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Voice Onset Time of Mankiyali Language: An Acoustic Analysis

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ABSTRACT

The endangered Indo-Aryan language Mankiyali, spoken in northern Pakistan, lacks linguistic documentation and necessitates research. This study explores the Voice Onset Time (VOT) values of Mankiyali's stop consonants to determine the duration of sound release, characterized as negative, positive, and zero VOTs. The investigation aims to identify the laryngeal categories present in the language. Using a mixed methods approach, data were collected from five native male speakers via the Zoom H6 platform. The study employed the theoretical framework of Fant's (1970) source filter model and analyzed each phoneme using PRAAT software. Twenty-five tokens of a single phoneme were recorded across the five speakers. The results reveal that Mankiyali encompasses three laryngeal categories: voiceless unaspirated (VLUA) stops, voiceless aspirated (VLA) stops, and voiced unaspirated (VDUA) stops. The study highlights significant differences in VOTs based on place of articulation and phonation. In terms of phonation, the VLUA bilabial stop /p/, alveolar stop /t/, and velar stop /k/ exhibit shorter voicing lag compared to their VLA counterparts /p^h, t^h, k^h/. All VLUA and VLA stops display +VOT values, while all VDUA stops exhibit -VOT values. Regarding place of articulation, the bilabial /p/ demonstrates a longer voicing lag than the alveolar /t/ but a shorter lag than the velar /k/. Additionally, the results indicate similarities in voicing lag among the VDUA stops /b, d, g/. This study offers valuable insights into the phonetic and phonological aspects of Mankiyali and holds potential significance for the language's preservation.

Keywords: VOT; Indo-Aryan; place of articulation; aspiration; acoustic analysis

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INTRODUCTION

Language is categorized based on shared linguistic properties, including morphology, grammar, and syntax. Despite the vast number of languages spoken across the world, many have not received adequate attention from researchers in terms of investigating their structures and properties, including Indo-Iranian and Indo-Aryan (IA) languages. These languages are primarily spoken in countries such as Pakistan, India, Bangladesh, Nepal, Maldives Islands, and Sri Lanka, and have not been investigated, as noted by Anjum, Khan, and Gulzar (2016) and Yutaka (2018). Zarifian and Fotuhi (2020) argue that IA languages belong to the Indo-European family. Given the diversity of languages and the importance of understanding their structures and features, it is crucial to investigate and document these lesser-known languages.

According to Krauss's (1992) classification of spoken languages, there are three categories: moribund, endangered, and safe. Moribund languages are no longer learned by younger generations, while endangered languages are still being learned but are at risk of becoming moribund as the number of speakers dwindles. Safe languages are those with more than 100,000 speakers. Unfortunately, Mankiyali, an Indo-Aryan language spoken in northern Pakistan, falls under the endangered category with less than 500 speakers (Hussian, 2020; Kochetov, Petersen, & Arsenault, 2020; Ullah, Hussain, & Anjum, 2020). Therefore, the documentation of its orthography, phonology, morphology, and syntax becomes crucial to preserve and understand its linguistic properties, as these are dominant aspects of any language.

Moreover, Mankiyali is an Indo-Aryan (IA) language, but it comes under the Dardic group of languages. According to Hussain (2021), Dardic group of languages are mainly spoken in the mountainous regions of northern Pakistan which stretches into northern Afghanistan on the West and Kashmir on the East. Khowar is considered the main language of Chitral which is Dardic. Along with this, Palula, Kalasha, Damiei, and Indus Kohistani also belong to Dardic which are spoken in Chitral. Bateri, Gowro, Chilisso, Kalam Kohistan, Torwali Kohistan, and Ushojo are spoken in hilly areas (Anjum, Kiani, & Khan, 2018).

Mankiyali language, an endangered language with less than 500 speakers, is a part of the Dardic branch of the Indo-Aryan (IA) language family. As depicted in Figure 1, Mankiyali has a significant relation with other languages belonging to the Dardic group. The existence of Dardic languages is mainly observed in the Hindu Kush region of Pakistan, including districts Gilgit, Chitral, Baltistan, Azad Kashmir, Hunza, Swat, and Dir. Pashto language, also spoken in Swat and Dir, belongs to the Iranian family and is considered the mother tongue of these speakers. Grierson (1919; as cited in Arsenault, 2017) divides Dardic languages into three different groups: Kafir group, Khowar, Chitrali or Arniya group, and Dard group, proper. The Dard group includes three languages, namely Shina, Kashmiri, and Kohistani.

Generally, languages have been categorized based on their phonological and grammatical characteristics into different families. Mankiyali language is part of the Indo-Aryan language family, as shown in Figure 1, which represents the relationship of Mankiyali with other sister languages and its connected ancestor languages. According to Eberthard, Gary, and Charles (2019), languages are classified based on their properties and regions. The family tree diagram clearly shows the relationship of Mankiyali with many languages. Mankiyali belongs to the Dardic sub-group of the Indo-Aryan language family. It is spoken in the hilly areas of northern Pakistan, particularly in the district of Mansehra, and has less than 500 speakers (Hussian, 2020; Kochetov, Petersen, & Arsenault, 2020; Ullah, Hussain, & Anjum, 2020). The current state of Mankiyali is seriously endangered, and its orthography, phonology, morphology, and syntax require immediate documentation to preserve the language (Ullah et al., 2020).

