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ARTICLE

Characteristics of Voice Onset Time among Speakers of Jordanian Arabic with Parkinson's Disease

Running Title: Voice Onset Time among Parkinson's Disease

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ABSTRACT

Background: The voice onset time (VOT) is an acoustic measure to assess speech neuroregulatory mechanisms. However, the VOT was not measured in individuals of Jordanian Arabic with Parkinson's Disease (PD). Therefore, this research aimed to measure the VOT using a cross-sectional design. Sixteen individuals with PD and 16 healthy controls had their VOT assessed under two treatment conditions (Off and On-medication). The VOT was measured in several phonetic contexts. The results revealed a higher VOT effect among voiceless consonants for the PD in both experimental conditions than controls. Whereas no effects were observed among the voiced consonants between the two groups. In comparison, no differences were observed in the VOT between the voiceless and voiced consonants among the PD group in the Off-medication condition. The administration of the levodopa affected the VOT measure; a significant decrease in VOT among the voiceless and voiced consonants was observed between the Off and On-medication conditions. Additionally, no significant impacts on VOT were found among the PD individuals when comparing front and back consonants, rounded and unrounded vowels, high and low vowels, and among words versus a sentence. However, the VOT may vary according to the phonetic characteristics of speech and medication status among patients with PD. The VOT is still considered a sensitive acoustic measure to investigate speech production's neuroregulatory mechanisms and levodopa's effect among

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individuals with PD in Arabic. Notably, these acoustical markers only represent the first step in the objective biological screening of PD from speech signals.

Keywords: Parkinson's Disease; Voice Onset Time; Voiceless Consonants; Voiced Consonants; Off-Medication; On-Medication

1. Introduction

Parkinson's disease (PD) is a progressive neurodegenerative condition that affects more than 1% of the population and more than six million individuals worldwide[1]. About one million individuals in the United States suffer from PD[2]. In recent years, PD has become extensively prevalent in Arab countries[3]. In Jordan, the prevalence of PD is moderate with a crude rate of 59/100,000. However, the clinical characteristics are similar to those observed in other countries[4]. A prominent increase in the age-standardized prevalence of PD has been observed in the past thirty years mainly in the Middle East and North Africa region[5]. This upward trend in the prevalence of PD may continue to intensify and henceforth warrants medical attention and skilled screening programs.

PD is caused by loss of Dopamine in the substantia nigra in the region of the midbrain; as a consequence, leading to changes in the neuronal activities connecting the basal ganglia and related areas of the thalamus and brain cortex. These changes may take the form of altered neuronal firing rates and patterns that may impact the synchronization of motor impulses[6]. Such asynchronization may affect many parts of the patient's life often displayed as a range of deficits across the speech mechanism including the ability to speak with adequate intelligibility. The characteristic motor speech symptoms associated with PD may include hypophonia, monopitch, reduced stress, long pauses, slow speaking rate, short rushes of speech, prolonged syllables, and reduced phonation time[7, 8]. Moreover, voice disorders mainly "hypophonia" appear in about 90% of individuals with PD, whereas articulation impairments and fluency disorders affect 45% and 20% respectively[9]. Generally, individuals with PD demonstrate a slow speech rate particularly when the effect of antiparkinsonian medication is diminished. While, in other conditions, the rate of speech becomes abnormally accelerated as an effect of the medications[10] or after surgical intervention with deep brain stimulation (DBS)[11].

