Acoustic analysis of vowels in Konkani

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Konkani is an under-resourced language mainly spoken on the west coast of India. Although linguistic analyses of vowel sounds in various dialects of Konkani have been done in the past, more accurate analysis of Konkani vowels, especially an acoustic-phonetic analysis, was never carried out. In this paper, we present a detailed analysis of nine Konkani vowels, namely /i/, /e/, /ɛ/, /u/, /o/, /ɔ/, /a/, /ə/, and /ɨ̞/. The dataset used for the analysis was created from audio recordings of 28 native speakers of Goan Konkani. Based on the experimental results, we propose a vowel chart for Konkani. We also observed a partial loss of Konkani vowel /ɨ̞/ in the regular speech of native speakers. This change is also evident in the substitution analysis of vowel phonemes that was carried out by us as a part of this study.

Additional Key Words and Phrases: Acoustic analysis, Formant analysis, Konkani, Vowel phoneme

1 INTRODUCTION

Konkani is the southernmost Indo Aryan language spoken in India by approximately 2.2 million speakers [6], just 0.19% of the total Indian population. It is still an under-resourced language[3] mainly spoken on the west coast of India.

The earliest written inscription in Konkani is found at the foot of the colossal Jain monolith at Shravanabelagola in Hassan district of Karnataka. This inscription dates back to 981 CE [13] [8]. During the Portuguese occupation of Goa from 1510 CE to 1961 CE, a large mass of native speakers migrated and settled in neighbouring states over many centuries. People also settled outside Goa for employment opportunities, education, etc. Due to these factors, modern Konkani literature was produced in five different scripts, i.e. Devanagari, Roman, Kannada, Malayalam and Arabic [12]. Konkani is recognised as the official language of the state of Goa in 1987 CE and is now included in the 8th Schedule of the Indian Constitution from 1992. Devanagari script is recognised as the official script and the Antruzi dialect as the standard dialect. A considerable mass of speakers is still using Roman and Kannada scripts.

Based on the historical events and cultural ties, linguists such as N.G. Kalelkar[17] has classified Konkani dialects into three major groups: Northern Konkani, Central Konkani, and Southern Konkani. The Northern group consists of Konkani dialects spoken in the Ratnagiri district of Maharashtra, the Central group encompasses the Konkani dialects spoken in Goa, whereas the Southern group comprises of the Konkani dialects spoken in the

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2375-4699/2022/8-ART111 $15.00
https://doi.org/https://doi.org/10.1145/3474358

North Kanara district of Karnataka. Linguists such as Madhavi Sardesai[16] , Fr. Pratap Naik[18] also make a reference to regional and social sub-dialects of the language. Sardesai mentions Konkani regional dialects such as Goan Konkani (along with its regional and social sub-dialects), Manglorean (Manglluri) Konkani and Konkani of Cochin and social dialects spoken by Salcete Hindus, Christian Brahmins, etc. Fr.Pratap makes a reference to regional dialects of Konkani such as Sawantwadi Konkani, Belgav (Belgaum) Konkani, Goan Konkani, Karwari Konkani, Manglluri (Mangalore) Konkani, Keral (Kerala) Konkani and social dialects such as Karnatak (Karnataka) Christian Konkani, Goan Hindu Konkani, etc [17][18].

The primary purpose of this study is to classify Konkani vowels and quantitatively measure and analyse their acoustic properties. Although vowel classification studies have been performed in the past, more accurate analysis of Konkani vowels, especially an acoustic-phonetic analysis, has not been reported. In this work, we present the results of our experimental work carried out on the acoustic-phonetic properties of Konkani vowels. All the authors of this paper are native Konkani speakers residing in the state of Goa.

This paper is organised into six sections. Section 1 provides a brief introduction of the Konkani language and states the primary purpose of our work. Section 2 is a review of earlier studies carried out in acoustic phonetic analysis and classification of Konkani vowels. The details of the proposed work are discussed in Section 3. Section 4 provides the details of the methodology that was followed for our experimental work. Section 5 presents observations and results of our experiment, followed by the section on conclusion and future work in Section 6.

