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Acoustic Analysis of Dysarthria: A Comparative Study with Healthy Controls

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Plosive sounds involve complex coordination among anatomical structures, including the respiratory system, larynx, and supra-laryngeal structures, often resulting in divergent acoustic measurements in individuals with speech-language disorders. Dysarthria, characterized by impaired speech motor control, significantly affects speech articulation. This study, conducted in Islamabad, Pakistan, explores Voice Onset Time (VOT) in dysarthric individuals compared to healthy controls. Thirty participants, 15 with dysarthria and 15 age-matched healthy speakers, were recruited from the National Institute of Rehabilitation Medicine and the Armed Forces Institute of Rehabilitation Medicine, both based in Islamabad. Employing a quantitative design, acoustic analysis was performed using PRAAT (v5.3.56), and statistical analysis was conducted using SPSS (v21). This study offers a novel contribution by analyzing VOT variations in a linguistically diverse population, including Urdu, Punjabi, and Balti speakers, across different types of dysarthria. Results indicated that dysarthric speakers had consistently longer VOT values, with a mean difference of -33.52 milliseconds (dysarthric) compared to -18.74 milliseconds (healthy), a statistically significant gap ($p < 0.05$). Voiced/voiceless distinctions and place of articulation were identified as factors influencing VOT in both groups. The

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findings provide strong evidence of prolonged VOT in dysarthric speech, emphasizing the relationship between speech motor control deficits and phonetic features. Future research could benefit from longitudinal studies tracking changes in VOT over time, offering insights into the progression of dysarthria and aiding the development of more targeted therapeutic interventions.

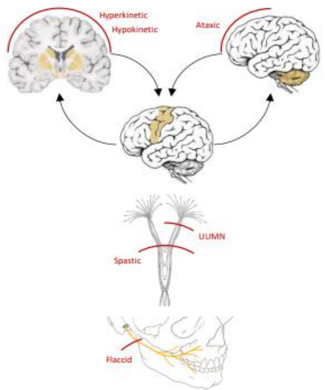
Keywords. Dysarthria, voice onset time (VOT), speech motor control, acoustic analysis, articulatory disorders, therapeutic interventions

The phenomenon of human speech production has long intrigued scholars, with phoneticians providing a comprehensive framework to unravel its complexity. Honda (2003) meticulously outlined three essential mechanisms that underlie the orchestration of speech: respiration, phonation, and articulation. This scholarly investigation delves into the intricate tapestry of these mechanisms, shedding light on their interplay and contribution to the remarkable act of human speech (Fernández-García et al., 2021; Dogar et al., 2024; Safeer et al., 2024; Saleem & Saleem, 2023).

The journey of speech production commences with the mechanism of respiration, which harnesses the lungs as a potent source of energy for the generation of speech sounds. While the lungs are primarily tasked with the vital function of breathing, the air expelled from them becomes the raw material for the creation of speech sounds. This pivotal role of respiration sets the stage for the subsequent phases of speech production. The second mechanism, phonation, emerges as a symphony orchestrated within the larynx, commonly known as the "voice box." Comprising an intricate assembly of cartilage and muscles, the larynx assumes a central role in sound production. It acts as the gateway through which the airflow from the lungs must pass. At its heart lie the vocal folds, responsible for the generation of voiced sounds. The glottis, a slender gap between the vocal folds, serves as the gatekeeper, deciding the voiced or voiceless nature of a sound (Asmat et al., 2024; Khan et al., 2023; Noffs et al., 2018). An open glottis during airflow results in voiceless sounds, whereas a closed glottis, impeding the airflow and inducing vibration, yields voiced sounds. This finely tuned process exemplifies the remarkable precision inherent in human speech production. The third and final mechanism, articulation, emerges as the artisanal touch that sculpts and refines speech sounds (Aqeel et al., 2016; Carl & Icht, 2021; Rusz, 2021; Rauf et al., 2014). It entails a consortium of articulatory organs within the oral cavity, including the lips, teeth, tongue, palate, alveolar ridge, uvula, velum, and even the nasal passages. These articulate components collaboratively mold and filter the sounds engendered by the preceding mechanisms, culminating in the rich tapestry of distinct speech sounds that define human language.