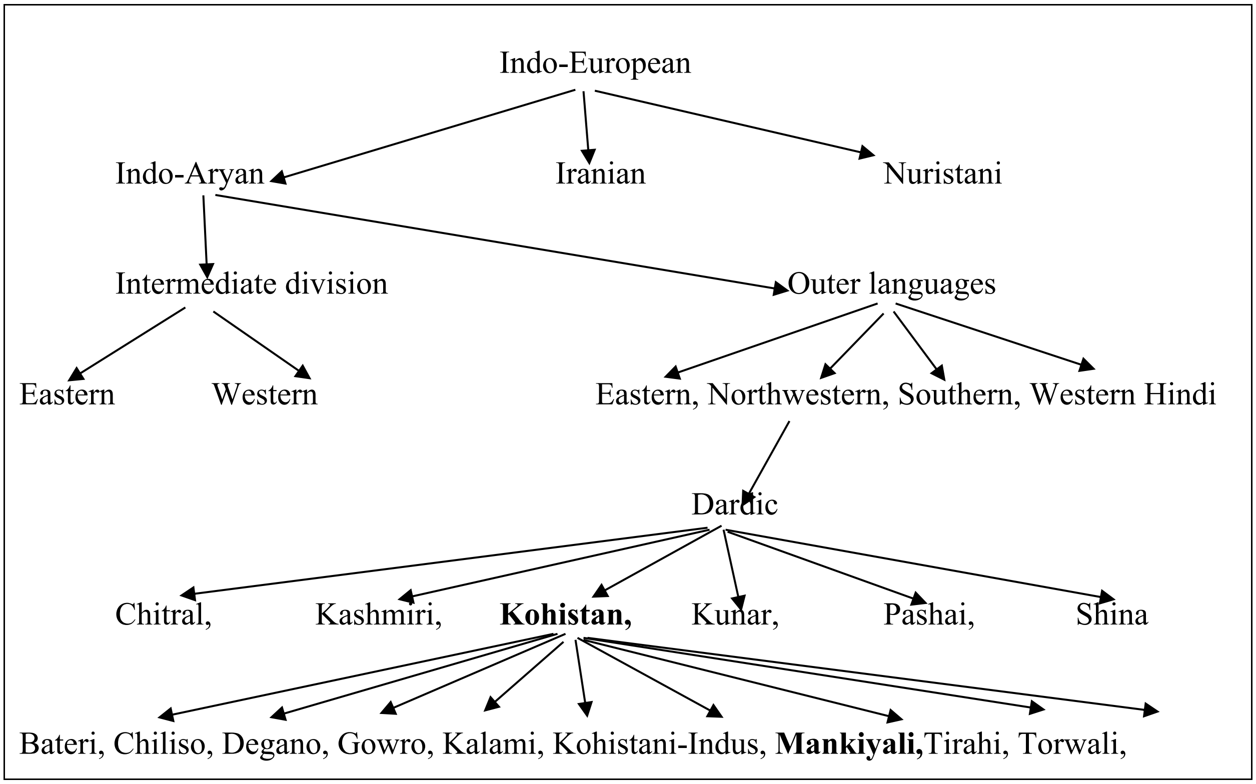

FIGURE 1. Family Relation of Mankiyali

Mankiyali is an endangered language spoken in Danna village, which is part of the union council Bandi Shungli near the city of Mansehra (Anjum et al., 2016; Kochetov, & Arsenault, 2019). Several studies have investigated Mankiyali language, identifying it as endangered (Anjum et al., 2016; Anjum et al., 2018; Anjum et al., 2020; Torwali, 2021). However, further linguistic investigation is needed to thoroughly understand its unique features. In particular, the present study focuses on investigating the voice onset time (VOT) values acoustically and identifying their various features.

STATEMENT OF THE PROBLEM

The Mankiyali language, an endangered Indo-Aryan language spoken in the hilly region of northern Pakistan, lacks sufficient linguistic research and documentation. Despite its classification as part of the Dardic group within the Indo-Aryan language family, Mankiyali and other Dardic languages have not received extensive attention. With less than 500 speakers, Mankiyali falls under the endangered category, making the preservation and understanding of its linguistic properties crucial. This research paper aims to address this gap by investigating the phonological and grammatical characteristics of Mankiyali, focusing on the voice onset time (VOT) values of its stop consonants. By analyzing the VOT values acoustically, the study seeks to identify the unique features of Mankiyali's phonetic and phonological systems. The research aims to contribute to the documentation and preservation of Mankiyali, shedding light on its linguistic properties and

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providing insights into its relationship with other Dardic languages and the broader Indo-Aryan language family. This investigation is essential for understanding the structure and features of lesser-known languages like Mankiyali and ensuring their cultural and linguistic preservation.

LITERATURE REVIEW

Speech sounds are composed of bundles of constituent and distinctive features that are classified into different categories based on their place of articulation, manner of articulation, nasal-oral, and voicing (Cangemi & Baumann, 2020; Cheng, 2021; Cathcart, 2020; Cho, Whalen, & Docherty, 2019). Phonetic research investigates the physical properties of speech sounds through articulatory, auditory, and acoustic branches, with acoustic phonetics analyzing the duration, amplitude, and other features of speech sounds (Chodroff & Wilson, 2020). The temporal measurement of voice onset time (VOT) is crucial in articulation and perception of speech, with previous studies (Bosen, Monzingo, & AuBuchon, 2020; Horo, Sarmah, & Anderson, 2020) emphasizing its importance. The classification of voiced stops based on their VOT and phonation is observed in some Indo-Aryan languages (Samudravijaya, 2021), which further underscores the significance of studying VOT in acoustic phonetics. Basically, the properties of VOT reveal the diversity of languages (Alshamiri, Shahidi, & Jaafar, 2022). Additionally, the distinct properties of consonant sounds such as plosive sounds are important to investigate, as they vary according to their acoustics and articulatory properties (Hussain & Mielke, 2020; Stevens, 1998). Therefore, research in acoustic phonetics plays a crucial role in understanding speech sounds and their properties.

The acoustic properties of phonemes in human speech are influenced by various sources such as speaker, speaking rate, phonetic context, and syllable position, and one of the main features that distinguish phonemes from each other is VOT (Hauser, 2021). VOT is the time interval between the release of stops and the onset of voicing phase for the voiced stop that comes next, and it distinguishes between phonemes and languages (Reetz & Jongman, 2020). VOT is affected by several factors such as speech rate, the following vowel, age and gender of speaker, physiological differences, pathological conditions, and various performances (Subramaniam & Ramamurthy, 2020; Zhou, Li, & Guo, 2020). However, the measurement of VOT can be challenging in certain circumstances such as in pathological voices or when there is difficulty in determining the burst location during articulation (Cohn, Segedin, & Zellou, 2022; Lopez-Backstrom, & Koffi, 2020). Furthermore, there are conflicting reports on gender-based differences in VOT measurement, with some studies showing that women have longer VOTs than men, while others suggest that this difference depends on the communicator (Ditewig, Smorenburg, Quené, & Heeren, 2021; Giovannone & Theodore, 2021). Despite its importance in distinguishing phonemes, VOT is often overlooked in human speech recognition, perception, and accent detection, highlighting the need for further research in this area (Hauser, 2021; Feehan, 2020).