2. Literature Review

The voice onset time (VOT) is considered a relatively sensitive measure in evaluating laryngeal function. The VOT is "The interval between the initial articulatory release of a stop consonant and the onset of voicing for the subsequent vowel"[12]. However, Little data is available on the relative speech timing patterns in individuals with PD. Although previous studies on VOT among individuals with PD were limited, they produced a wide range of findings. For example, a study showed 7–9 milliseconds (ms) VOT longer than those of the healthy controls (HC) particularly among the stop consonants /b/ and /p/. The difficulty to initiate and coordinate laryngeal motions was the cause of the lengthier VOTs mainly for the voiced consonant[13]. Contrary findings were reported, in a study conducted on ten individuals with PD and ten age-matched HC, and results showed no differences in VOT between the two experimental groups[14]. Other studies suggested lower VOT levels among individuals with PD characterized by shorter voiceless stop closure durations. Decreased VOT resulted either from laryngeal rigidity assuming an essentially closed glottis[15] or the effect of DBS[16]. Such reduction in VOT was associated with a decrease in overall articulation rate. Such findings may be interpreted cautiously because the DBS may produce variable results depending on the basal ganglia stimulation site. Other possibilities affecting changes in the VOT such as the complexities of the language, the severity course of PD, and the effect of antiparkinsonian medications were not attempted particularly among speakers of Arabic with PD.

Literature suggests that speaking rate influences VOT. On the contrary, PD may impact the speaking rate. Therefore, more studies on VOT among patients with PD are necessary focusing on both the traditional VOT and the VOT ratio (i.e., with the effect of speech rate removed). Additionally, VOT and VOT ratio had been reported to change as an effect of the place of articulation of the stop consonant as well as the subsequent vowel height among individuals with PD and HC[17]. In the same context, levodopa was regarded

as the gold standard pharmacological treatment of PD[18]. Levodopa-related variations effects on speech and voice production have been the subject of several investigations[19]. These included research on vowel production, speech rate[10], and phonation[20]. Other reports investigated the relationship between articulation rate and levodopa fluctuations; the articulation rate decreased more quickly as the drug began to diminish[10].

Few researchers have looked into Arabic VOT. In a study conducted by[21] on normal speakers, results showed that the average VOT for the phonemes /t/, /d/, and /t̪/ were 39, 42, and 21 msec, respectively.[22] examined the VOT of stop consonants in Jordanian Arabic. The findings showed that the VOT values were correlated with vowel length where long vowels reflected longer VOT of the stop consonants compared to short vowels. Like English, VOT measures were discrepant between voiced and voiceless Arabic stop consonants. Further findings showed similar VOT duration for the voiceless alveolar stop (/t/) and voiceless velar stop /k/[22]. Additionally, the VOT measures for the consonants /d/, /t/, /k/, and /g/ when preceding the long vowel /i: / were 23, 64, 60, and 20 msec respectively. Unfortunately, similar reports investigating these characteristics among individuals with PD are lacking, furthermore, reports revealed the acoustic norms of VOT among healthy individuals are scarce.

Owing to the lack of validated clinical acoustical scales in native speakers of Jordanian Arabic with PD, we tested the VOT in a linguistically rich context. The prominence of the unique features in the Arabic language, particularly the production of stressed consonants, highlights how these structural aspects of the language can influence neuroregularities of speech production. As a clinical tool, the VOT may serve as a convenient objective assessment method for diagnosing PD and prescribing levodopa.

2.1. Purpose of the Study

Despite all of the progress made in this area among different languages mainly English, there is certainly much need for further investigations of the effect of PD on VOT and VOT ratio among speakers of Arabic language. Therefore, the main focus of the present study was to investigate the VOT and VOT ratio among native speakers of Jordanian Arabic with PD and to identify whether there were differences between speakers with PD and the HC. Another stated purpose was to rule out the effects of antiparkinsonian medications on the VOT and VOT ratio by comparing the patients in the Off and On-MCs.

3. Methodology

3.1. Research Design

The current study followed an experimental research design to explore the VOT and VOT ratio measures of voiceless and voiced stop consonants word-initially among individuals with PD and HC.

