hVd” context. The other task was to read the “caterpillar passage” (Patel et al., 2013). The participants were asked to perform both tasks in two different speaking styles, i.e., (a) In their habitual pitch, loudness, and rate. (b) As clearly and loudly as possible, as though someone across the table couldn't hear or understand them. PRAAT and MATLAB software were used to extract and plot formants and VSA, respectively. The vowel space area increased significantly from habitual to clear speaking styles in both groups. However, compared to the controls, the experimental group had a smaller increase in the VSA. A semiautomatic algorithm was used for the formant extraction, which could have resulted in a few erroneous outputs. Also, the authors state that the subtle differences in vowel articulation could have been missed as the task employed was reading and repetition rather than speaking. Hence, future studies should emphasize using different speech materials and perceptual measures to quantify perceptual differences in clear speech and habitual speech.

Sorianello (2021) studied the contribution of VSA and other acoustic measures to speech intelligibility in native Italian speakers. The study was conducted across two disordered populations, including individuals with Down syndrome (comprising 4 males and four females, with a mean age of 22.2 years) and individuals with hearing impairment (consisting of 4 males and 4 females, with a mean age of 23.5 years). A control group of 8 participants (4 males and 4 females, with a mean age of 24.3 years) were also recruited for the study. By employing the Fast Fourier transform (FFT) within the PRAAT software, the authors extracted formant information for the corner vowels (/a/, /i/, /u/) from the picture description narratives of the participants. Subsequently, various acoustic metrics, including Vowel Space Area (VSA), Formant centralization ratio (FCR), and Vowel Articulation Index (VAI) were derived. When these parameters were compared, the authors could distinguish the two experimental groups from the control group. VSA was compressed in both the experimental groups compared to a more well-defined vowel space area in the control group. FCR clearly showed a similar centralization tendency in the disordered population. Lower VAI was found in the experimental group and was attributed to vowel undershoot. Though both the disordered groups exhibit linguistic impairment, the acoustic metrics show deviations and have different reasons. The deviations are noted in the hearing-impaired individuals due to a lack of auditory feedback and the ability to manipulate the articulators. Whereas, in individuals with Down Syndrome, the articulatory gestures are determined by their anatomical and functional capacities, such as a small oral cavity, palate shape, poor muscle tone, and limited movement of the tongue, which could be due to a structurally thick tongue. Hence, these measures, such as VSA, FCR and VAI, can be good predictors of speech intelligibility.

In a recent study, Susan et al. (2020) conducted a comparison of VSA for three short-duration corner vowels (/a/, /i/, /u/) in a group of 10 children who had received a unilateral cochlear implant (aged between 3-7 years) and an age-matched control group of 10 typically developing children in the Tamil language. Picturable words with vowels in the medial position were used as stimuli and presented to the children thrice. The samples were recorded, and the formant frequencies were extracted using a Computerized Speech Lab (Model 4500). The study revealed notable differences in formant frequencies between the two groups, with a notable reduction in vowel space observed in the cochlear implant group. It was attributed to the deviant articulatory skills during the production of vowels when compared to the typically developing children.

Nikitha et al. (2017) used VSA to evaluate the degree of hypernasality in the speech of 18 children (11 males and 7 females, between the ages of 7-12 years) with cleft lip and palate (CLP). Three categories- normal, mild, and moderate-severe- were considered according to the degree of hypernasality. All the participants were native speakers of the Kannada language. Three repetitions of vowels (/a/, /i/, /u/) in CVCV words in different phonetic contexts (/p/, /t/ & /k/) and sustained phonation of these three vowels were used to extract the formants using PRAAT software and plot the vowel triangles in MATLAB software. The reduction of vowel space was highest for the moderate-severe group, followed by the mild nasality group compared to the normal nasality group. Also, the CLP group showed a trend of having large VSA in the phonetic context /p/, followed by /t/ and then /k/. A target sound's formants get influenced by hypernasality and could be used as acoustic evidence for grading hypernasality. Future studies could use formant estimation techniques to develop automatic tools for classifying hypernasality severity.

VSA across Languages and Dialects

Chung et al. (2012) examined five different languages across three age groups in order to determine how shared vowels vary between languages. Greek, Japanese, Korean, Cantonese, and American English were among the languages studied. The study involved three distinct age categories: 2-year-olds, 5-year-olds and adults. Each age group included ten monolingual speakers, evenly distributed with five males and five females. The common vowels /a/, /i/, and /u/ embedded in the familiar and picturable words that were easy to recognize and repeat even for young children were used as stimuli. Each vowel occurred in three words, and the task was to repeat the words. The native speakers transcribed the recordings, and formants were extracted using PRAAT software. The shape and size of VSA differed in each of the languages. The Cantonese adults produced the largest and most distantly situated VSA in the acoustic vowel space, whereas it was more centralized in English and Japanese speakers. Across all languages, the production pattern for /i/ was the most consistent. When examining the age groups, it was observed that the VSA of 5-year-olds resembled the adults, displaying language-specific patterns. In contrast, the productions of 2-year-olds exhibited more variability and inconsistency, still adhering to language-specific characteristics but to a lesser degree of adult likeness. The authors concluded that the slow process of phonetic refining varies depending on the acoustic properties of each vowel in each language.

VSA has been extensively used to study regional variation and speech intelligibility. One such study was conducted by Fox and Jacewicz (2017) in which various regional dialects of American English were compared. The regional dialects were the southern variety of American English spoken in North Carolina (NC), the Midland variety spoken in Central Ohio (OH) and the Midwestern variety spoken in Southeastern Wisconsin (WI). 45 female participants were selected from each dialect. Four age groups were considered, i.e., 8-14 years, 27-47 years, 50-60 years, and 70-91 years. Stimuli included 14 short vowels of American English in /bVd/ context. MATLAB was employed to acquire the formant values by utilizing Linear Predictive Coding (LPC), and the same software (MATLAB) was used to construct the Vowel Space Area. VSA for the NC dialect was significantly smaller than the other two dialects, which did not vary significantly from each other. Also, children exhibited the largest VSA; as age increased, the VSA progressively became smaller. The identified cross-generational trend is common to all three dialects, regardless of the relative size and form of the quadrilaterals, as evidenced by the lack of significance of the dialect and age group relationship. According to the authors, future studies should focus on conversational speech as the vowel density patterns vary, unlike the highly balanced and controlled speech material used in this study.

Schoormann et al. (2017) investigated the vowel system of Saterland Frisian across different dialects. It is one of Europe's most endangered minority languages, the last existing variant of East Frisian. Saterland Frisian is recognized for its extensive vowels, encompassing as many as 20 distinct monophthongs and 16 diphthongs in stressed positions. Ramsloh, Scharrel, and Strücklingen are the regional dialects of this language. Participants in the study included 35 males (50-75 years) Saterland Frisian native speakers. All the participants were trilinguals as they knew low German and high German in addition to their native language. The classification of low and high German is based on the geographical location in which they are spoken. Low German is spoken in northern Germany; high German is considered the standard form of the language and is spoken in Southern Germany. In order to account for the effect of the phonetic environment, 36 vowel categories were recorded within monosyllabic words in the /hVt/ context. Using PRAAT, various acoustic measures were elicited, such as F1, F2 and vowel duration. Significant differences were observed across dialects, particularly in the F1 dimension, for mid and open monophthongs and individual diphthongs. These findings support the assumption of Heeringa et al. (2014), suggesting that the phonemic distinction between short and long close tense vowels has collapsed, as these short tenses vowels /i/, /y/, /u/ have converged with /i:/, /y:/, u:/. For all three regional dialects, this fusion was observed. Additionally, compared to Ramsloh and Strücklingen, the dialect of Scharrel exhibited significantly lower spectral rates of change and shorter trajectory lengths. Cross-dialectal assessments of vowel groups and their acoustic characteristics, did not reveal any additional systematic variations, including vowel duration. The authors have limited the study participants to males and the use of spontaneous speech as stimuli would have provided a better idea regarding the occurrences of the vowels and their variations in the dialects of Frisian language.

Similarly, various studies have been done in the Indian context, to study the dialectal differences across the languages. Studying the dialectal differences across languages will help assess and treat individuals with various speech and language disorders.

Skaria (2016) attempted to investigate VSAs in 92 Malayalam speakers (20-30 years of age) in 4 regional dialects of Malayalam: (a) Kozhikode (N=20), (b) Thrissur (N=22), (c) Ernakulam (N=26), and (d) Thiruvananthapuram (N=24). An equal number of males and females were present in each dialect. A standard Malayalam passage was used as stimuli and the three corner vowels (short vowels) were considered for the analysis. The participants were asked to read the passage and then narrate it in their own dialect. The author perceptually assessed the narratives to check for adequacy and verify the inclusion of all three vowels. Further, formants were extracted using PRAAT software and VSAs were plotted in MATLAB software. The main outcome of the study indicated variations in VSA among the dialects. Mean VSA was the largest in the Ernakulam dialect followed by Kozhikode, Thiruvananthapuram and Thrissur dialects. Perceptually, speakers of Ernakulam dialect produced vowels with greater stress and long duration. Another important finding was the effect of gender on VSA. Across all 4 dialects, males had a smaller VSA when compared to females. Additionally, males VSA was influenced by the dialects whereas, there was no significant effect of dialect on VSA in females. Future studies could include a larger number of participants across different age groups and also other dialects could be explored.

Another study was done in Malayalam by Abraham (2015), where the author aimed to study the VSA in two tribal languages. 60 adult individuals (aged 20-40 years) participated in the study who were divided into 3 groups: (a) Paniya tribal community (N=20), (b) Kuruma tribal community (N=20) and (c) Native Malayalam speakers (N=20). Each group consisted of 10 males and 10 females. The stimuli consisted of nine non-words in CV1CV2 context where the three corner vowels (/a/, /i/, /u/) were taken into consideration. The vowels considered for analysis were longer in duration and in V1 position. The consonants selected were /p/, /t/ and /k/. The participants were asked to repeat each non-word three times. Formants were extracted through PRAAT and VSAs were calculated in MATLAB software. The results revealed that the VSA was higher in native Malayalam speakers when compared to the other two tribal languages. When VSA was compared across genders, females showed a higher value than males. With respect to the phonetic context VSA was the largest for phoneme /k/, followed by /p/ and the least for phoneme /t/. This study used non words as stimuli, sfuture studies could use more natural stimuli such as spontaneous speech.

Srinivasan (2016) compared the Vowel Space Areas across different regional dialects of Kannada (Mangaluru, Mysuru, Dharwad and Kalaburagi). The study included 80 native Kannada speakers aged between 20 and 30 years (20 in each dialect: 10 males & 10 females). A similar method of data collection as the previous study (Skaria, 2016) was employed where participants had to narrate a standard passage in their own dialects as naturally as possible. Formants were extracted from the three corner vowels (/a/, /i/ and /u/) using PRAAT software and VSA was plotted using MATLAB software. Speakers of Mangaluru dialect had the maximum mean VSA which was attributed to the clear diction. Speakers of Kalaburagi dialect had the least mean VSA which was due to the fast rate of speech which contributed to less speech clarity. A gender effect was observed as seen in previous studies where females had larger VSA when compared to males. Future studies could study other age groups and other dynamic measures rather than static formants could be used to study vowel articulation.

Lyngkhoi (2020) studied the VSA across two dialects of the Khasi language (Maram & Nongstoin) spoken in the state of Meghalaya. 20 participants (20-30 years) were selected from each of the dialects consisting of equal males and females (10 in each gender). Words consisting of the three corner vowels in different phonetic contexts (/p/, /b/, /t/, /d/, /k/) in the form of C1V1C2 or C1V1C2V2 were used as stimuli, where the participants were asked to read each word thrice. Vowel in the medial position (V1) was considered as the target vowel. Using PRAAT, formants were extracted from three trials, were averaged and VSA was plotted using MATLAB software. The author reported insignificant difference in the VSA across the two dialects of Khasi. The total mean VSA of Maram dialect was 255.68 KHz^2 and 245.59

KHz^2 for Nongstoin dialect. Females had larger VSA when compared to males in both the dialects. The study had a limited sample size and the participants were selected from only one district of Meghalaya. Future studies can replicate the current study across different age groups, other dialects of Khasi and also could include different speech disorders.

It is clear from the literature review that, acoustic VSA varies across age, gender, disorders, languages and dialects. VSA can be used as a potential tool in understanding developmental patterns, gender effects, dialectal variations, language influence and speech intelligibility issues in clinical population and so on. As there is a dearth of studies on the acoustics of speech as a function of dialect in Konkani language, this study is warranted.