2 RELATED WORK

Vowel analysis is an essential part of an acoustic study performed for any language. Acoustic analysis is needed to provide an accurate classification of vowels. Similar works have been reported in the past for different languages. Agrawal et al. presented an acoustic analysis for Hindi vowels for native and non-native speakers[1]. Chakrasali et al. presented formant analysis for Kannada vowels speech signals[5], Loakes et al. presented acoustic-phonetic analysis for the Wunambal language in Australia [9], Roux and Holtzhausen for the Xhosa Language in Africa [14] and Hillenbrand et al. for the American English [7].

With regard to the Konkani language, we came across three works that presented inventories of vowel phonemes of the language. These works form the basis of our study. Almeida S. J., in his work [2] provides examples of 20 different vowel phones, which he broadly classifies into eight phoneme vowels. These include three front vowels [i, e, ɛ] and five back vowels [u, o, ɔ, ə, a]. All back vowels are rounded except [a]. Konkani is a highly nasalised language, and each oral vowel sound can also be nasalised. The author, a native of the Kundapur-Kalyanpur region of Karnataka, thus analyses vowel sounds of the Canara dialect of Konkani. His work is summarised in Table 1[1].

Sardesai, mainly in her dialect-specific work, refers to nine Konkani vowels and classifies them into three groups: front vowels [i, e, ɛ], central vowels [ɨ, ə, a] and back vowels[u, o, ɔ] [15] [16]. Although the her work is specific to her dialect- Gauda-Saraswat Brahmin dialect spoken in the Salcete region of Goa, it broadly covers all the dialects spoken in different regions of Goa. SardesaiâĂŹs work is summarized in Table 2.

Lobab suggests eight vowel phonemes for Konkani [i, e, ɛ, u, o, ɔ, a, ə] and expresses doubt regarding the presence of vowel sound [ʌ] in the language, though he does give an example of that sound [10]. LobabâĂŹs work is mainly based on two dialects of Konkani spoken on the west coast of South Karnataka, namely South Saraswat Canara (SSC) dialect and Mangalorean Christian (MC) dialect. The Mangalorean Christian dialect geographically spoken in the southern part of Karnataka is very similar to the Bardez dialect of Goa. This is due to the migrations that occurred during the Portuguese occupation of Goa. Table 3 summarizes LobabâĂŹs work.

[1]Vowel length is not phonemic in Konkani. It depends on the syllabic pattern and hence is predictable. Therefore, no discussion on those lines has been included in this paper[16].

Sr No	Vowel	Examples	Gloss
1	i	[k i: r] [ʃ i k t a]	parrot learns
2	e	[p e r i]	guava trees
3	ɛ	[p ɛ r a d] [p ɖʒɿ. r]	guava jelly guava
4	u	[k u: s] [k ʊ s ɾ ɔ]	side rotten
5	o	[t o r i]	towers
6	ɔ	[t ɔ r ã] [t ɒ˞ r]	green mangoes green mango
7	ɵ	[t ɵ r]	if
8	a	[t ʌ s t a] [t a: s]	scrapes hour

Table 1. Vowel sounds in the Christian Canara dialect spoken in the Kundapur-Kalyanpur region of Karnataka.

Sr No	Vowel	Examples	Gloss
1	i	[k i r]	Parrot
2	e	[p e r]	Guava tree
3	ɛ	[r ɛ m v]	sand
4	u	[s u t]	thread
5	o	[m o r]	peacock
6	ɔ	[ts ɔ r]	thieves
7	ɨ	[e k v ɨ t]	union
8	ə	[k ə r]	tax
9	a	[h a: t]	hand

Table 2. Vowel sounds in the Salcete Gowda-Saraswat brahmin dialect.