As a result, the involvement of various speech-related components results in distinct 'acoustic outputs.' Nevertheless, certain individuals may encounter challenges in effectively and smoothly communicating, primarily due to processing deficits. These deficits can give rise to speech and language impairments or disorders and may stem from insufficient linguistic knowledge, difficulties in speech processing, or a lack of motor control over speech (Hammarström et al., 2015; Haroon et al., 2023). Dysarthria is a speech motor disorder that affects a person's ability to control or execute speech sounds due to weak muscles required for speech production or an inability to control them. This condition is typically caused by neurological impairment or sensorimotor abnormalities and can result in various abnormalities in the strength, speed, range, steadiness, tone, or accuracy of movements required for the basic aspects of speech production, including breathing, phonation, resonance, articulation, and prosody (Duffy, 2013; Saleem & Khan, 2024). There are several types of dysarthria.

Figure 1: *Causes of Dysarthria: Affected Areas of Nervous System Resulting in Different Types of Dysarthria*



Flaccid dysarthria is characterized by difficulties in speech due to issues with the nuclei, axons, or neuromuscular junctions that form the motor units of the final common pathway (FCP) (Duffy, 2013). This condition results from damage to the peripheral nervous system or the lower motor neuron. On the other hand, spastic dysarthria is mainly a problem of neuromuscular execution and is caused by damage to the direct and indirect activation pathways of the central nervous system or upper motor neuron disease (Duffy, 2013; Saleem et al., 2023). This damage is typically bilateral in nature. Ataxic dysarthria is a motor control disorder caused by damage to the cerebellum or cerebellar control circuit. In contrast, hypokinetic and hyperkinetic dysarthria are associated with the basal ganglia control circuit. Unilateral Upper Motor Neuron dysarthria (UUMN) results from damage to the upper motor neuron (UMN) pathways, which carry messages to spinal and cranial nerves. When more than one type of dysarthria occurs simultaneously, it results in a mixed dysarthria. The underlying cause of mixed dysarthria can be several neurological conditions, such as multiple strokes or neurologic diseases like PD and strokes. Therefore, it can result from various diseases or events that affect one or multiple parts of the central nervous system (CNS) (Duffy, 2013; Ullah et al., 2023).

Dysarthria is a condition that can cause a range of speech and communication difficulties. These can include rapid, slow, slurred, or abnormal speech, as well as difficulties in moving the tongue, lips, and jaw. Unfortunately, these deficiencies may lead to social isolation, as individuals may find it difficult to maintain their social relationships and engage in daily-life activities, ultimately affecting their quality of life (Batool & Saleem, 2023). Additionally, dysarthria may increase the risk of developing psycho-emotional disorders, such as anxiety, depression, and worsening cognition. During the production of speech, various levels of motor control and coordination are involved in the process. Plosive sounds require the coordination of breathing and the laryngeal and supra-laryngeal structures. One aspect of plosives is their voicing, which can be examined through auditory and perceptual evaluations. However, patterns that cannot be evaluated through these methods can be examined using acoustic analysis. Voice onset time (VOT) is one of the acoustic cues used for this purpose. It is considered the most reliable cue for differentiating between voiced and voiceless sounds. Hammarström et al. (2015) emphasized that auditory and perceptual evaluations are important for assessing the voicing aspect of different plosives, while acoustic analysis provides additional information.

In Kisomi et al. (2021) spastic dysarthric patients were compared acoustically to healthy speakers. The study found that dysarthric patients produced longer voice onset times (VOTs) than healthy speakers, although the difference was not significant. Morris (1989) conducted a study, and he examined VOTs in dysarthric speakers with four different types of dysarthria: Spastic, flaccid, ataxic, and hypokinetic. The study used utterances of *pa*, *ta*, *ka* and spectrographic analysis was performed. The results showed that spastic dysarthric speakers exhibited shorter VOTs than those with ataxic, flaccid, and hypokinetic dysarthria. Additionally, there was greater variability in the VOTs of ataxic and flaccid dysarthric speakers than hypokinetic and spastic dysarthric participants. Therefore, different types of dysarthria result in distinct VOT values, which indicate that phonetic errors displayed by speakers with different types of dysarthria are distinct depending on their speech motor control.

By including dysarthric patients who speak Urdu, Balti, and Punjabi, this study acknowledges the importance of considering linguistic diversity when studying dysarthria. It can provide insights into how dysarthria manifests differently across languages, which can be crucial for speech therapy and intervention in linguistically diverse regions like Pakistan. Previous studies have often focused on one specific type of dysarthria, limiting the generalizability of their findings. This study's inclusion of patients with flaccid, spastic, ataxic, and mixed dysarthria caused by various diseases broadens the scope of understanding and allows for comparative analyses. This can help identify common acoustic features across different types of dysarthria and aid in more accurate diagnosis and treatment planning.