CHAPTER III

METHOD

Participants

A total of 60 participants between the ages 18-30 years were included in this study. These participants were divided into two groups. Group I included 30 native Konkani speakers of the Saraswat dialect. Group II included 30 native Konkani speakers of the Catholic dialect. Equal number of males and females were considered in each of the groups (15 males and 15 females).

Inclusion criteria

- Native speakers of the respective dialects with no major influence of other dialects were considered.
- Individuals with no history of speech, language, hearing, and cognitive impairment participated in the study. The researcher carried out an informal assessment through interview.
- Participants with no structural or functional deficits in Oro-motor examination were included in the study.
- Individuals who could read and write Kannada language and had completed at least tenth standard of formal education were included in the study.

Stimuli

The three corner vowels (low central, high front and high back) /a/, /i/ and /u/ were considered in the study which are of long duration (long vowels). A separate list of words with the vowels in initial, medial, and final positions were made in both the dialects of Konkani. A total of 27 words (3 vowels x 3 positions x 3 words in each position = 27 target words) were made in each dialect. The familiarity of the words was judged by three native speakers of each dialect. The native speakers rated the individual words on a 3-point rating scale- 0 indicating unfamiliar and 2 indicating most familiar. Only the words rated 1 and 2 were considered for the study. The stimulus used in the study for Saraswat dialect and Catholic dialect are shown in Appendix 1 and 2, respectively.

Procedure

After explaining the aim and objectives of the study, informed consent was obtained from the participants. They were made to sit comfortably and individual recordings of the samples were carried out in a room with minimal interference in the background. The samples were recorded in PRAAT (Version 6.3) software using a laptop (DELL Inspiron 15 3000, core i3 8th Generation) with sampling frequency of 44.1 kHz and was saved in .wav file format. A headphone with an external microphone (JBL Quantum 100) was used to record the samples. It was positioned at a distance of 10 cm and angled at 45 degrees from the mouth of the participant. To ensure even stress and a consistent pattern, participants were instructed to repeat the target words after the carrier phrase "/ho sobdh (target word)/" (this word is ___). Each word was written on a flashcard. One card was shown at a time and participants were instructed to repeat each word using their comfortable rate, pitch and intensity. As there was a paucity of words for /i/ in the initial position and /u/ in the final position in the Saraswat dialect, only one word was used as stimuli. The participants were asked to repeat only those words three times.

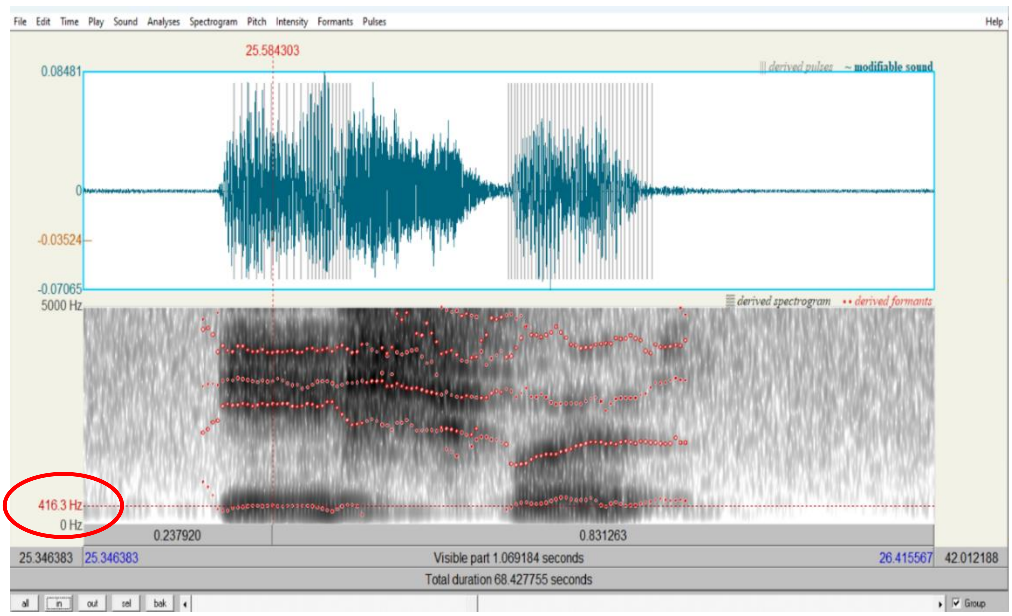
Data Analysis

a) Acoustic analysis

For each vowel, the three trials of the words read by the participants were opened in PRAAT software (version 6.3, Boersma & Weenink, 2011) to extract F1 and F2 formants from the target vowels. The spectrogram of each recording was opened and the cursor was kept at the steady state portion of the vowel. F1 and F2 were extracted from three long vowels that were extracted from the target words in initial, medial and final position. F1 and F2 values were averaged and tabulated separately for three vowels across three positions, between two dialects and between males and females. Formant frequency (F1 and F2) were compared between two dialects, vowel positions and between genders. Figure 3.1 shows an illustration of the extraction of formant frequency (F1) of vowel /i/ from the word initial position of the word /i:st/.

Figure 3.1

Illustration of Extraction of Formant frequency (F1) for vowel /i/

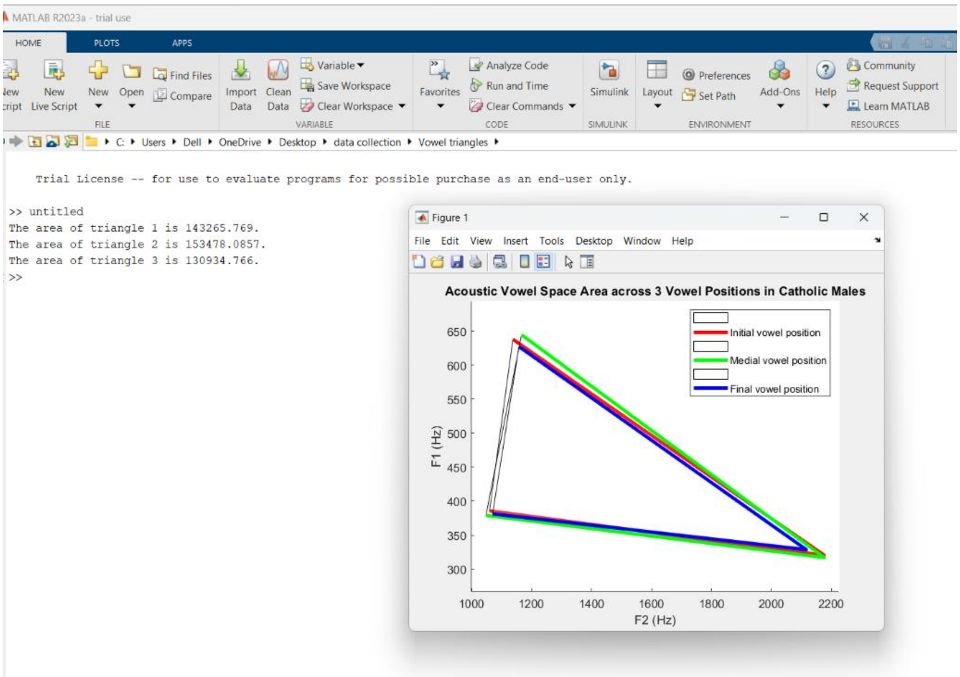


b) MATLAB Analysis

Vowel Space Area (VSA) calculation and plotting of vowel triangles was done using MATLAB (version R2023a) based software. Using the Heron's formula $A = \sqrt{s(s-a)(s-b)(s-c)}$ where, $s = a + b + c2$, a custom-made MATLAB program was made with the help of a software engineer and an algorithm was created to calculate the vowel space area of vowel triangles. A total of six formants (F1 and F2 of /a/, /i/ and /u/) were fed into the program to get the three co-ordinates of a triangle. VSA was calculated for each of the participant of both dialects in three vowel positions. The triangles were colour-coded to represent different positions, genders or dialects. Vowel Space Area was compared between two dialects, vowel positions and between the genders.

Figure 3.2

Illustration of calculation of Vowel Space Area in MATLAB



c) Statistical Analysis

The statistical analysis was performed using SPSS (version 26) software. To assess the normality of the collected data, the Shapiro-Wilk test was applied. After confirming normal distribution, suitable parametric tests were chosen for conducting the subsequent statistical analysis. To obtain the Mean and Standard deviation of formant frequencies and Vowel Space Areas, descriptive statistics were carried out. Mixed ANOVA (Repeated measures) was carried out to study the main and interaction effects of vowel positions (Initial, Medial and Final), gender (Males and Females) and dialects (Catholic and Saraswat) on the formant frequencies. Vowel position was considered as a factor varying within subjects, while gender and dialects were factors varying between subjects.

To study the effects of vowel position on Vowel Space Area in males and females separately, One-way Repeated measures ANOVA was carried out. One-way MANOVA was administered to determine how Vowel Space Area varied across the dialects. Similarly, to study the effect of vowel position, dialect and gender on the Vowel Space Area, Mixed ANOVA was carried out.

CHAPTER IV

RESULTS

This study aimed to compare the Vowel Space Area (VSA) between two dialects of Konkani (Catholic and Saraswat) spoken in Dakshina Kannada and Udupi districts of Karnataka. The study also explored the effect of vowel position on formant frequencies (F1, F2) and Vowel Space Area (VSA).

A total of 60 Konkani-speaking individuals between the ages of 18-30 years participated in the study. A list of meaningful words consisting of the three corner vowels /a/, /i/ and /u/ in three-word positions (Initial, Medial and Final) were prepared separately for both dialects. The participants were instructed to repeat each word and the formants (F1, F2) were extracted using PRAAT software (version 6.3) and VSA was calculated using MATLAB (version R2023a). Statistical data analysis was carried out using SPSS (version 26) software.

The results of this study are explained under the following headings:

1. Test of Normality
2. Formant frequencies (F1, F2) of the vowels (/a/, /i/ and /u/)
3. Effect of vowel position (Initial, Medial and Final) on the formant frequencies in the two dialects of Konkani
4. Vowel Space Area in Catholic dialect
5. Vowel Space Area in Saraswat dialect
6. Comparison of Vowel Space Area between dialects
7. Comparison of Vowel Space Area between genders

1. Test of Normality

Shapiro-Wilk's test of Normality was performed to check if the data was distributed normally. Test results revealed that the data (Formant frequencies and Vowel Space Area) obtained from all the groups followed a normal distribution ($p > 0.05$). Hence, further analysis was carried out with parametric tests.

2. Formant frequencies (F1, F2) of the vowels

To obtain the mean (in Hz) and standard deviation (SD) of the formant frequencies of vowels in each of the word position, descriptive statistics was conducted. Table 4.1, 4.2, and 4.3 shows the F1 and F2 values of three corner vowels in both the dialects in word- Initial, Medial and Final position, respectively.

Table 4.1

Mean (Hz) and Standard Deviation (SD) of formant frequencies of corner vowels in word- initial position between males and females

Dialects	**Vowels**	**Formants (Hz)**	**Males**		**Females**	
			Mean	**SD**	**Mean**	**SD**
Catholic	**/a/**	F1	637	26.81	830	59.27
		F2	1137	47.40	1258	51.18
	/i/	F1	320	26.45	363	21.67
		F2	2175	80.76	2771	62.96
	/u/	F1	385	23.45	423	27.27
		F2	1059	98.33	1230	92.42
Saraswat	**/a/**	F1	668	32.03	854	21.92
		F2	1209	68.13	1310	57.58
	/i/	F1	333	16.71	366	17.11
		F2	2140	57.03	2781	67.66
	/u/	F1	378	37.09	434	20.93
		F2	1064	58.26	1179	87.50

Table 4.2

Mean (Hz) and Standard Deviation (SD) of formant frequencies of corner vowels in word- medial position between males and females

Dialects	Vowels	Formants (Hz)	Males Mean	Males SD	Females Mean	Females SD
Catholic	/a/	F1	644	24.53	826	64.14
		F2	1166	71.86	1286	86.66
	/i/	F1	317	30.85	361	26.67
		F2	2176	79.12	2752	73.81
	/u/	F1	379	26.46	434	30.32
		F2	1047	75.85	1117	94.64
Saraswat	/a/	F1	661	39.52	848	21.15
		F2	1213	55.97	1328	64.82
	/i/	F1	332	18.83	361	20.36
		F2	2161	54.67	2761	71.43
	/u/	F1	356	24.10	417	18.29
		F2	1029	88.27	1179	49.83

Table 4.3

Mean (Hz) and Standard deviation (SD) of formant frequencies of corner vowels in word- final position between males and females

Dialects	Vowels	Formants (Hz)	Males Mean	Males SD	Females Mean	Females SD
Catholic	/a/	F1	627	23.74	812	42.44
		F2	1157	92.90	1279	64.76
	/i/	F1	328	34.43	363	18.75
		F2	2116	66.90	2703	46.02
	/u/	F1	381	29.79	418	40.52
		F2	1070	58.22	1111	97.96
Saraswat	/a/	F1	617	44.45	805	36.93
		F2	1203	52.73	1262	47.75
	/i/	F1	321	19.99	337	14.83
		F2	2154	54.14	2730	61.39
	/u/	F1	365	28.67	414	27.96
		F2	1080	68.27	1161	57.25

It can be observed that in the word-initial position, except for F2 of /i/ and F1 of /u/ in males and F2 of /u/ in females, the Saraswat dialect has slightly higher formants when compared to the Catholic dialect (Table 4.1). Similarly, in the word-medial position, the formants are higher in the Saraswat dialect except for F2 of /i/, F1 and F2 of /u/ in males and F1 of /u/ in females. In the word- final position, in both genders, the F1 values for all the three vowels is greater in Catholic dialect. F2 values are greater in Saraswat dialect except for F2 of /a/ in females.

