Speech Acoustics of Temporal Patterns in Plosive Production

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Abstract

This study examines the speech acoustics of English produced by adult second-language learners, with a particular emphasis on a critical phonological feature influenced by laryngeal tension. It investigates voiceless unaspirated English and Sindhi plosives by analyzing the phonatory and articulatory mechanisms involved in producing initial-position plosives, along with their acoustic timing and dynamics in both L1 and L2 speakers (N=10) (n=5 female & n=5 male). The present Voice Onset Time analysis is grounded in the acoustic framework established by Lisker and Abramson (1964), which categorizes stop consonants according to the temporal interval between the release burst and the onset of voicing. We conducted acoustic measurements within the source-filter framework (Fant, 1960) using PRAAT (Boersma & Weenink, 2023). The stimuli comprised six lexical items recorded within a controlled environment in an anechoic chamber measuring 2.134 × 3.253 meters at the FM Radio Studio. This chamber was equipped with an audio mixer, condenser microphones, monitor speakers, microphone stands, a computer, a microphone filter, headphones, a sound card, and a monitor stand. The study identified significant differences in voiceless plosives /p, t, k/. The study found no notable gender differences in the mean values for /t/. Acoustic variations depend on articulation position, even though voiceless features are gender neutral. A separate t-test comparing male and female speech acoustics means for /p, t, k/ revealed a statistically significant difference ($t=3.746$, $df=8$, $p<0.01$). Mean scores did not differ significantly between genders. The findings demonstrate that adult learners transfer L1 phonological traits, producing voiceless plosives with de-aspiration at the onset. Gender differences were minimal; however, articulation placement significantly influenced the temporal aspects of plosive production. These results underscore the importance of co-articulatory context in L2 phonetic development and its interaction with native neuro-phonology.

Keywords acoustics, adults, articulation, phonetics, speech sounds, vowels, voiceless plosives.

Paper type Research paper

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Introduction

This study explores speech acoustic values in normal speech produced by adult speakers after they have completed acquiring speech acoustics in light of the Critical Period Hypothesis. Speech acoustics is a phonetic measure that quantifies the temporal interval between the release of a plosive consonant and the onset of vocal cord vibration or voicing. The purpose of this descriptive study is to measure speech acoustics produced by adult learners who speak regular speech. These are essential elements of vocal cord vibration and the plosives, for instance /p/, /t/, /k/, /b/, /d/, and /□/. Phonetically, voiced sounds, e.g., /b/, /d/, /□/, have short speech acoustics, whereas voiceless sounds, e.g., /p/, /t/, /k/, have longer speech acoustics. Speech acoustics helps acquire language pronunciation. It also supports speech pathology by helping diagnose speech disorders. This field is closely related to phonetic science, in which speech acoustics is crucial for understanding phonetic differences between languages. This has research applications in linguistic studies of speech acoustics, helping to understand language-specific phonetic patterns. In terms of speech recognition, speech acoustics analysis can improve speech recognition systems. Speakers with normal voices probably use distinct musculature to raise pitch rather than increasing vocal strain and effort.

Speech acoustics measures phonetic variation in temporal aspects that reflect articulatory movements and physiological adjustments, often known as a noise burst: a significant phonological phenomenon affected by laryngeal tension. This study measured the acoustic properties of the voiceless plosive sounds /p/, /t/, and /k/in voice samples produced by Sindhi L2 adult learners. The study further investigates the effects of gender and place of articulation on speech acoustics. The principal objective of this study is to examine average measures of speech production in speech acoustics acquired by normal speakers, with a view to adding new outcomes to the body of literature on the subject.

In phonetics, a voicing onset that occurs before the release is considered negative speech acoustics, whereas a plosive consonant produced before the voice onset is considered positive speech acoustics. The difference between the point of articulation and speech acoustics is widely recognized. The study focuses on measuring the temporal interval between the release burst of three voiceless plosives and the onset of voicing in the subsequent vowel. The study will also examine contrasts between aspirated and unaspirated plosive consonants in relation to speech acoustics; however, the author believes this distinction is absent in Pakistani English. English speakers from Pakistan do not aspirate plosives word-initially, unlike native English speakers. The focus is on variations in speech acoustics caused by articulation position.

