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ACOUSTIC REALIZATION OF /s/ ACROSS ACCENTS OF URDU

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ABSTRACT

This study investigates acoustic characteristics that distinguish three Urdu accents spoken predominantly in Punjab: Pothowari, Multani, and Jhangochi. We examined four spectral moments—center of gravity (CoG), standard deviation (SD), skewness, and kurtosis—of the fricative /s/ to identify acoustic variations between these accents. 1200 /s/ tokens were annotated from a spontaneous speech corpus, focusing on 10 speakers per accent (5 male, 5 female), with 40 tokens per speaker. The results reveal distinct ordering of accents by CoG values, along with notable patterns in SD, skewness, and kurtosis, offering deeper insight into accent-based differences. Additionally, our findings demonstrate gender-specific changes in the energy trajectories of the fricative within each accent. These findings contribute to a better understanding of Urdu's phonetic diversity and have broader implications for speech processing, sociolinguistics, and practical applications such as accent recognition in speech technologies.

Index Terms— fricative, accent, center of gravity, kurtosis, skewness

1. INTRODUCTION

Urdu is the official language of Pakistan. It is the native language of about 70 million people and a second language for more than 100 million people, primarily in Pakistan and India [1]. Its language diversity reflects the unique fabric of cultural traditions and historical influences that dominate the region. The contact between Urdu and Punjabi is reciprocal in Pakistan, with each language influencing and being influenced by the other. Punjabi, an Indo-Aryan language, is spoken globally, particularly in the province of Punjab, Pakistan, and in the Indian state of Punjab. It is one of the most widely spoken native languages in the world with approximately 113 million native speakers [2]. It exhibits diverse dialects influenced by various geographical regions. Among these, Multani, Jhangochi, and Pothowari are prominent variants of Punjabi in Pakistan due to regional influence. Each accent carries its phonetic characteristics and sociolinguistic significance. The current study aims to investigate the variability present within these accents in the production of /s/.

Many researchers identify the importance of fricative sounds in accent identification and linguistic variation [3]-[6]. Most of the studies focused on single language variety such as Korean [7] and English [8]-[10]. /s/ as one of the voiceless alveolar fricatives is considered significant in accent classification [11]. When produced, the /s/ sound involves turbulent airflow through a narrow constriction in the vocal tract, resulting in a spectrum of acoustic features that vary across speakers and accents [11]. These acoustic properties, including spectral moments such as the center of gravity (CoG), standard deviation (SD), skewness, and kurtosis, serve as crucial markers for differentiating between accents and understanding the underlying phonetic processes [3], [6]. Previous studies on acoustic gender and accent variation have reported that female speakers show higher values in terms of peak frequency and center of gravity [9], [12]-[15]. Some other studies show that skewness is also another factor in identifying gender variation [12], [16], [17]. Among all the fricatives, the most prominent speakers and accent variations were shown by /s/ [13], [18]. Additionally, some other studies presented that the spectral moments show ques of discriminating speakers in /s/ and /f/ [19].

Recent research has shown that dialectal factors have a major impact on the acoustic properties of fricatives. One such study [3] compared the phonological properties of Athenian and Cypriot Greek. Voiced and voiceless dental, alveolar, palatal, and velar fricatives from female speakers of both dialects were the main focus of this study. It was discovered via spectral moments analysis that all locations of articulation in the two dialects had different spectral characteristics for fricatives. These results highlight the role that dialect plays in influencing fricatives and offer important new understandings into the ways in which dialectal information can be encoded in small changes in speech production.

While previous research on accent variation in Urdu has primarily focused on segmental features like vowels and consonants [20], [21], exploring /s/ sound offers a unique perspective into the intricate nuances of accentual diversity. Studying how the spectral characteristics of the /s/ sound vary across Pothowari, Multani, and Jhangochi, Pothowari accents can provide valuable insights into the phonetic landscape of Urdu and shed light on the complex interplay between language, culture, and identity.

Furthermore, the influence of gender on accent variation adds another layer of complexity to the analysis. Gender-based differences in speech production have been documented in various languages, with studies highlighting differences in vocal tract dimensions, articulatory gestures, and acoustic properties [22], [23]. Investigating how gender interacts with accent variation in Urdu fricatives can offer deeper insights into the sociolinguistic dynamics of the region and provide a more comprehensive understanding of phonetic variation.