3. Effect of vowel position (Initial, Medial and Final) on the formant frequencies in the two dialects

Mixed ANOVA (Repeated measures ANOVA for comparison between positions with dialect and gender as between factors) was carried out to study the main and interaction effects of within subject variable (vowel position) and between subject variables (dialect and gender). Results revealed a significant main effect of vowel positions and gender on formant frequencies. Table 4.4 and Table 4.5 shows the results of Mixed ANOVA on main effects and interaction effects of three independent variables in formant frequencies (F1 and F2), respectively.

Table 4.4

Results of Mixed ANOVA on main effect of three independent variables on formants

			/a/		/i/		/u/	
			F1	**F2**	**F1**	**F2**	**F1**	**F2**
Within-subject effects	**Position**	**df**	2	2	2	2	2	2
		F	28.709	4.562	1.513	10.465	4.414	4.806
		p-value	0.000*	0.012*	0.013*	0.000*	0.014*	0.010*
Between-subject effects	**Dialect**	**df**	1	1	1	1	1	1
		F	2.296	8.523	0.008	0.204	2.424	0.503
		p-value	0.135	0.005*	0.931	0.653	0.125	0.481
	Gender	**df**	1	1	1	1	1	1
		F	488.56	59.318	44.421	2288.18	68.987	58.440
		p-value	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*

(*indicates a significant difference at $p < 0.05$ level)

Table 4.5

Results of Mixed ANOVA on interaction effects of three independent variables on formants (F1 and F2)

		/a/		/i/		/u/	
		F1	**F2**	**F1**	**F2**	**F1**	**F2**
Position*Dialect	**df**	2	2	2	2	2	2
	F	28.109	4.234	12.851	2.871	4.113	2.426
	p-value	0.000*	0.17*	0.000*	0.061	0.019*	0.093
Position*Gender	**df**	2	2	2	2	2	2
	F	7.770	1.478	2.925	1.959	2.305	4.868
	p-value	0.001*	0.233	0.058	0.146	0.104	0.009*
Position*Dialect*Gender	**df**	2	2	2	2	2	2
	F	0.128	1.650	0.240	1.036	0.389	3.514
	p-value	0.880	0.197	0.787	0.358	0.679	0.66
Dialect*Gender	**df**	1	1	1	1	1	1
	F	0.000	1.098	2.287	0.609	0.979	0.630
	p-value	0.983	0.299	0.136	0.439	0.327	0.431

(*indicates a significant difference at $p<0.05$ level)

a) F1 of /a/

Mixed ANOVA (repeated measures) showed a main effect of position [F (2, 112) = 28.709, p < 0.05] and gender [F (1, 112) = 488.56, p < 0.05]. Among the interactions, position*dialect [F (2, 112) = 28.109, p < 0.05] and position*gender [F (2, 112) = 7.77, p < 0.05] were significant. It is clear from the graph (Figures 4.1 and 4.2) that in males and females, F1 of /a/ is higher in the Saraswat dialect in the initial and medial position, whereas, in the final position it is higher for the Catholic dialect. Figures 4.1 and 4.2 show mean and 95% confidential interval values of upper and lower boundaries of F1 for vowel /a/ across three vowel positions in males and females, respectively.

Figure 4.1

Mean and upper-lower boundary of F1 of /a/ across three vowel positions in males

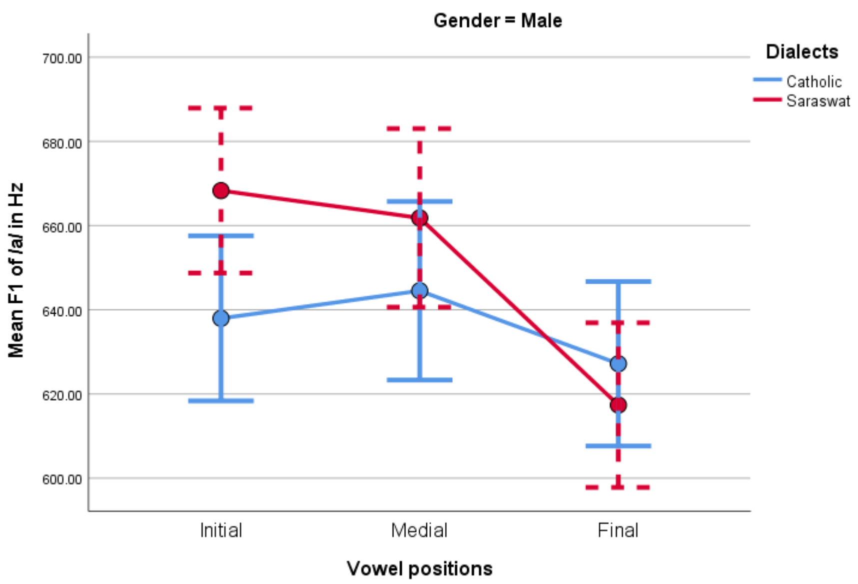
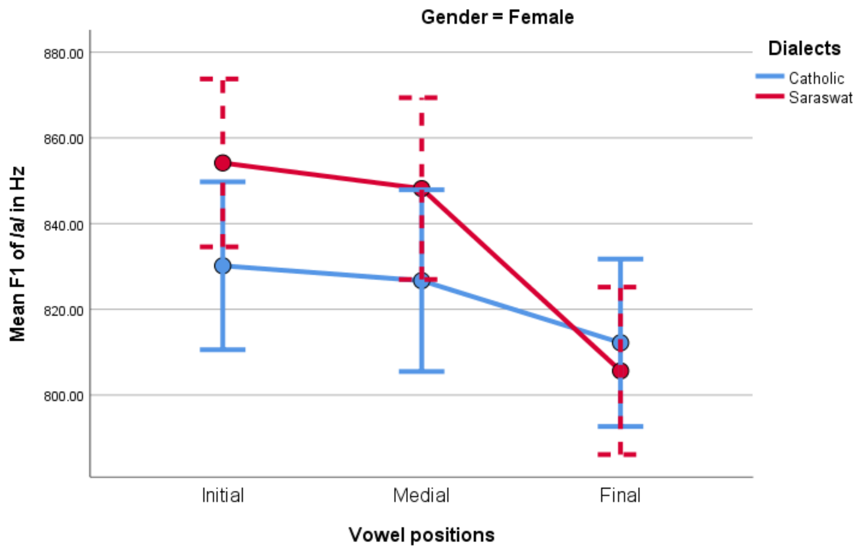


Figure 4.2

Mean and upper-lower boundary of F1 of /a/ across three vowel positions in females



b) F2 of /a/

Mixed ANOVA (repeated measures) showed a main effect of position [F (2, 112) = 4.562, p < 0.05], gender [F (1, 56) = 59.318, p < 0.05] and dialect [F (1, 56= 8.523), p < 0.05]. Among the interactions, position*dialect [F (2, 112) = 4.234, p < 0.05] was significant. In males, F2 of /a/ is higher in all the three vowel positions for the Saraswat dialect whereas, in females, F2 is higher in the Saraswat dialect in initial and medial position and higher for the Catholic dialect in word-final position. Figures 4.3 and 4.4 show mean and 95% confidential interval values of upper and lower boundaries of F2 for vowel /a/ across three vowel positions in males and females, respectively.

Figure 4.3

Mean and upper-lower boundary of F2 of /a/ across three vowel positions in males

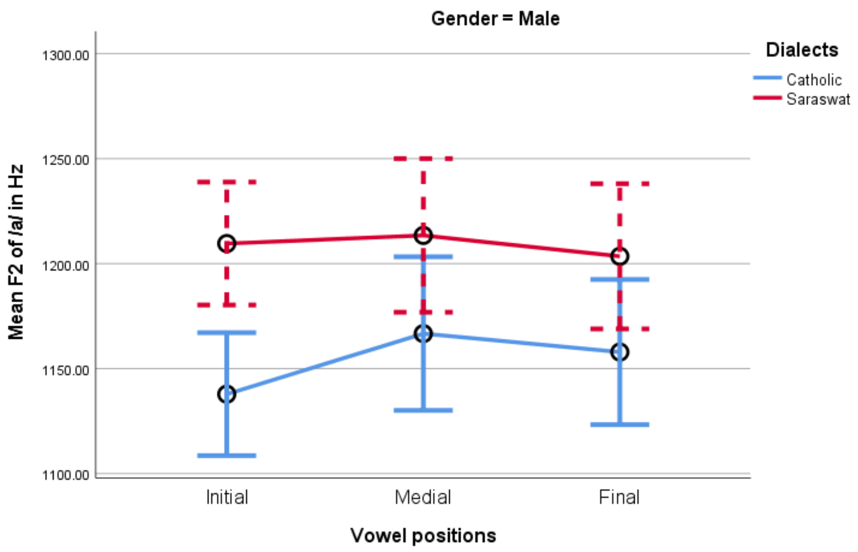
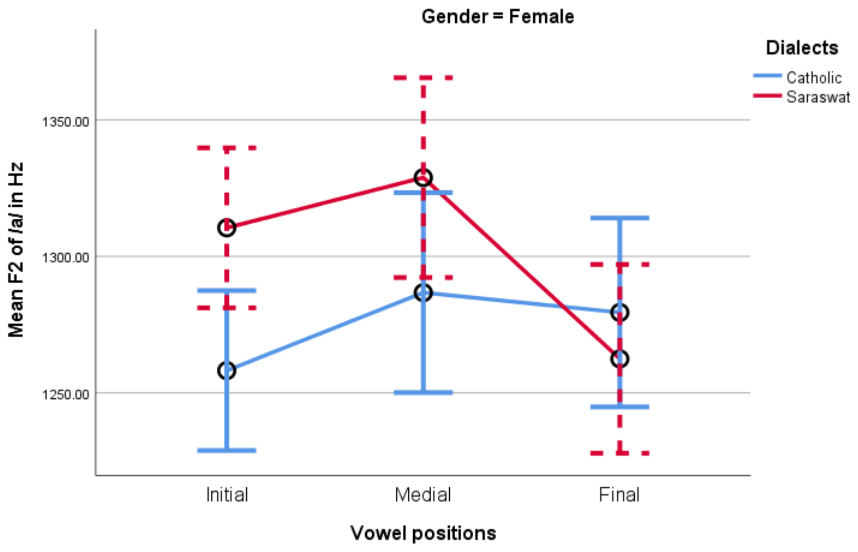


Figure 4.4

Mean and upper-lower boundary of F2 of /a/ across three vowel positions in females



c) F1 of /i/

Mixed ANOVA (repeated measures) showed a main effect of position [F (2, 112) = 1.513, p < 0.05) and gender [F (1, 56) = 44.421, p < 0.05]. The study did not find a main effect for the variable ‘dialect’ for F1 of vowel /i/. Among the interactions, position*dialect [F (2, 112) = 12.851, p < 0.05] was significant and other interactions like position*gender, gender*dialect and position*dialect*gender did not show any significant interaction effects. In males, F1 of /i/ was higher for Saraswat dialect in initial and medial position. In final position it was higher for Catholic dialect. In females, Saraswat dialect had slightly higher formant values in initial position and Catholic dialect had higher formant values in final position. In word- medial position, both the dialects showed equal mean formant values. Figure 4.5 and 4.6 shows mean and 95% confidential interval values of upper and lower boundaries of F1 for vowel /i/ across three vowel positions in males and females, respectively.