3 PROPOSED WORK

Acoustic analysis is essential for providing a qualitative description of sounds in a language. Based on the literature presented on the vowel phoneme set of Konkani (Section 2 above), we propose the following classification for Konkani vowels. This classification forms the basis of our proposed work. Konkani vowel phonemes can be classified into three categories (a) Front vowels, (b) Central vowels and (c) Back vowels:

(a) **Front vowels** consist of vowels /i/ /e/ and /ɛ/.
(b) **Central vowels** consist of vowels /ɨ/ /ə/ and /a/.
(c) **Back vowels** consist of vowels /u/ /o/and ɔ/.

All the vowel properties and IPA notations are summarized in Table 4. We have also mapped Roman, Devanagari and Kannada graphemes to vowel phonemes. Examples of words containing vowel sounds are taken from Central Konkani dialects and may vary with respect to Northern and Southern Konkani dialects. Our investigation therefore focuses mainly on vowel sounds found in Central Konkani dialects.

Sr. No	Vowel	Example		Gloss
		SSC	MC	
1	ə	kəri	kər	do
		dhəri	dhər	hold
		vəiri	vəir	up
2	a	mari	mar	hit
		kaḍi	kaḍ	remove
3	u	guṇə	guṇ	character
4	i	tini	tin	three
5	o	doni	don	two
6	e	teru	ter	Car festival
7	ɔ	bɔṭə	bɔṭ	finger
8	ɛ	mɛṇ		wax
9	ʌ	kamʌ ?		(What) job (do you do)?
		haw̃ʌ	-	me
		-	mhʌjɛ	mine

Table 3. Vowel sounds in South Saraswat Canara (SSC) dialect and Mangalorean Christian (MC) dialect.

Our investigation makes the first attempt to carry out an acoustic phonetic analysis of nine Konkani vowels with the purpose of investigating their dispersion which would further aid in the more accurate categorization of these vowels.

4 METHODOLOGY

This section discusses the methodology we followed in our experiment. Section 4.1 to Section 4.4 describes the process of dataset creation, which includes data collection details, preprocessing steps performed on the data, data verification and data annotation process. Section 4.5 provides details about formant extraction, and Section 4.6 provides details of substitution analysis.

4.1 Data collection

This process had three main steps:

(1) **Selection of speakers:** 28 native speakers (15 males and 13 females) from different parts of Goa were chosen for this study. Figure 1. shows a map of speakersâĂŹ native place. All the speakers were between the age group of 20 to 40 and had formal education. Each speaker was given a unique speaker Identifier.

(2) **Preparation of speech reading material and Data elicitation methodology:** For our experimental purpose, a speech reading material was created with the help of a Cognitive Linguist (author 2 of this paper). The reading material consisted of nine independent vowel sounds and 28 common words in isolation (containing the nine vowels considered for study) to be produced by the speakers. Some of the words included in the reading material can be seen in Table 4. At least two words were included for each vowel sound. For the purpose of elicitation of data, the reading material was provided to the speakers as a word list on an A4 size paper. The speakers were first instructed to read out (pronounce) the individual sounds (vowels) and then the words in isolation in the most natural way they could (i.e. according to their natural way of speaking). Each speaker was given the same word list to be read out. The second author noted down

Sr No	Approximate IPA Notation	Equivalent grapheme			Examples	English meaning	Vowel type
		Roman	Devanagari	Kannada			
1	i	i	इ and ई	ಇ and ಈ	[v i: s]	twenty	Front
					[k ə v i:]	poet	
2	e	e	ए	ಎ	[p e: r]	guava tree	
					[k^h e: ɭ]	game	
					[m e: dʒ]	count (imperative.2 p.sg.)	
3	ɛ		ऍ	ಏ	[p ɛ: r]	guava fruit	
					[k^h ɛ: ɭ]	play (imperative.2 p.sg.)	
					[m ɛ: dʒ]	table	
4	ɨ	a	अ	ಅ	[k ɨ :r]	do (imperative.2 p.sg.)	Central
					[b ɨ s]	sit (imperative.2 p.sg.)	
					[p ɨ ɖ]	a traditional measure	
5	ə				[k ə r]	tax	
					[b ə s]	bus	
					[p ə ɖ]	fall (imperative.2 p.sg.)	
6	a		आ	ಆ	[a ɖ s ə r]	tender coconut	
					[r a dʒ a]	king	
7	u	u	उ and ऊ	ಉ and ಊ	[u:s]	sugarcane	Back
					[p u: l]	bridge	
8	o	o	ओ	ಒ	[ts o: r]	thief	
					[d o: n]	two	
9	ɔ		ऑ	ಓ	[ts ɔ:r]	thieves	
					[b ɔ: l]	ball	