Dysarthria can result from various underlying conditions, including stroke, muscle weakness, damage to motor neurons, traumatic brain injury (TBI), and others. This study's consideration of these different etiologies allows for a comprehensive examination of dysarthria's acoustic characteristics and may reveal unique patterns associated with specific diseases. Such insights can be valuable for differential diagnosis and prognosis. VOT is a crucial acoustic feature that can provide insights into the articulatory control and coordination in dysarthria. By focusing on plosive sounds across different languages and types of dysarthria, this study can shed light on how VOT measurements vary across these variables. This information can contribute to our understanding of the articulatory aspects of dysarthria and their implications for treatment. Considering the influence of variables such as voiced/voiceless and place of articulation on VOT measurements is important for a more detailed analysis of dysarthria. This study's focus on specific plosive consonants (e.g., /p, b, t, d, k, g/) allows for a nuanced examination of how dysarthria affects these speech sounds. Understanding these influences can guide targeted speech therapy interventions.

Nevertheless, the current study addresses a significant gap in understanding the acoustic properties of dysarthric speech in a linguistically diverse population, including Urdu, Punjabi, and Balti speakers. While previous studies (Uludag, 2024; Favaro et al., 2023) have examined VOT variations in monolingual dysarthric patients, there is limited research on how dysarthria manifests across languages. Given the distinct phonetic structures of these languages, this research aims to provide insights into cross-linguistic variability in dysarthria. Furthermore, the findings have direct implications for clinical practice, potentially informing more culturally and linguistically tailored therapeutic interventions to improve speech intelligibility in dysarthric patients.

Research Questions

The current study proposed the following research questions:

1. How does the Voice Onset Time of the plosives, /p, b, t, d, k, g/, produced by Pakistani dysarthric speakers compare to that of healthy speakers?
2. What are the voice onset time differences among speakers with the five different types of dysarthria?
3. What is the relationship between the place of articulation and the voiceless/voiced variables and the differences between dysarthric and healthy groups?

Method

This quantitative study follows a positivist paradigm and employs a detailed acoustic analysis of voice onset time (VOT) in plosive consonants. The research design is based on Lisker and Abramson's (1964) framework, which categorizes stop consonants into three VOT production categories. Acoustic measurements were performed using PRAAT v5.3.56, a tool widely regarded for its precision in capturing acoustic features, such as VOT, through waveform and wide-band spectrogram views. Statistical analysis was carried out using SPSS v21, with an independent samples *t*-test employed to compare VOT values between dysarthric and healthy participants. Several confounding variables were considered in the design of this study. First, speech speed variations between groups were monitored to ensure that differences in VOT were not solely due to speaking rate. Age and gender were matched between the dysarthric and control groups to control for their potential influence on VOT values. Additionally, given the linguistic diversity of the participants, VOT measurements were normalized across different languages to account for phonetic differences. Comorbid conditions, such as neurological impairments, were documented and their possible impact on speech production was considered in the analysis.

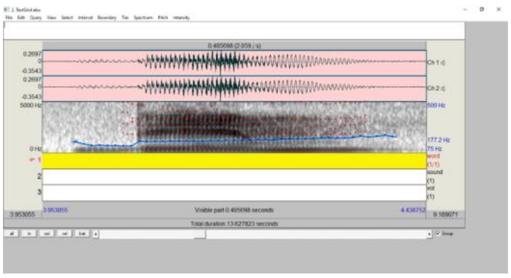
Procedure

The current study involves a comparison of voice onset time in plosive consonants (/p/, /b/, /t/, /d/, /k/, and /g/) between two distinct groups: Healthy speakers and dysarthric speakers. The purpose is to examine how these two groups produce these sounds differently. To gather data, researchers collected information from two centers for speech pathology: the National Institute of Rehabilitation Medicine (NIRM) and the Armed Forces Institute of Rehabilitation Medicine (AIRM). A list of words consisting of the aforementioned plosive consonants was created, and the participants were asked to repeat the words after the researchers narrated the list. The words were inserted into carrier phrases such as "Speak ________ again." The data was then recorded and analyzed acoustically using PRAAT software version 5.3.56.