Accent and gender variations in the articulation of the fricative /s/ in three English accents: London, Cambridge, and Belfast were observed in [6]. By using multilevel modeling, the authors reported significant differences in the dynamic acoustic characteristics of the alveolar fricative /s/ among accents. They also observed significant gender differences in the trajectories of fricative energy metrics within each dialect group. The study supported the significance of taking a dynamic approach to sociophonetic acoustic variability in understanding the interaction of gender and accent in English fricative realization.

Similarly, an examination of adult speakers of English found consistency in differentiating between /s/ and /ʃ/ based on spectral mean, but not spectral skewness [4]. These findings contrasted with group-level data comparisons, emphasizing the relevance of investigating individual speech patterns in both theoretical and clinical research contexts. Examining time history plots across multiple productions emerges as a viable speakers-centered analysis tool because of its capacity to capture dynamic changes and convey both the consistency and amplitude of the distinction.

Unless of the documented studies, no specific study regarding the /s/ spectral analysis across different accents and genders of Urdu spoken in Punjab has been observed. Our study hypothesizes that spectral analysis of the /s/ sound will uncover the substantial differences across various accents and genders of Punjabi Urdu.

2. METHODOLOGY

2.1. Data Selection

For the current study, we have used the spontaneous speech Urdu corpus recorded at different locations in Punjab Pakistan. Table 1 presents accents and their respective locations in Punjab, Pakistan. For recordings, speakers were questioned about different topics in Urdu related to childhood, favorite food, friends, sports, hobbies, etc. Demographic information such as age, gender, region, and native language was also gathered for each speaker. All audios were recorded on a sampling rate of 16kHz using USB headsets (HS), hands-free, and laptop microphone. Data was recorded in both indoor and outdoor environments. Only HS speakers were used for the analysis as the speech signal was noise free for HS. 5 males and 5 females from each accent were selected and 40 /s/ tokens of each speaker were extracted. The data was collected from university students whose ages range from 18-25 years. Specifically, all speakers were from middle-class families, and bilingual in Punjabi and Urdu.

Table 1: *Accents and their locations*

Sr. no	Accent	Location
1.	Multani	Multan
2.	Pothowari	Rawalpindi
3.	Jhangochi	Jhang

2.2. Data annotation

The first author, an expert linguist, manually annotated the fricative boundaries in accordance with the rules and guidelines outlined by Skarnitzl and Machac [24]. The second author checked the boundaries of the annotated corpus to maintain consistency and discrepancies were resolved with discussion. The */s/* boundaries have been marked very carefully as the spectrogram features have been analyzed for each speaker. The /s/ tokens having the strong influence of neighboring consonants or the less visible /s/ have not been selected. E.g., *stops* preceded by */s/* have not been selected as a strong coarticulatory effect has been observed in this case. As a result, 10 speakers from each accent and 35 tokens from each speaker were kept for further analysis.

2.3. Analysis

2.3.1 Spectral moment extraction

We used a Praat script [25] to calculate the four spectral moments. The script analyzed the middle 80% of the total duration of the fricative by excluding 10% from each side. Then the first four spectral moments that correspond to the CoG, SD, skewness, and kurtosis were calculated from the fricative spectra. The CoG, also known as the spectral centroid, measures the average energy concentration of fricatives. It denotes the average frequency at which the energy of the fricative sound is dispersed over the frequency range. SD is a measure of how far spectral values deviate from the CoG. It represents the distribution or dispersion of spectral energy around the spectral centroid. A higher SD indicates a greater spread of spectral energy, whereas a smaller SD indicates a more concentrated energy distribution. Skewness measures the shape of the spectral distribution. A positive skewness indicates a right-tailed distribution, which means the right side has a longer tail than the left. In contrast, a negative skewness indicates a left-tailed distribution, with a longer tail on the left side. The Kurtosis measures the distribution's shape, indicating how heavy its tails are. A positive kurtosis indicates that the distribution has heavier tails and a sharper peak, whereas a negative kurtosis indicates a flatter distribution with lighter tails. Kurtosis in the context of fricatives reveals the concentration of energy around specific frequencies as well as the overall shape of the spectral envelope.

2.3.2 Statistical analysis

A linear mixed effects analysis was conducted by using the lme4 package in R. The CoG, SD, skewness, and kurtosis were employed in the model as response variables. The dialect and gender were employed in the model as fixed factors. Random intercepts for speakers were added to the models. The values of duration and intensity were also extracted during analysis but were not added for statistical analysis as no specific variations have been observed.

3. RESULTS

3.1. Comparing mean values across genders within accents

For the female speakers in the Jhangochi accent, the CoG is approximately 4,463.8 Hz and for male speakers it is 3,833.7 Hz.

For the male speakers in the Jhangochi accent, the CoG is slightly lower suggesting a shift towards lower frequencies compared to the female speakers. For the female speakers, the SD is around 2,178.1 Hz, indicating a relatively wide spread of frequencies. For the male speakers, the SD is slightly lower at approximately 1,755.88 Hz, suggesting a narrower spread of frequencies compared to the female speakers. For the female speakers, the skewness is approximately -0.61, indicating a slight skew towards higher frequencies. For the male speakers, the skewness is slightly less negative at approximately -0.303, suggesting a less pronounced skew towards higher frequencies compared to the female speakers. For the female speakers, the kurtosis is around -0.01, suggesting a relatively flat distribution of frequencies. For the male speakers, the kurtosis is notably higher at approximately 1.34, indicating a more peaked distribution of frequencies compared to the female speakers. Table 2 elaborates mean values across genders and accents.

Table 2: *Mean values across genders and accents*

Accent	CoG	SD	skew-ness	Kurt-osis	Gender
Jhangochi	4,463.8	2,178.1	-0.61	-0.01	Female
	3,833.7	1,755.8	-0.30	1.34	Male
Multani	4,878.8	1,447.6	-0.82	3.24	Female
	4,739.8	1,605.4	-0.74	2.52	Male
	5,322.0	1,423.0	-1.13	2.86	Female
Pothowari	4,913.9	1,304.4	-0.57	3.26	Male

The CoG of the spectrum for the female speakers of Pothowari, 5322.0, is higher than that of the male speakers, 4913.9. The SD of the spectral distribution for the male speakers, 1304.4, is slightly lower than that of the female speakers, 1423.0. This suggests that the spectral components of the male speakers' speech may be more concentrated around the mean compared to the female speakers. The skewness of the spectral distribution for the male speakers, -0.57, is closer to zero compared to that of the female speakers, -1.13, indicating a more symmetrical distribution of spectral components for the male speakers. The kurtosis of the spectral distribution for the male speakers, 3.26, is slightly higher than that of the female speakers, 2.86, suggesting that the spectral components of the male speakers' speech may have heavier tails compared to the female speakers.

For Multani, the mean value for CoG is 4878.8 for females and 4739.8 for males. This suggests that, on average, female speakers have a slightly higher COG value compared to male speakers in the Multani accent. The mean value for SD is 1447.6 for females and 1605.4 for males. This indicates that, on average, male speakers have a slightly higher spread or dispersion of spectral values around the CoG compared to female speakers in the Multani accent. The skewness value is -0.82 for females and -0.74 for males. Both values are negative, indicating a left-tailed distribution of spectral values for both genders in the Multani accent. However, the skewness is slightly more pronounced for females compared to males. The kurtosis value is 3.24 for females and 2.52 for males. Both values are positive, indicating that the distribution has heavier tails and a sharper peak. However, the kurtosis value is slightly higher for females compared to males in the Multani accent. Overall, females have higher CoG across all accents.

3.2. Linear mixed model analysis

3.2.1 Gender

To analyze the gender effects, a model was estimated for each accent. For the model, gender was employed as a fixed factor and four spectral moments were employed as response variables. Table 3 presents results from linear mixed effect models across genders and accents.

Table 3: *Comparison of spectral moments across genders and accents using linear mixed effect models*

		Estimate	SE	t value	p value
CoG	Jhangochi:F	4,428.6	396.8	11.16	0.001
	Jhangochi:M	4,410.6	512.1	8.61	0.001
	Multani:F	5,273.7	318.2	16.57	0.001

	Multani:M	3,727.5	318.3	11.71	0.001
	Pothowari:F	5,558.5	275.2	20.2	-
	Pothowari:M	4,913.4	275.6	17.83	-
SD	Jhangochi:F	2,250.6	158.3	14.21	-
	Jhangochi:M	1,943.9	204.4	9.51	-
	Multani:F	1,778.2	93.56	19.01	-
	Multani:M	1,780.3	93.62	19.02	-
	Pothowari:F	1,341.5	122.2	10.97	-
	Pothowari:M	1,304.7	122.4	10.66	-
skewness	Jhangochi:F	-0.54	0.26	-2.09	0.04
	Jhangochi:M	-0.39	0.33	-1.15	0.2
	Multani:F	-1.22	0.24	-5.12	0.002
	Multani:M	-0.14	0.24	-0.60	0.546
	Pothowari:F	-1.41	0.29	-4.92	0.001
	Pothowari:M	-0.57	0.29	-2.00	-
kurtosis	Jhangochi:F	-0.002	0.61	-0.01	0.9
	Jhangochi:M	0.735	0.79	0.93	0.3
	Multani:F	2.28	0.71	3.19	0.01
	Multani:M	0.43	0.71	0.6	0.54
	Pothowari:F	4.97	2.96	1.68	0.1
	Pothowari:M	5.36	2.99	1.79	0.1