3.2. Population

Throughout 2022, patients attending the outpatient neurology clinics at King Abdulla University Hospital (KAUH) diagnosed with Idiopathic PD were recruited. The participants were sixteen, 13 men and 3 women aged 43 to 75, with a mean age of 52.56. All PD participants complied with the following inclusion requirements: 1. Native speakers of Jordanian Arabic and from the same dialectal region, 2. Diagnosed with idiopathic PD by their neurologists, 3. Consuming prescribed antiparkinsonian medications, 4. Free of speech and language disorders other than hypokinetic dysarthria associated with PD, 5. Free of neurological conditions or history of head-and-neck surgeries, and 6) Passing a hearing screening of 25 dB HL at 0.5, 1, 2, and 4 kHz. Participants who showed speech symptoms other than hypokinetic dysarthria associated with PD were disqualified. The severity of hypokinetic dysarthria was determined based on the item (3.1 Speech) of the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS)[23]. Rating the speech severity component i.e., (MDS-UPDRS) was obtained by the consultant neurologist during the patient's regular follow-up clinic visits, particularly in the morning before the patients take their morning antiparkinsonian medications. The (3.1 Speech/MDS-UPDRS) rating score was obtained by subjective listening to the participants' free-flowing speech. On the other hand, the HC group showed normal health status, normal speech and hearing functions, and was devoid of any neurological conditions, notably PD. The study has been approved by the institutional review board at KAUH and all the participants' informed consents were secured before participation.

3.3. Instrumentation

The ICD-TX50 handheld digital tape recorder (Sony Corp., 2021) was used to collect the data. The distance between the speaker's mouth and the microphone was kept at 15 cm during the recording while the tape recorder was set on a tabletop stand. The recorded speech samples were downloaded to the computer digitally, all the analyses were conducted using the PRAAT software package. To quantify the acoustic differences between the PD and HC subjects, the sampled words and sentences were examined using the PRAAT software[17].

3.4. Data Sampling

On the recording day, every member of the PD group provided two recordings. The first recording was obtained before receiving their morning antiparkinsonian medications. This phase was termed as the "Off-medication" condition (Off-MC). The second speech sample was collected 60 minutes after the patients swallowed their morning antiparkinsonian medications. This phase was termed the "On-medication" condition (On-MC). The HC group was recorded once to control for possible variation in the acoustic structure of the speech stimuli. All the recordings were obtained in a sound-treated booth with a background noise level below 30 dB SPL as tested by a calibrated sound level meter. Both experimental groups were instructed to read the speech samples at their habitual speech rate while maintaining their ordinary pitch and loudness levels.

3.5. Reading Materials

The reading materials included several words and a sentence. The word list consisted of seven words, three of which had voiceless stop consonants, and the other four words contained voiced stop consonants. The voiceless and voiced stop consonants were followed by the three corner vowels on the cardinal vowel chart (/i/, /ae/, and /u/). The list was created to satisfy two criteria. First, the phonetic load of the speech stimuli was kept to a minimal level of effort to prevent stress testing among the PD group. Second, to maintain clear speech sampling to meet the speech rate goal and avoid whispering, aphonia, dysphonia, or respiratory distress. The words and the sentences were chosen conveniently to represent everyday language and maintain a familiar semantic component. The core syllable intended for measuring VOT took the "CV" syllable type, where C stood for voiced/voiceless stop consonants and V for corner vowels. The words list and sentence used in this study are displayed in **Table 1**.

Table 1. The words and sentence used for VOT sampling.

	Vowels		
Consonants	**/ ae /**	**/u/**	**/i /**
/b/	باب /ba:b/	بوت /bu:t/	بير /bi:r/
/t/	تاسع /tasıʂ/	تونس /tunis/	تين /ti:n/
/d/	داكن /dakin/	دولاب /dulab/	دينار /dinar/
/t̲/	طالع /ʈalıʂ/	طوبار /ʈubar/	طين /ʈi:n/
/d̲/	ضامن /ɖamın/	ضوء /ɖu:ʔ/	ضيق /ɖi:q/
/k/	كامل /kamıl/	كوسا /kusa/	كيس /ki:s/
/g/	قادون /gadɔn/	قوم /gu:m/	قيم /gi:m/
Sentence	/tunis asımət tunis əlkhadraa/	تونس عاصمة تونس الخضرا	

3.6. Data Analysis

The main acoustic parameter in this study was the VOT; thus, the VOT was determined initially by measuring the interval between the burst of the stop and the onset of periodicity of the subsequent vowel. This interval was calculated precisely from a coupled waveform and wide-band spectrum exhibiting the initial stop consonant for the burst and the periodicity of the successive vowel. Vertical cursors were placed at these two marks and the time between the cursors was calculated to denote the VOT[24].