To conduct the present study, we performed an acoustic analysis of the plosives /p/, /b/, /t/, /d/, /k/ and /g/ using PRAAT software version 5.3.56. Additionally, we conducted an independent samples *T*-test to compare two groups: the healthy and dysarthric group. This analysis was carried out using the IBM SPSS statistics version 21. To begin with the analysis on PRAAT, the researchers first annotated the data into a TextGrid, extracting word, sound/plosive, and VOT information. The acoustic analysis was then performed through the waveform and wide-band spectrogram views on PRAAT. PRAAT is a highly versatile software tool for acoustic analysis, which is freely available online and was developed by Paul Boersma and David Weenink at the Phonetic Sciences department at the University of Amsterdam. It is extensively used for speech analysis and offers both standard and non-standard procedures for acoustic examination. With PRAAT, users can conduct spectrographic analysis, articulatory synthesis, and even work with neural networks. Furthermore, the software enables users to measure word durations and frequencies.

According to Lieshout (2003), Figure 2 illustrates the waveform and wide band spectrogram view on PRAAT software.

Figure 2: *View of Waveform and Spectrogram on Praat Software*



The computer program, PRAAT, is a useful tool not only for phoneticians but also for clinicians. Clinicians need to perform acoustic, auditory, and perceptual analysis to evaluate vocal status and voice and speech physiology. PRAAT offers several advantages in this regard. Firstly, it is freely available software and can be easily downloaded. Secondly, it is compatible with different computer operating systems, including Windows and Macintosh. Moreover, clinicians can control all of its parameters, which enhance their flexibility to use it as they desire. PRAAT provides numerous vocological markers, such as fundamental frequency, formants, and spectral configurations. Additionally, clinicians can effortlessly edit the data and generate various statistics and graphs, including spectrum, oscillogram, spectrogram, and waveform, on PRAAT (Maryn, 2017).

Ethical Considerations

The current study meticulously adhered to ethical considerations outlined by BERA (2018). These ethical guidelines served as a robust framework to ensure the responsible and respectful conduct of research involving individuals with dysarthria and healthy controls. The study prioritized the well-being, privacy, and informed consent of all participants, maintaining the highest standards of ethical research conduct. Further, the collection of data for this study was approved by both the National Institute of Rehabilitation Medicine and Armed Forces Institute of Rehabilitation Medicine. Informed consent was also obtained from each subject prior to data collection. Additionally, all collected information and data were kept confidential by using a password-protected computer.

Results

Table 1 presents the results of an independent samples t-test comparing the mean scores of healthy speakers and dysarthric speakers for different categories of stop consonants. The sample sizes for both groups were 15 for each category. For the bilabial-voiceless category, healthy speakers had a significantly lower mean score (M = 14.13, SD = 8.903) than dysarthric speakers (M = 25.93, SD = 2.949), t (28) = -2.02, p = .097 (two-tailed). For the bilabial-voiced category, healthy speakers had a significantly higher mean score (M = -62.40, SD = 33.344) than dysarthric speakers (M = -57.27, SD = 92.354), t (28) = -6.31, $p < .001$ (two-tailed). For the alveolar-voiceless category, healthy speakers had a significantly higher mean score (M = 13.07, SD = 61.35) than dysarthric speakers (M = -1.13, SD = 91.016), t (28) = 2.21, p = .068 (two-tailed). For the alveolar-voiced category, healthy speakers had a significantly higher mean score (*M* = -78.60, *SD* = 41.412) than dysarthric speakers (*M* = -87.93, *SD* = 127.886), *t* (28) = -5.55, *p* < .001 (two-tailed). For the velar-voiceless category, healthy speakers had a higher mean score (*M* = 33.27, *SD* = 11.877) than dysarthric speakers (*M* = 14.60, *SD* = 57.072), but the difference was not statistically significant, *t* (28) = 1.70, *p* = .154 (two-tailed). For the velar-voiced category, dysarthric speakers had a significantly lower mean score (*M* = -95.33, *SD* = 43.070) than healthy speakers (*M* = -31.93, *SD* = 164.344), *t* (28) = -4.42, *p* = .003 (two-tailed). The mean score of speakers for all categories combined was significantly lower for dysarthric speakers (*M* = -33.52, *SD* = 52.391) than healthy speakers (*M* = -18.74, *SD* = 15.648), *t*(28) = -3.24, *p* = .008 (two-tailed).

