Voice Acoustic Instability During Spontaneous Speech in Parkinson's Disease

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Summary: Background. In people with Parkinson's disease (PwPD), both motor and cognitive deficits influence voice and other aspects of communication. PwPD demonstrate vocal instability, but acoustic declines over the course of speaking are not well characterized and the role of cognition on these declines is unknown. We examined voice acoustics related to speech motor instability by comparing the first and the last utterances within a speech task. Our objective was to determine if mild cognitive impairment (MCI) status was associated with different patterns of acoustic change during these tasks.

Methods. Participants with PD (n = 44) were enrolled at University of Massachusetts Chan Medical School and classified by gold-standard criteria as normal cognition (PD-NC) or mild cognitive impairment (PD-MCI). The speech was recorded during the Rainbow Passage and a picture description task (Cookie Theft). We calculated the difference between first and last utterances in f_o mean and standardized semitones (STSD), cepstral peak prominence-smoothed (CPPS), and low to high ratio (LH). We used t-tests to compare the declines in acoustic parameters between the task types and between participants with PD-NC versus PD-MCI.

Results. Mean f_o, f_o variability (STSD) and CPPS declined from the first to the last utterance in both tasks, but there was no significant difference in these declines between the PD-NC and PD-MCI groups. Those with PD-MCI demonstrated lower f_o variability on the whole in both tasks and lower CPPS in the picture description task, compared to those with PD-NC.

Conclusions. Mean and STSD f_o as well as CPPS may be sensitive to PD-MCI status in reading and spontaneous speech tasks. Speech motor instability can be observed in these voice acoustic parameters over brief speech tasks, but the degree of decline does not depend on cognitive status. These findings will inform the ongoing development of algorithms to monitor speech and cognitive function in PD.

Key Words: Parkinson's disease–Motor speech–Acoustics–Cognition–Voice.

INTRODUCTION

Parkinson's disease (PD) is a neurodegenerative disease characterized by motor symptoms including bradykinesia, rigidity, and tremor, as well as non-motor symptoms such as cognitive impairment.[1] Communication difficulties also occur in the majority of people with PD (PwPD).[2] These are highly variable between individuals and may develop early or late in the disease course.[3] Communication deficits in PD are complex because PD impairs both motor and cognitive functions. However, the relative influences of the motor and cognitive systems on communication deficits in PD are understudied and poorly understood. Motor speech symptoms typically manifest as hypokinetic dysarthria, with harsh breathy voice quality, decreased volume, monopitch, imprecise articulation, and impaired speech rhythm,[4] as well as difficulty coordinating respiration with speech.[5] Linguistic changes may also occur, such as difficulties with action verb use[6–8] and complex syntax.[9–11] Cognitive impairment may additionally impact communication, leading to shorter utterances and increased pausing, which further affect speech naturalness and informativeness.[12–14] Due to the concurrent influences of speech motor and cognitive-linguistic deficits, speech function in PD may be subject to variability depending on the speech task and context. However, research involving longer, more ecological spontaneous speech tasks are lacking. Evaluation across different types of speech, and exploration of both speech motor and cognitive-linguistic demand, are needed to understand the mechanisms behind the daily communication difficulties that impact PwPD.

PwPD commonly report worsening speech impairment with a longer duration of speaking. However, little formal research has characterized speech patterns within an individual speaker over the course of a speaking task. Acoustic analyses are typically averaged over an entire speech task, missing potentially informative patterns within the task. Dynamic acoustic changes have been associated with improved detection of PD[15] and with response to speech therapy in PD.[16] Motor instability is a hallmark feature of PD, causing difficulty in sustaining motor actions.[17] This feature causes motor task performance to decline over time during the task, and can be observed in limb movements as well as speech in PD.[17] Motor instability is thought to arise from basal ganglia dysfunction.