This study provides a thorough phonetic examination of speech acoustics in voiceless plosive consonants, illuminating the pathophysiological aspects of speech production and cross-linguistic phonetic variability. Specifically, it investigates the ontogeny of speech-acoustic patterns for plosives in both languages, using acoustic diagnostics to quantify temporal intervals and elucidate the articulatory physiology underlying plosive consonant production. We compared the times of the two voice onsets. Numerous scholars have studied speech acoustics across speakers of different languages. This study contributes average speech-acoustic values, recording the mean duration of voiceless, unaspirated plosives produced by Sindhi L2 learners.

Objectives

To examine the phonatory and articulatory mechanisms underlying the production of voiceless plosives in the word-initial position.

To assess the speech acoustics, chronometry, and temporal dynamics of articulatory gestures produced by L1 and L2 speakers.

Speech acoustics denote the temporal interval between the release of an oral constriction and the initiation of glottic vibration. Speech acoustics are characterized as positive if the plosive release precedes vocal cord vibration, and negative if

phonation commences before release. This occurs because plosives are produced as aspirated plosives in syllable-initial position, devoid of concomitant vocal cord adduction during articulation. The English plosive consonants /p/, /t/, and /k/ exhibit this phenomenon.

Preliminary investigations suggest that protracted negative and positive speech-acoustic values predict voiced and voiceless plosive obstruents preceding high, tense vowels such as /i:/ and /u/. The abrupt diminution of the transglottic pressure gradient below the requisite 2 cm/H2O threshold for phonation, consequent to airway occlusion, renders sustained voicing during interruptions biomechanically challenging. To sustain voicing, the vocal tract is often subjected to passive or active volumetric augmentation (Westbury, 1983). The locus of articulation modulates speech acoustics, with speech-acoustic duration positively correlated with the distance of articulatory closure (Bell-Berti, 1975). The extent of the contact area contributes to increased speech acoustics. Conversely, increased articulator velocity is associated with reduced speech acoustics.

The voicing terms are sometimes considered misleading because different languages have different voicing conventions, although not all pairings have a divergence in voicing, not in the phonological sense, either. Obstruents differ in voicing in both directions in the language, such as /p/ and /p/, and /v/ and /f/. Moreover, the voicing group is found in several languages, including French, Japanese, and Russian. The disparity between sounds in the other category, known as aspiration languages, like /b/ and /p/, does not, in a precise sense, suggest whether there is voicing. As opposed to /b/, which is phonetically silent, aspirating /p/ (in strong syllables) is possible. This quality sets it apart. The aspiration group speaks German, Swedish, and English; therefore, the element |L| or the feature [voice] is not appropriate for them. Laryngeal Realism proponents favor using the element |H| or the trait [spread glottis] to fittingly articulate the important difference, as they refer to the existence of being voiceless or contrasting aspiration (Chen 1970). The argument put forth by many experts in phonetics is that, in general, vocalic durations are protracted preceding voiced plosives relative to voiceless plosives (Fischer, 1954; Batuk & Emel, 2020; Lisker & Arthur, 1964; Maddieson, 1977).

Additionally, the study suggests that the differential volume of the supraglottic cavity posterior to the point of constriction contributes to heterogeneity in speech acoustics. Notably, the velar plosive is characterized by a smaller subjacent cavity volume than that of apical or bilabial plosives (Cho & Sun-Ah, 2000). Variations in speech acoustic values are predicated on the articulatory contact space. The velar plosives, namely /k/ and /□/, are articulated via contact between the dorsum and the soft palate, resulting in a more extensive contact space relative to bilabial and alveolar plosives. Similarly, a phonological phenomenon has been observed in the duration of contact between laminal and apical plosives, concomitant with dental and alveolar distinctions, influencing speech acoustics metrics (Peterson & Ilse, 1960). Certain trends are apparent: speech acoustics positively correlate with distance from the closure locus. Speech acoustics also increase with contact area, whereas they decrease with articulator velocity. Although these patterns are discernible in traditional cross-linguistic speech acoustics analyses, they do not constitute the specific parameters of the articulation locus (Ö□ü et al., 2006). Previous research highlights the complex interaction between language identity, educational practices, and the use of Urdu and Sindhi in Pakistan's multilingual context (Pathan et al., 2024), providing an important sociolinguistic backdrop for examining acoustic variation in plosive production among speakers of these languages.