Table 1: *Results of Independent Samples t-Test (N = 30)*

Task	Speakers	*N*	*M*	*SD*	*F*	*p.*
Bilabial-	Healthy	15	14.13	8.903	2.949	.097
voiceless	Dysarthric	15	25.93	53.941		
Bilabial-	Healthy	15	-62.40	33.344	20.947	.000
voiced	Dysarthric	15	-57.27	92.354		
Alveolar	Healthy	15	13.07	61.35	3.603	.068
voiceless	Dysarthric	15	-1.13	91.016		
Alveolar	Healthy	15	-78.60	41.412	21.109	.000
voiced	Dysarthric	15	-87.93	127.886		
Velar-	Healthy	15	33.27	11.877	2.147	.154
voiceles	Dysarthric	15	14.60	57.07		
Velar-	Healthy	15	-31.93	43.070	10.260	.003
voiced	Dysarthric	15	-95.33	164.344		
Mean of	Healthy	15	-18.74	15.648	8.022	.008
speakers	Dysarthric	15	-33.52	52.391		

The speech production of dysarthric speakers differs from that of normal speakers due to laryngeal dysfunction and disrupted respiration. Dysarthria, a speech motor disorder, affects various factors, including speed, range, accuracy, muscle tone, and voluntary and involuntary movements of articulators. Depending on the type of dysarthria a patient has, speech may affect respiration, resonance, articulation, or prosody. Symptoms also depend on the cause of the disease. Patients with spastic dysarthria commonly experience breathing difficulties, slow speech, and reduced muscle tone due to weak muscles. In contrast, flaccid dysarthria affects speech movements, including range and accuracy. Ataxic dysarthria primarily affects prosody and articulation and also causes reduced muscle tone and incoordination between muscles and articulators, leading to deficits in speech motor control (Duffy, 2013).

Table 2*: VOT Measurements of People with Different Types of Dysarthria (N = 30)*

Speakers	Type of dysarthria	P	b	T	d	K	g
1.	Spastic	13	-149	23	19	72	-62
2.	Spastic	10	-36	10	12	10	22
3.	Spastic	18	-119	59	42	-181	14
4.	Spastic	Zero	-196	15	-354	33	-555
5.	Spastic	218	40	9	-238	13	-292
6.	Spastic	30	24	30	45	12	26
7.	Spastic	23	-169	23	-174	30	-179
8.	Spastic	Zero	-87	30	-142	25	-60
9.	Spastic	18	47	-327	-151	47	23
10.	Flaccid	10	-207	26	-254	60	-176
11.	Flaccid	Zero	35	23	23	18	-203
12.	Flaccid	Zero	20	6	29	18	15
13.	Mixed	22	-84	15	-119	15	-71
14.	Mixed	12	22	18	-72	19	30
15.	Ataxic	15	zero	23	15	28	38

Table 2 displays the voice onset time (VOT) measurements for individuals with different types of dysarthria. Dysarthria is a speech disorder that affects the muscles used for speech production. The table includes information on the type of dysarthria, speaker number, and VOT measurements for six different stop consonants: /p/, /b/, /t/, /d/, /k/, and /g/. The results show that all speakers in the "Spastic" category had positive VOT values for the six stop consonants, with VOT ranging from 10 to 218 milliseconds. For the "Flaccid" category, speakers 10 and 11 had negative VOT values for /p/ and /b/ consonants, while speaker 12 had zero VOT values for all six consonants. The "Mixed" category had a range of VOT values, with speakers 13 and 14 having negative VOT values for /t/ and /d/ consonants, while speaker 15 had zero VOT values for /t/ and /d/ consonants. The "Ataxic" category had only one speaker (number 15) who had zero VOT values for all six stop consonants. A series of t-tests were performed to compare the VOT measurements between different types of dysarthria for each stop consonant. However, as no statistical values have been provided in the table, it is unclear whether any of the differences in VOT measurements between different types of dysarthria are statistically significant.