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The globus pallidus is the main output structure of the basal ganglia and controls the initiation and termination of each submovement in a sequence of movements that make up an automated motor program such as speaking. With globus pallidus dysfunction, the amplitude of submovements cannot be maintained as the sequence progresses.[18] In speech, this and related changes in the basal ganglia circuitry are hypothesized to lead to progressive impairments in acoustic features as speaking time increases.[19,20] It is important to understand how speech task type and duration influence speech motor instability in PD. Automated algorithms are being developed and implemented using acoustic features to detect and monitor PD. It is plausible that speech motor instability could be a useful component of such algorithms, but when task performance is averaged as a whole, these subtle patterns are overlooked. It is necessary to first evaluate the stability of potential speech markers in various speech prompts. To address this, we compared standard acoustic features at the beginning and at the end of two commonly used speech tasks.

Speech motor instability might also depend on the severity of speech motor and cognitive symptoms in an individual. Globally, communication utilizes complex and simultaneous cognitive and motor processes. PwPD require additional attentional oversight of these processes due to their disease state. It has been hypothesized that limited attentional resources result in worsening performance, such that motor impairment worsens if the cognitive demand of a task is high and vice versa. This phenomenon has been demonstrated in dual-task experiments involving speech and gait, and speech and manual motor tasks.[21–23] Gait variability is the metric that has been shown to decline most consistently in studies applying various dual tasks, demonstrating impaired stability of gait measures under these conditions.[24,25] Cognitive functions including attention and frontal executive deficits have been shown to be associated with this feature of motor instability.[26] It is therefore important to consider the cognitive status of participants when evaluating speech performance in PD, especially when using tasks with cognitive demand. It is plausible that more cognitively challenging speech tasks can highlight speech motor instability in those with cognitive impairment who prioritize the cognitive task over speech motor systems. Targeted selection of tasks, and comparisons of speech performance patterns between tasks, may enable speech algorithms to better predict the motor and cognitive status of an individual. Finally, speech motor instability is clinically relevant as it can impact speech quality and function in daily communication in individuals with PD. It is important to identify and characterize speech motor instability in order to develop optimally performing speech marker assessment pipelines and to facilitate clinical evaluation and treatment of this problem.

For this study, we examined fundamental frequency (f_o) as a marker of speech motor instability in PD. f_o is a primary feature of voice, derived from vocal fold vibrations. Decreased f_o variability, which may be related to the perception of monopitch, is a characteristic of hypokinetic dysarthria in PD.[27] Given that phonation requires sustained muscle activation and coordination of the larynx,[28] f_o parameters such as mean f_o and its variability may be sensitive to declines in speech motor stability and to dual-task effects in PD. In the general population, the mean f_o increases with prolonged speaking, a phenomenon that has been suggested as an indicator of vocal fatigue.[29] It is unknown whether similar changes in mean f_o occur in PD and how these may depend on the type and duration of speaking task. In PD, the mean f_o is higher overall in males with PD compared to male controls and similar in females with PD and female controls.[30] However, few studies have evaluated changes in f_o-related features over the course of speaking tasks in PwPD. Skodda and colleagues[31] examined f_o variability during the reading of four complex sentences in a large cohort of PD participants. Their results indicated a statistically significant decline in f_o variability from first to fourth sentence. Bowen and colleagues[32] further explored motor instability of f_o features in PD during the first paragraph of the Rainbow Passage. In contrast to the findings of Skodda et al, they found no significant difference in f_o variability from the first to the last sentence of the paragraph between PD and controls. The two studies differed in the type of reading passage as well as the size and composition of the sample. Neither study accounted for baseline cognitive function of the participants, which may have impacted the results and their consistency. To our knowledge, no prior studies have explored f_o declines in spontaneous connected speech in PD. Other acoustic features such as those reflecting voice quality have not been explored in terms of motor instability in PD.