The voice onset time (VOT) measurement is an essential tool used to study the phonetic characteristics of stop consonants in different languages. The VOT measurement is performed both before and after the release sounds. The measurement before the release sound is identified with negative numbers, known as voicing lead, while measurement after the release of sound is recognized with positive numbers, termed as voicing lag. Cross-linguistic studies of languages have classified three categories of stop consonants based on their VOTs: voicing lead, short voicing lag, and long voicing lag. The VOTs in English consonants remain somewhere from 0 to 75 ms. Previous studies have reported varying ranges and median values for the different categories of stop consonants in English. For instance, Levi (2021) describes that labial stops have short VOTs (0-50 ms), alveolar stops have (10-65 ms), and velar stops have (20-80 ms). However, Chodroff, Golden, and Wilson (2019) have the opposite notion that alveolar stops have longer VOTs than velar stops. Hussain (2018) clarified that VOTs of affricates have longer values than VOTs of stops. Chodroff and Wilson (2020) expressed that different languages have different VOTs in terms of voiced and voiceless stop consonants, while Earle, Landi, and Myers (2018) found that bilingual speakers have significantly different VOTs than those speakers who are monolingual. Thus, VOT measurement has proven to be an important tool for studying phonetics across different languages and populations.

The Indo-Iranian language family is divided into three main families, namely Iranian, Nuristani, and Indo-Aryan, with Dardic languages belonging to the Indo-Aryan family (Hussain & Mielke, 2020). Among the Indo-Iranian languages, Hindi has gained widespread attention due to its voiced aspirated stops, and it is extensively studied in the field of phonetics and phonology (Zarifian & Fotuhi, 2020). Many studies have been conducted on the Iranian languages, which have revealed that they have two laryngeal categories, including voiceless unaspirated stops and voiced unaspirated stops, with examples found in Balochi, Dari, and Kurdish. Additionally, Khotanese and Tumshgese have three laryngeal categories, including voiceless unaspirated, voiced unaspirated, and voiceless aspirated. Parachi, on the other hand, has four laryngeal contrasts, including voiceless aspirates and unaspirates, and voiced aspirates and unaspirates. These distinctions are unique features of Parachi (Hussain & Mielke, 2020; Jahani & Korn, 2009; Baker, 2016; McCarus, 2009; Emmerick, 2009; Keiffer, 2009).

Hussain (2018) conducted a study on ten languages, including two Iranian, seven Indo-Aryan, and Burushaski, and found a clear distinction between aspirated and unaspirated voiceless stops, with shorter VOTs noted for aspirated voiceless stops. Indo-Aryan languages have distinctive laryngeal contrasts in plosives and affricates. Zero VOTs occur when the vocal tract burst starts at the same time as the onset, positive VOTs occur when vocal fold vibration starts after the burst, and negative VOTs occur when vocal fold vibration starts before the burst. Previous studies (Hussain, Proctor, Harvey, & Demuth, 2020; Hussain, 2021; Kochetov, Petersen, & Arsenault, 2020) have analyzed the VOTs of various languages and showed their values. However, Mankiyali is an undocumented Indo-Aryan language with no acoustic analysis of its VOT values presented to date. Thus, the current study aims to acoustically investigate the VOTs of Mankiyali using Praat (Boersma & Weenink, 2017) to fill this gap in the literature.

THEORETICAL FRAMEWORK

The source filter model, developed by Fant (1970), is adopted as the theoretical framework for the current research. This model offers a linguistic perspective on Mankiyali, guiding the data collection and analysis process. The source filter model is widely used for the acoustic analysis of speech sounds, as it encompasses the fundamental aspects of sound production.

According to the model, speech production involves the integration of various components, including the sound source, vocal cords, acoustic filter, and vocal tract. These components work together to shape the production of speech sounds. The vocal tract's unique configurations filter the sound source in distinct ways, resulting in the formation of vocalic phonemes. The resonant responses of the vocal tract modify the sound source, contributing to the quality of individual segments.

In this study, the source filter model by Fant (1970) serves as the framework, specifically focusing on the speech of native Mankiyali speakers. An extensive corpus of oral data was compiled, and linguistic analysis was conducted on specific segments. By applying reliable tools and techniques, phonemes were identified and subjected to acoustic analysis using the lens provided by the source filter model. This theoretical framework facilitates the examination of the acoustic properties of Mankiyali speech sounds, enabling a comprehensive understanding of the language's phonetic features.

The objectives of this study are to investigate the acoustic properties of Voice Onset Time (VOT) values in Mankiyali stop consonants using Praat, address the research gap regarding this undocumented Indo-Aryan language, and examine the duration of sound release categorized as negative, positive, and zero VOTs. The findings will contribute to the existing literature on VOT values and fill the gap in knowledge about Mankiyali. Additionally, the results will have implications for the phonological analysis of Mankiyali and its classification within the Indo-Aryan language family. Based on these objectives, the following research questions have been formulated:

Research question 1: What are the acoustic properties of the Voice Onset Time (VOT) values of Mankiyali stop consonants?
Research question 2: What are the VOT values (positive or negative) exhibited by these phonemes?
Research question 3: Which phonemes demonstrate longer VOT values based on their place of articulation?
Research question 4: What is the duration difference observed between aspirates and unaspirates?

METHODOLOGY

The methodology utilized in this research study is shaped by the research questions, design, data collection, and analysis methods required to address the research problem. To comprehensively investigate the subject matter, a mixed methodology approach, combining both qualitative and quantitative approaches, has been adopted. Qualitative research methods are employed to delve into subjective experiences, involving the utilization of various data collection tools, organizing and archiving data, engaging in discussions with native speakers, and employing observational techniques. On the other hand, quantitative research focuses on statistical analysis, encompassing the measurement of Voice Onset Time (VOT) values and the creation of corresponding figures. By integrating these two distinct methodologies, this study aims to provide a more comprehensive understanding of the research topic and ensure a robust analysis of the gathered data.

The Voice Onset Time (VOT) has been widely used as a critical acoustic parameter to differentiate voiceless and voiced speech sounds. It has been analyzed in various languages, including Indo-Aryan, Iranian, and Burushaski. However, the undocumented Indo-Aryan language Mankiyali has not been explored in this context. Therefore, this study aims to investigate the VOT values of Mankiyali sounds and explore the duration of sound release in terms of negative, positive, and zero VOTs. The study employed a stop-consonant production task where participants produced words containing stop consonants while their recordings were captured. The recorded audio was analyzed using Praat software to measure and compare the VOT values across different speech sounds. The statistical analysis of VOT values would provide insights into the phonetic features of Mankiyali and its distinction from other Indo-Aryan languages.