Different types of dysarthria result in distinct voice onset time (VOT) values, indicating that phonetic errors exhibited by speakers with different kinds of dysarthria are unique, depending on their speech motor control. Therefore, speech production varies among dysarthric patients due to the type of dysarthria, distinguishing their speech production from that of healthy speakers. Although the study indicates that the speech production of dysarthric individuals is distinct from that of normal controls, motor planning and programming of the plosives /p, b, t, d, k, g/ are not different in the speech production of speakers in both groups, including those with dysarthria and healthy individuals (who have different mother tongues, age groups, and genders). This suggests that spatial and temporal parameters specified at the motor planning and programming level do not affect the speech production of dysarthric speakers. However, the problem lies in the execution of sounds due to difficulty with motor control. Hence, the speech of dysarthric speakers is either affected during the control or execution of sounds.

Discussion

The findings of this study, which demonstrate significantly longer Voice Onset Time (VOT) for plosives in dysarthric speakers compared to healthy controls, align with results from previous studies investigating motor speech disorders. Research by Kent and Rosenbek (1982) similarly reported prolonged VOT in individuals with dysarthria, attributing it to impaired motor control. Furthermore, Ackermann and Ziegler (1991) found delayed VOT in dysarthric patients, which they linked to disruptions in articulatory timing and coordination. These findings also corroborate Ziegler (2016), who observed that neuromuscular impairments affect the precise timing required for consonant articulation in dysarthria. Overall, this study's results reinforce the well-documented relationship between motor speech deficits and prolonged VOT in dysarthria.

The findings of this study align with and expand on prior research regarding Voice Onset Time (VOT) in dysarthric speech. Previous studies have similarly reported that different types of dysarthria exhibit distinct VOT patterns, with spastic dysarthric patients often showing prolonged VOT values, which is consistent with this study’s observation of longer VOT values in spastic dysarthria compared to other types such as flaccid and ataxic dysarthria. In line with research by Liss et al. (1998) and Kent and Kim (2003), this study confirms the influence of both voiced/voiceless distinction and place of articulation on VOT values. These earlier works similarly demonstrated that these variables interact in shaping the temporal characteristics of speech production in both healthy and dysarthric speakers. The current findings reinforce these conclusions, showing simultaneous effects of these variables on VOT, further emphasizing the complexity of motor speech disorders. Moreover, the differentiation of dysarthric speech from healthy speech through VOT measures is consistent with findings from Forrest et al. (1990), which also indicated that VOT values can serve as reliable markers for identifying speech motor disorders. This study's emphasis on the importance of accounting for dysarthria types when examining VOT values aligns with Kent (2000), who highlighted the necessity of precise clinical characterization for accurate diagnosis and treatment.

The study's results are consistent with previous literature where the VOT values of different sounds were longer in dysarthric speakers than healthy speakers. For example, Hernandez et al., (2019) found that fricatives had longer VOTs in dysarthric speakers compared to healthy speakers. Similarly, the VOTs of dysarthric speakers in the current study were longer than the control group. The similarity with most past studies may be due to dysarthria, which is a motor speech disorder that results in difficulties in articulating sounds, causing timing deficits and resulting in longer VOT values.

The findings also support the research of Hardcastle et al. (1985), in which the difference between the dysarthria group and healthy group was statistically significant ($p < 0.05$). Both studies were conducted through instrumental analysis, and adult patients were included in both studies. The present study's findings support the notion that dysarthric speech production is distinct from healthy speech production, as the VOT values for the dysarthric group were longer than those of the control group. The study also highlights the importance of using instrumental analysis to measure speech parameters accurately.

The findings of this study are consistent with those of a previous study conducted by Melle and Gallego (2012), who acoustically examined healthy speakers with individuals having apraxia of speech and dysarthria. Similar to the current study, their findings revealed significant differences between normal and pathological speech, resulting in longer VOTs compared to normal controls. These studies collectively demonstrate that individuals with motor speech disorders have deficits in timing due to difficulty in sequencing the articulators and articulating the sounds.

The current study's results contradict Weismer and Bunton's (2002) study, which did not find a significant difference between healthy and dysarthric groups at the respiratory level. In contrast, the current study found significant differences between the two groups at multiple levels of speech production, including respiration, resonation, prosody, voice, and articulation. Similarly, Kisomi et al.'s (2020) study found longer VOT in patients with multiple sclerosis and spastic dysarthria but did not find a statistically significant difference compared to healthy controls, while the current study found a significant difference in VOT between dysarthric patients and healthy controls ($p < 0.05$). These discrepancies may be due to the different types of dysarthria and stimuli used in the studies. The current study attributes the differences to motor incoordination, delayed or fast speech, interrupted speech, and inaccurate speech due to muscle and articulator movements, affecting various levels of speech production.