Figure 4.5

Mean and upper-lower boundary of F1 of /i/ across three vowel positions in males

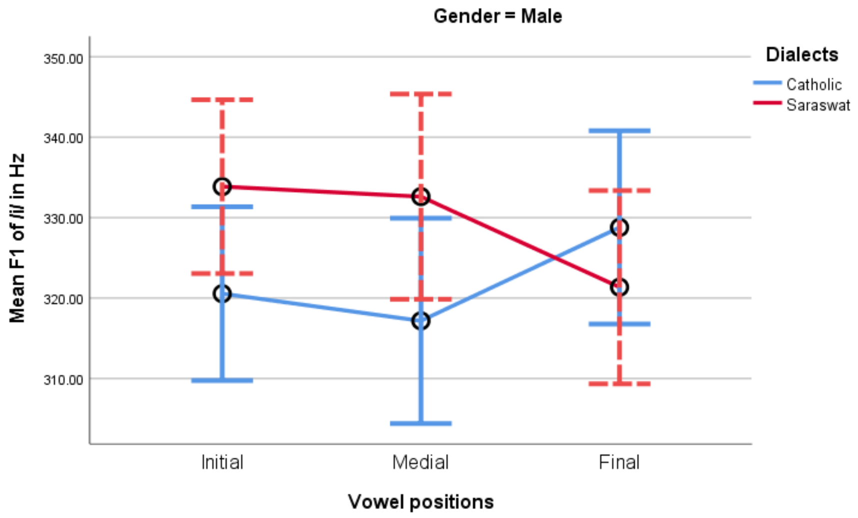
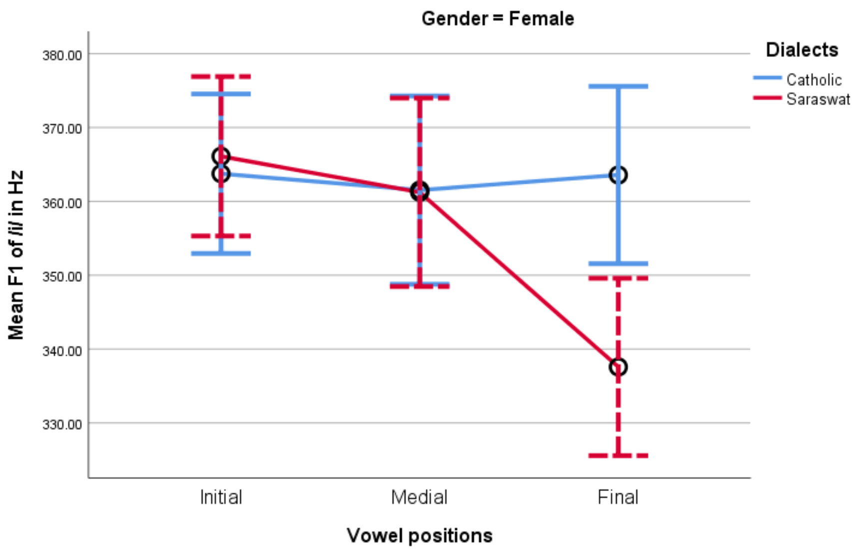


Figure 4.6

Mean and upper-lower boundary of F1 of /i/ across three vowel positions in females



d) F2 of /i/

Mixed ANOVA (repeated measures) showed a main effect of position [F (2, 112) = 10.465, $p < 0.05$] and gender [F (1, 56) = 2288.18, $p < 0.05$]. In males, Catholic dialect had higher F2 for vowel /i/ in initial and medial position, Saraswat dialect had higher formant values in the final position. In females, Saraswat dialect had the higher formants in all the three vowel positions when compared to Catholic dialect. In both Catholic and Saraswat dialects, the second formant frequency for /i/ is higher in the initial position. As the placement of vowel moves from initial to middle to final position, the F2 of /i/ keeps on decreasing. Figure 4.7 and 4.8 shows mean and 95% confidential interval values of upper and lower boundaries of F2 for vowel /i/ across three vowel positions in males and females, respectively.

Figure 4.7

Mean and upper-lower boundary of F2 of /i/ across three vowel positions in males

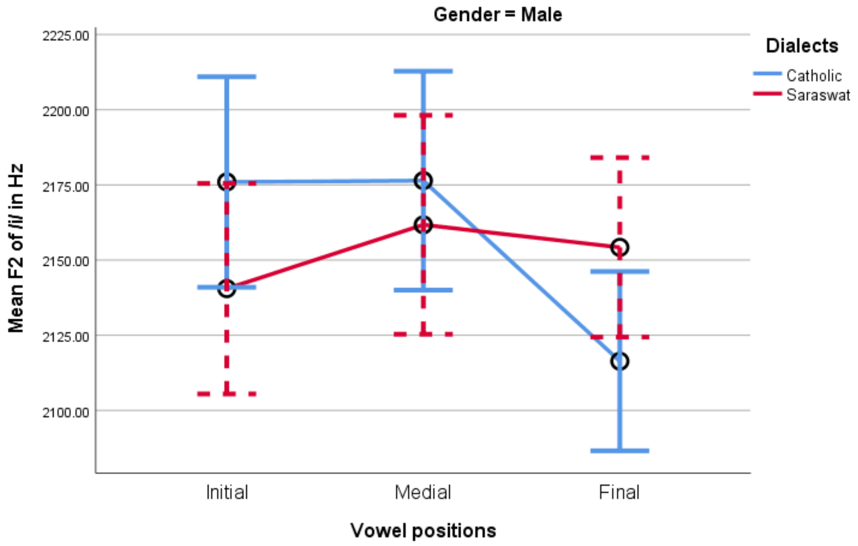
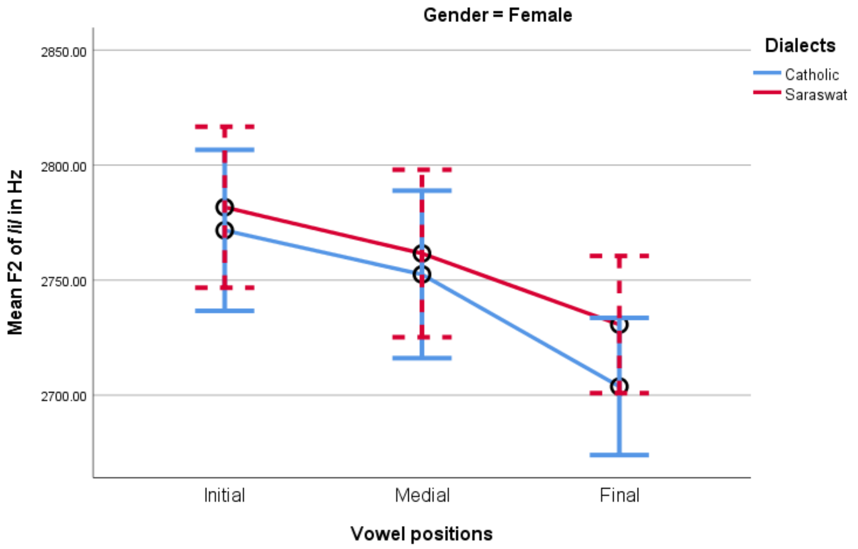


Figure 4.8

Mean and upper-lower boundary of F2 of /i/ across three vowel positions in females



e) **F1 of /u/**

Mixed ANOVA (repeated measures) showed a main effect found for position [F (2, 112) = 4.414, p < 0.05] and gender [F (1, 56) = 68.987, p < 0.05] and not for dialect. Among the interactions, position*dialect [F (2, 112) = 4.113, p < 0.05] was significant and no interactions were found for other variables. In males, in all the three vowel positions, Catholic dialect had higher formants when compared to Saraswat dialect. In females, Catholic dialect had higher formant values in medial and final positions whereas Saraswat dialect had higher formant values in initial position. Figure 4.9 and 4.10 shows mean and 95% confidential interval values of upper and lower boundaries of F1 for vowel /u/ across three vowel positions in males and females, respectively.

Figure 4.9

Mean and upper-lower boundary of F1 of /u/ across three vowel positions in males

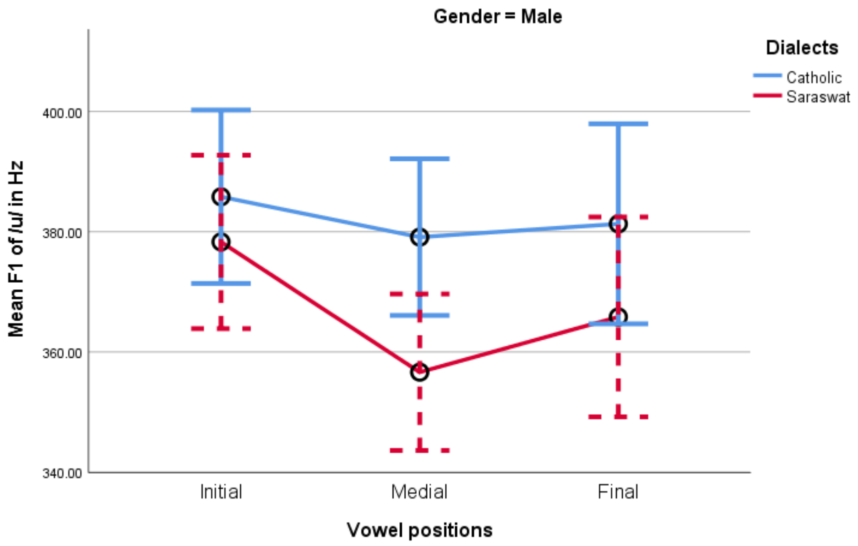
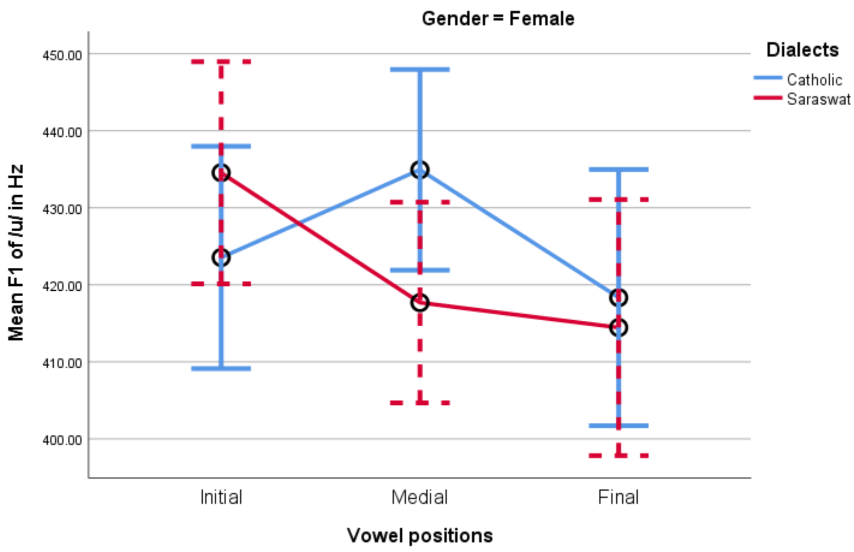


Figure 4.10

Mean and upper-lower boundary of F1 of /u/ across three vowel positions in females



f) F2 of /u/

Mixed ANOVA (repeated measures) showed a main effect for position [F (2, 112) = 4.806, p < 0.05] and gender [F (1, 56) = 58.44, p < 0.05] but not for dialect. Among the interactions, only position*gender [F (2, 112) = 4.868, p < 0.05] showed a significant interaction effect and other variables did not show any interaction effect. In males, Saraswat dialect had higher formant values in initial and final positions and Catholic dialect had higher F2 of /u/ only in medial position. In females, Saraswat dialect had higher formants in medial and final positions and Catholic dialect had higher formant value in initial position. Figure 4.11 and 4.12 shows mean and 95% confidential interval values of upper and lower boundaries of F2 for vowel /u/ across three vowel positions in males and females, respectively.