Pre-phonatory voicing patterns were evident in the speech acoustic profiles of Sindhi and Pakistani English during voiced plosive production, indicating that glottic vibration had begun before the release of these articulatory gestures (Abbasi, 2025). The study demonstrated that females have a relatively narrower vocal tract than males, which correlates with higher formant frequencies. Additionally, English vowel duration averaged 66 ms in unstressed syllables and 75 ms in stressed syllables. The mean durational disparity between stressed and unstressed long vowels was 40 ms in Sindhi, contrasting

with 9 ms in English. Pilot data revealed negative values in word-initial speech acoustics for voiced plosives in both Sindhi and English, indicating pre-voicing phenomena (Abbasi et al., 2018).

The investigations (Abbasi, 2017; Abbasi et al., 2018) reveal that mean F1 and F2 values are generally lower for unstressed long and English vowels, whereas they are higher for stressed long and English vowels. A phonetic examination of the acoustics of Sindhi speech and of Pakistani English speech produced by Sindhi adult learners was undertaken, leading to a systematic analysis of Pakistani English speech acoustics. Audio-phonetic studies have provided substantial evidence of stress-correlated shifts in phonetic exponents, corroborating Sindhi's designation as a stress accent language (Abbasi & Hussain, 2015).

In another study, Abbasi (2010) evaluated English consonantal phonemes posing difficulties for Sindhi adult learners, identifying frequent challenges with labial, alveolar, and velar plosives /p/, /t/, /k/; palato-alveolar affricates /tʃ/, /dʒ/; labio-velar glide /w/; liquid consonant /r/; and labiodental voiced fricative /v/. The Sindhi syllable structure comprises five templates that incorporate various free or bound morphemes (Abbasi, 2012). Additionally, another study indicates that the differential volume of the supraglottic cavity posterior to the point of constriction contributes to heterogeneity in speech acoustics. A smaller subjacent cavity volume characterizes the velar plosive compared to apical or bilabial plosives. In contrast, the cavity anterior to the velar plosive exhibits a greater volumetric capacity relative to those preceding bilabial and alveolar plosives (Cho & Peter, 1999). Articulators' contact space drives fluctuations in speech acoustic values. In this space between the back of the tongue and the soft palate, the velar plosives /k/ and /□/are articulated. They have a longer contact space than bilabial and alveolar plosives. The length of time that the apical and laminal plosives interact is another phonological feature that has been noted. This relates to differences between alveolar and dental plosives. Certain trends, such as the speech acoustics rising with distance from the closure, rising with contact area length, and falling with articulator movement speed, are mentioned. Traditional cross-linguistic examinations of speech acoustics show these, but they are not specific to articulation place (Maddieson, 1977). The Sindhi language features a phonological inventory that includes a complete set of voiceless /p/, /t/, /k/ and voiced /b/, /d/, /□/ plosives, with superimposed aspiration contrasts (/p/, /pʰ/, /b/, /bʰ/; /t/, /tʰ/, /d/, /dʰ/; /k/, /kʰ/, /g/, /gʰ/), yielding a total of 12 plosive phonemes (Abbasi et al., 2018; 2024).

H1: In instances where L1/L2 English voiceless plosives are produced in word-initial position, the voiceless plosives /p/, /t/, /k/ are realized as unaspirated phonemes.

H2: If the phonetic realization of English/Sindhi plosives conforms to distinct patterns, then the speech acoustics durational parameters exhibit disparities between L1 and L2 English plosive consonants.