In this study, the focus was on the acoustic analysis of word-initial stops consisting of voiceless unaspirated /p, t, k/, voiceless aspirated /pʰ, tʰ, kʰ/ and voiced unaspirated /b, d, g/ in combination with /i/. Previous research by Hussian et al. (2017) and Mitleb (2001) have suggested that the quality of vowels can affect the measurements of VOT. To ensure the accuracy of the results, a single vowel was chosen to eliminate any potential distractions. All phonemes were used in word-initial positions, consisting of three bilabial, three alveolar, and three velar sounds. The VOT values were obtained through acoustic analysis using Praat, and statistical analysis was conducted using R (R Core Team). Despite previous research on VOT values in various languages, there is a lack of research on the acoustic analysis of Mankiyali.

TABLE 1. Stimuli Used for VOTs, Stop Followed by High Close Vowel

Nonsensical words	Consonants
pim	p
pʰim	pʰ
bim	b
tim	t
tʰim	tʰ
dim	d
kim	k
kʰim	kʰ
gim	g

DATA COLLECTION PROCEDURES

In this study, data collection was conducted on a purposive sample comprising five male Mankiyali speakers aged between 30 to 40 years. These speakers were specifically selected from Danna village, where they had spent both their childhood and adulthood. The choice of speakers from this particular village aimed to minimize the potential impact of dialectal variation on the research findings. It is important to note that these participants exhibited no language disorders in terms of perception and production and demonstrated fluency in speaking Mankiyali. Due to ethical and societal restrictions, the study was limited to male speakers only. Women in the community are generally not permitted to interact and engage in discussions with individuals outside their immediate family members. Furthermore, the study specifically focused on investigating a single linguistic feature, namely the Voice Onset Time (VOT) of Mankiyali stop consonants. This decision was motivated by the recognition that VOT serves as a crucial and reliable cue for distinguishing between voiced and voiceless consonants in numerous languages. Moreover, the study aimed to analyze the VOT values of Mankiyali stop consonants and compare them with existing literature to identify the distinctive characteristics of Mankiyali stop consonants. Consequently, the delimitation of this study to a single feature is justified, and the data collection process was conducted with careful consideration of ethical and societal norms.

In the present study, nonsensical words (see Table 1) consisting of stop consonants followed by a high close vowel /i/ were used for data collection. These words were arranged in CVC forms, and a total of 09 words were included, all with a stop at the initial position. The selection of nonsensical words was based on the view that the qualities of vowels affect the measurements of VOT. Having the same vowel in all words reduces distractions and leads to correct results. Although all the sounds in the chosen data set are existing phonemes of Mankiyali, they were selected to obtain the desired results for this study. This methodology will provide valuable insights into the VOTs of Mankiyali stop consonants and contribute to the understanding of the phonetics of this language.

In this study, the data collection process involved presenting lists of words containing the target phonemes to native speakers of the language in English script. Before recording, multiple practice sessions were conducted to ensure that the participants understood and could comfortably pronounce the words. The participants were then asked to utter the words in a normal voice and comfortable rate, both in isolation and within carrier sentences. Each word was repeated eight times, resulting in a total of 360 entries. However, only five tokens were measured for each speaker for a single phoneme, resulting in 25 responses per phoneme for each speaker, and a total of 225 responses for the study. The focus of the study was on the VOTs of the target phonemes, which were provided in Table 2. The use of multiple repetitions allowed for greater accuracy and reliability of the results.

RECORDING

The present study ensured the highest quality data collection by using a portable Zoom H6 recorder to record the participants' utterances. The device was checked multiple times before starting the recordings, and the settings were adjusted accordingly to ensure the best possible sound quality. The recordings were made in a single village to avoid any variations in environmental factors that could affect the results. The files were saved in uncompressed WAV format, which helped in preserving the original quality of the recordings. For better results, the recordings were converted into mono using Praat software, which allowed for the elimination of any background noise or other artifacts that could have affected the data. The researchers took special care to ensure that the data collected was of the highest quality, which will ensure the accuracy and validity of the results obtained from the study.

ACOUSTIC ANALYSIS OF DATA

The collected data were processed and analyzed using Praat software. The recordings were first edited and converted to mono files before segmentation. Acoustic analysis was performed on the segmented data, and the VOT values were recorded in milliseconds. The boundaries of the VOTs were carefully marked for all stop consonants, and the release interval and closure interval were marked according to the burst of stop consonants. An additional aspiration was marked for aspirated phonemes. Boundaries were marked during segmentation to obtain the acoustic features of each phoneme and contrast it with others. The analysis focused on three laryngeal categories in Mankiyali stop consonants: voiceless unaspirated, voiceless aspirated, and voiced unaspirated. The VOTs of all VLUA and VDUA stop consonants followed by a high close vowel /i/ were marked from burst release to closure interval as shown in Figures (2 and 3). The VOT values and their ranges for each category were presented in various tables for easy reference and comparison. The acoustic analysis of the data provided the necessary information for the study's findings and conclusions.

TABLE 2. Voice Onset Time of All Five Speakers in Milliseconds (stop + high close vowel + stop)

Sounds	**p**	**pʰ**	**b**	**t**	**tʰ**	**d**	**k**	**kʰ**	**g**
Values of Speaker 1	16.6	72.2	-97	9.8	45.8	-96	38	68.8	-78
Values of Speaker 2	14.6	59.8	-101.2	11.4	56.4	-109	27.6	75.4	-95
Values of Speaker 3	14.6	49.6	-119.8	13.2	41.4	-129	31.4	77.6	-114
Values of Speaker 4	9.4	45.2	-119	9	34.4	-95.4	35	84.8	-86
Values of Speaker 5	13.4	64.6	-119	9	56.2	-107	25.5	74.8	-107
Range	9.4: 16.6	45.2: 72.2	-97: -119	9: 13.2	34.4: 56.4	-95.4: -129	25: 38	68.8: 84.8	-78: -114
No of Tokens	5	5	5	5	5	5	5	5	5

The data collected from the participants were analyzed carefully to obtain accurate results. Table 2 presents the results of the stimuli presented in Table 1. Five responses were measured and recorded for each of the phonemes /p, pʰ, b, t, tʰ, d, k, kʰ, g/. The values obtained from each participant were recorded and presented in the table. The values and their ranges were presented respectively under the phonemes arranged in the first row of the table. It is important to note that all the words in Table 1 were uttered by all five speakers. This provides a robust dataset to analyze the phonetic properties of these stop consonants and their respective VOT values in Mankiyali. The collected data will be used for further analysis and interpretation to understand the characteristics of these stop consonants and their phonetic properties in Mankiyali.