Figure 4.11

Mean and upper-lower boundary of F2 of /u/ across three vowel positions in males

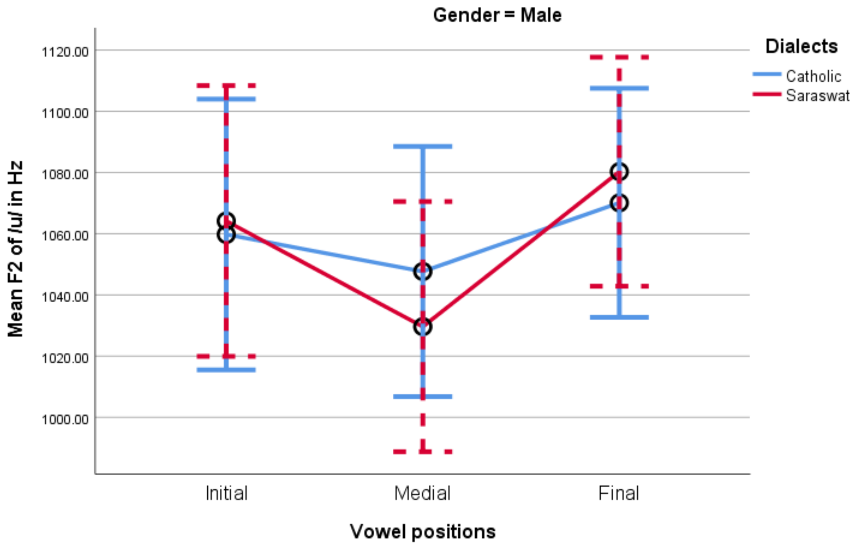
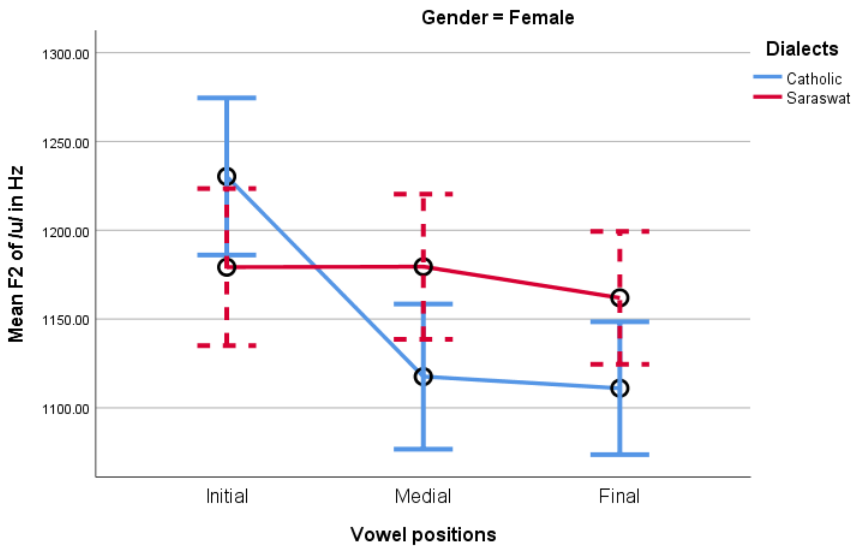


Figure 4.12

Mean and upper-lower boundary of F2 of /u/ across three vowel positions in females



4. Vowel Space Area in Catholic dialect

Descriptive statistics was conducted to acquire the mean and standard deviation values of Acoustic Vowel Space Area in two dialects of Konkani. Table 4.6 shows the mean (in KHz^2) and standard deviation (SD) of VSA in three vowel positions between males and females in Catholic dialect. For both males and females, the VSA is higher in medial position followed by initial position and final position. That is, VSA is the least for word final position in both genders.

Table 4.6

Mean and Standard Deviation (SD) of Vowel Space Area (VSA) across three vowel positions between genders in Catholic dialect

	Males		**Females**	
Vowel Position	**Mean (KHz^2)**	**SD**	**Mean (KHz^2)**	**SD**
VSA_i	143.65	33.14	313.58	50.61
VSA_m	153.84	32.01	328.26	68.67
VSA_f	130.18	21.25	300.56	56.88

Note: VSA_i = Vowel Space Area in Initial position, VSA_m = Vowel Space Area in Medial position, VSA_f = Vowel Space Area in Final position.

The acoustic VSA is calculated by measuring the area of the triangle that was plotted with formant values by placing the second formant frequency in X-axis and first formant frequency in Y- axis. Figure 4.13 and 4.14 shows the Vowel Space Area in Catholic males and females, compared across three vowel positions.

Figure 4.13

Comparison of Vowel Space Area across 3 vowel positions in Catholic males

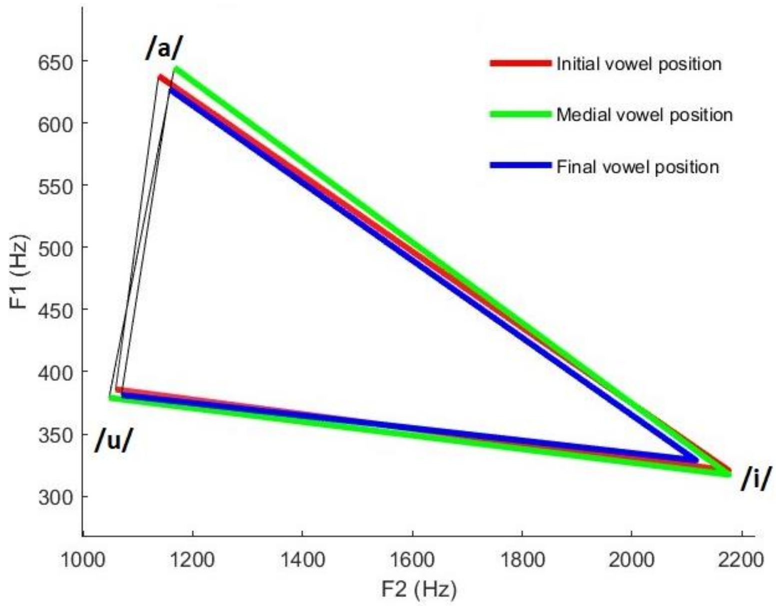
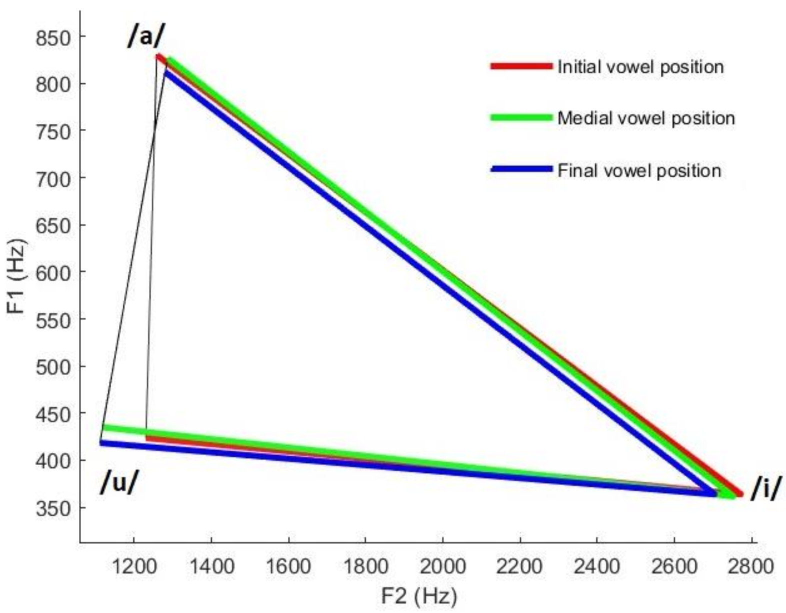


Figure 4.14

Comparison of Vowel Space Area across 3 vowel positions in Catholic females



One-way Repeated measures ANOVA was carried out to determine the effect of vowel position on the Vowel Space Area in both males and females. There was no significant difference found between the Vowel Space Areas compared across three vowel positions in both Catholic males and females.

5. Vowel Space Area in Saraswat dialect

Table 4.7 shows the mean (in KHz^2) and standard deviation (SD) of VSA compared across three vowel positions in males and females in Saraswat dialect. For both males and females, the VSA is higher in medial position followed by initial position and then final position.

Table 4.7

Mean and Standard Deviation (SD) of Vowel Space Area (VSA) across three vowel positions between genders in Saraswat dialect

Vowel Position	Males		Females	
	Mean (KHz^2)	**SD**	**Mean (KHz^2)**	**SD**
VSA_i	158.98	24.57	340.88	39.17
VSA_m	175.03	32.73	344.73	24.88
VSA_f	137.64	32.81	310.84	35.42

Note: VSA_i = Vowel Space Area in Initial position, VSA_m = Vowel Space Area in Medial position, VSA_f = Vowel Space Area in Final position.

Figure 4.15

Comparison of Vowel Space Area across 3 vowel positions in Saraswat males

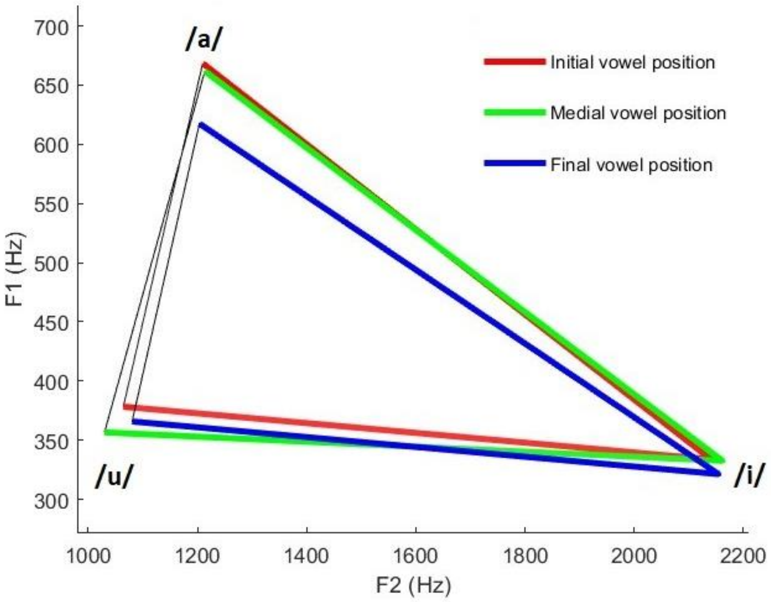
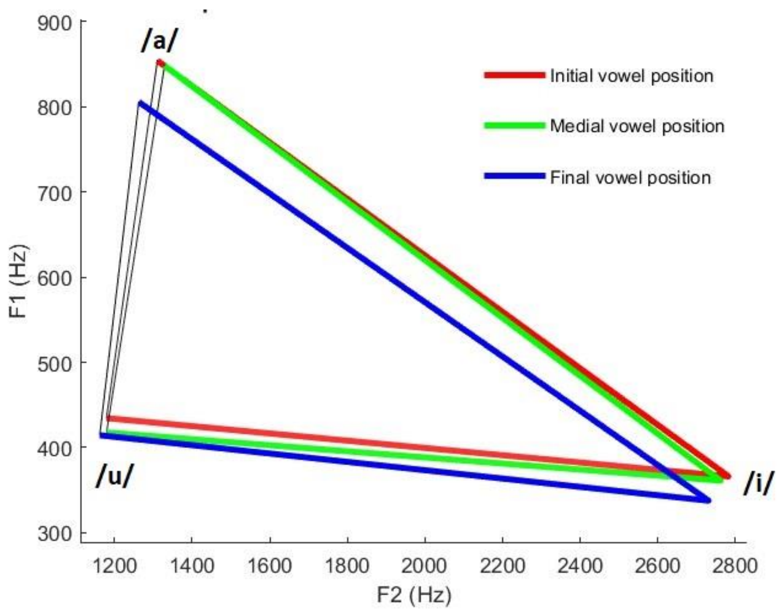


Figure 4.16

Comparison of Vowel Space Area across 3 vowel positions in Saraswat females



One-way repeated measures ANOVA in male group of Saraswat dialect, revealed a significant main effect of the vowel position on Vowel Space Area [F (2, 28) = 8.737, $p < 0.05$]. Pairwise comparison revealed a significant difference between VSA of medial position and final position at 0.05 level of significance. No significant difference was found for initial- medial and initial- final position. Similar results of repeated measures ANOVA were found in the female group ie., there was a significant main effect of vowel position on the VSA [F (2, 28) = 5.862, $p < 0.05$] and pairwise comparison showed a significant difference between medial and final positions only and not for other positions.

6. Comparison of Vowel Space Area across dialects

On visual inspection of VSAs, the Saraswat dialect had larger VSA in all the three vowel positions ie., initial, medial and final in both males and females. Figure 4.17 to 4.22 shows vowel triangles in three vowel positions for both the dialects, separately for males and females.