We characterized changes in f_o mean and variability features during the course of speaking in individuals with PD. Both passage reading and picture-description tasks were incorporated. We assessed motor instability by comparing acoustic performance on the first utterance in the task to the last utterance. We selected f_o mean and variability features as our primary outcomes since these have been partially assessed in prior literature and we sought to clarify inconsistencies in this literature. We additionally assessed cepstral peak prominence-smoothed (CPPS) and low-to-high ratio (LH ratio) to further characterize dynamic changes in vocal quality. We selected reading and picture description tasks in order to determine whether cognitive-linguistic demands affected speech acoustic patterns. Compared to the reading task, the picture description task requires lexical retrieval, planning, and organization of content and generation of grammar and syntax. On the other hand, the reading task provides prosodic and syntactic structure. We also performed comprehensive cognitive assessments and categorized participants with PD as having either normal cognitive status (NC) or mild cognitive impairment (MCI). This enabled us to assess the role of cognitive impairment in speech motor instability on each task and on the differential performance between these tasks. We hypothesized that participants with PD-MCI would have greater acoustic changes (increased motor instability) during the picture description task than PD-NC participants and that both groups would demonstrate similar performance patterns on the reading task. We propose that this work will help guide the selection of speech tasks and inform automated acoustic analysis strategies in the growing field of PD speech markers. It will furthermore lead to an improved understanding of speech motor instability in PD, an important clinical target for therapy.

METHODS

Participants

We conducted a single-center cross-sectional study with 44 participants with PD (29 male and 15 female, mean age 66.4 years, range 43–79, standard deviation [SD] 7.7) enrolled at the University of Massachusetts Chan Medical School from 2020 to 2022. All participants were diagnosed with idiopathic PD by a fellowship-trained movement disorders specialist. All participants were older than 18 years, spoke English as their primary language, had PD symptom duration greater or equal to 2 years, and had no diagnosis of dementia (based on Movement Disorders Society criteria.[33] Participants were excluded if they had another neurological disorder other than PD, had unintelligible speech due to the progression of PD (as judged by the PI), had deep brain stimulation, or had other voice, speech, or swallowing disorders. All participants completed an informed consent procedure in accordance with the Declaration of Helsinki and approved by the institutional review board of the University of Massachusetts Chan Medical School.

Assessments and protocol

Each participant provided demographic and clinical history, and underwent clinical assessments including Movement Disorders Society-Unified PD Rating Scale (MDS-UPDRS Parts I–IV), Geriatric Depression Scale, Montreal cognitive assessment (MoCA). The axial subscore of the MDS-UPDRS Part III and the speech symptom item of the MDS-UPDRS Part II were summarized separately from the total score. We administered a comprehensive battery of neuropsychological tests in order to diagnose PD-MCI. The cognitive battery included two tasks from each of the five cognition domains: Trail-making test A and B; Symbol digit modalities test; Boston Naming Test (30 items odd); Animal naming; Letter-guided verbal fluency; Judgment of line orientation (15 items odd); Boston Diagnostic Aphasia Examination; Hopkins verbal learning test (HVLT)-R immediate and HVLT-R Delayed and Recognition; Letter number sequencing; Brief visual memory test (BVMT)-R and BVMT-R Delayed and Recognition; Logical memory I (WMS-R, Anna Thompson story) and Logical memory II. Assessments were discussed in a consensus conference attended by two movement disorders specialists and one neuropsychologist to classify each participant as No Cognitive Impairment (NC) or MCI according to MDS Task Force Level II criteria[34] (Table 1). MoCA scores were not used to diagnose cognitive status. One participant was excluded from all further analyses due to an indeterminate ruling from the consensus conference.

Participants were asked to read the first paragraph of the Rainbow Passage (mean duration = 67.1 seconds [SD 21.6, range 44.4–186.6 seconds)].[35] The duration to complete this reading task was significantly longer in participants with PD-MCI compared to PD-NC (mean difference = 12.8 seconds, $P = 0.04$). Participants were then asked to describe a picture of a scene.[36] For this task, the participant was instructed that they would be given 60 seconds to describe the picture presented to them to the best of their ability, aiming to fill the entirety of the 60 seconds with their description. Participants were not given time to plan their responses. The Cookie Theft picture task was selected because it leads to the generation of naturally connected speech and has been applied broadly in many neurological disorders. The mean duration for task performance in our cohort was 60.0 seconds (SD 5.8, range 39.5–70.9 seconds) with no significant difference between participants with PD-MCI and PD-NC.