The present study recorded the values of different stop consonants uttered by five speakers, with the aim of analyzing the phonetic features of Mankiyali, a language spoken in Pakistan. The values of the voiceless unaspirated bilabial phoneme /p/ ranged from 13 ms to 19 ms for S1, 11 ms to 16 ms for S2, 11 ms to 18 ms for S3, 9 ms to 10 ms for S4, and 10 ms to 17 ms for S5. The voiceless aspirated bilabial phoneme /pʰ/ had values ranging from 69 ms to 79 ms for S1, 46 ms to 70 ms for S2, 42 ms to 65 ms for S3, 34 ms to 54 ms for S4, and 55 ms to 74 ms for S5. The voiced unaspirated bilabial phoneme /b/ was recorded with values ranging from -82 ms to -115 ms for S1, -75 ms to -119 ms for S2, -114 ms to -131 ms for S3, -113 ms to -127 ms for S4, and -111 ms to -127 ms for S5. The data were obtained from the sum of five tokens for each speaker, and each value was carefully recorded and presented in Table 2, indicating the average and range of each phoneme. These results provide valuable information for further analysis of the phonetic features of Mankiyali stop consonants.

This study aimed to investigate the acoustic properties of phonemes /t, tʰ, d/ (alveolar) in the speech of five speakers. The data collection process involved carefully measuring five responses for each phoneme using Praat software. The results presented in Table 2 show the values and ranges of the phonemes for each speaker. The voiceless unaspirated phoneme /t/ was recorded as 9.8 ms by S1, 11.4 ms by S2, 13.2 ms by S3, 9 ms by S4, and 9 ms by S5. The voiceless aspirated phoneme /tʰ/ was recorded as 45.8 ms by S1, 56.4 ms by S2, 41.4 ms by S3, 34.4 ms by S4, and 56.2 ms by S5. The voiced unaspirated phoneme /d/ was recorded as -96 ms by S1, -109 ms by S2, -129 ms by S3, -95.4 ms by S4, and -107 ms by S5. The ranges for each phoneme varied across the speakers but generally lasted from 7 ms to 13 ms for /t/, 31 ms to 61 ms for /tʰ/, and -78 ms to -155 ms for /d/. These findings provide valuable insights into the acoustic characteristics of alveolar phonemes in speech production and could inform the development of speech recognition technology and language teaching practices.

In this study, the researchers collected data on the values of three different phonemes, namely voiceless unaspirated VLUA /k/, voiceless aspirated VLA /kʰ/, and voiced unaspirated VDUA /g/ from five different speakers, denoted as S1 to S5. The values of VOT for the phonemes were recorded by measuring the duration between the release of the stop closure and the onset of the following vowel. The results showed that the average value of VOT for VLUA /k/ ranged from 25.5 ms to 38 ms, while the range of VOT for this phoneme varied from 20 ms to 43 ms among the speakers. The average VOT value for VLA /kʰ/ ranged from 68.8 ms to 84.8 ms, while the range of VOT for this phoneme varied from 60 ms to 90 ms among the speakers. The average VOT value for VDUA /g/ ranged from -78 ms to -114 ms, while the range of VOT for this phoneme varied from -68 ms to 129 ms among the speakers. These findings highlight the variability in VOT values for the same phoneme among different speakers, indicating that individual differences play a crucial role in speech production.

The waveforms of speaker 1 were analyzed to investigate the acoustic representations and physical properties of phonemes. Figures 2 and 3 show the waveforms of the voiceless unaspirated (VLUA) and voiced unaspirated (VDUA) sounds /p, b, t, d, k, g/ and the voiceless aspirated (VLA) sounds /pʰ, tʰ, kʰ/, respectively. These figures provide a detailed visual representation of the phonemes produced by speaker 1, allowing for a deeper understanding of their acoustic characteristics. By analyzing these waveforms, we can gain insights into how the phonemes are produced and perceived, which is important for developing accurate models of speech production and perception.

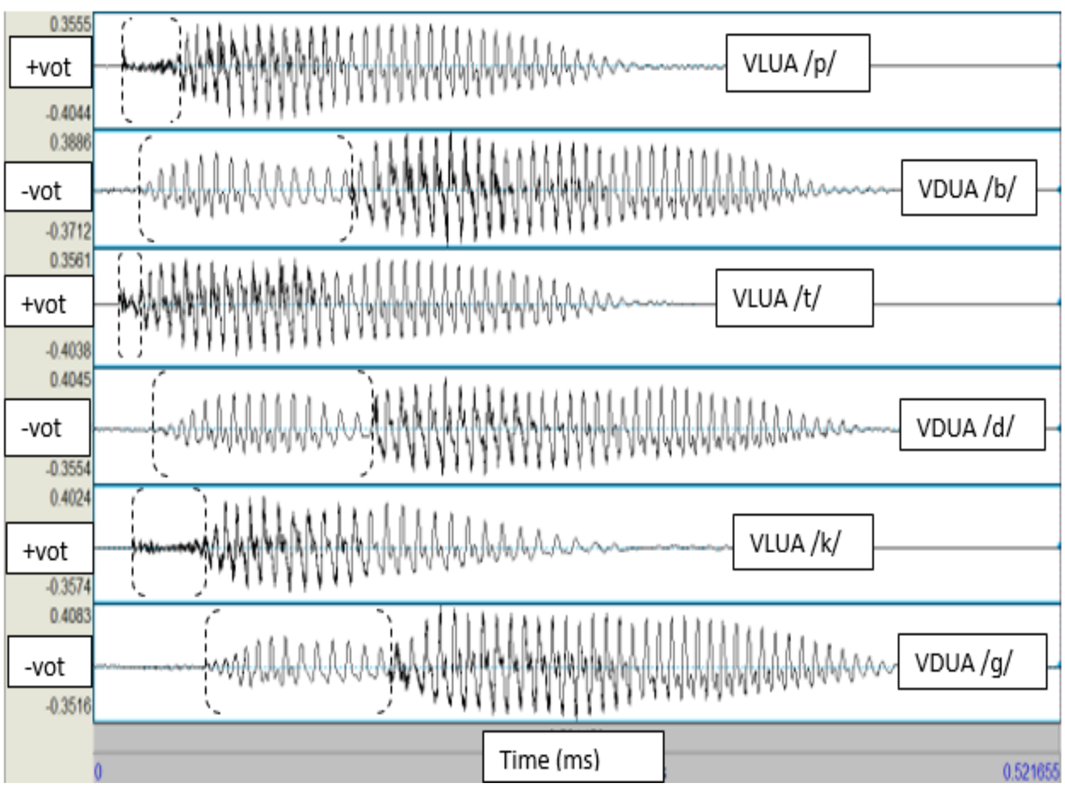

FIGURE 2. Waveforms of Mankiyali's stops (VLUA) /p/, (VDUA) /b/, (VLUA) /t/, (VDA) /d/, (VLUA) /k/, and (VDUA) /g/ produced by speaker 1. ±VOT boundaries are indicated with double dotted brackets. The following vowel is /i/.

