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Comparison of acoustic measures of dysphonia in Parkinson's disease and Huntington's disease: Effect of sex and speaking task

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Abstract

This study investigated whether voice quality is differentially affected in two distinct basal ganglia disorders causing hypokinetic and hyperkinetic dysarthria, including effects of gender and speaking task. The sustained vowel phonations and monologues of 40 de novo Parkinson's disease (PD) patients, 40 Huntington's disease (HD) patients, and 40 healthy control participants were evaluated. Using cepstral peak prominence extracted from sustained phonation, differences from controls were found for male and female HD patients ($p < 0.05$) but only male PD patients ($p < 0.05$). Using the glottal-to-noise excitation ratio obtained from monologue, differences from controls were detected for male and female PD groups ($p < 0.\ 05$) but only male HD group ($p < 0.05$). In general, female patients show better voice quality. Our findings highlight that selecting suitable acoustic measures and speaking material is essential for adequate evaluation of dysphonia severity across differing etiologies.

1. Introduction

Depending on the underlying pathophysiology, movement disorders can be accompanied by two types of dysarthria, with sometimes having mixed features, hypokinetic and hyperkinetic. Hypokinetic dysarthria, typically present in Parkinson's disease (PD), is associated with akinesia and bradykinetic-rigid syndromes [1]. In contrast, hyperkinetic dysarthria is commonly manifested in Huntington's disease (HD), resulting from involuntary movements and chorea, although it can also be present in other neurological conditions such as dystonia, Tourette's syndrome, and essential tremor [1]. Since both PD and HD are primarily disorders affecting basal ganglia in the brain, they can be used as a theoretical model to evaluate speech patterns associated with hypokinetic and hyperkinetic dysarthria, which often have opposite characteristics. For instance, hypokinetic dysarthria in PD is characterized by a quiet voice, monotonicity, and an increased speech rate, while hyperkinetic dysarthria in HD may present as excessive loudness and pitch and a slower speech rate [1].

An acoustic analysis of voice quality provides an objective and low-cost evaluation that can be used to track disease progression and monitor the effectiveness of treatments in neurodegenerative diseases. The perturbation measures, such as jitter and shimmer are commonly used when screening for voice abnormalities and provide well-known diagnostic biomarkers of a decrease in the quality of the vocal fold functions [2]. It has been hypothesised that changes in voice quality are often one of the earliest signs of neurodegenerative disorders [3]. Patients with PD may experience a reduction in vocal loudness, a monotone voice, and changes in speech rate and articulation [4]. Similarly, in HD, changes in voice quality are also commonly observed. Patients with HD may exhibit hoarseness, dysphonia, and a strained vocal quality [5]. However, to the best of our knowledge, potential phenotypic differences in voice quality between hypokinetic and hyperkinetic dysarthria have never been investigated by direct comparison of PD and HD. To assess these differences, three voice quality measures were selected based on their established physiological significance. Cepstral peak prominence (CPP) is a measure of the prominence of the highest peak in the cepstrum of a voice signal. It has been shown to correlate with breathiness in dysarthric speech [6][7]. Harmonic-to-noise ratio (HNR) and glottal-to-noise ratio (GNE) are measures of the ratio of harmonic components to noise components in a voice signal. These measures reflect the degree of hoarseness in speech, which is a characteristic of both hypokinetic and hyperkinetic dysarthria [8][9].

Speech is a skill that is typically impacted by gender due to the differences in vocal fold lengths. Women usually have shorter vocal folds, which results in higher-pitched voices [10]. Very little is known about the potential gender effect on patterns of voice abnormalities and their relation to voice quality features.

The quality of voice is commonly investigated via the paradigm of sustained vowel phonation. However, sustained vowel phonation does not represent the patient's daily voice. Analyzing voice changes in connected speech may provide a more natural and passive digital biomarker of disease progression without adding cost or burden to the patient or investigator. Additionally, some vocal features are more evident in connected speech than in sustained vowels, making auditory-perceptual voice evaluation essential [11]. For instance, in PD, speech performance is particularly altered during connected speech production [12], compared to simple tasks like sustaining vowel phonation, that tend to be more automatic and require less attention. However, the sensitivity of different vocal tasks for assessing voice quality changes remains not fully investigated.