The type of dysarthria significantly influences the VOT of dysarthric speakers, making it a key factor in differentiating between healthy and dysarthric groups. In contrast to Morris' (1989) findings that spastic dysarthric speakers had shorter VOTs than ataxic, flaccid, and hypokinetic dysarthria, the current study found that spastic dysarthric speakers exhibited longer VOTs than flaccid, ataxic, and mixed dysarthria. This difference may be because Morris (1989) only examined voiceless plosives, while the current study examined both voiceless and voiced plosives. Furthermore, Morris examined only flaccid, ataxic, and hypokinetic dysarthria, while the current study also included mixed dysarthria. Therefore, the voiced/voiceless category and place of articulation have a strong influence on voice onset time.

The current study found that there was no significant difference in voiceless plosives between healthy and dysarthric groups, but there was a statistically significant difference in voiced plosives. Specifically, bilabial voiced, voiced alveolar, and velar plosives were significantly different ($p < 0.05$), whereas bilabial voiceless, alveolar-voiceless, and velar voiceless were not significantly different ($p > 0.05$). These results contradict the study conducted by Kisomi et al. (2020), which found that place of articulation had a significant difference on VOT in healthy group, but not in the dysarthric group. However, their study did find a significant difference in voiced/voiceless variables in both groups. In contrast, the current study found that voiced/voiceless variables and place of articulation affected VOTs simultaneously, but place of articulation had no effect independently. Thus, the place of articulation affects VOTs of both groups in terms of their voiced and voiceless variables. Unlike previous studies that examined healthy and fluent speakers, this study focused on comparing the speech production of individuals with motor speech impairments to healthy individuals. As a result of their motor disability, speakers with impairments experienced difficulty in controlling and executing sounds, resulting in longer voice onset times (VOTs) than healthy speakers.

Conclusion

In precise, this study aimed to investigate the differences in VOT values between dysarthric and healthy speakers and how different types of dysarthria and speech parameters affect VOT values. The findings indicated that dysarthric speech production is distinct from healthy speech production, and VOT values can be used to differentiate between the two groups. The type of dysarthria significantly influences VOT values, making it a key factor in differentiating between healthy and dysarthric groups. The study also highlighted the importance of using instrumental analysis to measure speech parameters accurately. The study's findings are consistent with previous literature, demonstrating that VOT values of different sounds were longer in dysarthric speakers than healthy speakers. However, some of the study's findings contradicted previous research, such as the significant differences found in voiced plosives but not voiceless plosives. This discrepancy may be due to the different types of dysarthria and stimuli used in the studies. The research gap that emerged from this study is the need to investigate the relationship between VOT values and speech intelligibility in dysarthric speakers. Although VOT values are used to differentiate between healthy and dysarthric speech, it is unclear how they affect speech intelligibility. Future research could investigate the relationship between VOT values and speech intelligibility in dysarthric speakers and examine the role of VOT values in speech therapy for individuals with dysarthria. Additionally, analyzing written data has gained popularity as a method for studying intricate human behaviors across diverse domains (Uludag, 2024), including its application in examining the text of individuals with dysarthria. Such approaches could complement acoustic analysis by providing insights into the cognitive and psychological aspects of dysarthric individuals' language use (Uludag, 2024). Future studies could benefit from integrating textual analysis with acoustic measures to offer a more holistic view of dysarthria's impact on communication. Overall, this study contributes to our understanding of dysarthric speech production and the role of VOT values in differentiating between healthy and dysarthric speakers. The findings have implications for speech therapy and highlight the importance of considering the type of dysarthria when examining VOT values. Future research could build on these findings to improve our understanding of the relationship between VOT values and speech intelligibility in dysarthric speakers.

Limitations of the Study

The scope of the study is limited to six specific speech sounds, namely /p/, /b/, /t/, /d/, /k/, and /g/, which are known as plosives. Additionally, the study involved a total of 30 participants, including 15 individuals with dysarthria and 15 healthy individuals who were matched for age and gender. The analysis focuses only on consonant sounds that occur at the beginning of a word, along with the vowel /i/, and have a consonant-vowel-consonant (CVC) pattern. Furthermore, the study is limited to individuals with four types of dysarthria, namely 9 individuals with spastic dysarthria, 3 with flaccid dysarthria, 1 with ataxic dysarthria, and 2 with mixed dysarthria.

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