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The Change of Vocal Tract Length in People with Parkinson's Disease

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***Abstract*— Hypokinetic dysarthria is one of the early symptoms of Parkinson's disease (PD) and has been proposed for early detection and also for monitoring of the progression of the disease. PD reduces the control of vocal tract muscles such as the tongue and lips and, therefore the length of the active vocal tract is altered. However, the change in the vocal tract length due to the disease has not been investigated. The aim of this study was to determine the difference in the apparent vocal tract length (AVTL) between people with PD and age-matched control healthy people. The phoneme, /a/ from the UCI Parkinson's Disease Classification Dataset and the Italian Parkinson's Voice and Speech Dataset were used and AVTL was calculated based on the first four formants of the sustained phoneme (F_1-F_4). The results show a correlation between Parkinson's disease and an increase in vocal tract length. The most sensitive feature was the AVTL calculated using the first formants of sustained phonemes (F_1). The other significant finding reported in this article is that the difference is significant and only appeared in the male participants. However, the size of the database is not sufficiently large to identify the possible confounding factors such as the severity and duration of the disease, medication, age, and comorbidity factors.**

***Clinical relevance*— The outcomes of this research have the potential to improve the identification of early Parkinsonian dysarthria and monitor PD progression.**

I. Introduction

Parkinson's disease (PD) [1] is the second most prevalent neurodegenerative disease, ranked second after Alzheimer's disease. More than 0.5% of the population have the disease and this is expected to significantly increase with an aging population. The disease is highly disabling, and untreated PD results in loss of mobility, high risk of falls, and inability to perform routine activities and communicate. Often the motor symptoms such as tremors appear late and there is a necessity for screening tools that can assist in detecting the disease at the early stage.

To diagnose Parkinson's disease, medical professionals evaluate a range of motor symptoms such as tremors, rigidity, bradykinesia, and postural impairment, as well as non-motor symptoms like dysarthria, functional impairment, and cognitive issues [2]. These assessments are used to calculate a Unified Parkinson's Disease Ranking Score (UPDRS). Speech impairment termed Parkinsonian hypokinetic dysarthria is reported by 90% of people with PD [3]. Parkinsonian hypokinetic dysarthria is characterized by several disturbances in speech. These can include reduced voice intensity, increased voice nasality, increased acoustic noise, reduced speech prosody, imprecise articulation, a significantly narrower pitch range, mono loudness, longer pauses, vocal tremor, harsh and breathy voice quality, and disfluency [4], [5].

Hypokinetic dysarthria is caused by poor activation and coordination of the speech-production muscles [5] [6]. The stiffness and tremor of the larynx muscle affect the vibration pattern of the vocal cords and cause changes to the fundamental frequency, and irregular or asymmetrical closed phases of the vocal during phonation [5] [7]. The reduced controllability of the diaphragm muscles causes unstable phonatory airflow and pneumatic pressure to the larynx [5] [8] [9]. The problem of speech muscle activation and coordination in PD also has reduced the control of vocal tract muscles such as the tongue and lips.

Many acoustic features from sustained phonemes such as pitch frequency variation, number of pulses, jitter, shimmer, autocorrelation, MFCCs, and harmonics-to-noise ratio have been investigated for computerized detection of hypokinetic dysarthria in people with PD [10]–[14]. While there is an argument for the association of the length of the vocal tract with PD, however, this has not yet been reported in the literature.

The length of the vocal tract is mainly dependent on the anatomy. However, the study of Pisansky et al. [15] found that a person may voluntarily or involuntarily modify the length of the vocal tract by up to 25%. Pah et al. [16] identified the usefulness of features related to the vocal tract length in identifying people with pulmonary symptoms due to COVID-19. It was an indication that pathological conditions may change the length of the vocal tract during the pronunciation of the sustained vowels. Gillivan-Murphy [17] identifies the change in the vocal tract as the possible source of the voice tremor identified in the phonation of people with PD. The previous study by the authors reported in [18] showed the significance of the apparent vocal tract length (AVTL) features for differentiating between people with PD and healthy controls.