Therefore, the current study aimed to investigate voice quality via three essential acoustic descriptors in PD and HD. An additional aim was to explore the sensitivity of dysphonia features on gender and different vocal tasks.

2. Methods

2.1. Participants

A total of 120 native Czech participants were enrolled for this study. Forty de novo, untreated PD patients (20 female with a mean age of 53.2 ± SD 10.0 years and 20 male with a mean age of 46.9 ± SD 7.0 years), who had been diagnosed based on the Movement Disorder Society's clinical diagnostic criteria [13]

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were included in the study. Moreover, fourty HD participants (20 female with a mean age of 50.3 ± SD 15.6 years 20 male with a mean age of 48.6 ± SD 9.9 years) diagnosed according to a genetic test confirming $\geq$ 36 CAG repeats in one of the HTT alleles were investigated. The exclusion criteria for HD and PD were history of communication or significant neurological disorders unrelated to HD or PD, such as severe intellectual impairment that would interfere with study protocol. The healthy control (HC) group consisted of 40 age-matched volunteers (20 female with a mean age of 47.8 ± SD 12.8 years and 20 male with a mean age of 52.6 ± SD 11.0 years old), who had no record of any neurological or speech disorders. All of the PD patients had mean score of 28.9 ± SD 12.2 on the motor part of the Movement Disorder Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS III) [14]. HD patients had score of 27.7 ± SD 12.5 on Huntington's disease rating scale (UHDRS). The symptom duration was estimated based on the participants' self-report. The clinical data for the patients are shown in Table 1.

2.2. Speech data

All voice recordings were captured in a quiet environment with minimal background noise, using a head-mounted condenser microphone (Beyerdynamic Opus 55, Heilbronn, Germany) placed about 5 cm from the participant's mouth. Voice signals were sampled at 48 kHz and quantized at a 16-bit resolution. Participants were instructed to complete two vocal tasks:

1. sustain the phonation of the vowel /a/ for as long and steadily as possible in one breath (recorded twice per session);
2. provide a monologue of around 90 seconds on a given topic.

2.3. Acoustic Analysis

The initial step of the signal processing computation consisted of a direct current (DC) offset removal from the acoustic signal followed by a normalization of its overall power. Each signal was down-sampled to 16 kHz to limit the frequency range in the speech signal and reduce the computational demands. To avoid the results being influenced by unequally long pauses in the utterances, a voice activity detector was used to eliminate the parts of the acoustic signals in which no speech was present. In addition, unvoiced parts of the speech were also removed using an automatic segmentation tool for connected speech [15] as in most cases it negatively affects the computation of the voice quality features. Three acoustic features describing voice quality were extracted from the recordings. Harmonic-to-noise ratio (HNR) and Glottal-to-noise ratio (GNE) were calculated using PRAAT [16]. The GNE was extracted using 30 ms window with 10 ms window shift. The bandwidth was set to 1000 Hz with 300 Hz step as concluded by Ignacio Godino-Llorente at al. [9] to be a good trade-off between performance and computational load. The cepstral peak prominance (CPP) implementation was performed in MATLAB [17] and followed the definition of the original study by Hillenbrand et al. [18]. Median value was taken to represent the overall measure of individual acoustic features for each recording.

2.3.1. HNR

The HNR is defined as a parameter that quantifies the relationship between the harmonic and noise components of a speech signal expressed in dB [2]. The unit of measurement reflects the energy conveyed by the voiced signal through the glottal impulses and the energy of the glottic noise fraction after being filtered through the vocal tract. The noise is generated by turbulence when the airflow passes through the glottis during phonation, such as when the vocal cords close improperly [19].

2.3.2. CPP

The cepstral peak prominence (CPP) is very popular and widely accepted parameter in the acoustic analyses for assessing voice quality [20]. The acoustic analysis of the overall voice quality based on CPP has been shown to be strongly correlated with increases in the severity of dysphonia and breathiness in various languages [21] [22]. As the CPP computations is not based on a pitch-tracking algorithm but on the peak to an average calculation, it can be used to analyze the connected speech signals and quality of the voice more efficiently even if acoustic signals are severely dysphonic [23].