Methods

Sampling

The study cohort comprised participants recruited from an academic institution, with a total sample size of N=10, consisting of (n=5) male and (n=5) female subjects. The sample

Table 1. English and Sindhi plosive stops

SN	English Stops	English Words in IPA		Sindhi Plosive Stops	Sindhi Words in IPA
1	/p/	Poll	/pəʊl/	/p/	/pi:ruʊ/
2	/t/	Toll	/təʊl/	/t/	/to:lʊ/
3	/k/	Call	/kɔ:l/	/k/	/kʊ:no/

included native Sindhi-speaking adults aged 18 to 25 years who were learning English as a second language, with a gender distribution of five males and five females. During school, college, and university, they spent roughly 10 years studying and using English in formal academic work. The authors noted no speech impairments, including in two final-year MBBS medical students, supporting the study's speech experiment with adult Sindhi learners.

Embedded Vowels in Stimuli

The research design was experimental and controlled the vowel environment across cross-linguistic target words to isolate place of articulation and cross-language transfer.

Recording Procedure

To acquaint adult speakers with lexical stimuli, we conducted a brief orientation session to explain the recording protocol. We generated and transcribed six indexing cards in both Sindhi script and English, for a total of 12 cards. Each of the 10 participants (6×10×3=180 tokens) contributed voice samples, which we analyzed using Praat speech processing software, yielding 180 voice samples. Participants were administered a set of six cards, printed in both Sindhi and English, which were shuffled and presented after each trial to facilitate concurrent voice sample recording. Each lexical token was iterated three times, with intervening pause intervals of 1 minute, 2 seconds, 3 seconds, and 1 minute between cycles. The recording sequence entailed capturing Sindhi word tokens after three cycles of English word tokens. The recording sessions were conducted in a controlled, acoustically isolated environment, shielded from extraneous urban noise, to ensure a quiet, peaceful setting with minimal ambient noise. The microphone was positioned approximately 15 cm from the participants. They were instructed to articulate the token sounds in isolation, at a neutral focal point, and at a normal conversational speech rate, mirroring natural discourse. The recording procedure was conducted in an anechoic chamber (2.134 × 3.253 m) at the institute's FM Radio Studio, using a high-fidelity microphone and the Praat voice processing software (Boersma & David, 2022). The chamber was equipped with advanced instrumentation, including an audio mixer, a condenser microphone, a monitor speaker, microphone stands, a computer system, a microphone filter, a headphone sound card, and a monitor wood stand. Participants recorded English word tokens in three consecutive trials, followed by Sindhi word tokens, to capture a natural speech tempo. Participants self-reported no speech impairments, which the author corroborated as an English language instructor.

Results

According to the findings, Sindhi features voiceless unaspirated plosives /p/, /t/, /k/ in word-initial position in English words. The adult speakers did not begin, terminate, or modify any words using English plosives. This is because there is a distinct aspirated and unaspirated pause in the language for the phonemes /p^{h}/ and /p/. Native speakers of Sindhi also produce unaspirated English plosive sounds. We investigated how the following vowel's identity, place of articulation, and gender affected mean speech acoustic values. The average durational values of the plosives are as follows: the alveolar values were 36 ms, the Sindhi bilabial values were 32 ms, and the velar values were 42 ms. The velar, alveolar, and bilabial English sound values, however, are 39, 35, and 36 ms, respectively. The English velar speech acoustics value is shorter, and Sindhi velar sounds are longer. In contrast, the English bilabial plosive is longer than the Sindhi bilabial plosive. The speech acoustics value for male speakers of Sindhi and English sounds is shown in ig. 1. The speech acoustics values of both languages were analyzed as positive. The following waveform figures 1-6 illustrate six speech acoustics of English and Sindhi voiceless plosives by male and female speakers.

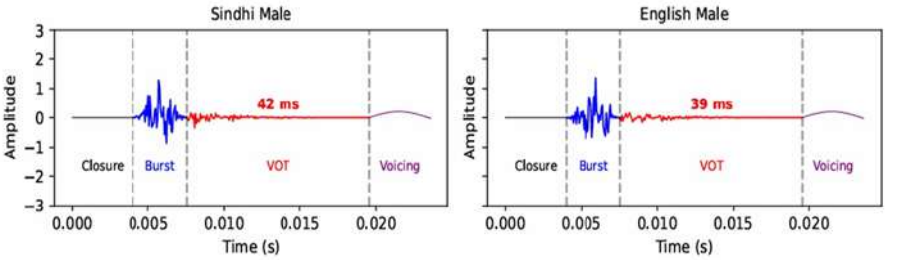


Figure 1. It illustrates Sindhi & English voiceless unaspirated plosive /p/ speech acoustic waveforms.