The above indicates the possible relation between the modification of the vocal tract length with dysarthria symptoms of PD. However, this has not been investigated. This paper reports the result of a preliminary study that has measured the average difference in the AVTL of people with PD and age-matched control participants of the sustained phoneme /a/.

The paper is divided into six sections. Section I introduces the topic, while Section II provides a brief overview of the concept of apparent vocal tract length. Sections III, IV, and V describe the experimental procedure, present the results, and discuss the findings, respectively. Finally, Section VI

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concludes the paper.

II. The Apparent Vocal Tract length

The vocal tract length is the length of the midline along the vocal tract measured from the glottis to the lips. The length of the vocal tract plays a significant factor in the variability in speech production [19]. The vocal tract length is highly variable across speakers. The vocal tracts of an adult vary from approximately 13 cm to 20 cm in length with an average of about 16 cm [20].

It has been studied that the length of vocal tracts is strongly correlated with the formant frequencies [21] [22]. Many models have been developed to estimate the length of the vocal tract based on the formants frequencies. One of the models is the apparent vocal tract length (AVTL). AVTL is the estimation of the physical length of a subject's vocal tract while producing a particular sound based on the frequencies of the formats. AVTL is utilized in various voice analyses, including speaker verification [23] and identifying body measurements [24] [25]. AVTL (in cm) is derived from the four formants, $\{\mathrm{Fi}\}_{\mathrm{i\ =\ 1,2,3,4}}$, as defined by Pisanski et al in [24] as follows.

$$AVTL(F_i) = (2i-1)\frac{c}{4F_i} \tag{1}$$

The constant, c = 33,500 cm/s, is the speed of sound traveling in a uniform tube with one end closed.

III. Methods

The existence and characteristics of change in the length of the vocal tract of people with PD were investigated in this work by observing the change in the AVTL statistical distribution of people with PD in comparison to the age-matched healthy control (HC) participants. The AVTL of the four formants (F_1, F_2, F_3, and F_4) was extracted from the recording of the sustained phoneme /a/ in two publicly available datasets. The datasets were the UCI Parkinson's Disease Classification Dataset of Okan Sakar [12] and the Italian Parkinson's Voice and Speech Dataset [26], abbreviated in this paper with UCI and ITA, respectively. The datasets were approved by the clinical research ethics committee of Bahcesehir University and Universita' degli Studi di Bari Aldo Moro, respectively. The demographic information of the two datasets is presented in Table I.

The sustained phoneme /a/ in the UCI dataset was recorded from Turkish participants using a common microphone with a 44.1 kHz sampling rate and 16-bit resolution in an uncontrolled environment. The ITA dataset was recorded from participants of predominantly Italian using a common microphone located about 15 – 25 cm from the subject in a quiet, echo-free room. The recordings were sampled at 16 kHz and 16 bits of resolution.

The AVTLs were calculated by using equation (1) from the formant's frequencies. The formants of the UCI dataset were provided in the downloaded tabulated matrix of the extracted features in the form of a CSV file. The formants of the WAV recordings in the ITA dataset were calculated using a publicly available speech analysis software, Praat [27].

TABLE I
Demographics of The Datasets

Features	PD		HC	
	Male	Female	Male	Female
UCI Parkinson's Disease Classification Dataset (UCI)				
# Subject	107	81	23	41
Age (years)	65.1 ± 10.9		61.1 ± 8.9	
Italian Parkinson's Voice and Speech Dataset (ITA)				
# Subject	19	9	10	12
Age (years)	67.2 ± 8.7		67.1 ± 5.2	

Before the statistical analysis, the AVTL data were examined for their normality using the Anderson-Darling test [28]. Due to the non-normality of the AVTL distribution, the Mann-Whitney U-test [29] was used to compare the AVTL of PD and HC groups with a 95% confidence level. A p-value$<$0.05 indicated a significant difference between the groups. The effect size, ES [30] [31], of the cases with p-value$<$0.05 were calculated to indicate the strength of the difference. The AVTL calculation and the statistical distribution were calculated using Matlab 2022 of MathWorks.