Figure 4.17

Comparison of VSA between two dialects in males (Initial position)

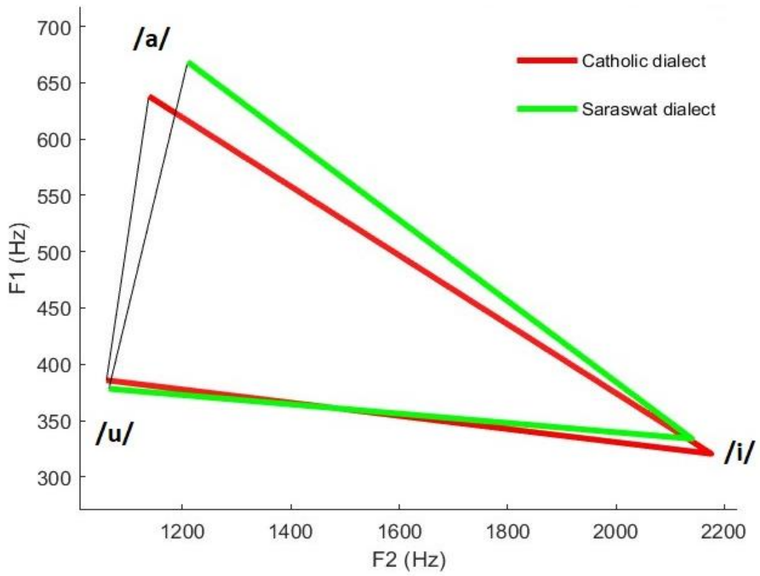


Figure 4.18

Comparison of VSA between two dialects in females (Initial position)

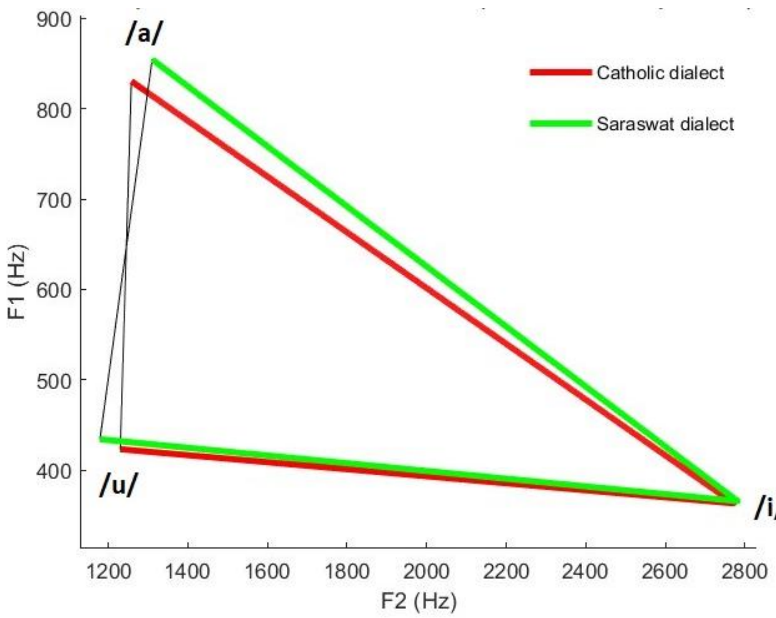


Figure 4.19

Comparison of VSA between two dialects in males (Medial position)

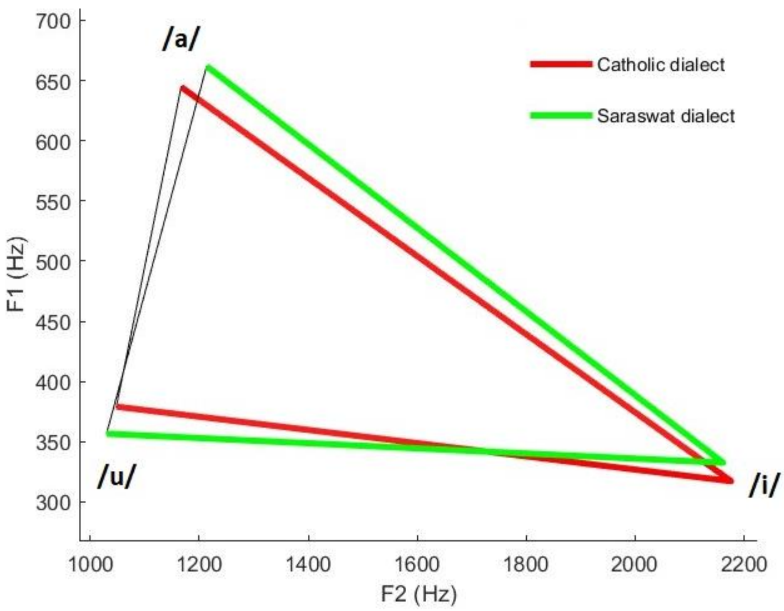


Figure 4.20

Comparison of VSA between two dialects in females (Medial position)

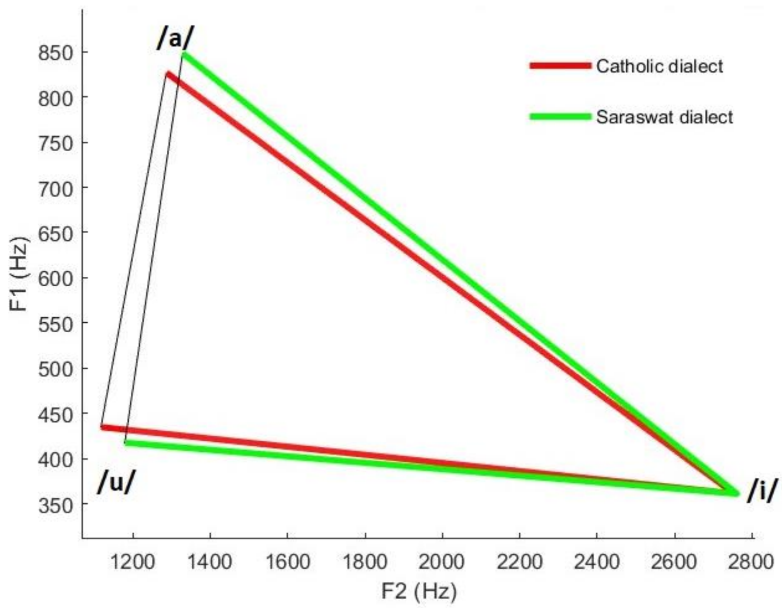


Figure 4.21

Comparison of VSA between two dialects in males (Final position)

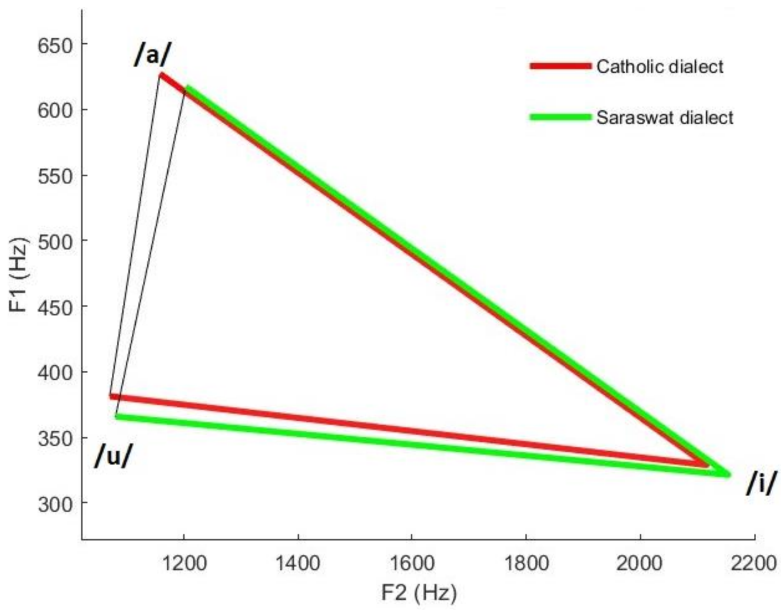
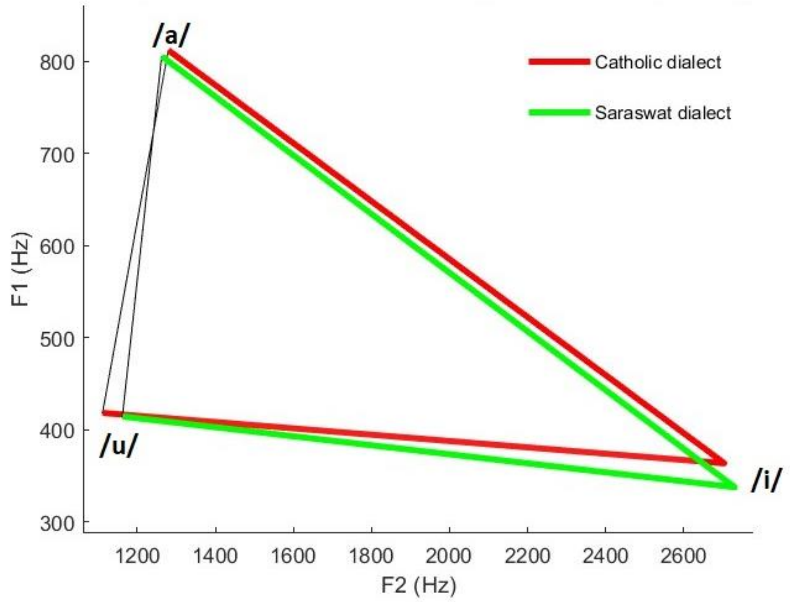


Figure 4.22

Comparison of VSA between two dialects in females (Final position)



One-way MANOVA was administered to study the main effect of dialect on the VSA. In males, no statistically significant difference was found in VSA between the two dialects [F (3, 26) = 1.175, p = 0.338; Wilk's Ʌ = 0.881, partial $ŋ^2$ = 0.119] in any of the vowel positions. Similar results were obtained for females, where the VSAs were not significantly different between two dialects [F (3, 26) = 0.881, p = 0.464; Wilk's Ʌ = 0.908, partial $ŋ^2$ = 0.092].

Mixed ANOVA was conducted to study the main effect of vowel position, dialect and gender on Vowel Space Area. The results showed a main effect of position [F (2, 112) = 14.261, p < 0.05] and dialect [F (1, 56) = 4.311, p < 0.05].

Figure 4.23

Mean VSA across 3 vowel positions between dialects in males

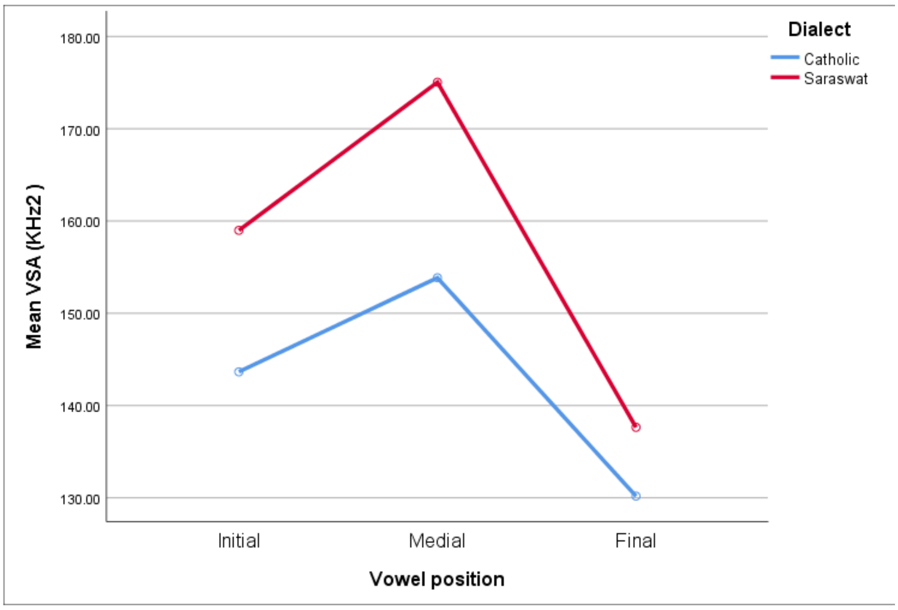


Figure 4.24

Mean VSA across 3 vowel positions between dialects in females

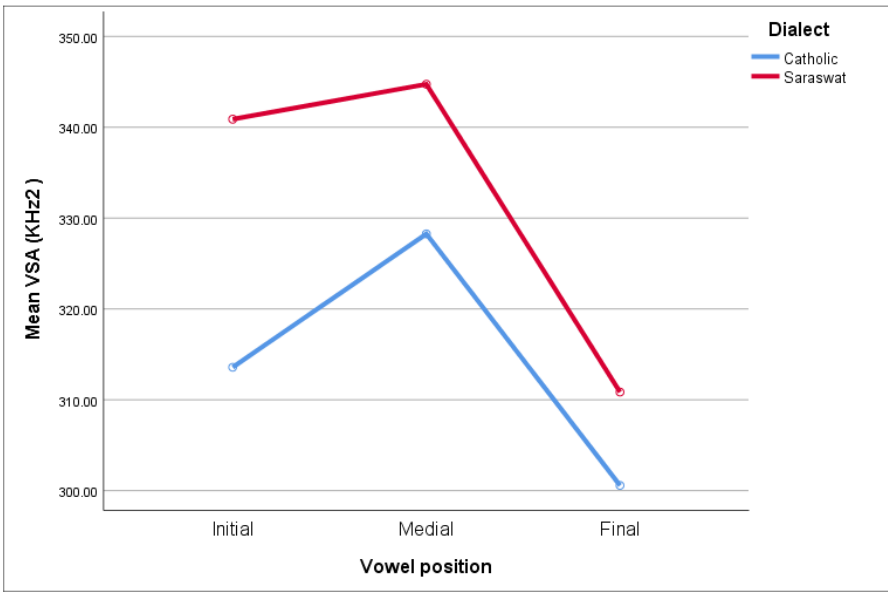


Figure 4.23 and 4.24 shows the mean VSA across three vowel positions in two dialects for males and females, respectively. In both the dialects, a similar trend can be observed. The VSA is larger in the medial position then followed by initial position. The least VSA is observed in final position (M>I>F). In general, Saraswat dialect has relatively higher VSA across three vowel positions in both genders.