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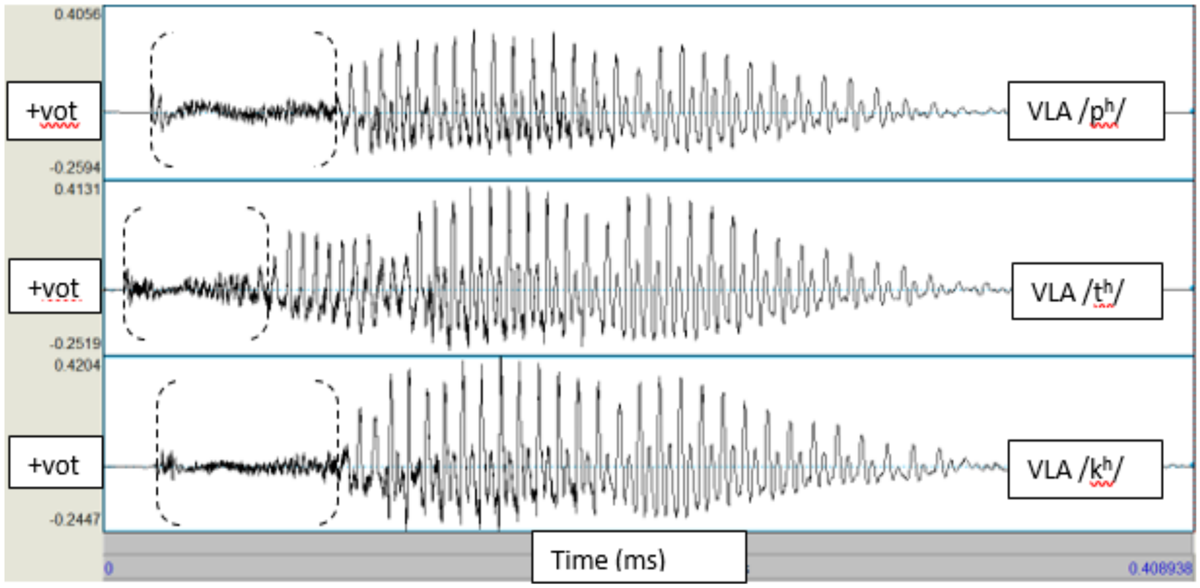

FIGURE 3. Waveforms of Mankiyali's stops (VLA) /pʰ/, (VLA) /tʰ/, and (VLA) /kʰ/ produced by speaker 1. ±VOT boundaries are indicated with double brackets. The following vowel is /i/.

The waveforms shown in Figures 2 and 3 correspond to speaker 1 and were used to illustrate the acoustic analysis and spectrograms of all phonemes. The same process was applied to all speakers for each phoneme, except for the VOT spectrographic representation, which is only presented in Figures 2 and 3.

RESULTS AND DISCUSSION

The present study focused on analyzing the VOT values of consonantal phonemes using a single dataset of stimuli consisting of stops followed by a high close vowel, as presented in Table 1. The use of the same vowel in all words ensured that the results obtained were of high quality. In this study, the focus remained on the initial stop consonants of the five speakers, and 25 tokens were analyzed acoustically for each phoneme. Table 3 shows the collected values of all speakers, with the waveforms of each speaker taken using the same process. However, the spectrograms of only speaker 1 were presented in Figures 2 and 3, with Figure 2 showing the waveforms of (VLUA) /p/, (VDUA) /b/, (VLUA) /t/, (VDUA) /d/, (VLUA) /k/, and (VDUA) /g/ produced by speaker 1, while Figure 3 exhibited the waveforms of (VLA) /pʰ/, (VLA) /tʰ/, and (VLA) /kʰ/ produced by S2. Although the spectrograms of all speakers were analyzed, only the representations of speaker 1 were presented in the figures.

TABLE 3. Grand averaged values of VOTs of all 5 Speakers in ms (stop + high close vowel + stop)

Sounds	**p**	**pʰ**	**b**	**t**	**tʰ**	**d**	**k**	**kʰ**	**g**
Values	13.7	58.2	-111	10.5	46.8	-108	31.6	76.2	-96.4
Range	9.4: 16.6	45.2: 72.2	-97: -119	9: 13.2	34.4: 56.4	-95.4: -129	25: 38	68.8: 84.8	-78: -114
No of Tokens	25	25	25	25	25	25	25	25	25

To ensure data accuracy, five tokens were recorded for each speaker, and an average was calculated for each token set. Next, the average of the five speakers was computed, and the resulting values were used for analysis. The range of values and number of tokens used for each speaker were also noted.

In this study, the VOT values of different phonemes were also analyzed and compared. The results showed that the VOT values of VLUA /p/ and VLA /pʰ/ were significantly different. The value of VLUA /p/ was recorded as 13.7 ms, while the value of VLA /pʰ/ was recorded as 58.2 ms, almost four times longer than VLUA /p/. The value of VDUA /b/ was negative, recorded as -111, indicating a voicing lead. The VOT values of VLUA /t/ and VLA /tʰ/ were also significantly different. The value of VLUA /t/ was recorded as 10.5 ms, while the value of VLA /tʰ/ was recorded as 46.8 ms, three times greater than VLUA /t/. The averaged value of VDUA /d/ was recorded as -108 ms, indicating a voicing lag. These results suggest that there are substantial variations in VOT values of different phonemes, and these values may vary depending on the type of phoneme and speaker. These findings can provide a better understanding of the production and perception of consonantal phonemes and can be used in future studies related to speech production and speech disorders.