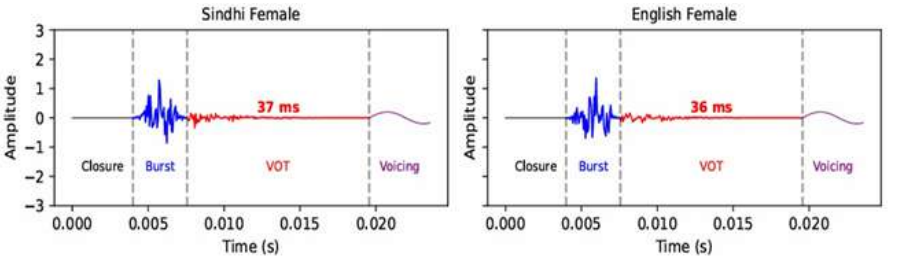


Figure 2. It shows Sindhi & English voiceless unaspirated plosive /p/ speech acoustic waveforms

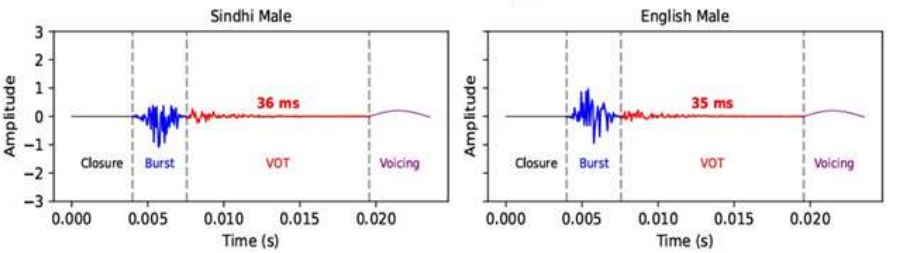


Figure 3. It illustrates Sindhi & English voiceless unaspirated plosive /t/ speech acoustic waveforms.

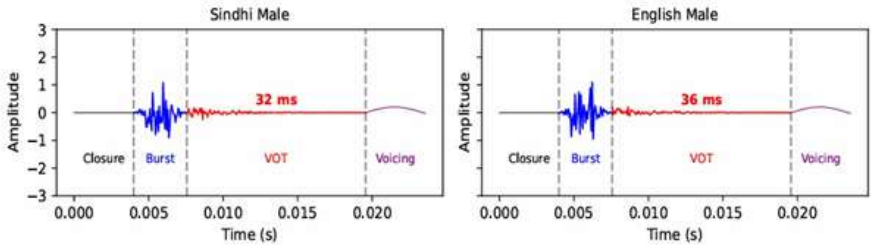


Figure 4. It illustrates Sindhi & English voiceless unaspirated plosive /k/ speech acoustic waveforms

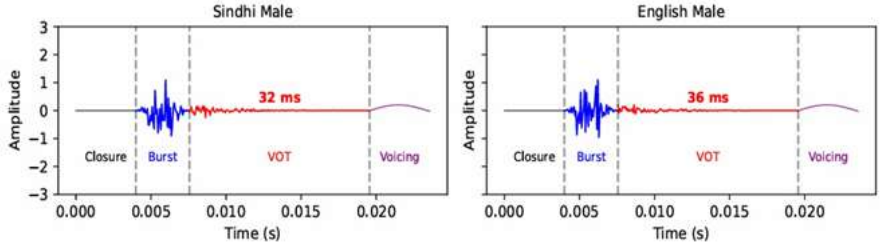


Figure 5. It illustrates Sindhi & English without voice unaspirated plosive /p/ speech acoustics of waveform.