7. Comparison of Vowel Space Area across Genders

Mixed ANOVA results showed a significant effect of gender on Vowel Space Area [$F(1, 56) = 484.639$, $p < 0.05$]. From Table 4.6 and 4.7, it can be noted that females had significantly higher VSA when compared to males in both the dialects. Figure 4.25 to 4.27 depicts the comparison of VSA between males and females across three vowel positions in Catholic dialect. Figure 4.28 to 4.30 depicts the comparison of VSA between males and females across three vowel positions in Saraswat dialect.

Figure 4.25

Comparison of VSA between genders in Catholic dialect (Initial position)

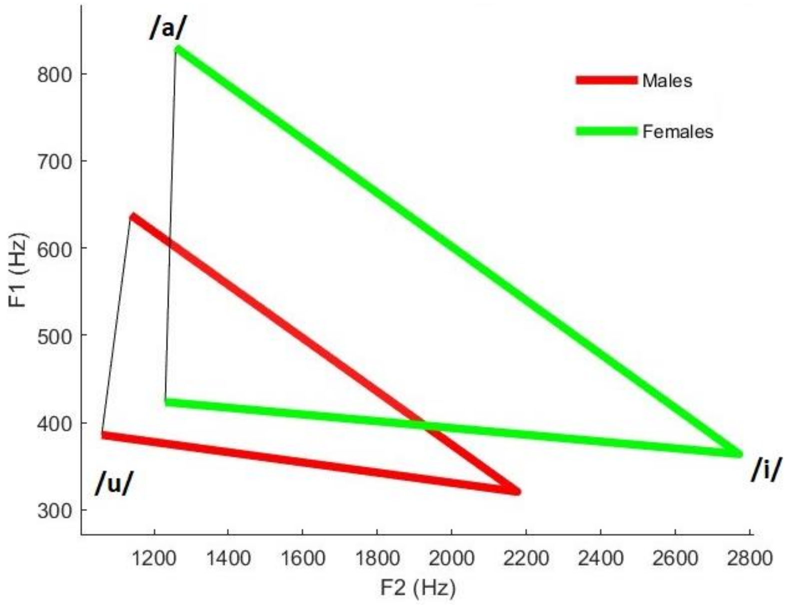


Figure 4.26

Comparison of VSA between genders in Catholic dialect (Medial position)

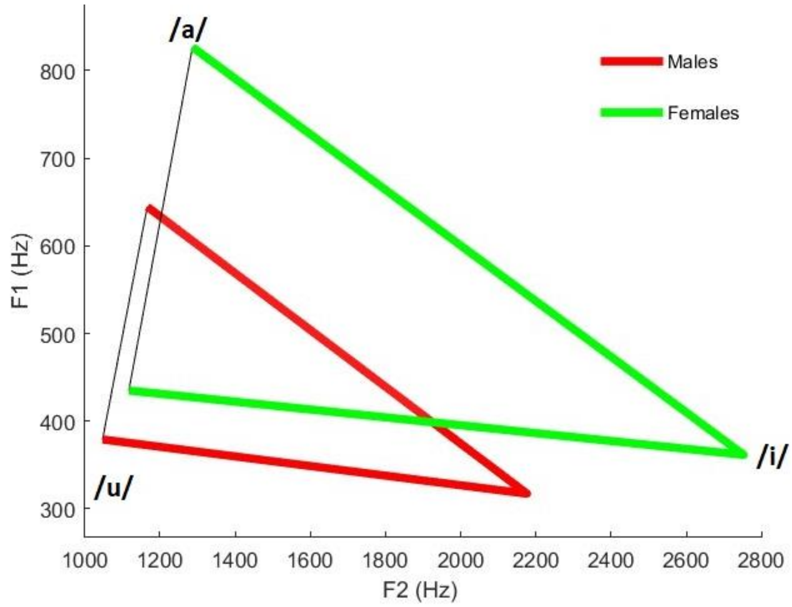


Figure 4.27

Comparison of VSA between genders in Catholic dialect (Final position)

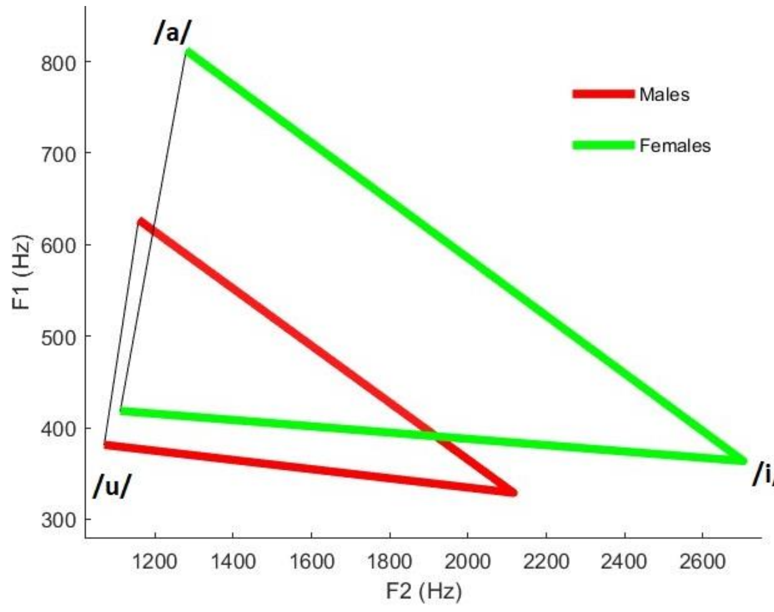


Figure 4.28

Comparison of VSA between genders in Saraswat dialect (Initial position)

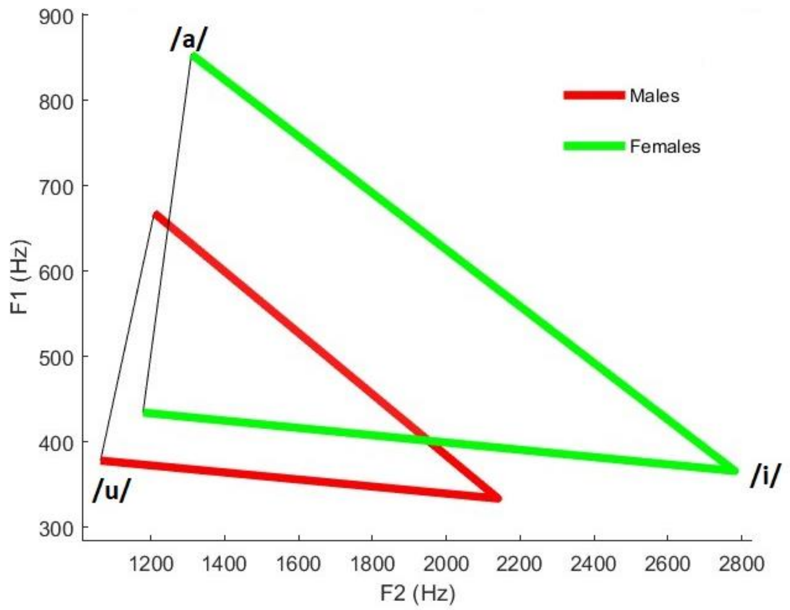


Figure 4.29

Comparison of VSA between genders in Saraswat dialect (Medial position)

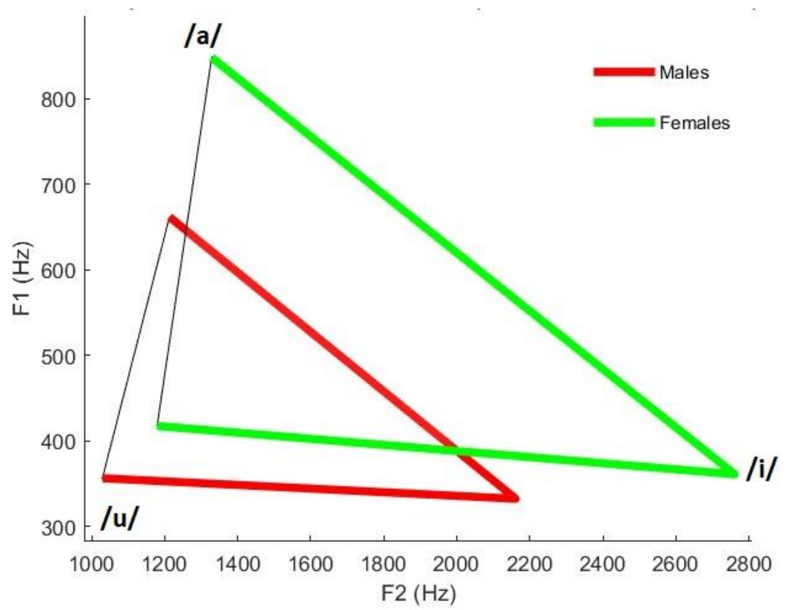
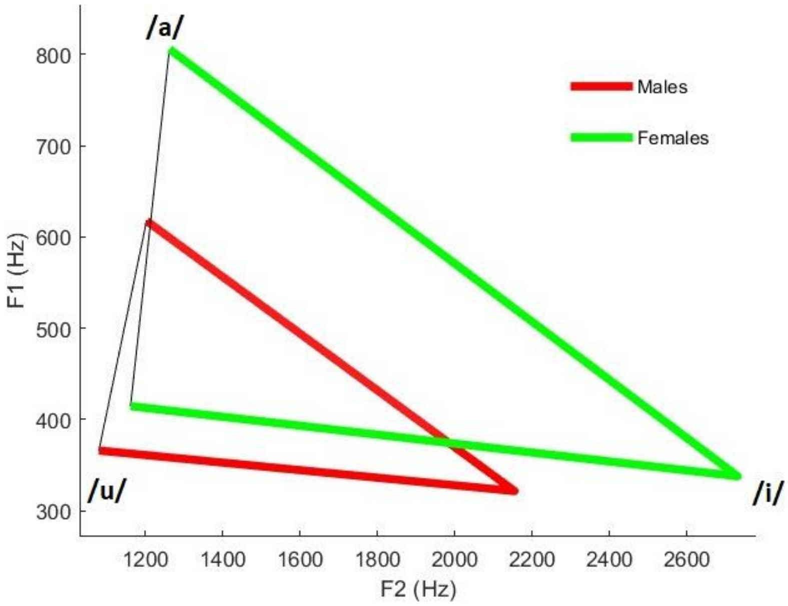


Figure 4.30

Comparison of VSA between genders in Saraswat dialect (Final position)



It can be concluded from the results that, though there was no statistically significant difference in the Vowel Space Areas across Catholic and Saraswat dialects of Konkani language, the Saraswat dialect had slightly higher VSA when compared to Catholic dialect across three vowel positions. When VSA across vowel position is concerned, VSA is higher in medial position followed by initial and then final position (M>I>F). The females were found to have significantly larger Vowel Space Areas when compared to males in both dialects and across the vowel positions.

CHAPTER V

DISCUSSION

The primary objectives of the present study were to explore, analyze and compare the Vowel Space Areas between two dialects of Konkani (Catholic and Saraswat) spoken in coastal areas such as Dakshina Kannada and Udupi districts in Karnataka. The study encompassed 60 participants, categorized into two groups based on their spoken dialect. These participants were then asked to repeat words embedded in a carrier phrase consisting of the three corner vowels (/a/, /i/ and /u/). Additionally, the study also assessed the impact of vowel position (initial, medial, final) on the formant frequencies.