2.3.3. GNE

The GNE acoustic feature was initially introduced by Michaelis et al. in their study [24][9]. It provides a method for evaluating the level of excitation caused by vocal fold oscillations as opposed to the excitation caused by turbulent noise. Compared to other acoustic parameters, the GNE stands out due to its robustness in estimating noise levels, particularly in the presence of strong amplitude and frequency perturbations, without requiring prior estimation of the fundamental frequency, a challenging task in the presence of vocal pathology. In the case of turbulent signals such as pathological or whispered voices, a narrow-band noise is excited in each frequency channel, which is uncorrelated and, thus, leads to lower values of GNE [9].

2.4. Statistical Analysis

The one-sample Kolmogorov-Smirnov test confirmed the normal distribution of the calculated features. The estimation of the differences between the individual groups (HC versus PD versus HD) was evaluated using a one-way analysis of variance with a post hoc least square significant difference. The level of significance was set to $p < 0.05$. In addition, we performed a binary logistic regression followed by leave-one-subject-out cross-validation to assess the ability of a combination of acoustic features to distinguish between groups (i.e., sensitivity/specificity). An overall indication of diagnostic accuracy was reported as the area under the curve (AUC), which we obtained from the receiver operating characteristic curve.

3. Results

The GNE values extracted from the monologues revealed a significant group effect $[F(2, 57) = 3.58, p < 0.05]$ for men, which was associated with the differences between the male HC and PD ($p = 0.03$) groups as well as between the male HC and HD ($p = 0.01$) groups. For women, post hoc analysis detected statistical significant differences for monologue task between female HC and PD groups ($p = 0.04$). No statistically significant differences were found for the GNE in the phonation task. The results for the group differences of GNE measure are shown in Fig 1.

The CPP values extracted from the sustained phonation were sufficiently sensitive to differentiate the examined groups statistically for male participants $[F(2, 57) = 3.35, p < 0.05]$. The post hoc analysis revealed statistically significant differ-

Table 1: *The demographic and clinical data for the patients. The data show the mean (standard deviation, SD). MSD-UPDRS signifies Movement Disorder Society - Unified Parkinson's Disease Rating Scale, UHDRS signifies Unified Huntington's Disease Rating Scale*

	PD (male, n = 20)	**HD** (male, n = 20)	**PD** (female, n = 20)	**HD** (female, n = 20)
Mean age (yr)	46.9 (SD 7.0)	48.6 (SD 9.9)	53.2 (SD 10.0)	50.3 (SD 15.6)
Mean symptom duration (yr)	2.3 (SD 1.7)	6.0 (SD 3.1)	1.9 (SD 1.1)	5.0 (SD 4.0)
Mean MDS-UPDRS III total	26.9 (SD 9.2)	-	30.9 (SD 14.6)	-
Mean UHDRS total	-	26.0 (SD 13.2)	-	29.5 (SD 11.9)

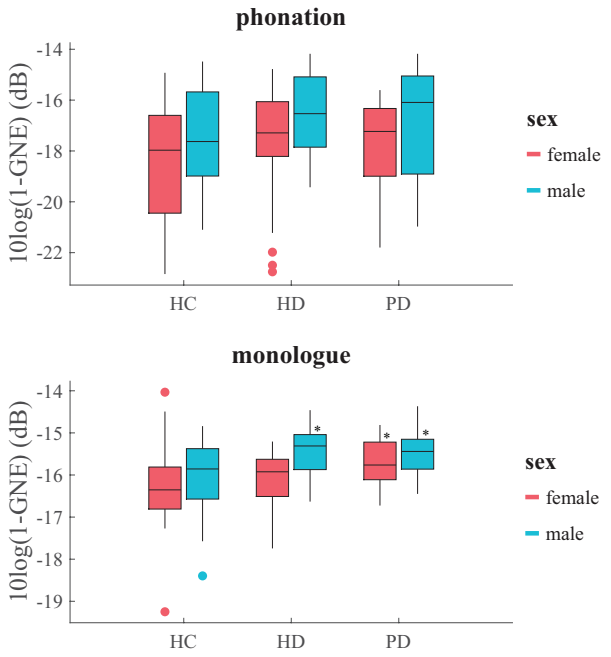

Figure 1: *The results of the group differences in the GNE measures among the HC, PD and HD participants across the sustained phonation (up), and monologue (down). The bars represent the mean of the GNE and the rectangles show the interquartile ranges. The outliers are signified by dots. The significant differences are label by* $*, p < 0.05$ *referred to HC group.*