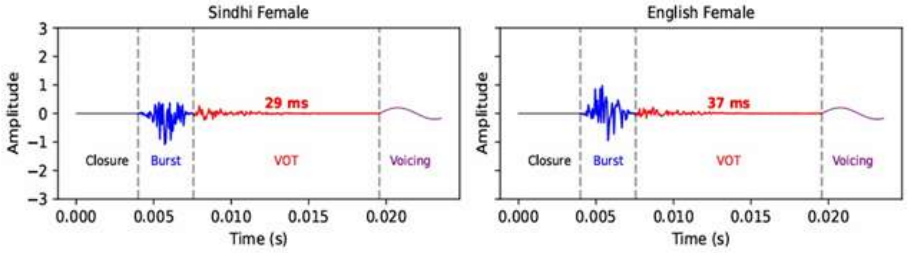


Figure 6. An illustration of the Sindhi & English voiceless unaspirated plosive /k/ speech acoustic waveform.

Group Statistics

	Gender	N	Mean	Std. Deviation	Std. Error Mean
p	Male	10	33.70	3.164	1.001
	Female	10	29.00	3.055	.966
t	Male	10	35.70	3.164	1.001
	Female	10	33.20	5.959	1.884
k	Male	10	40.70	4.347	1.375
	Female	10	36.30	3.268	1.033

Table 2. T-test on the differences between speech acoustics values (male-female)

Table 3 illustrates the statistical values of speech acoustics and their differences across speakers as follows:

Group Statistics

	Language	N	Mean	Std. Deviation	Std. Error Mean
p	English	10	32.30	5.034	1.592
	Sindhi	10	30.40	2.066	0.653
t	English	10	36.20	5.007	1.583
	Sindhi	10	32.70	4.138	1.309
k	English	10	37.50	3.598	1.138
	Sindhi	10	39.50	5.017	1.586

Table 3. T-test on the differences between speech acoustics values (across speakers)