IV. Results

Figures 1 and 2 show the statistical distribution of the four AVTLs, i.e. AVTL(F_1), AVTL(F_2), AVTL(F_3), and AVTL(F_4) extracted from the phoneme /a/ of the two datasets. The figures show that the AVTL calculated using the first formant F_1 was between 10 – 15 cm while the AVTL(F_2) was much longer (15 – 25 cm). The AVTL calculated using F_3 and F_4 were having a similar range of around 15 cm.

The figures show the existence of a change in vocal tract length due to PD. The figures show that the AVTL calculated using F_1 was the most effective feature in capturing the difference in vocal tract length between PD and HC participants. People with Parkinson's disease tend to have longer AVTL compared to healthy people when pronouncing the sustained phoneme /a/. The AVTL(F_1) distribution of UCI and ITA datasets were having a p-value of less than 0.05 with ES of 0.64 and 0.62, respectively. The statistical p-value was calculated using the non-parametric Mann-Whitney U-test [29].

The phenomenon of having a longer vocal tract length in people with Parkinson's was also evidenced in the AVTL(F_2) distribution but with less consistency and statistical significance. The AVTL(F_2) of the phoneme /a/ in UCI and ITA datasets of people with PD were longer than that of HC, however, the difference was only significant in UCI dataset. The AVTL of F_3 and F_4 could not identify any change due to PD. The other interesting finding in this work is that the change in the vocal tract length captured by AVTL(F_1) and AVTL(F_2) has only appeared in the male participants as shown in the figures. The result indicates that the lengthening of the vocal tract during the pronunciation of /a/ was only happening in male PD patients. The phenomenon was observed in both datasets with different demographics.

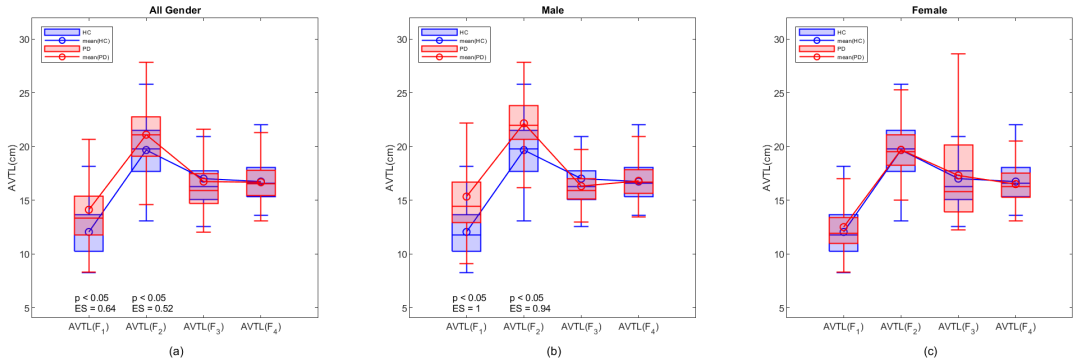

Fig. 1. The statistical distribution of apparent AVTL(F_1), AVTL(F_2), AVTL(F_3), and AVTL(F_4) or the sustained phoneme /a/ extracted from UCI dataset. (a) The distribution of all participants (b) The distribution of male participants, (c) The distribution of female participants. The effect size (ES) was displayed for the cases with a p-value of less than 0.05 and ES>0.5.