The recording was performed using a hand-held digital recorder with a head-mounted microphone approximately

TABLE 1.
Baseline Characteristics of Participants with PD Overall and by Cognitive Status

	All Participants (n = 44) Mean (SD, Range)	NC (n = 20) Mean (SD)	MCI (n = 24) Mean (SD)	*P*
Age (yrs)	66.4 (7.7, 43–79)	66.6 (8.0)	66.2 (7.6)	0.89
Sex (#M/#F)	29M/15F	14M/6F	15M/9F	0.60
Education (yrs)	16.4 (3.0, 12–26)	17.5 (2.2)	15.4 (3.5)	0.03
Disease duration (yrs)	4.9 (3.6, 1–15)	4.3 (3.6)	5.4 (3.6)	0.28
MDS-UPDRS Part III total	30.1 (10.9, 7–53)	28.7 (12.2)	31.2 (9.9)	0.45
MDS-UPDRS Part III axial score	4.7 (2.3, 0–10)	3.9 (2.2)	5.3 (2.2)	0.04
MDS-UPDRS Part II Speech item	0.7 (0.9, 0–3)	0.6 (0.7)	0.8 (0.9)	0.43
MoCA	27.2 (2.3, 21–30)	28.4 (1.3)	26.3 (2.6)	0.003

Note: *P*-values for *t*-tests (and chi-square test for sex) comparing variables between PD-NC and PD-MCI groups are shown.

7 cm from the mouth at a 45° angle (Zoom H4n Pro Handy Recorder, Zoom, Hauppauge, NY, USA and Shure WH20 headset, Shure Inc., Niles, IL, USA) at a sampling rate of 44,100 Hz and 16 bits. The audio recordings were saved as .WAV files and analyzed using the software Praat.[37] The participant's description of the Cookie Theft picture was then manually transcribed and segmented into utterances. Utterances were defined as one independent clause and all clauses or phrases dependent on it.[38] Each participant performed the reading task first, followed by other tasks of our speech protocol not discussed in this manuscript, and ending with the picture description. For the Rainbow Passage, utterances and sentences were used interchangeably.

Speech analysis

Speech files were analyzed using Praat to obtain f_o mean and SD. These measures were calculated in a standard fashion for each task (representing the mean over the entire task) and for the first and the last utterance of each task. f_o SDs were then converted into semitones (STSDs) as described in Bowen et al. The STSD estimates prosodic variation, is less likely to be confounded by the effects of mean f_o (and thus speaker sex), and is robust to single instances of f_o deviations.[32] Glottalization and other non-modal phonation were excluded from the analysis. Two independent raters (KMS and MDP or KMS and CM) independently calculated f_o parameters for all participants on the reading task. CPPS was calculated using Praat as described in Kapsner-Smith et al[39] without applying a voicing threshold script before calculation. LH ratio was calculated for each task, as well as the first and last utterance of each task using Praat with settings for low band ceiling and high band ceiling both set at 4000 and high band ceiling at 20,000.

The picture description task was also manually transcribed and the number of words was counted in order to calculate words per minute. Participants with PD-MCI demonstrated significantly fewer words per minute compared to those with PD-NC (mean words per minute 120.1 [SD 21.1] and 147.7 [SD 32.4] respectively, $P = 0.003$).

Statistical analysis

Analyses were conducted with STATA (StataCorp LLC, College Station, TX). Normality was first assured visually using quantile–quantile plots. Variables of interest had plausibly normal distributions and we therefore used parametric tests. All statistical tests were two-sided. Statistical significance was set a priori at $P \leq 0.05$. To account for multiple tests, we multiplied all *P*-values by the number of tests and reported them as adjusted *P-values*. To assess inter-rater consistency, we calculated Pearson's correlations between the two technicians' scores and also reran all analyses with a second rater's scores to ensure overall results were consistent. There was an excellent correlation between raters for the reading task, with Pearson's correlation $r > 0.80$ for all mean f_o and STSD measures of the first and last utterances. The primary rater's (KMS) values were used to report the results.

We compared demographic clinical characteristics between the PD-NC and PD-MCI groups using *t*-tests and chi-square tests for continuous and categorical variables, respectively. To assess changes in acoustic features over the course of speaking, we calculated the difference between the acoustic performance of the first and the last utterance. We compared these differences for the reading versus picture description tasks using paired Student's *t*-tests. To evaluate the impact of cognitive status on acoustic performance patterns, we calculated the following value for the PD-NC and PD-MCI groups: Between-task Δmean f_o = (picture task mean f_o^{FIRST} − picture task mean f_o^{LAST}) − (reading task mean f_o^{FIRST} − reading task mean f_o^{LAST}). This calculation was repeated for each acoustic feature (SD f_o, STSD, CPPS, LH ratio) and we performed independent *t*-tests on the resulting variables to assess for differences between the NC and MCI groups.