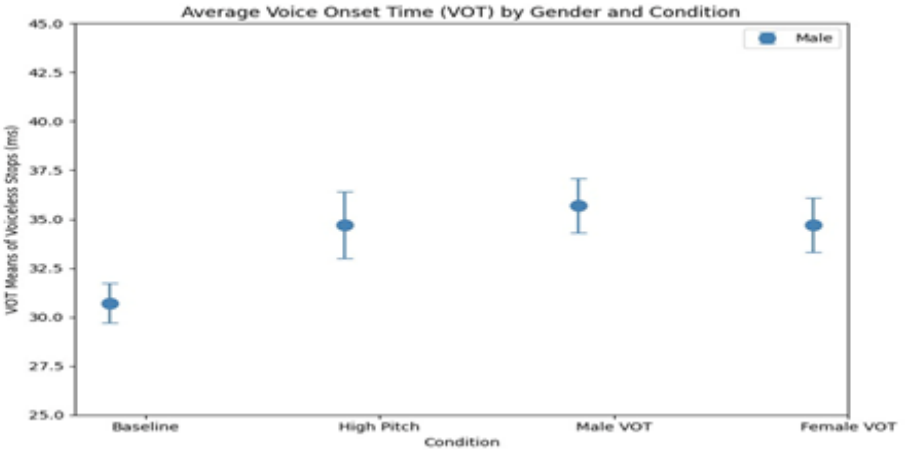


Figure 7. Scatter VOT plot for male speakers

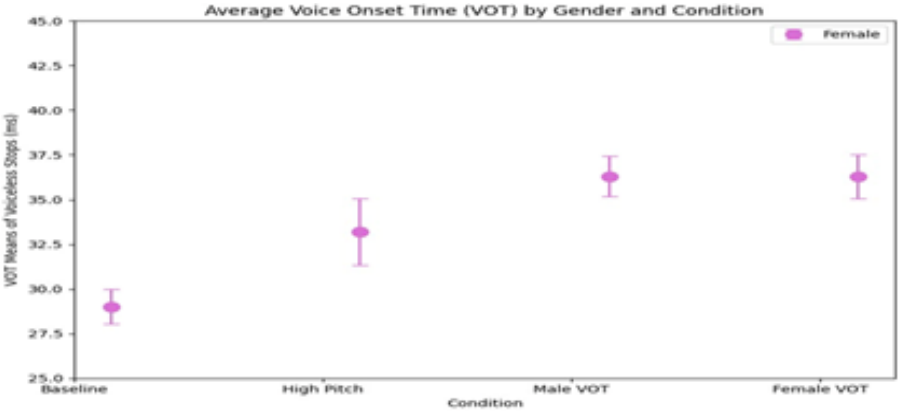


Figure 8. Scatter VOT plot for female speakers

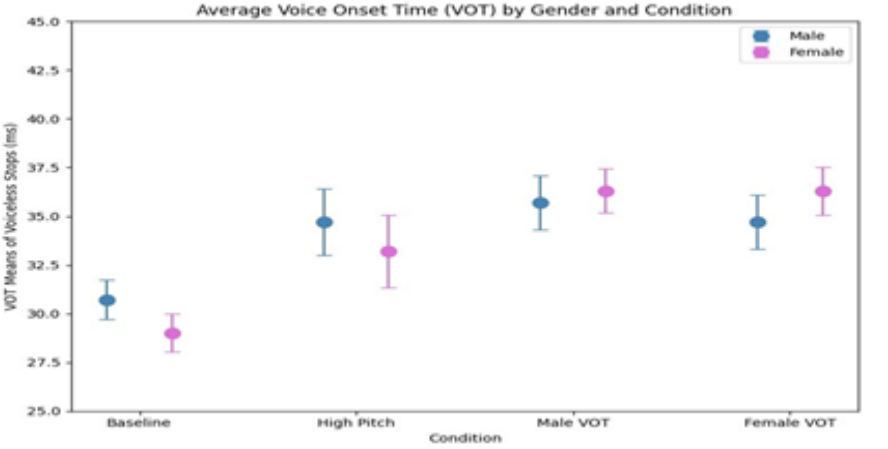


Figure 9. Scatter VOT plot for male and female speakers

Discussion

The scatter plot shows how factors such as baseline, pitch changes, and gender affect speech acoustics. Comparing different conditions: Variations in speech acoustics are evident across conditions. For example, if the High-pitch points indicate higher speech acoustics than the Baseline, this implies that pitch may influence speech production without voice pauses. Speech acoustics are displayed on the Y-axis. Speech acoustics is calculated as the time it takes for vocal fold vibration to begin after a plosive consonant is released. The graph shows how this time changes for female speakers under various conditions. The graph illustrates that speech acoustics for voiceless plosives in women's speech are affected by high pitch or other factors. Pitch alterations may affect speech acoustics; for instance, a higher-pitch condition may yield higher speech acoustics than the baseline. Male speech acoustics average about 30 ms in the baseline condition, but female speech acoustics are slightly lower at about 28 ms. Both male and female speech acoustics increase when pitch is raised under the high condition; male speech acoustics reach around 33 ms, while female speech acoustics climb to approximately 32 ms. Both cohorts show speech-acoustic values close to 35 ms under the male and female speech-acoustic conditions, with males showing somewhat higher values than females under these settings.

Impact of Pitch on Speech Acoustics Differences

Under all circumstances, there is a noticeable difference between male and female speech acoustics, with males consistently showing somewhat higher speech acoustics values than females. Physiological variables, such as variations in vocal fold characteristics and acoustic features specific to male and female voices, could cause this discrepancy. Both males and females exhibit increased speech acoustics when pitch is raised. Still, the effect is more pronounced in female speakers, suggesting that pitch elevation may affect female speech more than male speech. This graph shows the variance in speech acoustics for both male and female speakers under various conditions. Female speakers' baseline speech acoustics are consistently lower than those of male speakers, and both groups' speech acoustic values increase as pitch rises. These distinctions are pertinent to speech production research and could help us better understand gender-based variations in speech patterns and phonetic traits.