Word length is provided as the principal measure of the speech rate at which the word was produced. Word length was measured as the interval between the onset of the initial stop consonant burst to the offset of acoustic signal concomitant with the following vowel in the same CV syllable structure.

Provided that VOT may vary as a function of speech rate, statistical analysis was also completed by using a ratio of VOT to word duration. This measurement was used to analyze VOT independent of speech rate variations. The VOT ratio for each stimulus was calculated by dividing the VOT of each syllable by the duration of the same syllable using the following formula; the ratio is measured in milliseconds (msec).

$$\text{VOT ratio} = \frac{\text{VOT}}{\text{Word duration}}$$

Independent group t-test statistic was employed to compare the mean age of the PD and HC participants. A Repeated-Measures Analysis of Variance (RMANOVA) was conducted to compare the VOT and VOT ratio in the study groups i.e., (PD vs. HC) in the Off-MC. The "between" factor for this analysis was the Off-MC involving 2 levels: (PD vs. HC). Whereas, the "within" factors for this analysis included: the place of articulation (3 levels: (bilabial, alveolar, and velar), vowel height (high vs. low), roundedness (rounded vs. unrounded), and sentence length (word vs. sentence). The syllable "tu" was used twice; the first time, it was used as a single word in the word "Tunis," and the second time, it was used in the sentence "/Tunis asemat Tunis al khadra'a/." Determining if any of the discrepancies between the means were statistically significant also affected how the primary findings were interpreted. These analyses were completed separately for voiced and voiceless stop consonants. Post hoc t-tests were interpreted after applying the Bonferroni adjustment to the alpha levels as correct for statistically significant univariate findings. The post hoc tests were conducted to ensure that the assumptions of these tests (e.g., sphericity) were met, the alpha level was set at (0.05). A separate RMANOVA was used to compare the PD participants in Off-MC vs. On-MCs. There were four within factors and no between factors in this analysis. The first within factor was medication condition involving 2 levels (ON-MC vs. OFF-medication) and the second within factor was place of articulation (3 levels: (bilabial, alveolar, and velar). The third within factor was vowel height (2 levels: high vs. low) and the fourth within factor was vowel roundedness (rounded vs. unrounded). Data were again analyzed separately for voiced and voiceless stops. Post hoc t-tests were interpreted after applying the Bonferroni adjustment. Analysis of variance (ANOVA) was conducted with the within factors of place of articulation (2 levels: Front (bilabial and alveolar) and back (velar) and vowel height (2 levels: high vs. low). The HC data were analyzed separately for voiced and voiceless sounds with Bonferroni adjustment to post hoc t-tests considered as appropriate.

4. Results

4.1. Demographic Characteristics

Comparison of the mean age scores between the PD and HC groups was accomplished using an independent groups t-test. The mean age was not statistically significant ($t(14) = -0.856$, $p > 0.05$. Despite this finding, the PD group's median age was slightly higher than the HC group's ($M = 51.75$, $SD = 7.6$) ($M = 52.56$, $SD = 9.9$) respectively. The results of the mean speech symptoms severity rated by the consultant neurologist as per the (MDS-UPDRS) was 3.18 revealing moderate to severe hypokinetic dysarthria. Demographic data for the PD and HC participants and the severity of the speech symptoms were displayed in **Table 2**.

4.2. Comparison of VOT among Voiced and Voiceless Consonants

One-way ANOVA was used to examine the dependent variable VOT for voiced consonants between the PD patients and HC in the Off-MC. Results demonstrated no statistically significant difference in the VOT between the two experi-

mental groups (F (75, 68) = 1.445, p = 0.062). Results also suggested no statistically significant difference between the PD and HC for voiced consonants in the On-MC (F (75, 68) = 0.548, p = 0.994).

Table 2. PD and HC demographic data.