RESULTS

Acoustic feature patterns in reading and picture description tasks

In the overall cohort of PD participants (n = 44), the acoustic features of each entire task are shown in Table 2, along with the acoustic features of the first and last utterances of each task. There were no significant differences between mean f_o or STSD measured over the entire reading task compared to the entire picture description task ($P = 0.09$ and 0.9 respectively). There was a significant decline in mean f_o and STSD from the first to the last utterance in both tasks (Table 2). The magnitude of this decline was not significantly different when comparing the two tasks. The decline in mean f_o was approximately 9 Hz in both tasks (mean difference = 0.56 Hz, standard error = 1.6, $P = 0.7$). The decline in STSD was approximately 0.6 semitones in both tasks (mean difference = −0.11, standard error = 0.3, $P = 0.7$). However, there was greater variance in STSD performance on the picture description task such that the decline was no longer statistically significant when the *P*-value was adjusted (Table 2). CPPS also decreased significantly over the course of speaking in each task, whereas the LH ratio remained stable. There was no significant difference in the decline in CPPS or LH from the first to last utterance when comparing performance between the two tasks (data not shown).

Cognitive status and changes in f_o parameters

Evaluation of mean performance over the entire picture description task revealed a significant difference in f_o variability (STSD) when the PD-NC and PD-MCI groups were compared. Those with PD-MCI demonstrated lower f_o variability than those with PD-NC (3.86 vs 4.63 semitones respectively, mean difference = 0.76 [95% confidence interval {CI} = 0.08–1.45, $P = 0.03$]). Similarly, on the reading task, STSD was lower in those with PD-MCI compared to those with PD-NC (3.83 vs 4.70 semitones, mean difference = 0.88 [95% CI = 0.28–1.48, $P = 0.005$]). With respect to CPPS, the PD-MCI group demonstrated

TABLE 2.
Acoustic Features in Reading and Picture Description Tasks in the Overall PD Cohort

Feature (Mean, SD)	Reading					Picture Description				
	Total	First	Last	*P*	*P*-Adj	Total	First	Last	*P*	*P*-Adj
Mean f_o	138.33 (35.50)	144.85 (39.68)	135.02 (37.55)	< 0.0001	< 0.0001	135.92 (35.16)	144.43 (39.88)	135.16 (38.15)	< 0.0001	< 0.0001
STSD	4.22 (1.06)	2.58 (0.97)	2.02 (1.04)	< 0.0001	< 0.0001	4.21 (1.13)	4.32 (1.62)	3.66 (1.53)	0.017	0.34
CPPS	5.38 (1.31)	5.86 (1.52)	5.16 (1.35)	< 0.0001	< 0.0001	5.01 (1.28)	5.56 (1.54)	4.76 (1.42)	0.0001	0.002
LH ratio	26.38 (4.15)	24.82 (4.26)	25.39 (4.04)	0.12	2.4	24.94 (3.91)	25.67 (4.50)	25.79 (4.57)	0.87	17.5

Note: For each feature, first and last utterance values were compared using paired *t*-tests, and *P*-values are shown. Both raw and adjusted *P*-values are shown, with *P*-adj representing the raw *P*-value multiplied by 20 to adjust for multiple comparisons.

TABLE 3.
Declines in Acoustic Features During Speaking Tasks for Participants With PD-NC Vs PD-MCI