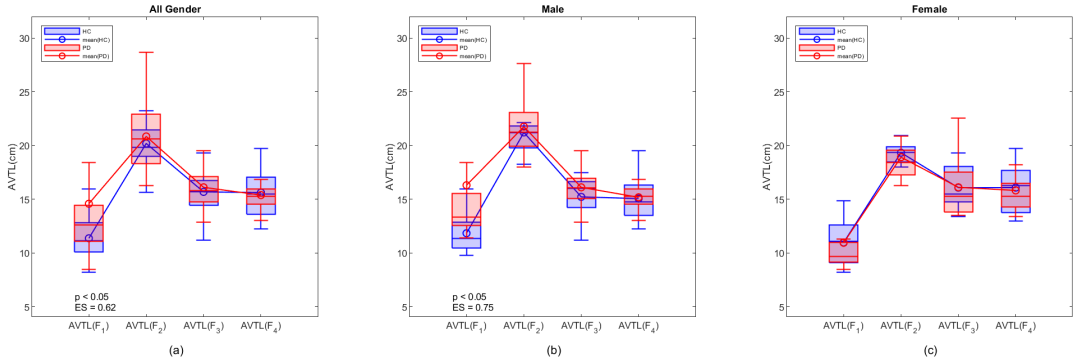

Fig. 2. The statistical distribution of apparent AVTL(F_1), AVTL(F_2), AVTL(F_3), and AVTL(F_4) or the sustained phoneme /a/ extracted from ITA dataset. (a) The distribution of all participants (b) The distribution of male participants, (c) The distribution of female participants. The effect size (ES) was displayed for the cases with a p-value of less than 0.05 and ES>0.5.

V. Discussion

The reduction in the ability of people with PD to control and initiate speech-production muscle activities has been known to be the cause of their speech impairments, known as hypokinetic dysarthria [5] [6]. This has been investigated based on voice features of vocal cord vibrations such as the pitch frequency variation, number of pulses, jitter, shimmer, the change in the vocal tract harmonics such as formants, autocorrelation, MFCCs, and harmonics-to-noise ratio, and the change in voice intensity [18]. One of the changes in the vocal tract harmonics is related to the change in the length of the vocal tract.

PD has been found to alter the resonance properties of the vocal tract [16] [17] [18]. This preliminary study identified the change in the vocal tract length of patients with PD through the statistical distribution of the apparent vocal tract length (AVTL) features.

The result of this study indicates that people with PD tend to extend the length of their vocal tract by 2 – 3 cm when performing the pronunciation of the sustained phoneme /a/. The consistent results were observed in two datasets of different demographic settings. The result indicates that due to the reduced ability of the PD patients in controlling or activating their vocal tract muscle, a modification was made to the position of voice production organs in the vocal tract that resulted in the lengthening of the vocal tract. At this point, the authors have not been able to specifically identify the source or the vocal tract change.

Among the four AVTLs investigated in this work, the AVTL derived from the frequency of the first formant, the AVTL(F_1), was the most suitable feature to represent the difference between the voice of PD and healthy controls. The range of AVTL(F_1) was between 10 – 15 cm which agrees with the actual anatomical length of the vocal tract as reported in [15]. The AVTL(F_1) could capture the change in the vocal tract length with an effect size (ES) of 0.62 to 1. The AVTL calculated on the second formant, F_2, was also sensitive to the vocal tract change but with less consistency and accuracy. The third and fourth formants, F_3 and F_4, were not suitable to represent the length of the vocal tract.

In this study, it was discovered that the alteration in vocal tract length, as measured by AVTL(F_1) and AVTL(F_2), only occurred in male participants as depicted in the figures. This suggests that lengthening of the vocal tract during the pronunciation of /a/ is specific to male PD patients. This observation was found in both datasets consisting of different groups of people. The possible explanation of the phenomenon is that, anatomically, a man has a relatively

longer vocal tract than a woman [15]. However, further works need to be done to investigate the cause of the finding.

VI. Conclusion

This study has investigated the existence and the characteristics of differences in the vocal tract length of people with PD and healthy, age-matched people. It has been found that the AVTL of males with PD is extended while pronouncing the sustained phoneme /a/. The alteration, however, only occurred in male PD patients. This study also found that the most suitable feature to represent the length of the vocal tract is the AVTL(F_1).

Additional research is required to better understand this phenomenon. This would require a larger sample size, a wider range of sustained sounds, and people separated based on the severity of PD. To investigate the underlying causes of the changes in the vocal tract caused by PD, the subglottic pressure and dynamic imaging of the larynx will be required.

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