The formant frequencies (F1 and F2) extracted from /a/, /i/, and /u/ align closely with the formant values obtained in the previous studies carried out by Gunjawte (2021) in the Catholic dialect of Konkani and Fadte (2022) in Goan Konkani. In comparison to the formant frequency values obtained in other languages, the values of this study are also in close proximation with formant values obtained by Peterson & Barney (1952); Hillenbrand et al. (1995); Sreedevi (2000); Ladefoged et al., (2011); Kent (2018).

The next objective of the study was to establish the effect of vowel position on the formant frequencies. It was observed that, for most of the formants, the values were highest in the medial position, followed by the initial position, and least in the final position. This can be attributed to the co-articulatory effects. Co-articulation is a phenomenon in speech production wherein the manner of production of one sound influences the articulation of nearby or adjacent speech sounds (Fant, 1960). There are different types of co-articulation; the most common ones include Anticipatory coarticulation, where the "following sound influences the production of a speech sound." Another type of coarticulation is Carryover coarticulation, in which the "preceding sound influences the articulation of a speech sound". When the vowel is in the word-medial position, it is highly susceptible to both types of coarticulation, i.e., anticipatory and carryover coarticulation. Also, unstressed vowels such as /a/, /i/, and /u/ are most susceptible to coarticulation in the carryover position (Mok, 2013). Similar results were obtained in a study carried out by Hegde (2015) in which the author studied the effect of vowel position on the formant frequencies in the Tulu language and found that the formant values were highest in the medial position when compared to the initial and the final positions.

Another finding was that the formant frequencies were the least in the word-final position. This finding is in consensus with the study by Johnson and Martin (2001). They studied the effect of word position on the acoustic vowel reduction in the Creek language. The reduction in the formant frequencies could be due to the centralization of vowels in the final position. This occurs as the words are produced with lesser effort towards the end of the sentence. Herman et al. (1997) described the term 'final fade' as an acoustic and articulatory phenomenon seen at the end of prosodic units. Towards the end of the utterance, there is a reduction in the subglottal pressure, fundamental frequency, and formant frequencies. Vayra and Fowler (1992) reported an effect of 'supra-laryngeal declination,' which is attributed to the gradual declination towards the end of the sentence. This declination was noted for various parameters such as fundamental frequency, amplitude, duration, and formant frequencies. Authors explain it as a phrasal-level phenomenon; it could potentially explain lower formant frequencies in the word-final position found in the current study, as the stimulus used was presented at the phrase level.

Another notable finding from the study indicated no statistically significant difference in Vowel Space Areas between the two examined dialects (Catholic and Saraswat). Since both dialects are spoken in the neighboring regions of Dakshina Kannada and Udupi districts, it might be assumed that the two dialects share a common vowel system. However, it’s important to consider the methodology employed in the study. The participants were asked to repeat words presented within a carrier phrase, which could potentially influence the results. Upon visual examination, it was noted that the Saraswat dialect exhibited a higher VSA than the Catholic dialect. This observation could imply that speakers of the Saraswat dialect tend to speak at a slower rate and clear articulation, in contrast to the speakers of the Catholic dialect. This finding agrees with the findings of Jacewicz et al. (2007), in which they studied the three regional dialect variations of American English (Central Ohio, South-central Wisconsin, and Western North Carolina). The authors compared the VSAs obtained from the four corner vowels (/a/, /i/, /u/ & /æ/) and extended VSA obtained from five vowels (/a/, /i/, /u/, /æ/ & /oɪ/). The three dialects did not vary in their VSAs, which were obtained from 5 vowels (extended VSA), but the dialectal variation was seen for the VSA obtained from 4 corner vowels. The authors explain the finding in terms of a ‘general vowel space,’ i.e., shared characteristics exist in vowel systems across languages. However, the actual configuration and specific sounds can significantly vary across dialects. Hence, the four- Vowel Space Area might not fully represent the complete range of the vowel space, which encompasses the production of all vowels, including monophthongs and diphthongs. While the placement of “corner vowels” (and thus, the configuration of the vowel space) might vary, the overall size of the vowel space area utilized by male and female speakers of the three distinct regional dialects of American English remains consistent.

In another cross-linguistic study by Al-Tamimi and Ferragne (2005), the authors compared the VSAs across French and two dialects of the Arabic language (Moroccan and Jordanian). The results revealed that the VSA of French was significantly larger than the other two Arabic dialects. The two Arabian dialects did not vary significantly in their Vowel Space areas. Similar studies have been conducted in Indian languages. Lyngkhoi (2020) studied the two Khasi dialects spoken in the state of Meghalaya (Maram and Nongstoin). This study yielded comparable outcomes, revealing no notable distinction in the Vowel Space Area between the two examined dialects. The author attributed the results to the regional proximity where those two dialects were spoken.

Contrary to the findings of this study, various studies reveal that the dialects of a language vary significantly in terms of their Vowel Space Areas. Schoormann et al. (2017) studied the VSA in three dialects of Saterland Frisian (Ramsloh, Scharrel and Strücklingen) spoken in Germany. The three dialects varied in terms of their VSAs. The VSA of Scharrel was significantly higher than the VSAs of the other two dialects.

Skaria (2016) studied VSA in 4 regional dialects of Malayalam (Kozhikode, Thrissur, Ernakulam and Thiruvananthapuram). Mean VSA varied across the dialects, being the highest for Ernakulam dialect, followed by Kozhikode and then by Thiruvananthapuram dialect, and the least for Thrissur dialect. Abraham (2015) also compared the VSA of Malayalam and two other tribal languages (Paniya and Kuruma) spoken in Kerala. The VSA of Malayalam was significantly higher than the two tribal languages. Srinivasan (2016) compared the VSAs of four regional dialects of the Kannada language (Mangaluru, Mysuru, Dharwad and Kalaburagi). Comparable results indicated that the VSA differed among the four dialects. The Mangaluru dialect demonstrated the highest VSA, followed by the Mysuru, Dharwad dialects and the Kalaburagi dialect with the least VSA. In the studies by Srinivasan (2016) and Skaria (2016), the variation in VSA across the mentioned dialects can be ascribed to the geographical placement of these regions. Given the considerable geographical separation, a significant contrast in VSA becomes evident, confirming that vowels take on distinct positions within the vowel system (Jacewicz et al., 2007). Similarly, the outcomes of the present study can be substantiated, given that both the Catholic and Saraswat dialects of Konkani are spoken within the regions of Dakshina Kannada and Udupi districts of Karnataka. This close proximity in geographical distribution suggests a possibility of similarities in the vowel systems of the two dialects. However, it’s important to note that the current study had a relatively limited sample size. Therefore, it would be valuable to conduct further research with larger and more diverse participant groups to validate the robustness of these results and ensure their consistency. In the current study, the employed stimuli consisted of words embedded within a carrier phrase. Utilizing spontaneous speech as stimuli would yield more natural, precise, and authentic outcomes concerning the measurement of Vowel Space Area.

When analyzing VSA across both dialects in relation to gender, it was observed that females displayed a larger VSA than males in the present study. These results align with the findings of previous studies conducted by Krishna and Rajashekar (2012); Krishnan (2015); Narasimhan and Karunarathne (2021); Albuquerque et al. (2023); Johnson and Martin (2001); Srinivasan (2016); Skaria

(2016); Abraham (2015); Lyngkhoi (2020). Differences in vocal tract configuration between males and females lead to variations in formant frequencies. The size and shape of the oral and pharyngeal cavities influence the resonance of the voice. The larger cavities often lead to a deeper and lower resonance in males. In females, the presence of smaller cavities results in an elevated resonance, a characteristic that is clearly observed in the present study. This is substantiated by the fact that females exhibit higher formant frequencies, ultimately leading to a more extensive Vowel Space Area than males. Similarly, Goldstein (1980) concluded that anatomical distinctions explain only a portion of the variations in vowel formant between males and females. A hypothesis proposed by Sachs et al. (1973), building upon Mattingly's (1966) work, posits that these differences in articulation may stem from speakers employing a strategy to enhance or amplify the acoustic outcomes of anatomical variations. This approach aims to achieve a distinctly masculine vocal quality in males and a distinctly feminine vocal quality in females.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A vowel is a sound produced with a comparatively open vocal tract configuration. Vowel Space Area (VSA) refers to the geometric representation of the vowels in an F1-F2 plane. The VSA is used to represent and compare vowels based on the articulatory productions of the speakers of a particular language and dialect. The size, shape, and configurations of different spaces within the vocal tract affect the formant frequencies. The movement and positions of the articulators influence these configurations. Vowel Space Area has been studied across various languages and dialects. Previous research has yielded diverse outcomes, with certain studies revealing dialectal differences while others indicating the absence of such variations. Also, very few attempts have been made to explore the acoustic characteristics of the Konkani language and its dialects. Hence, the present study aimed to explore and compare the Vowel Space Area between the two dialects of Konkani (Catholic and Saraswat) spoken in Dakshina Kannada and Udupi districts of Karnataka. Other objectives of the study were to determine the effect of vowel position on the formant frequencies and compare the VSAs between the genders across two dialects.

The present study included 60 participants categorized into two distinct groups according to their dialect (Group 1: Catholic dialect, Group 2: Saraswat dialect). Each of these groups consisted of 30 participants, with an equal number of males and females within each group. Distinct word lists were created for the two dialects, incorporating the corner long vowels /a:/, /i:/, and /u:/ in the initial, medial, and final word positions. These words were presented on a flashcard as stimuli, and the participants had to read each word embedded within a carrier phrase. Using PRAAT (version 6.3) software, the formant frequencies (F1 and F2) were extracted. Using a custom-made MATLAB program, the formants of participants from Catholic and Saraswat dialects were plotted in an F1-F2 plane to obtain the vowel space area. They were compared between dialects and between males and females.

The formant frequencies and the vowel space areas were subjected to statistical analysis (SPSS, version 26). The results of the present study revealed several points of interest;

First, higher formant values were found in the vowel medial position, followed by the initial position, and the least in the final position. The high formant values for the words with vowels in the medial position could be attributed to the co-articulatory effects. The least formant values in the word-final position could be due to the 'declination' effects or reduction in the effort during production towards the end of the sentence/ word utterance.

Second, when vowel space areas were compared between the dialects, on visual inspection, the Saraswat dialect had a slightly higher VSA when compared to the Catholic dialect in both males and females. However, these results were not statistically significant. This could be attributed to the close regional proximity as both these dialects are spoken in the same region, i.e., the Dakshina Kannada and Udupi districts of Karnataka.

Third, a gender comparison was made between the males and females regarding VSA, the females had significantly larger VSA when compared to males. The larger VSA in females is due to the comparatively smaller vocal tract and cavities than in males. It also indicates that females have a slower and clearer enunciation than males.

Clinical implications of the study

- The study helps to understand the vocal tract's articulatory dynamics in the two dialects of Konkani.
- The study adds to the literature on acoustic characteristics of vowels in Konkani and can be used as reference data for clinical use.

Limitations of the study

- The present study included a limited number of participants in its sample.
- The stimuli used in the study was restricted to only 3 long corner vowels at the word level.

Future directions

- A similar study could be carried out using a more extensive sample size to assess the reliability of the findings.
- To obtain a more robust and accurate representation of the Vowel Space Area, future studies can be planned by employing spontaneous speech as stimuli.
- The Vowel Space Area can be explored in other dialects of Konkani and across different age groups.

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APPENDIX-1

Stimuli used for the Saraswat dialect speaking participants

Vowels	Initial position	Medial position	Final position
/a/	a:dʒi a:t a:d	pa:ti ka:l d̪a:t	amˈa: amka: asˈa:
/i/	i:ʃvar	mi:t t̪i:k ki:d	t̪i: d̪i: bi:
/u/	u:ne u:s u:n	t̪u:p d̪u:k pu:t̪	vasrũ:

APPENDIX-2

Stimuli used for the Catholic dialect speaking participants

Vowels	Initial position	Medial position	Final position
	a:ŋ	pa:t	sabʰa:
/a/	a:d	d̪a:t	pida:
	a:ndʒ	ka:l	vet̪a:
	i:st	t̪i:k	d̪oni:
/i/	i:ʃvar	bi:k	st̪ri:
	i:t	gi:t	d̪i:
/u/	u:t	ku:d	pu:
	u:d	t̪u:p	vasrũ:
	u:n	gu:nd	zũ: