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Acoustic Analysis of the Liquid Class of Consonant Sounds of Sindhi

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Abstract: Sindhi is widely spoken in the Sindh province of Pakistan, and is one among the officially recognized lngauges of the country. This paper presents the acoustic analysis of the liquid class of consonant sounds of Sindhi language inventory. The entire study is based on the collected voice samples from the native Sindhi speakers. The voice samples recording were made as VCV format. The acoustic analysis and results are mainly based on the three main acoustic parameters determined from the recorded voice samples comprising the liquid consonants of Sindhi. The acoustic waveform and the spectrogram for each sound are generated for the detailed acoustic analysis and discussion. Subtle and major differences among the lateral and trill consonants of the liquid class of consonants are highlighted. The overall obtained results are positive and highly encouraging.

Keywords: Acoustics, Formants, Fundamental Frequency, Liquid Consonants.

1. INTRODUCTION

In this paper the acoustic-phonetic characteristics of the liquid class of consonants are presented. The liquid class of consonant can further be subcategorized as lateral /l/ ل, and a trill /r/ ر of Sindhi. In order to measure the acoustic features of the liquid consonants each phoneme was framed in a VCV (Vowel Consonant Vowel) sequence of phonemes. The voice samples and acoustic analysis is carried out in two ways: first the liquid consonantal phonemes embedded in the word utterance and pronounced as isolated word utterances; and the second is the words embedded in the meaningful language sentences read by speakers as continuous speech. The two way analysis of these sounds enables us to highlight the acoustic variation of these sounds when produced by changing the sounds or the sequence of sounds in the utterances referred to as the contextual variety of these sounds in Sindhi. The two way analysis of these sounds helps to determine the changing acoustic behavior of the consonants when vocal tract configurations are set to produce only the target analysis phoneme part of the isolated word utterance and when the vocal tract configurations are set to produce the next utterance once the production of the target phoneme is finished part of the carrier sentence. The main reason for this two way analysis is when the vocal tract configurations are set to produce only the target analysis phoneme; there is enough time for the moving articulators to produce the utterance and come back to the normal position. Whereas in continuous speech the articulators when they produce one utterance cannot move quickly to come back to the normal position and quickly move for the production of the next utterance in sequence. Therefore the most significant acoustic difference between the two types of speech signals is the duration; however the other differences are also observed and are discussed in the subsequent sections of this paper. The main acoustic parameters mean values and the standard deviation for each liquid class of the consonantal phonemes is given in table I. The history of phonetic research of the consonantal phonemes of Sindhi shows that these sounds have been studied so far on the basis of the available articulatory-phonetics knowledge which refers to the work of authors (Jatoi, 1996; Jennifer, 2006; Raza, 2004). To the best of our knowledge and literature survey there is no evidence that the acoustic-phonetics based knowledge of these sounds has been incorporated for the identification and classification of these sounds phonetically. The importance of the acoustic-phonetic features has been widely accepted in determining the place of articulation and the voicing feature of the consonant sounds in phonetics (Ali, 2001; Zue, 1979). This work incorporates the obtained acoustic-phonetic features of the liquid consonants in addition to the available articulatory-phonetics knowledge for their identification and classification.

The lack of such a study that comprehensively presents the acoustic-phonetic analyses of the liquid consonant sounds provides the motivation to conduct this research. The consonant sounds that share some common articulatory characteristics are grouped in one natural class i.e. the stops and nasals. Keeping in view the fact that the consonant sounds that are the members of one natural class share some common articulatory as well as the acoustic-phonetic characteristics (Olive, 1993; Kent, 2002; Stevens, 2000). The main acoustic parameters measured for each consonant of liquid class are: the fundamental frequency, formant frequencies, duration, and the energy etc.