The study recorded the values of VOT for three voiceless stops, VLUA /k/, /t/ and /p/, and their voiced counterparts, VLA /kʰ/, /tʰ/ and /pʰ/, along with VDUA /g/, of 5 speakers. The results showed that the averaged VOT value of VLUA /k/ was 31.6 ms, while the VLA /kʰ/ was 76.2 ms. Similarly, substantial variations were noted between the durations of VOTs of VLUA /t/ and VLA /tʰ/. The averaged value of /g/ was -96.4 ms, indicating negative VOTs. Tables 2 and 3 presented the whole data in values obtained from the utterances of all 5 speakers. The results revealed notable variations in VOTs of stops based on their place of articulation, aspiration, and positive/negative VOTs. The study also found that the shorter voicing lag of VLUA stops and longer voicing of VLA stops were due to the substantial variations in aspiration. The study provides valuable insights into the phonetic characteristics of stops, and the results could be used in various fields, including language teaching, speech recognition technology, and speech therapy.

The current research analyzed the variations in VOT values of different stop consonants. The study revealed that the durations of VLUA phonemes /p, t, k/ were different from one another. The bilabial stop /p/ had a longer voicing lag compared to the alveolar stop /t/, but shorter voicing lag than the velar stop /k/. The VOT values of /k/ were almost two times longer than /p/ and three times longer than /t/. The results also showed that the VOTs of stops varied based on the place of articulation and aspiration. The VOTs of VLA /pʰ/ and /tʰ/ were found to be 4 to 5 times longer than their VLUA counterparts /p/ and /t/, and the VLA /kʰ/ was 2 to 3 times longer than its VLUA counterpart /k/. In addition, the study found that the VOTs of VDUA /b, d, g/ were relatively close to each other, and there was no considerable variation in terms of place. The data presented in Tables 2 and 3 showed substantial variations between the durations of VOTs of VLUA /k/ and VLA /kʰ/. The reasons behind the substantial variances in VOT values of stops were attributed to

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the differences in aspiration. The study provides useful insights into the acoustic characteristics of stop consonants and their considerable variations based on different phonetic features.

The above values were obtained from the utterances of all five speakers, with each phoneme repeated twenty-five times. The averages were then analyzed using R software, which was used to create box plots and conduct statistical analysis. The results of the analysis are presented in the Figure 4 below.

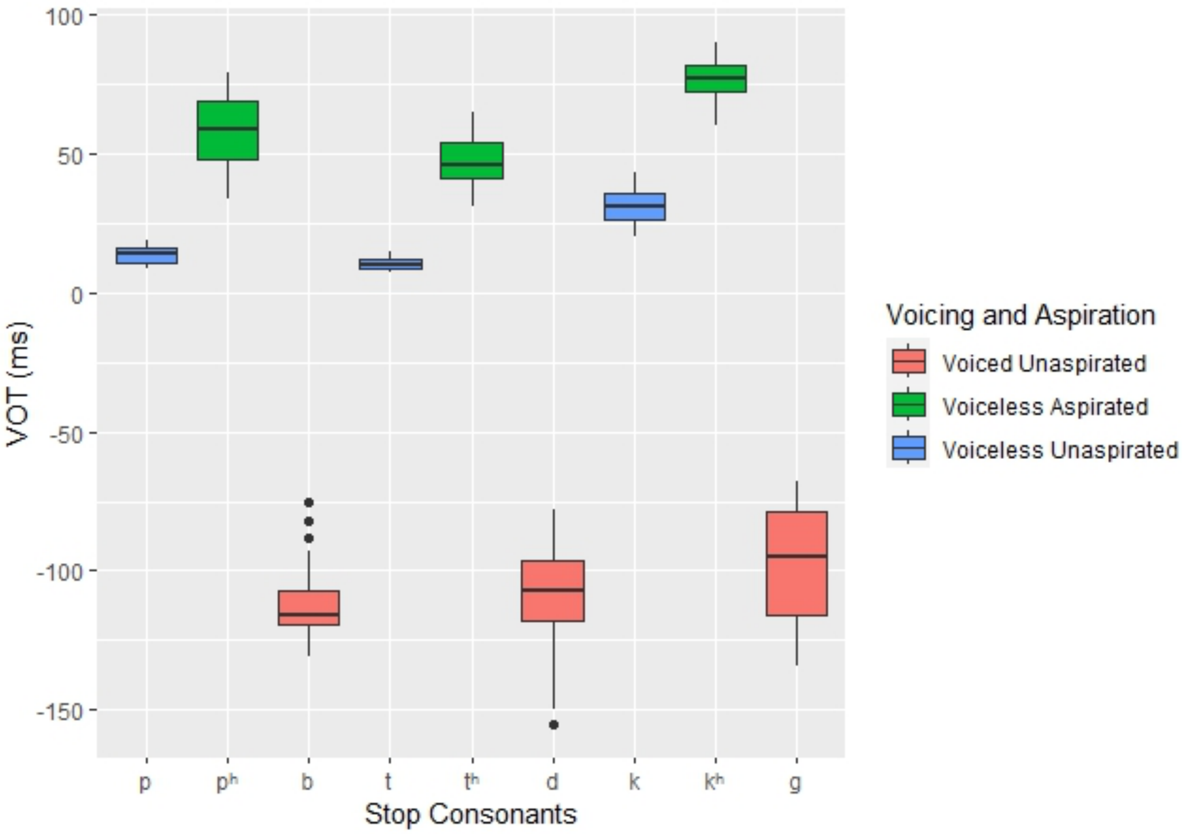

FIGURE 4. Boxplot of VOTs (ms) of the Stop Consonants of Mankiyali

The results of the VOTs of Mankiyali stop consonants are presented in Figure 4, which displays the phonemes in different colors for ease of understanding. Red color represents VDA, green represents VLA, and blue represents VLUA. The data used for the analysis were from Table 2, and R software was used to generate the results. The variations in places of articulation and voicing were clearly shown in the figure. All VLA and VLUA consonants had positive VOTs, while VDU consonants had negative VOTs, which were marked with the middle horizontal line. It was observed that VLUA stops had a smaller voicing lag than their VLA counterparts, and among VLA, the velar /k/ had a longer voicing lag compared to bilabial /p/ and alveolar /t/. These variations were further noticed in more statistical analysis which was given below in Table 4.