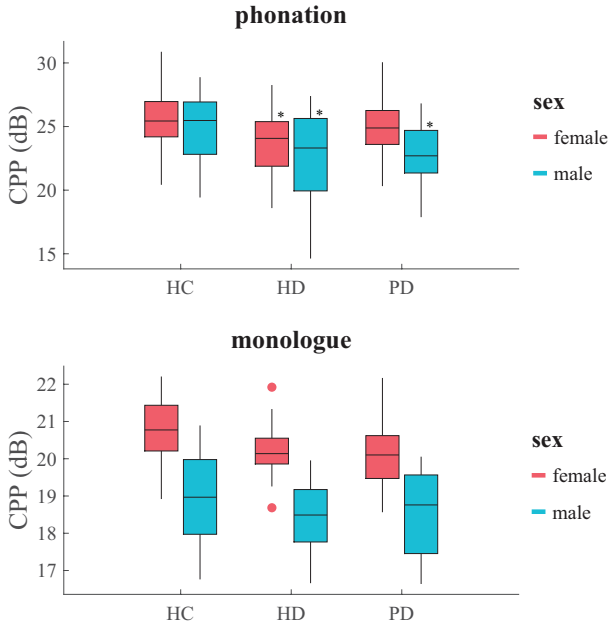

Figure 2: *The results of the group differences in the CPP measures among the HC, PD and HD participants across the sustained phonation (up), and monologue (down). The bars represent the mean of the CPP and the rectangles show the interquartile ranges. The outliers are signified by dots. The significant differences are label by* $*, p < 0.05$ *referred to HC group.*

ences in the CPP parameters between the male HC and PD ($p = 0.03$) groups, and between the male HC and HD ($p = 0.02$) groups. In case of female subjects, statistical significance of the examined groups was also found $[F(2, 57) = 2.9, p < 0.05]$. Significant post hoc differences were detected between the female HC and HD ($p = 0.02$) groups. No statistically significant differences were detected for the CPP in the monologue task. Fig. 2 shows results of group differences for CPP.

Considering the HNR parameter, no statistical significance was found in any task for both men and women. Results for HNR group differences are shown in Fig. 3.

Combination of acoustic features across both tasks achieved the best accuracy to discriminate the PD as well as HD groups from control subjects. Results can be found in Table 2.

4. Discussion

The present study investigated the differences in voice quality via acoustic measures of CPP, HNR and GNE between hypokinetic and hyperkinetic dysarthria of PD and HD, including the effect of sex and speaking tasks. We found that the GNE as well as the CPP measures are capable of differentiating between both basal ganglia disorders and controls. Nevertheless, certain phenotypic differences for voice quality between PD and HD were noted. CPP seems to be more sensitive in HD patients. In fact, it is widely recognized that HD patients suffer from respiratory dysfunction [25], which negatively affects the speech production. In contrast, the GNE measure exhibited greater sensitivity in case of PD. The results likely point out that hoarseness manifests more in hypokinetic dysarthria. Indeed, harshness and hoarseness are described as one of the first signs of hypokinetic dysarthria in parkinsonism [1].

Despite the fact that decreased voice quality appears in both male and female patients, female participants show better voice quality in terms of the acoustic analysis. This could also be supported by the classification experiment, where men achieved higher AUC on average than women. This is in accordance with recent study by Rusz et al. [26], where they found that women showed better speech performance in several acoustic dimensions relative to men and they hypothesized that in case of female PD patients, their hypokinetic dysarthria may be associ-

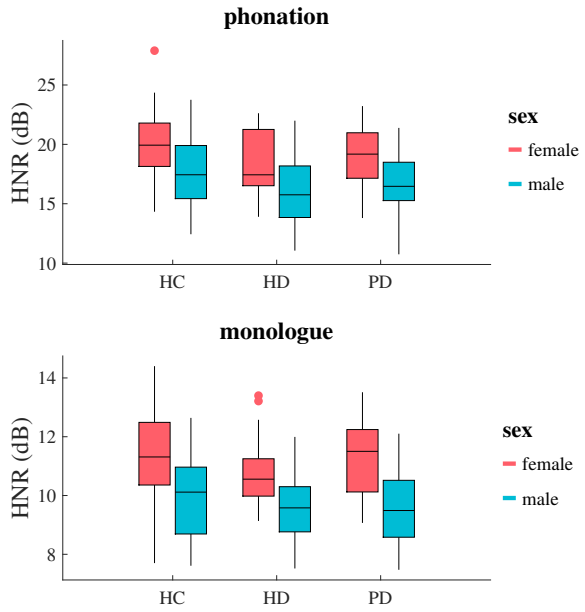

Figure 3: *The results of the group differences in the HNR measures among the HC, PD and HD participants across the sustained phonation (up), and monologue (down). The bars represent the mean of the HNR and the rectangles show the interquartile ranges. The outliers are signified by dots. No significant differences were found between the HC and HD/PD group.*