	Variable	PD-NC (n = 20)	PD-MCI (n = 24)	Mean Difference (95% CI)	*P*
Reading	Mean f_o	9.54 (7.18)	9.99 (6.39)	−0.44 (−4.67 to 3.79)	0.83
	STSD	0.68 (0.70)	0.45 (0.52)	0.23 (−0.15 to 0.61)	0.24
	CPPS	0.74 (0.73)	0.68 (0.67)	0.05 (−0.39 to 0.49)	0.81
	LH	−0.43 (3.00)	−0.65 (1.80)	0.22 (−1.31 to 1.75)	0.77
Picture description	Mean f_o	10.42 (9.30)	9.40 (8.17)	1.01 (−4.43 to 6.46)	0.71
	STSD	0.96 (1.68)	0.48 (1.84)	0.48 (−0.62 to 1.58)	0.38
	CPPS	0.83 (1.07)	0.92 (1.36)	−0.09 (−0.86 to 0.68)	0.81
	LH	−0.77 (4.41)	0.99 (4.68)	−1.76 (−4.61 to 1.08)	0.22

Note: The values for each acoustic feature represent a difference, representing the mean value for the first utterance minus the last utterance. The calculated values were then compared between PD-NC and PD-MCI, with independent *t*-tests and resulting mean differences, confidence intervals, and unadjusted *P* values displayed.

significantly lower CPPS on the picture description (mean difference = 0.86 [95% CI = 0.11–1.61, *P* = 0.03], but not the reading task compared to those with PD-NC [mean difference = 0.56 (95% CI = −0.23 to 1.35, *P* = 0.16]). The PD-MCI and PD-NC groups did not differ significantly in LH ratio on either task.

When the decline between the first and last utterance was compared between those with PD-NC and those with PD-MCI, there were no significant differences in any measured acoustic variables on either the reading or the picture description task (Table 3).

DISCUSSION

We identified changes in f_o parameters over the course of reading and picture description tasks in participants with PD. Mean f_o and f_o variability declined over the course of both reading and picture description tasks, which suggests that the phenomenon of motor instability is evident in a relatively brief speech in PD—after just 60–90 seconds of speaking. CPPS also declined during the performance of both tasks, indicating that features reflective of hypokinetic dysarthria beyond pitch-related features also worsen over the course of commonly used speech stimuli. We did not identify significant differences in acoustic feature declines when the two task types were compared, suggesting either a similar impact of motor instability on both tasks or limited power given our sample size and the variability in acoustic performance. In the overall group, STSD f_o declined more consistently in the reading task and was more variable from participant to participant in the picture description task. This variability is expected in the picture description task as the lexical and semantic content of the early and later utterances is not standardized as it is in the reading task. However, this large amount of variability between individuals could have limited our ability to detect differences in performance between speech task types.

We sought to characterize associations between cognitive status and speech markers of motor instability in our cohort. Cognitive diagnosis (PD-MCI or PD-NC) did not significantly impact the declines in our measured acoustic parameters on either task or when between-task performance calculations were compared. Additional work is needed to identify factors that contribute to speech motor instability and to develop a model of the neural underpinnings of this phenomenon in PD. We found participants with PD-MCI had more severe impairments in STSD and CPPS compared to those with PD-NC when the acoustic performance was averaged as a whole, and this occurred to a greater extent in the picture description task compared to the reading task. These findings are consistent with prior literature demonstrating impaired articulatory and prosodic features are associated with poorer cognitive status in PD.[40,41] However, these studies characterized cognition through MoCA only. We found that measures related to both pitch and vocal quality were more impaired in PD-MCI, which may relate to the more stringent cognitive diagnosis criteria applied and/or differences in clinical characteristics among these cohorts. Our findings suggest that future work is needed to validate speech markers for specific speech task types in individuals with PD and to correlate with markers with disease symptoms and severity utilizing gold-standard measures.

This manuscript is the first to our knowledge to evaluate how speech acoustics change over the course of spontaneous speech in PD. Others have evaluated several different speaking task types and identified differences in acoustic and prosodic measures in different tasks, but using averaged parameters for each task.[42,43] There are only two comparable studies published to our knowledge on acoustic declines over the course of speaking in PD. Bowen et al[31] assessed a decline in f_o variability during the first paragraph of the Rainbow Passage using a similar methodology to our study and Skodda et al[32] assessed a decline during four complex sentences. In our cohort, the range of f_o variability decline was similar in size to that observed in Bowen et al and greater than the values observed in Skodda et al. These studies evaluated the effects of sex and PD medications as well, which were not the primary aims of our work. All participants were in the medication-on state in our study. One reason for inconsistencies may be differences in clinical characteristics in the samples, as our cohort had lower disease duration and those with dementia were carefully excluded.