	PD Participants n = 16				HC Participants n = 16	
No.	**Age**	**Gender**	**Years Post-Diagnosis**	**MDS-UPDRS/Speech Severity in the Off-Medication Condition**	**Age**	**Gender**
1	57	F	21	(4)	53	F
2	53	F	17	(4)	52	F
3	60	F	15	(4)	56	F
4	32	M	6	(2)	60	M
5	58	M	9	(3)	55	M
6	53	M	14	(4)	48	M
7	50	M	16	(4)	55	M
8	30	M	4	(2)	40	M
9	45	M	8	(3)	42	M
10	43	M	4	(2)	38	M
11	73	M	15	(4)	53	M
12	58	M	9	(3)	68	M
13	52	M	17	(4)	54	M
14	62	M	5	(2)	52	M
15	58	M	11	(3)	45	M
16	57	M	9	(3)	57	M
Mean	52.56		11.25	3.18	51.75	

Symptoms severity was rated by the neurologist on a scale of 0–4 where 0 = normal, 1 = slight, 2 = mild, 3 = moderate, and 4 = severe.

One-way ANOVA was used to compare the VOT among voiceless consonants between the two groups in the Off-MC. The results showed a statistically significant difference (F (56, 135) = 1.844, p = 0.002). When comparing the VOT of voiceless consonants in the On-MC, results showed a statistically significant difference in VOT (F (56, 135) = 4.725, p = 0.000). Results of the VOT for voiced consonants between both experimental conditions were plotted in **Table 3**.

Table 3. Mean VOT durations in voiced/voiceless consonants for the PD and HC in the (Off/On) medication conditions.

Participants	**On/Off Medication**	**Voicing**	**Mean**	**SD**	**F**	**Sig**
PD	Off	Voiced	0.7543	0.42280		
HC		Voiced	0.6384	0.30363	1.445	0.062
PD	On	Voiced	0.5590	0.35284		
HC		Voiced	0.6384	0.30363	0.548	0.994
PD	Off	Voiceless	0.4006	0.17416		
HC		Voiceless	0.3598	0.15185	1.844	0.002
PD	On	Voiceless	0.3239	0.19195		
HC		Voiceless	0.3598	0.15185	4.725	0.000

Mean values for VOT, VOT ratio, and word duration (in ms) in voiced/voiceless consonants for the PD and HC in the (Off/On-MC) are displayed in **Table 4**.

4.3. Comparison of VOT between the Off and On-MCs

A one-way ANOVA was conducted to compare the VOT for voiceless and voiced consonants between the experimental conditions. The results revealed a statistically significant difference between the two conditions for the voiceless and voiced consonants, respectively (F (50, 141) = 4.750, p = 0.000) and (F (82, 61) = 3.419, p = 0.000).

Additionally, One-way ANOVA was carried out for the PD patients in the Off-MC, to compare voiced and voiceless consonants in the dependent variable VOT. The findings demonstrated no statistically significant difference between voiced and voiceless consonants in the Off-MC (F (58, 85) = 1.037 p = 0.434). **Table 5** displays the VOT for voiceless and voiced consonants in both conditions.

Table 4. Mean values for VOT, VOT ratio, and word duration (in ms) in voiced/voiceless consonants for the PD and HC in the (Off/On-MC).

	PD off		PD-on		HC	
	Voiceless	**Voiced**	**Voiceless**	**Voiced**	**Voiceless**	**Voiced**
VOT						
Alveolar						
High	0.582	0.189	0.585	−0. 081	0.601	−0.521
Low	0.573	−0.138	0.580	0.036	0.092	−0.403
Velar						
High	0.653	0.101	0.683	0.037	0.810	−0.714
Low	0.592	0.179	0.620	0.149	0.789	−0.176
VOT Ratio						
Alveolar						
High	0.316	0.350	0.277	−0.045	0.389	−0.453
Low	0.269	0.277	0.241	−0.106	0.325	−0.125
Velar						
High	0.350	0.422	0.329	0.561	0.498	−0.230
Low	0.289	0.322	0.277	0.921	0.396	−0.202
Word Length						
Alveolar						
High	0.166	0.161	0.145	0.321	0.772	0.489
Low	0.202	0.207	0.191	0.701	0.699	−0.399
Velar						
High	0.170	0.177	0.149	0.399	0.733	0.590
Low	0.201	0.215	0.183	0.871	0.682	0.499

Table 5. Comparison of VOT in voiced and voiceless consonants between the (Off/On-MC) and (Off-MC).