Significant variations in CoG were found between male and female speakers within each accent category (Jhangochi, Multani, and Pothowari). In the Jhangochi accent, male and female speakers had considerably different CoG values, with females showing slightly higher values than males. Similarly, in the Multani accent, females had much higher CoG levels than males. The Pothowari accent showed substantial differences, with females having higher CoG values than males.

There were substantial variations in SD between male and female speakers within each accent category. Females had higher SD values than males in the Jhangochi, Multani, and Pothowari accents, indicating greater acoustic frequency diversity among female speakers.

The Multani and Pothowari accents differed significantly in terms of skewness. In the Multani accent, females had much higher negative skewness than males, indicating a more extreme asymmetry in the distribution of acoustic components among female speakers. Similarly, in the Pothowari dialect, females had much larger negative skewness than males.

In terms of kurtosis, the Multani accent showed considerable variances, with females having significantly greater kurtosis values than males. This implies a more pronounced distribution of acoustic traits among female Multani speakers. Male and female speakers did not show significant differences in kurtosis in the Jhangochi and Pothowari dialects.

Overall, the analysis finds considerable gender-related differences in acoustic across different accents, with females frequently demonstrating distinct patterns from males. These findings highlight the importance of taking gender into account when identifying and analyzing accents. Gender based variations are presented in Figure 1.

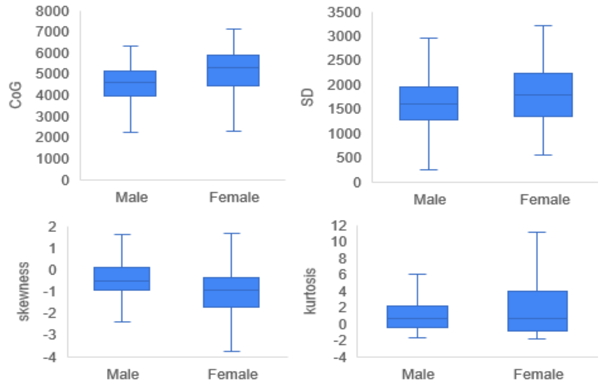

Figure 1: *Gender-based variations across 4 spectral moments*

3.2.2 Accent

The estimates for CoG SD, skewness, and kurtosis were analyzed across three different accents: Jhangochi, Multani, and Pothowari. The results indicate significant differences in acoustic features between the accents. CoG showed considerable variances across all three accents. Pothowari speakers had the highest CoG values, followed by Multani, and finally Jhangochi. It demonstrates that speakers of these dialects have different central tendencies for acoustic frequencies. Furthermore, the differences were statistically significant, with p-values less than 0.001 for each comparison. Table 4 presents results from linear mixed effect models across accents.

Table 4 *Comparison of spectral moments across accents using linear mixed effect models*

		Estimate	SE	t value	p value
CoG	Pothowari	5,236.4	274.3	19.09	0.001
	Jhangochi	4,421.0	307.0	14.4	-
	Multani	4,500.6	274.3	16.41	-
SD	Pothowari	1,323.2	86.62	15.28	-
	Jhangochi	2,134.9	97.06	22	-
	Multani	1,779.4	86.63	20.54	-
skewness	Pothowari	-1.00	0.22	-4.85	-
	Jhangochi	-0.48	0.25	-1.94	0.05
	Multani	-0.68	0.22	-3.08	0.002
Kurtosis	Pothowari	5.16	1.26	4.088	0.001
	Jhangochi	0.28	1.43	0.196	0.8
	Multani	1.36	1.26	1.07	0.2

There were considerable disparities in SD among the accents. Jhangochi speakers had the highest SD values, followed by Multani, and finally Pothowari. This demonstrates differences in the distribution of acoustic frequencies within each accent group. All accent comparisons showed statistically significant differences (p-values < 0.001).

There were substantial variations in skewness between accents. Pothowari speakers had the largest negative skewness, followed by Multani and Jhangochi. This shows that the distribution of acoustic elements varies asymmetrically among speakers of various accents. The differences were statistically significant, with p-values less than 0.05 for all accent comparisons except Jhangochi vs. Multani.