ated with different clinical parameters than in men. This may suggest that if speech features are to be used as an outcome measure in future clinical trials, it may be crucial to carefully stratify the participants by gender. This can help ensure that any observed differences in speech dimensions accurately reflect the effects of the disease or treatment being studied, rather than being confounded by gender-related factors.

With regard to the effects of the different vocal tasks, the results indicate that the HNR measure is not sufficiently sensitive to capture possible speech impairments in PD nor HD patients. This is in contrast with previous studies that reported reduced HNR in those with PD [27][28]. The reason behind this finding might be the fact that, due to matching of HD and PD individuals on age, our dataset consists of younger PD patients than those that are typically reported in previous literature. Indeed, a recent study by Rusz et al. [29] showed that dysphonia represents age-dependent phenotypic effect of PD that is typically profound in patients with late age at onset. In fact, studies exploring the impact of healthy aging on speech have already demonstrated the significant effect of age on measures related to voice harshness [30] [31]. In this study, CPP was able to differentiate between the groups in both male and female participants in sustained vowel phonation task. This is in agreement with previous study by Simek and Rusz [32], where CPP captured decreased voice quality in PD patients from early stages of the disease. In addition, previous research on acoustic voice analysis proposed the CPP as a metric that is generally more sensitive than the classical perturbation measures, such as HNR, for assessing the voice quality via sustained vowel phonation task [33]. Interestingly, we found that the GNE parameter was sufficiently sensitive to differentiate the investigated groups for monologue task, whereas no significant differences were found

Table 2: *Results of trained binary logistic regression classifier based on voice quality features. Area under curve (AUC), Sensitivity (SEN) and Specificity (SPEC) are reported. GNE_m signifies GNE extracted from monologue and CPP_b stands for CPP extracted from both tasks.*

AUC/SEN/SPEC	PD vs HC	HD vs HC
Female		
Phonation (CPP, GNE)	0.67/0.53/0.53	0.70/0.59/0.61
Monologue (CPP, GNE)	0.69/0.62/0.63	0.68/0.61/0.61
Combined (GNE_m, CPP_b)	0.71/0.62/0.63	0.72/0.60/0.63
Male		
Phonation (CPP)	0.71/0.59/0.60	0.72/0.61/0.60
Monologue (GNE)	0.73/0.63/0.60	0.71/0.62/0.61
Combined (GNE_m,CPP_b)	0.75/0.63/0.61	0.77/0.64/0.63

for sustained vowel phonation. To the best of our knowledge, such observation has never been reported but might have important implications for future clinical trials in neurodegenerative diseases. Tracking voice changes from connected speech may provide a very natural, passive digital biomarker of disease progression based on longitudinal data acquired without any cost or burden to the patient and investigator. Connected speech represents a very complex task and contains significant voice and frequency variations. As the GNE quantifies the amount of voice excitation due to vocal fold oscillations versus excitation by turbulent noise and the calculation is done for different frequency bands, we hypothesize that connected speech provides more accurate estimate about the vocal excitation as it contains more information in individual frequency bands. In addition, GNE is considered a reliable measure for the relative noise level even in the presence of strong amplitude and frequency perturbations [9]. Thus, the GNE appears to capture voice impairments more efficiently in connected speech rather than in sustained vowel phonation.

5. Conclusions

The results of the present study revealed that both the CPP and GNE are capable of differentiating between the HC and PD/HD patients. Yet, our findings suggest certain phenotypic differences with CPP more suitable for HD due to occurrence of breathiness and GNE for PD due to presence of harshness. Therefore, the CPP and GNE measures may serve as a promising progressive digital biomarker for assessing voice impairment due to basal ganglia dysfunction in clinical practice with low ambient noise. Further research is necessary to uncover the predictive significance of unique speech disorder patterns in the progression of PD and HD.

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