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TABLE 4. Results of the separate phoneme

Sounds	Mean	Standard Deviation	Range
p	13.7	3.17	10
p^h	58.3	12.4	45
b	-111	14.3	56
t	10.5	10.1	8
t^h	46.8	10.1	34
d	-108	20.2	77
k	31.6	7.29	23
k^h	76.2	8.49	30
g	-96.4	20.3	66

Table 4 provides a summary of the results obtained from the analysis of stop consonants in Mankiyali. The mean, standard deviation, and range of VOTs for all stops were calculated using R software. The data presented in Table 4 indicate that there were substantial variations in the VOTs of stops based on place of articulation and aspiration. All the VLA and VLUA consonants had positive VOTs, with the VLA stops having longer VOTs than their VLUA counterparts. Additionally, the bilabial /p/ and alveolar /t/ had shorter VOTs than the velar /k/. In contrast, all the VDU consonants had negative VOTs. These results are consistent with previous studies that have shown that aspiration is an important factor in the perception of stop consonants. Overall, the data presented in Table 4 provide valuable information about the acoustic properties of stop consonants in Mankiyali, which can inform our understanding of the phonetic and phonological processes involved in speech production and perception in this language.

The obtained results were compared among the informants, and greater accuracy was achieved when the results were more closely aligned with each other, although some contrasting results were observed. For the VLUA /p/ phoneme, the VOT values remained consistent across four informants, ranging from 13.4 ms to 16.6 ms, apart from one informant who had a value of 9.4 ms. The VOT values for the VLA /p^h/ phoneme were relatively stable, with three informants reporting values between 59.8 ms and 72.2 ms, and two informants reporting values of 45.2 ms and 49.6 ms. The VDUA bilabial /b/ phoneme displayed consistent VOT values, with three informants reporting values of -119 ms and two informants reporting values of -97 ms and 101.2 ms. Similarly, the VLUA alveolar /t/ phoneme exhibited consistent VOT values ranging from 9 ms to 13.2 ms. Conversely, the VLA alveolar /t^h/ phoneme had VOT values of 56 ms for two informants, 41.4 ms and 45.8 ms for two other informants, and 34.4 ms for the remaining informant. The VOT values for the VDUA /b/ phoneme remained constant for all informants except one, who had a value of -129 ms. The VOT values for the velar /k/ and /k^h/ phonemes were very similar, while the VDUA velar /g/ phoneme displayed three values ranging from -78 ms to -95 ms, with two informants reporting values of -107 ms and -114 ms.

Based on the findings of the present study, notable similarities can be observed in relation to previous research. Hussain (2020) reported similar results, as the present study found that voiceless unaspirated (VLUA) consonant stops exhibited shorter voicing lag compared to their voiceless aspirated (VLA) counterparts. This aligns with the findings of Puggaard and Goldshtein (2020) in their study on Jutlandic varieties of Danish, where they also observed shorter VOT values for unaspirated stops compared to aspirated stops (Chodroff, Bradshaw, & Livesay, 2022; Hussain, 2020; Puggaard & Goldshtein, 2020).

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Furthermore, the present study found that all voiced unaspirated (VDUA) stops demonstrated negative Voice Onset Time (VOT) values, which is consistent with the findings of Hussain (2020) (Chodroff et al., 2022; Hussain, 2020). This indicates that VDUA stops in Mankiyali share similar voicing characteristics as reported in other languages. In terms of place of articulation, the present study revealed that the bilabial /p/ had a longer voicing lag than the alveolar /t/ but a shorter lag than the velar /k/. This finding contrasts with Hussain's (2020) study, which found that VLUA velar stops exhibited longer voicing lag compared to VLUA stops with shorter voicing lag VOTs. These differences may be attributed to the specific phonetic and phonological characteristics of Mankiyali and the particularities of its stop consonants (Chodroff et al., 2022; Hussain, 2020).

On the other hand, the present study aligns with Levi's (2021) research, which observed short VOTs (0-50 ms) for labial stops, (10-65 ms) for alveolar stops, and (20-80 ms) for velar stops. This similarity suggests a potential cross-linguistic pattern in the voicing characteristics of stops. Additionally, Chodroff, Golden, and Wilson's (2019) study also supports the present findings, indicating that alveolar stops have longer VOTs than velar stops. This corroborates the present study's observation that the alveolar /t/ exhibited a longer voicing lag compared to the velar /k/ (Chodroff et al., 2022; Levi, 2021).

By comparing and contrasting the present findings with relevant studies, including the study by Puggaard and Goldshtein (2020), the present research contributes to the existing knowledge on phonetics and phonology. These comparisons help validate the findings and provide a broader perspective on the characteristics of Mankiyali's stop consonants (Chodroff et al., 2022; Puggaard & Goldshtein, 2020). Future research could further explore the acoustic analysis of nasal and glottal phonemes in Mankiyali to gain a comprehensive understanding of its phonetic and phonological system. Additionally, investigating the perceptual aspects of these phonemes and examining their usage in different linguistic contexts would provide valuable insights into the language's overall phonetic and phonological structure.

CONCLUSION

In brief, the present study has conducted a comprehensive analysis of the physical properties of stop phonemes in Mankiyali, focusing on aspects such as Voice Onset Time (VOT), duration, phonation, and place of articulation. The findings of this study reveal the existence of three laryngeal categories within the Mankiyali language, with significant variations observed among stops belonging to these categories. The Mankiyali language, an endangered Indo-Aryan language spoken in the hilly region of northern Pakistan, lacks sufficient linguistic research and documentation. Despite its classification as part of the Dardic group within the Indo-Aryan language family, Mankiyali and other Dardic languages have not received extensive attention. With less than 500 speakers, Mankiyali falls under the endangered category, making the preservation and understanding of its linguistic properties crucial. Moreover, notable differences were identified in negative and positive VOT values, and the voicing lag exhibited variability based on the place of articulation. This research has provided valuable insights into the phonological aspects of Mankiyali and has opened up new avenues for future investigations. By analyzing the VOT values acoustically, the study seeks to identify the unique features of Mankiyali's phonetic and phonological systems. The research aims to contribute to the documentation and preservation of Mankiyali, shedding light on its linguistic properties and providing insights into its relationship with other Dardic languages and the broader Indo-Aryan language family. Considering these findings, future research endeavours could explore the acoustic analysis of nasal and glottal phonemes in Mankiyali, further expanding our understanding of the language's phonetic properties. Additionally, this study contributes to the ongoing documentation of Mankiyali and serves as an encouragement for native speakers to engage in further research in the field. By addressing the gaps in linguistic research and understanding the unique characteristics of Mankiyali, this study aids in the preservation and appreciation of linguistic diversity.

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