Kurtosis showed significant differences between accents. Pothowari speakers exhibited the greatest kurtosis values, indicating a more peaked distribution of acoustic characteristics, followed by Multani, and finally Jhangochi. Pothowari vs. Jhangochi and Pothowari vs. Multani comparisons showed statistically significant differences (p-values < 0.001).

In conclusion, the study identifies significant acoustic characteristics among speakers with various accents. These findings have implications for identifying accents and comprehending acoustic diversity among linguistic varieties. Accent-based variations are presented in Figure 2.

4. DISCUSSION

Significant gender-based variations in the acoustic features among the accents under study were revealed by our investigation. Interestingly, all four spectral moments yielded significant differences between male and female speakers within each accent group. For instance, there were notable gender differences in skewness between the Pothowari and Multani accents, with female speakers exhibiting greater negative values than male speakers. Significant gender-based variations in the acoustic features among the accents under study were revealed by our investigation. Notably, all four spectral moments—Center of Gravity (CoG), Standard Deviation (SD), skewness, and kurtosis—demonstrated substantial differences between male and female speakers within each accent group.

The CoG for female speakers across all accents was generally higher compared to their male counterparts. For instance, in the Jhangochi accent, the CoG for female speakers is approximately 4,463.8 Hz, whereas for male speakers it is 3,833.7 Hz. This higher CoG value in female speakers suggests a shift towards higher frequencies, which could be attributed to anatomical differences such as vocal tract length and resonance characteristics.

Female speakers exhibited higher SD values, indicating a wider spread of frequencies. In the Jhangochi accent, the SD for female speakers is around 2,178.1 Hz, while for male speakers it is approximately 1,755.88 Hz. This implies greater variability in frequency distribution among female speakers, potentially due to differences in articulatory precision.

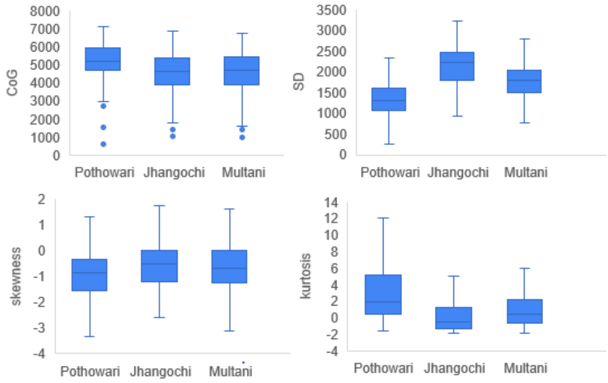

Figure 2: *Accent-based variations across 4 spectral moments*

Skewness: The skewness for female speakers was generally more negative, indicating a skew towards higher frequencies. For instance, in the Pothowari and Multani accents, female speakers show greater negative skewness compared to male speakers.

Kurtosis: Female speakers showed lower kurtosis values compared to males, suggesting a flatter distribution of frequencies. For example, the kurtosis for female speakers in Jhangochi is approximately -0.01, whereas for males it is around 1.34. This difference could be related to how frequently extreme spectral components occur in male versus female speech.

All the observed differences may be due to gender-specific articulatory mechanisms, sociocultural impacts, or a mix of anatomical and sociolinguistic factors [6]. This result reflects variations in how male and female speakers' articulate fricatives and other speech sounds. The results of this study indicate that gender is a significant factor in determining the acoustic characteristics of speech in a variety of linguistic contexts [22], [23], [26].

In addition to gender-based variations, significant differences were observed across accents. Pothowari speakers had the highest CoG values, followed by Multani, and then Jhangochi. This indicates that speakers of these accents have different central tendencies for acoustic frequencies. Pothowari speakers also exhibited the largest negative skewness and highest kurtosis values, reflecting a more pronounced and peaked distribution of acoustic characteristics compared to other accents. These accent-based differences underscore the importance of considering linguistic variety in acoustic analyses. The substantial variations in spectral features across accents suggest that accent-specific articulatory and acoustic properties play a crucial role in shaping speech characteristics.

6. CONCLUSIONS

In conclusion, our study reveals significant differences among the Pothowari, Jhangochi, and Multani accents. Additionally, our statistical analysis revealed notable gender variations in the acoustic properties of /s/. This study explores the complex relationship between accent variation, gender distinction, and acoustic features, particularly for the fricative /s/, providing insights into accent identification.

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