Table 4. Classification of vowels in Konkani.

speaker pronunciations, hesitations (including their pronunciation attempts), etc., for a possible future reference.

(3) **Recording environment** Audio recordings were done in a professional studio environment with the help of a Zoom H6 Handy Recorder. The audio was recorded at a 48,000 Hz sampling rate and with a sample size of 24 bits. Recordings were stored in a non-lossy WAV format. Each recording was given a unique recording Id.

4.2 Data preparation

All audio files went through a manual preprocessing, which included the following steps:

(1) Mapping between recording Id and speaker Id was captured in an Excel spreadsheet. This facilitated the masking of the speaker's personal information to ensure the privacy of each speaker.
(2) Reducing the duration of silent intervals to approximately 50ms so that the overall size and time duration of audio files were reduced without losing any acoustic information.

Fig. 1. Map of speakers' native place.

(3) After preprocessing, a single Excel file was created, which contained a row for each recording id followed by phoneme sequences expected as per the reading material.

4.3 Data verification

The second author listened to the vowel pronunciations in each recording to identify any differences from vowel pronunciation expected as per the reading material. Wherever such difference was noted, the same was captured in the Excel file (referred in section 4.2). This step was critical in identifying and removing unwanted phonemes for the acoustic analysis. Here unwanted phonemes refer to the mispronounced vowels either in their individual occurrences or when occurring in words. The process of data verification further helped in carrying out a detailed analysis of the vowel phonemes substitution process, which is reported in section 4.6. In this process, the mispronounced vowels were compared to the (expected) vowels for possible generalizations and insights regarding the use of vowels among the sample population.

4.4 Data annotation

After verifying the data, each recording file was manually annotated at the phoneme level with Praat software. A sample image of the Praat window is shown in Figure 2. It consists of three parts: the top part represents the speech waveform, the middle part represents the spectrogram, and the bottom part shows phoneme level annotation. We marked the approximate start and end of the phoneme. Each phoneme was labelled according to the IPA notation. A âĂŸsilentâĂŹ label was assigned to the silent part of the recording. The example shown in Figure 2 contains the disyllabic Konkani word aaDsar âĂŸtender coconutâĂŹ pronounced as [a ɖ s ə r]. It is separated by two silent parts (before and after the word) and is made up of five sounds, out of which two are

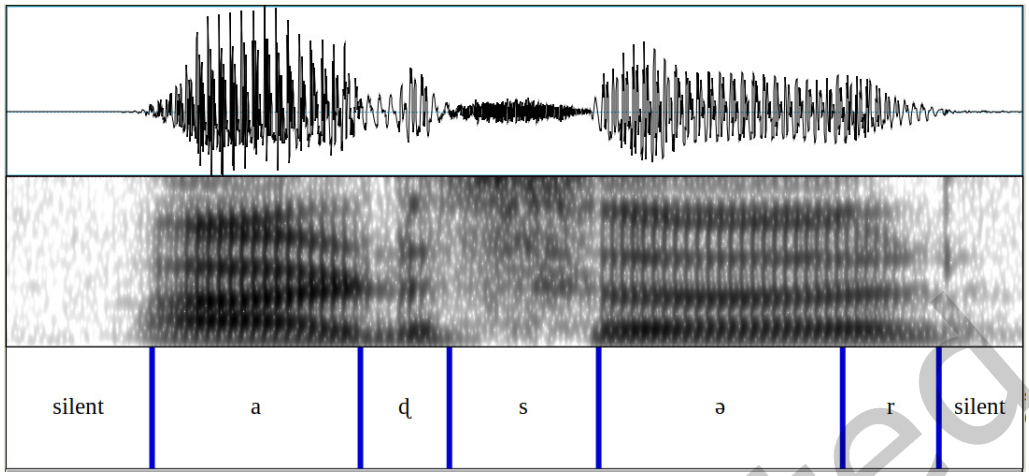

Fig. 2. Phoneme level annotation of recording in Praat.

vowel phonemes. Annotation was based on the phonemes present in the recorded file (i.e. as pronounced by the speaker) and not as per the expected phonemes (i.e. as per the reading material). A total of 4045 phonemes were annotated. Out of these, 1143 phonemes were vowel phonemes. Figure 3 shows the frequency distribution of the vowels present in the recordings. The reason for a higher number of occurrences of the vowe /ə/ is discussed in detail in section 5.

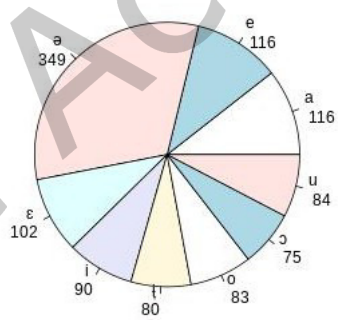

Fig. 3. Frequency distribution of vowels in the dataset.

4.5 Formant extraction

The dataset created by the above process was used for further analysis. The details of the analysis are provided here. Separate folders were created to store the recordings of male and female speakers. Audio files contained the recordings, and the text-grid files contained respective text labels. Both audio and text-grid files were used as inputs to the Praat script for formant estimation. Both the files were given the same name but were stored in different subfolders. The formant values were extracted from the vowel phoneme interval using the Burge

algorithm. The following parameters were set for the algorithm: number of formants to extract=5, frequency for male speakers=5000 Hz, frequency for female speakers =5500 Hz[19]. Formant measurement was taken for a single point in time which is the midpoint between the start and end interval of the label. Since this process had to be repeated for all vowel phonemes in the recordings, we automated this process using a Praat script. The newly created script identified vowel phonemes from the annotations and performed formant extraction from the midpoint of vowel phoneme interval. Praat software was chosen as it gives accurate formant extraction for an adult speech from available softwares[4]. Apart from F1, F2, and F3 formant values, the output file generated by the script also contained speaker id, gender, and vowel label. All the data created for each vowel phoneme was stored in a single text file in Comma Separated Value (CSV) format. Data used in our experimental study can be accessed from the following URL link https://tinyurl.com/yxnk77ox

4.6 Substitution Analysis

This process dealt with analysing vowels produced by the speakers differently from the expected vowels (i.e. those mentioned in the reading material and expected to be articulated so). The process of verification of phonemes (explained in 4.3) showed that the speakers produced some vowel phonemes differently from the way they were expected to be produced. Hence, these substitutions were investigated and classified into three broad categories. Category 1 looked at those cases wherein a totally different vowel phoneme was produced in place of the expected vowel, for example, production of /e/ or /i/ instead of /a/. Category 2 took into account those instances wherein an oral vowel was nasalized, and category 3 considered cases wherein a similar vowel phoneme was substituted in place of the expected vowel, for example, production of close-mid front vowel /e/ instead of the open-mid front vowel /ɛ/; similarly production of the close back vowel /o/ in place of the open back vowel /ɔ/.

5 OBSERVATION AND EXPERIMENTAL RESULTS

The data generated through formant extraction was visualized with the help of an R script. Vowel charts were plotted using the phonR package [11].

Boxplot of F1 and F2 values presented in Figure 4 show maximum variance for the vowel /a/ and a maximum variance for F2 with respect to the vowel /e/. It can also be seen clearly that variance for F2 is the least for back vowels [o, u, ɔ] and maximum for the front vowels /e/ and /ɛ/. Variance is also high for the central vowel /ɨ̞/.

Vowel space for males is smaller as compared to females, and its characteristics are shown in Figure 5. This figure helps in identifying the F1-F2 range for speakers based on gender.

The F1-F2 plot shown in Figure 6 helps in identifying the dispersion of the vowels in vowel space. Three extreme sounds [i, u, a] can be seen occupying three corners. All nine vowels seem to form three distinct groups: front, central and back (see Figure 6). Front vowels can be seen in the left part of the vowel diagram and consist of /i/, /e/, and /ɛ/, and there is no intersection for this category. Central vowels /ɨ̞/, /ə/, and /a/ can be seen occupying the middle part of the vowel chart. We can see some intersection happening with regard to vowels /ɨ̞/ and /ə/. This seems to be due to the centroid of /ə/ being closer to /ɨ̞/. Back vowels /u/, /o/ and /ɔ/ can be seen towards the right part of the vowel diagram.

Figure 7 compares the vowel spread of male and female speakers. We observed that the dispersion of vowels is consistent with the average dispersion in Figure 6. We see more intersections in the F1-F2 plot for female speakers as compared to male speakers.

Table 5 shows the average values for F1 and F2 formants for male and female speakers. We can clearly see that average F1-F2 values for female speakers are higher than those of male speakers.

Results of substitution analysis are presented in Table 6. It presents the frequency and percentage share of total substitutions in all recordings. In this table, we can see that the maximum amount of substitution has occurred for the vowel /ɨ̞/, which was replaced by the vowel /ə/. This is one of the main reasons for a higher frequency of

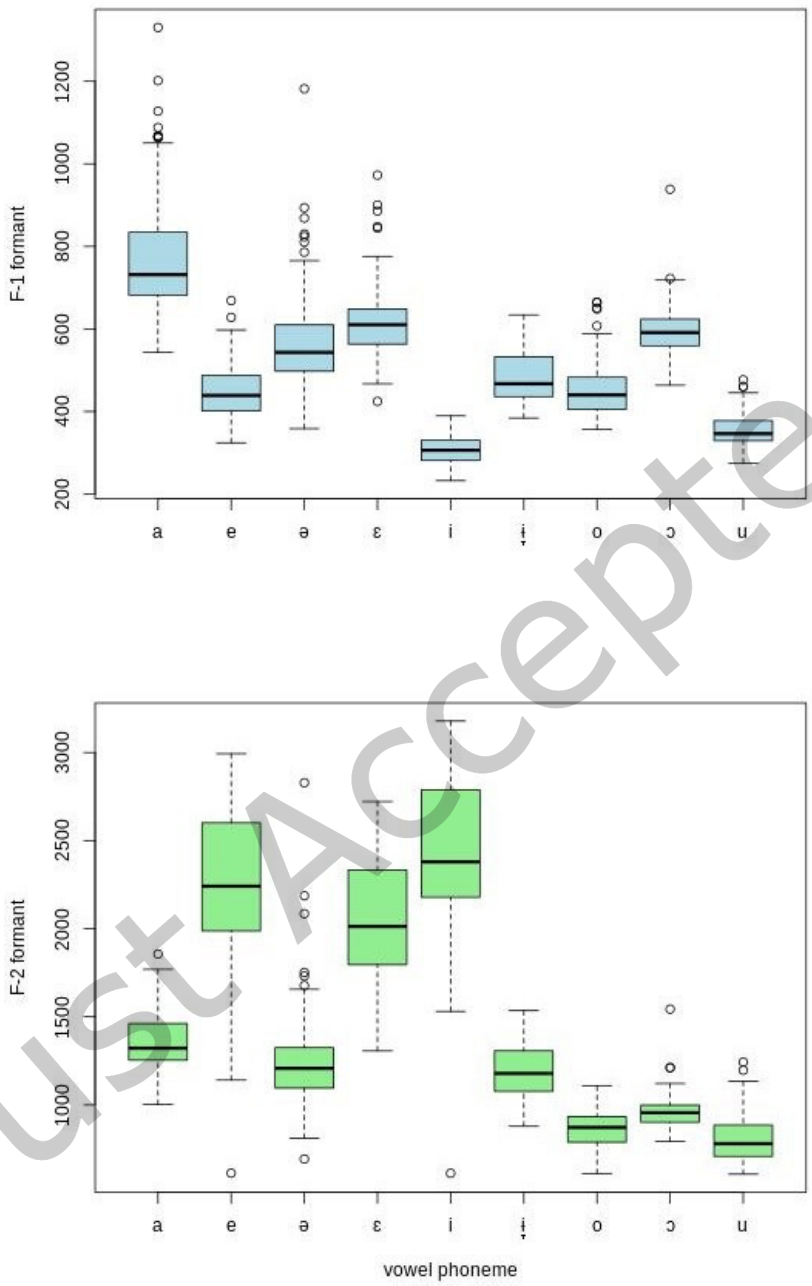

Fig. 4. Box plot for F1 and F2 formants.

/ə/ in the data set. At a few places, /ə/ replaced /ɨ̞/. The second common substitution occurred for /ɛ/ and /e/,

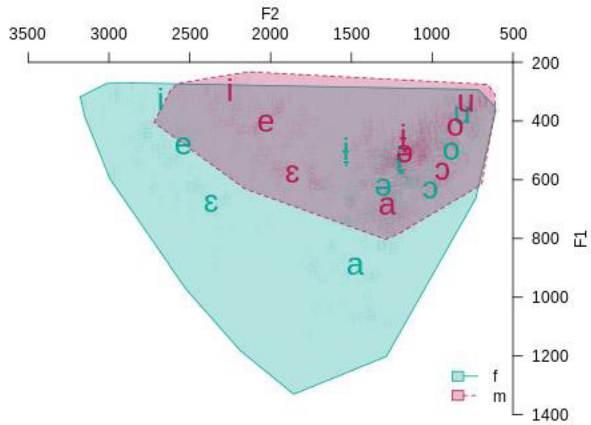

Fig. 5. Vowel space for male and female speakers.

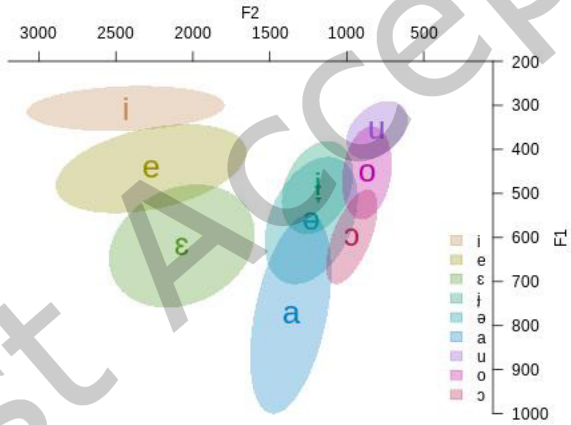

Fig. 6. Vowel chart for Konkani vowels.

which replaced each other. Similarly, /e/ was replaced by /ɛ/. There were no substitutions for /a/ and /i/, and only two substitutions occurred with respect to /u/.

6 CONCLUSION AND FUTURE WORK

Based on literature available on Konkani vowel phonemes, we have tried to categorise and propose a more accurate classification of Konkani vowels. Based on the proposed classification, we have created a dataset to be used for acoustic analysis. We have quantitatively measured all the Konkani vowels, and the same has been presented in the vowel chart (see Figure 6) . We observed that seven Konkani vowels /i/, /e/, /ɛ/, /u/, /o/, /ɔ/, and /a/ are dispersed without much intersection while vowels /ɨ̞/ and /ə/ have the highest intersection. Substitution

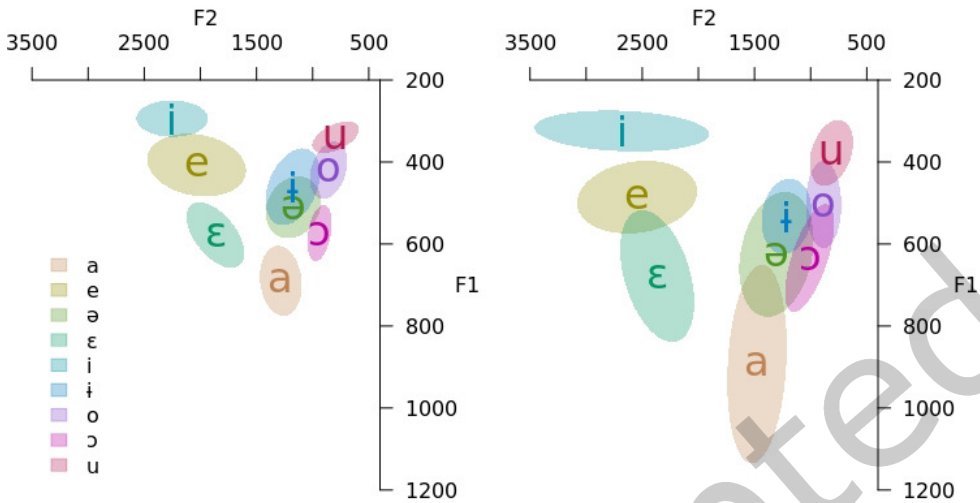

Fig. 7. Vowel chart for male and female speakers.

Phoneme	female F1	female F2	male F1	male F2
i	307	2887	275	2233
e	498	2522	404	1972
ɛ	664	2345	582	1842
ɨ̞	524	1172	470	1122
ə	575	1224	515	1142
a	829	1532	667	1260
u	324	864	342	813
o	507	889	421	867
ɔ	596	997	573	931

Table 5. Average F1 F2 values for Vowel phonemes.

analysis and verification of sounds show that /ɨ̞/ is commonly replaced by the vowel /ə/. The most probable reason for this seems to be vowel shifting (here, shifting of the vowel /ɨ̞/ towards vowel /ə/). Since our data elicitation was concerning pronunciations of individual vowels and in words in isolation, we wish to further refine our work by undertaking elicitation of Konkani vowels in more natural situations (natural speech) and compare the results with those presented herein.

Also, this work does not take into account the nasalised counterparts of the vowels. Since Konkani is a highly nasalised language, it is necessary to study the effect of nasalisation on vowels. Other phonemes like diphthongs and consonants also need to be studied in detail. This study has to be extended systematically in the above direction, only then the entire phoneme to grapheme mapping and vice versa can be provided. This will be covered in our future work.

Phoneme	Substitution	Frequency	% of total substitution
i	None	0	0.0
e	ɛ	13	6.8
ɛ	ə	3	1.6
	ɔu	1	0.5
	ɔ	2	1.1
	e	16	8.4
ɨ̞	ə	102	53.7
	ə̃	4	2.1
	e	6	3.2
	ɛ	2	1.1
	ã	1	0.5
	ə̃m	1	0.5
	a	1	0.5
ə	a	4	2.1
	ɨ̞	10	5.3
a	None	0	0.0
u	o	1	0.5
	ou	1	0.5
o	ou	1	0.5
	əu	1	0.5
	ɔu	2	1.1
	ɔ	3	1.6
	ɔ̃	1	0.5
ɔ	ɔu	2	1.1
	a	5	2.6
	ɛ	2	1.1
	ai	1	0.5
	ə	2	1.1
	o	2	1.1

Table 6. Substitution analysis of vowels and frequency of substitution.

ACKNOWLEDGMENTS

We acknowledge and thank Mr. Ramrao Wagh (Director), Directorate of Digital Learning and Initiative (DDLI), Goa University, for providing access to the Recording Facility. We also acknowledge the help provided to us by Mr. Sachin Sambhaji, Mr. Sachin Patil, Mr. Nitin Patil, Mr. Nandesh Naik and Mr. Veganand Gawas from the Directorate of Digital Learning and Initiative (DDLI), Goa University in the systematic collection of data during all the recording sessions.

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