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2. MATERIALS AND METHODS

The geographical region selected for the study is the Sindh province of Pakistan. Voice samples were recorded from the ten native male speakers of Sindhi. At least ten instances of each utterance were made for the subsequent process. The speakers for the voice sample recording were selected as Sindhi literate having no any speaking disorder. The target liquid consonant was embedded in word utterance as VCV sequence of phonemes and recording was made as isolated word utterance and the word part of the carrier sentence read by speakers. A Digital Audio Recorder used with an external microphone for the voice sample recording. Voice samples were recorded as single channel (mono mode) and stored as uncompressed .wav files for subsequent offline processing.

3. RESULTS

3.1 Liquid consonants of Sindhi

The lateral class of sound /l/ ل, and a trill class of sound /r/ ر, in Sindhi are jointly referred to as the liquid consonants of Sindhi (Keerio, 2010). Phonetically liquid consonant sounds are referred to as the frictionless speech sounds as these sounds are produced with a partial constriction in the vocal tract (Olive, 1993). Both liquid consonants of Sindhi are articulated at one place of articulation referred to as the alveolars; when the tip of the tongue touches the alveolar ridge in such a way (centered) so that the air passes through the two sides in mouth in this way the lateral sound /l/ of Sindhi is produced and when the tip of the tongue loosely touches the alveolar ridge, allowing the air stream to flow over the middle of the tongue rather than the sides; the air passage in this way causes vibration at the tip of the tongue and produces the trill sound /r/ of Sindhi. Two voicing characteristics are associated with liquids of Sindhi, these are: (i) if they appear at word medial or initial position, they are considered voiced phonemes and (ii) unvoiced if they appear at word final position. This section mainly presents the acoustic-phonetic analysis of the liquid consonants of Sindhi.

3.2 Acoustic analysis of alveolar trill /r/ ر

Fig. 1 below shows four waveforms of the trill sound /r/ ر, of Sindhi extracted manually from the isolated word utterances and the words embedded in a carrier sentence read by native Sindhi speakers. The four waveforms are shown for trill /r/ because it varies acoustically when produced within isolated word utterances and when produced as a phrase medially. This sound also showed varying acoustic features when followed by a short or a long vowel in the utterance. These differences are highlighted in the four waveforms of this sound. Fig 1(a) is the waveform extracted from the word utterance /dərə/ در embedded in a carrier sentence read by speakers. The waveform shows the slow varying periodic signals for a very short duration with relatively small amplitude of the modulation signal for the segment of the trill sound /r/ in the word utterance. This difference of the sharp drop in the amplitude of the signals and the presence of the weak energy for a very short duration can be seen in the waveform and spectrogram of Fig. 2 for the word utterance /dərə/ در. The speech signals of /r/ sound do not repeat when the vocal tract configurations are to be set for the production of the next sound in a sentence; this is shown in the waveform of the Fig. 1(a) and 2. Fig.1(b) shows another variation of this sound when produced within the isolated utterance of the word /sərə/ سَر of Sindhi. When the vocal tract configurations are not required to be set for the production of the next sound and hence the vocal tract configurations are only set and end with the trill sound /r/; the repeated occurrence of this sound signals are observed in the speech waveforms this is shown in the **(Figs. 1(b) and 3)**. The mean duration for the trill sound /r/ in the utterances where speech signals for this sound do not repeat is 0.0256 seconds, whereas the mean duration in the utterance where /r/ sound signals are repeated is 0.018sec for the first occurrence and 0.015sec for the second occurrence of the /r/ sound signals.

The second occurrence is uniformly observed smaller in duration compared to the duration of the first occurrence of signals for this sound. The waveform shown in Fig 1(c) which shows another variation of this sound, the three consecutive occurrences of the /r/ sound signals when produced within the word utterance /dərʊ/ درُ in isolation. The three repetitions of this sound are very rarely observed; only two out of ten speakers have produced such /r/ sound where three occurrences are observed this is shown in the waveforms of Fig1(c) and 4 for the word utterance /dərʊ/ درُ. However the two occurrences of the /r/ sound signals were observed among the utterances of seven speakers out of ten.

The analysis results show that when the trill sound /r/ is followed by a short vowel and the word utterance ends with this combination (the /r/ sound followed by a short vowel) then the repetitive occurrence of the /r/ sound signals can be seen in the speech wave. This is due to the fact that the tip of the tongue continues vibrating until the articulators are relaxed to the normal position; because the articulators are not required to move for the production of the next sound. Fig 1(d) shows the waveform of the /r/ sound followed by a long vowel in the word utterance /sɑro/ سارو of Sindhi. The trill sound /r/ if followed by a long vowel then the repetitive occurrence of the /r/ sound signals do not happen in either case; whether this sound is produced within the isolated word utterance or it is

produced within a carrier sentence this is shown in the waveforms **of (Fig. 1(d) and 5)**

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Another difference observed for the trill sound /r/ compared to the other consonants of Sindhi is that it does not exhibit formant discontinuities at the vowel junctures (the formant transitions coming into the trill sound /r/ from the preceding sound and going away from it to the following sound); rather the transitions are more continuous at the vowel junctures for trill sound compared to the highly constricted consonant phonemes such as fricatives and stops (Olive, 1993; Zhou, 2008).

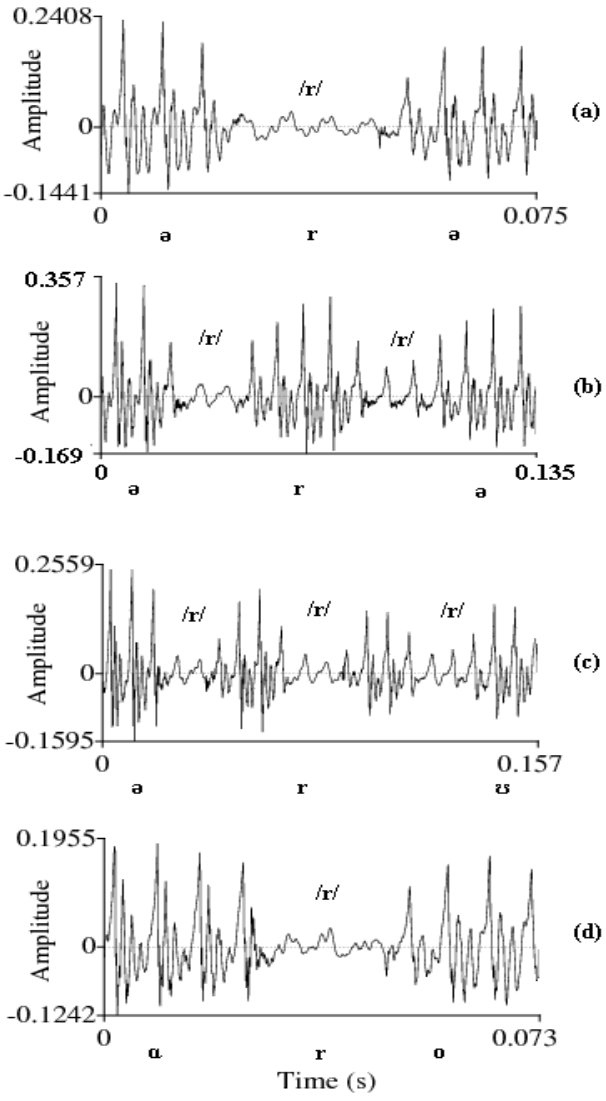

Fig. 1 Four waveforms of the trill consonant /r/ of Sindhi (a) waveform extracted from the word utterance /dərə/ در , embedded in a carrier sentence (b) waveform extracted from the the isolated utterance of the word /dərə/ در (c) waveform extracted from the isolated utterance of the word /dərʊ/ درُ (d) waveform extracted from the word utterance /sɑro/ سارو , embedded in a carrier sentence.

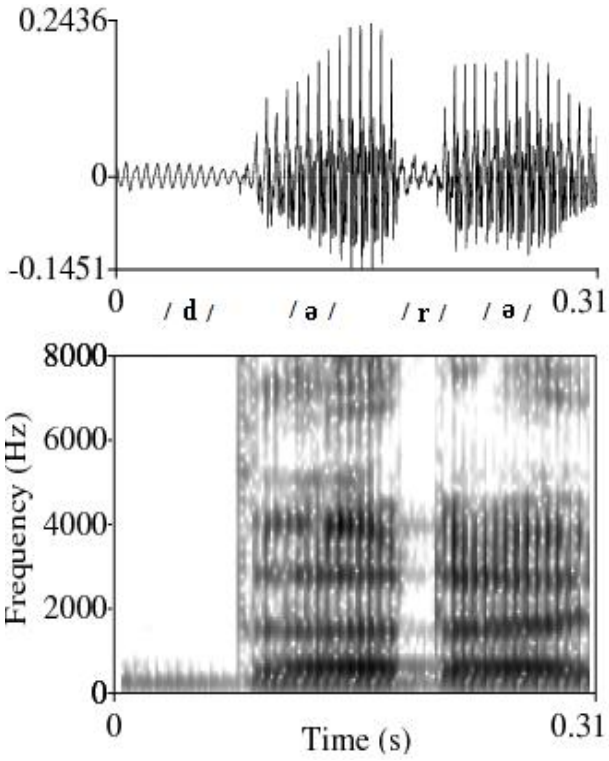

Fig. 2 Waveform and the spectrogram of the word utterance /dərə/ در , embedded in a carrier sentence.

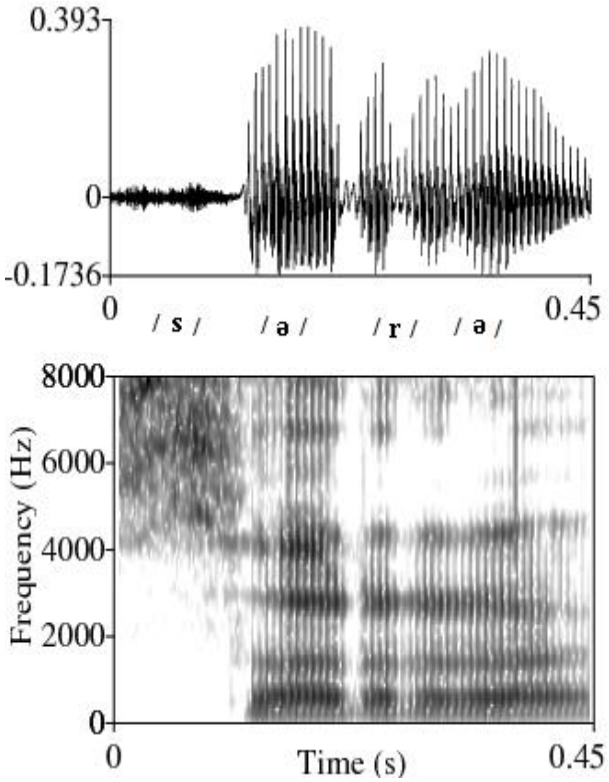

Fig. 3 Waveform and the spectrogram of the word utterane /sərə/ سَرَ, of Sindhi pronounced in isolation.

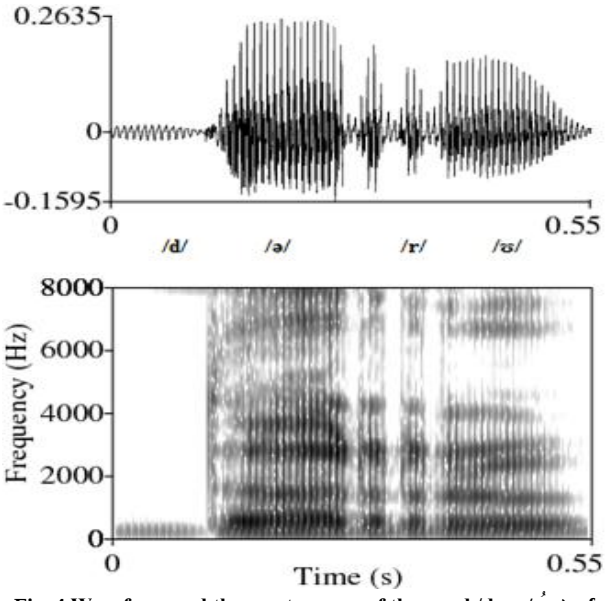

Fig. 4 Waveform and the spectrogram of the word /dərʊ/ دُ ر of Sindhi pronounced in isolation.

Table I. Mean and standard deviation of the acoustic parameters: F0, first four formants and duration of the Liquid consonants of Sindhi.

Liquid Consonants	/r/ ر		/l/ ل	
Parameter	Mean	STD	Mean	STD
Duration	0.0256	0.046	0.091	0.055
F0	149	7	130	0.72
F1	495	21	350	5
F2	1584	138	1550	33
F3	2841	61	2952	52
F4	3744	206	3785	90
Intensity (dB)	64	--	63	--

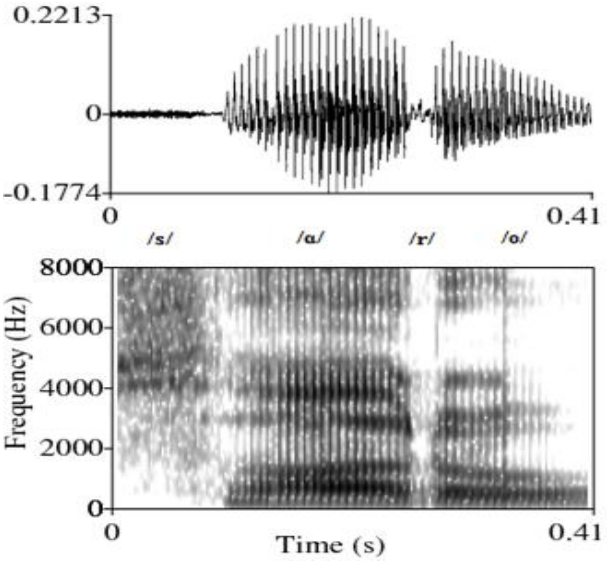

Fig. 5 The waveform and the spectrogram of the word /sɑro/ سارو of Sindhi embedded in a carrier sentence.

3.3 B Alveolar lateral /l/ ل

Fig. 6 below shows the waveform and spectrogram of the lateral liquid consonant /l/ of Sindhi present in the word utterance /kələ/ ڪلَ. The lateral sound /l/ shows a vowel like waveform, formant transitions and the presence of energy across wideband spectrogram including the presence of energy in the lower frequency range usually seen for vowels (Keerio 2014). The slow varying periodic signal activity at the word medial position in the utterance of word /kələ/ ڪلَ, confirm this sound a voiced phoneme of Sindhi. I.

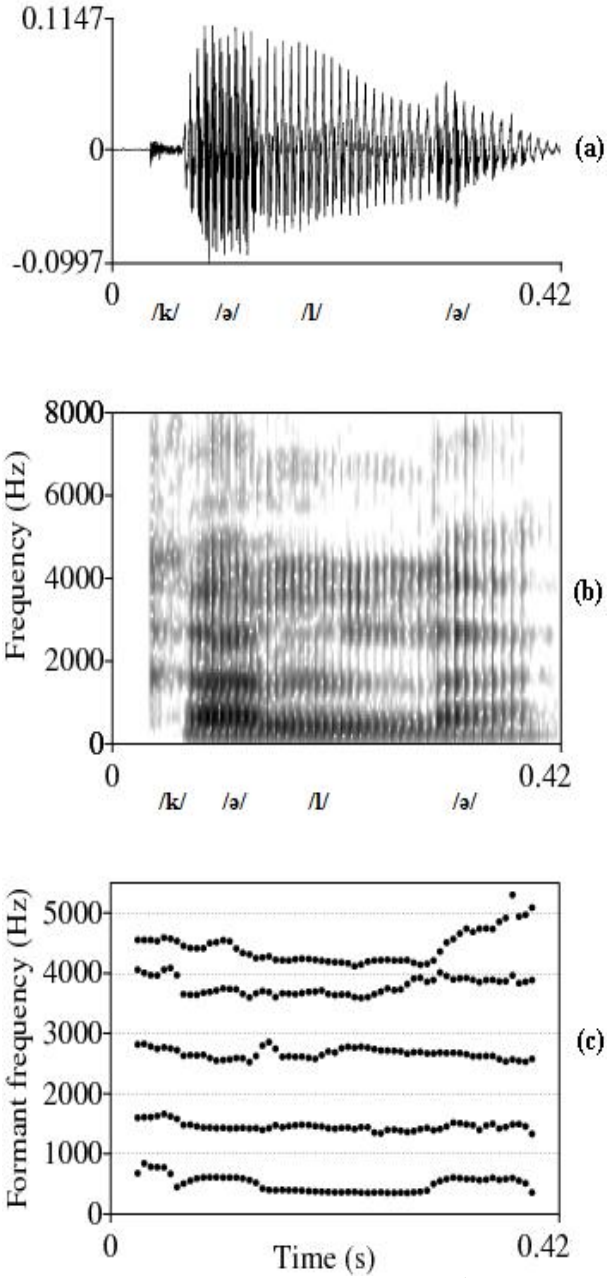

Fig. 6 (a) Waveform of the word utterance /kələ/ ڪلَ, containing the lateral phoneme /l/ of Sindhi, (b) the spectrogram and (c) the formant tracks.

The liquid /l/ has a formant configuration with a low F1; therefore the F1 motion for this sound is downward (the transitions coming into the lateral /l/ from the preceding sound) and the upward motion (for the transitions going away from it to the following sound). The lateral consonant /l/ has shown stable both F1 and F2 values and can be used for the identification of this sound like the vowels and diphthongs of Sindhi (Keerio 2011, Keerio 2014). One special acoustic property observed for the liquids of Sindhi is their occurrence at word final position make them voiceless sounds as the trill sound /r/ ر , at the final position in the word /sətər/ سَتَر, and the lateral sound /l/ ل , at the final position in the word /ədəl/ عَدل. The mean acoustic parameter values for the two liquids of Sindhi are given in Table I.

4. CONCLUSION

A thorough acoustic-phonetic analysis of the liquid consonantal phonemes of Sindhi is presented. It was observed that the acoustic properties of the liquid class of consonants are a bit difficult to identify and segment. The trill /r/ is bit typical liquid phoneme of Sindhi in a sense that it showed variant acoustic properties when followed by a short vowel and when followed by long vowel. It also showed different acoustic behaviour when utterd in isolation at word final position and word part of carrier sentence. The repeated occurece is witnessed for this sound when produced at word final position and followed by a short vowel otherwise the repeated occurece is not seen. It also showed formant continuities at vowel junctures if surrounded by the sononrant sounds (such as vowels in vcv format). However weak enegy is observed for the duration of trill /r/ sound in the spectrogram. The lateral /l/ of Sindhi showed vowel like acoustic characteristics such as periodic waveform and stable formant frequencies with presence of strong energy for the first two formants. The lateral /l/ also showed greater duration compared to the trill /r/ of Sindhi. It is also observed that in terms of articulatory phonetics the one one natural class of consonant sounds share some common acoustic phonetics characteristics but the laterl /l/ and trill /r/ class of liquid consonants in Sindhi possess difference in the acoustic properties of the two sounds.

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