Participants	Off/On Medication	Voicing	Mean	SD	F	Sig
PD	Off	Voiced	0.7543	0.42280	3.419	0.000
PD	On	Voiced	0.5590	0.35284		
PD	Off	voiceless	0.4006	0.17416	4.750	0.000
PD	On	voiceless	0.3239	0.19195		
PD	Off	Voiced	0.7543	0.42280	1.037	0.434
PD	Off	Voiceless	0.4006	0.17416		

4.4. Comparison of VOT between the Front/Back Stops and Words/Sentence

One-way ANOVA was used to compare the VOT among front and back consonants for the PD subjects in the Off-MC. The findings demonstrated no statistically significant difference between front and back consonants for the PD subjects in the Off-MC ($F(62, 129) = 0.936$, $p = 0.609$). One-way ANOVA was used to examine the consonant /t/ when it was pronounced in a single word versus in a sentence among PD patients, particularly in the Off-MC. The findings revealed no statistically significant difference in the VOT ($F(11, 4) = 1.824$, $p = 0.296$). Similarly, results showed no statistically significant difference for the consonant /t/ when uttered in single words versus in a sentence for the PD people in the On-MC ($F(14, 1) = 1.022$, $p = 0.661$). **Table 6** displayed the results of VOT in (front vs. back) consonants in the Off-MC and (words vs. a sentence) for the PD group in both the Off and On-MC.

Table 6. Comparison of VOT in (front and back) consonants in the (Off) and (word vs. sentence) in the (Off/On) medication condition.

Participants	Off/On Medication	Phonetic Context	Mean	SD	F	Sig
PD	Off	Front	0.4466	0.30133		
PD	Off	Back	0.4264	0.20898	0.936	0.609
PD	Off	Word	0.3919	0.01280		
PD	Off	Sentence	0.3631	0.00896	1.824	0.296
PD	On	Word	0.3125	0.01142		
PD	On	Sentence	0.3144	0.01139	1.022	0.661

4.5. Comparison of VOT between Plosives Followed by Rounded and Unrounded Vowels

One-way ANOVA was used to assess the dependent variable VOT between consonants followed by rounded and unrounded vowels for the PD individuals in the Off-MC. The results showed statistically significant difference ($F(15, 146) = -2.520$, $p = 0.024$) for the pairs (/ta/- /tu/, /ka - /ku/, /a/-/u/, /ba/-/bu/, /da/-/du/, and /a/-/u/). However, the results showed no statistically significant difference between the pair /qa/ - /qu/.

4.6. Comparison of VOT between Consonants Followed by High and Low Vowels

T-test was used to compare the dependent variable VOT between consonants followed by high and low vowels among the PD participants, specifically in the Off-MC. Results showed statistically significant differences between the pairs (/ta/- /tu/, /ka - /ku/, /a/-/u/, /ba/-/bu/, /da/ - /du/, and /a/-/u/), ($F15 = -2.520$, $p = 0.024$). However, results revealed no statistically significant difference for the pair /qa/ - /qu/.

5. Discussion

Before this investigation, the VOT for native speakers of Jordanian Arabic complaining of PD was unavailable. This study may be unique due to the linguistic properties of the Arabic language. For instance, producing emphatic sounds requires simultaneous articulatory movements that may add further load on the motor scheme for a given speaker. Consequently, these trajectories might impact speech-motor planning, especially among individuals with PD. Therefore, the primary objective of this study was to investigate the VOT and its modifications among native speakers of Jordanian Arabic with PD particularly during two speaking conditions, i.e., the Off-medication condition versus the On-medication condition.