We analyzed the data acoustically and observed differences between the Sindhi and English adult groups. These results underscore the importance of articulatory context in second-language phonetic production and highlight the nuanced interplay between native-language structures and L2 acquisition. A t-test was performed to compare the mean speech acoustics values of voiceless plosives /p, t, k/ between male and female speakers. The results showed a statistically significant difference ($t = 3.746$, $df = 8$, $p < 0.01$). Levene's test for equality of variances was used to compare the speech-acoustic values of voiceless plosives /p/, /t/, and /k/in English and Sindhi speakers. The results were: - /p/: $t = 3.379$, $df = 8$, $p < 0.01$; - /t/: $t = 1.172$, $df = 8$, $p > 0.01$; - /k/: $t = 2.558$, $df = 8$, $p < 0.01$. The speech acoustics means for voiceless plosives /p/ and /k/ differed substantially between male and female speakers, whereas /t/ showed no statistically significant difference. Levene's test for equality of variances between English and Sindhi speech acoustics for voiceless plosives yielded: /p/: $t = 1.104$, $df = 8$; /t/: $t = 1.704$, $df = 8$; /k/: $t = -1.024$, $df = 8$ ($p < 0.01$). The speech acoustics means for voiceless plosives /p, t, k/ did not differ significantly between Sindhi and English speakers. A separate t-test comparing male and female speech acoustics means for /p, t, k/ revealed a statistically significant difference ($t = 3.746$, $df = 8$, $p < 0.01$). The conclusion is that the mean speech acoustics of men and women do not differ significantly.

Conclusion

Men's and women's nonverbal expressions reveal no statistically significant differences. Furthermore, there is no aspiration on initial plosives, even when all tokens appear to be word-initial. Second-language speakers did not produce voiceless plosives accurately. The differences observed for each plosive are not statistically significant. This study's findings indicate that gender does not affect speech acoustics when comparing Sindhi voiceless plosives with English voiceless plosives. Measures vary by word position: onset, medial, and final. Additionally, it was essential to examine the anatomical and physiological effects of placement. The acoustic positioning of plosives warranted consideration, as it might vary depending on word or sound position, such as initial, medial, or final. Thus, this experiment indicates that Sindhi phonological constraints constrain English/Sindhi output. L1 phonological interference is hypothesized to impede native-like L2 production because English sounds are processed through the pre-existing Sindhi phonological framework. The initial hypothesis posits that Sindhi speakers exhibit reduced aspiration of voiceless plosives /p/, /t/, and /k/ in the word-initial position, in both L1 and L2, reflecting L1 phonological transfer. The initial hypothesis has been established, indicating that patterns of English Sindhi speech acoustics for voiceless plosives were examined as unaspirated in word-initial position. The second hypothesis posits that a comparison of male and female plosive patterns demonstrated a correlation with gender. The second hypothesis, asserting that gender does not influence English Sindhi speech acoustics in plosive patterns, has not achieved broad acceptance. The third hypothesis, embedded within the second, posits that alterations to English speech acoustics should serve as a benchmark for articulation. The perspective that the place of articulation influences speech acoustics in first and second languages has gained considerable acceptance.

Implications

The results can help language teachers understand the unique difficulties Sindhi speakers encounter when learning English, especially in producing voiceless plosives. This may lead to more targeted teaching methods to help students overcome these obstacles. Speech therapists can use the findings to develop more effective treatment plans for Sindhi speakers who have difficulty pronouncing English words correctly. Knowledge of typical speech acoustics patterns can aid the diagnosis and treatment of speech disorders. By offering information on speech acoustics patterns in a less-studied language pair, the study advances the field of phonetics and phonology. This phonetic experiment may benefit comparative research and theories of language perception and production. This study examines the distinctions and commonalities in speech acoustics between Sindhi and English, offering insights for linguists investigating cross-linguistic phonetic variation and its relevance to second-language acquisition. The results inform advances in speech recognition and synthesis technologies. Incorporating the specific speech-acoustic patterns of Sindhi English speakers can enhance the accuracy and user-friendliness of these technologies for this demographic. This study examined the impact of gender and place of articulation on speech acoustics, offering sociolinguistic insights into their influence on speech production among bilingual speakers. This study provides significant data to enhance language education, speech therapy, linguistic research, and technology development for Sindhi English speakers.

Declaration

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Statement of Ethics

The Office of Research and Innovation Commercialization (ORIC), SMI University, Karachi, approved the research. The students were ultimately permitted to volunteer and record their voice samples at the FM Radio Studio. The Central Research Committee and the HEC Research Ethics Committee # 2025-26-433 approved the research presented.

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