Furthermore, knowing how specific movement patterns of the speech apparatus change in the Parkinsonian state may help us develop treatments that specifically address these activity pattern changes. Movement disorders such as tardive dyskinesia associated with mental illness may influence the laryngeal function and therefore impact VOT [25]. In previous studies, it was found that there was a significant increase in VOT in PD compared to HC [13]. On the other hand, other studies found that the VOT decreased in PD compared to HC participants [16]. Other valid assumptions may postulate equal VOT durations between the two groups because people with PD may be reducing the range of articulatory movements to make up for the slow movement of the articulators [14]. The place of articulation is known to affect the VOT. According to a general rule; the farther back the place of articulation the longer the VOT values [26, 27]. The primary reason why velar stops were characterized by longer VOT than alveolar or bilabial stops was the relative size of the supraglottal cavity behind the place of constriction. Higher air pressure accumulates in the vocal tract because the space between the vocal folds and velum is small. It takes longer for the pressure to drop at the start of the release phase compared to the anterior place in the alveolar ridge characterized by lower air pressure that requires less time for the pressure to drop after the release phase. Likewise, prosodic position has been shown to have an impact on VOT values as well. For instance, stress in English enhances VOT contrasts, making underlying "voiced" stops more likely to be pre-voiced than in other prosodic positions and pre-vocalic voiceless stops have higher VOT in stressed syllables [28]. Consequently, increasing the VOT differences between the two stop categories can be viewed as a strategy for emphasizing this distinction through stress. Unfortunately, because of the motor insufficiencies in speakers with PD; they become unable to execute adequate stress, and such distinctions are compromised and interfere with the speech signal durations. Van Dam [29] displayed additional stress-related patterns in the language. Underlying voiceless stops in stressed syllables have higher VOT than voiceless stops in unstressed syllables. Additionally, this research demonstrated that stop consonants following stressed syllables might have intermediate VOT values.

5.1. Effect of Voicing

The current study included comparisons of VOT in voiced and voiceless consonants word initially. Unexpectedly, the results showed no significant differences in the VOT of voiced consonants mainly when comparing the PD group with the HC. These findings came in line with other reports, for example [17]. Interestingly, Forrest et al. [13] found that

people with PD had significantly longer VOT for the voiced bilabial stop /b/ compared to that of the HC group. On the other hand, the results of the current study showed significant differences in the VOT of the voiceless consonants when comparing the PD group with the HC in both experimental conditions. Similar reports demonstrated a reduction in VOT in people with PD in the On-medication condition compared to the Off-medication condition [15]. In the usual course of events, the results showed a tendency of longer VOT among the PD compared to the HC in the Off-medication condition and a decrease in the VOT duration in the On-medication condition among the PD group compared to the HC. The findings contradict previous reports that showed no differences in VOT in the voiceless consonants [17]. In contrast to the HC, individuals with PD had shorter voiceless stop closure durations (which included the stop-gap and VOT). Flint et al. [15] hypothesized that this decrease in duration might be caused by the stiffness of the laryngeal musculature of the PD group, which would reduce vocal fold opening. Therefore, people with PD were able to close their vocal folds faster than HC (decreasing closure duration and VOT). However, contrary research findings showed no effect of laryngeal rigidity on the decrease in VOT [16]. On a different scope, findings from individuals with spasmodic dysphonia showed longer VOT, especially when the spasm was in the abduction phase compared to the adduction phase. More studies on VOT in people with PD are necessary because the aforementioned studies used different methodologies to examine VOT and produced inconsistent results.

On the other hand, when the PD were compared to themselves in the "Off" and On-medication conditions, there were significant differences in the VOT, both in voiced and voiceless consonants. Contrary reports found no significant differences in VOT measures between the On and Off-MCs [17]. Minimal medication effect on the speech symptoms of the PD particularly the VOT measure might be explained by more severe symptoms in the advanced stage of the disease.

5.2. Effect of Place of Articulation and Vowel Features

When contrasting the PD participants in the Off-MC regarding the front versus back consonants, the results showed no significant effect. Although the present report showed no significant differences, a trend was observed that VOT tended to be longer among front consonants. Contrary studies found a significant effect on the place of articulation for people with PD [30]. Among voiceless stops, the bilabials had the shortest VOT, followed by alveolar and then velar stops. Similar findings were reported in a study on normal speakers of Najdi Arabic in Saudi i.e., the VOT was longer when the place of articulation of the consonants moved back in the oral tract [30]. As previously reported by [31], the bilabial stops have the shortest VOTs, including frequent pre-voicing, the alveolar stops have intermediate VOTs, and the velar stops have the longest VOTs. Furthermore, Bang et al. [32] found a significant increase in VOT in one of the PD females in the velar stops.

Moreover, the present report showed no differences in terms of vowel features such as height, roundedness, and front/back features. Fischer and Goberman [17] had previously demonstrated that vowel height affects the VOT of stop consonants. Vowel height was found to have a significant impact on voiceless stops. For both people with PD and HC, the VOT of voiceless consonants was longer for high vowels than for low vowels. Unpredictably, the present results contradicted previous studies. Perhaps, one of the most significant factors may relate to the difference in articulatory/linguistic structure of the Arabic language compared to previous studies conducted on speakers of the English language. When considering the place of articulation, vowel height, and roundedness features; only the alveolar voiced and voiceless consonants showed significant differences compared to other consonant strings.

5.3. Effect of Medication

The levodopa effect was considered when the recordings were collected in the two conditions. It is well established that among patients with PD, the levodopa plasma concentration level peaks within 1 hour after dosing and is maintained for 4 to 6 hours. The average half-life of levodopa/carbidopa to be metabolized is one hour and a half and is maintained from two to six hours depending on the severity and stage of the disease [33]. These facts were considered when designing the Off-medication (minimum 6–8 hrs) after the last dose overnight versus On-medication conditions (one hour after the morning dose) and the interpretations of the study findings. As noted from the results, there was a significant decrease in the VOT resulting from the

medication particularly when comparing the VOT among voiced and voiceless consonants. However, the VOT decrease as an effect of medication among words versus sentences didn't reach statistical significance. The tendency of VOT to decrease as an effect of medication may suggest an improvement in speech quality particularly related to laryngeal function. Previous reports showed similar findings that resulted in a VOT decrease with the treatment of antiparkinsonian medications[17]. Other reports showed contradictory findings, i.e., an increase in VOT after the administration of levodopa[10], whereas, other reports found no change[13].

Finally, the VOT may be added as an acoustic marker to the diagnostic guidelines for PD, particularly for patients with mis or underdiagnosis such as multiple system atrophy, corticobasal syndrome, vascular parkinsonism, ….etc. This recommendation requires further investigations to ascertain objective diagnostic criteria for PD.

6. Conclusions

Results suggested that the VOT of voiceless consonants and alveolar stops had significant differences among the PD when compared to the HC in both On and Off-medication states. However, no variation was observed among the VOT of the voiced consonants. Besides, significant effects were obtained when medicating the PD participants with levodopa. In conclusion, the present study supported the usefulness of the VOT measure among speakers of Jordanian Arabic when considering a diagnosis of PD. To ensure a diagnosis of PD the VOT among voiceless stops particularly the alveolar consonants is recommended as an acoustic marker.

7. Limitations and Future Research Direction

The study recruited a small sample size of individuals with PD, so the results may not be representative of the entire population. A larger sample size is recommended in future related studies. The majority of the participants in this study were males because PD is more common among males compared to females. Consequently, the results for female participants didn't reflect accurately those of the male speakers. The present findings may lack a homogenous categorization of patients based on disease severity (mild, moderate, severe) and disease duration (more than five years vs. less than five years). These limitations may be considered in further investigations for robust data generalization.

Authors Contributions

Conceptualization, F.S.A., M.A.B., and R.A.M.; methodology, F.S.A., and R.A.M.; validation, F.S.A., M.A.B., and R.A.M. formal analysis, F.S.A. and R.A.M.; investigation, F.S.A., and R.A.M.; resources, F.S.A. and R.A.M.; data curation, F.S.A., M.A.B., and R.A.M. writing-original draft preparation, F.S.A., M.A.B., and R.A.M.; writing-review and editing, F.S.A., M.A.B., and R.A.M.; supervision, F.S.A., and M.A.B. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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