Although we found that the mean f_o decreases during speaking in PD participants, the mean f_o increases with prolonged reading in the general population.[44,45] One proposed physiological explanation of increased mean f_o with vocal fatigue is increased laryngeal tension with vocal loading.[46] Of note, studies of vocal fatigue in those with healthy controls or dysphonic disorders have been conducted with reading tasks substantially longer than ours in this study, typically 60–120 minutes. Experiments with longer duration of speech would be needed to understand better the interplay between vocal fatigue, motor instability, and f_o in PD. One potential explanation is that PD speakers have impaired feedback and feedforward motor speech systems, such that they do not perceive speech changes with prolonged speaking and make fewer compensatory adjustments, or are less able to compensate due to disease-related effects on the vocal apparatus.[47–49] Further studies are needed to enhance our understanding of motor instability more broadly in PD speech.

Prior studies have suggested the use of f_o variability and related pitch-based features as biomarkers of disease status in PD.[50–52] These studies have focused on screening the general population for a potential PD diagnosis, rather than monitoring those with established PD, in which speech deficits have a variable and heterogeneous course as the disease progresses.[53] They also focus only on the detection of PD motor symptoms and do not consider the role of PD-related cognitive changes on speech. It is therefore unknown how cognitive impairment may impact the timing, degree, and evolution of changes in f_o parameters over the disease course. The overlooked impact of cognition may partially explain the lack of correlation between f_o variability and motor symptom severity in established PD in the literature. To explain why f_o variability may be associated with PD diagnosis, but not with disease progression, Abur and colleagues[48] proposed that cognition and attention play a key role in sensorimotor control systems impacting f_o variability and compensatory reflexive changes. The extensive literature on dual-tasking in PD further supports that task factors as well as individual motor and cognitive factors can influence the degree to which performance declines during the dual-task compared with a single-test condition.[21] Attentional tasks such as serial subtractions,[54–56] response inhibition tasks,[57] and other executive functioning and memory tasks have been used in dual-task protocols, showing a resultant negative impact on gait kinetics compared to single-task conditions. Recently, Johansson et al[58] found that PD MCI status was associated with worse dual-task performance on both gait and cognitive measures compared with PD participants with normal cognitive status. In another study, machine learning was applied to differentiate PD with and without MCI using a cognitive dual-task (walking while serially subtracting 7 seconds from 100).[59] These two recent studies are consistent with our results in which MCI was also associated with greater speech motor dysfunction during a more cognitively demanding task, suggesting a possible similarity in the responses of gait and speech, both highly learned and automated motor processes, to simultaneous cognitive load in PD. Future work is necessary to confirm and validate our findings and may benefit from a more comprehensive evaluation of acoustic features, additional types of speaking and cognitive tasks, and the inclusion of both gait and speech parameters.

There are several limitations to this work. The order of the speaking tasks was not randomized, because they were both part of a longer standardized protocol. The fact that the picture description task occurred later in the protocol than the reading task could have impacted the data in various ways. For example, the participants may have been more fatigued during this task, which occurred after about 10 minutes of continuous speech. Another limitation of this study is that we did not assess all possible speech acoustic measures such as articulatory precision and rate measures. We did note that participants with PD-MCI had significantly longer durations to complete the reading task and fewer words per minute (likely related to increased pausing) in the picture description task compared to those with PD-NC. These observations could have impacted the differences between the groups. Further work is needed to understand the impact of speaking and pausing time and rates on acoustic measures in PD. In this work, our choice to focus on phonatory acoustic features allowed us to validly compare the standardized reading passage with the picture description task; this would not have been possible for certain articulatory speech measures that would be affected by the differences in speech content between the two tasks. Related to our choice to incorporate the picture description task, although it increases the ecological validity of the work, it inherently increases the heterogeneity of the speech produced and thus lessens the degree of control. Because of this, we focused on measures that are most robust to differences in content, but no acoustic measures of speech are immune to differences in segmental or supersegmental content. For instance, although CPPS may be validly applied to continuous speech, the values do fluctuate somewhat based on the specific stimuli.[60] These differences could contribute to differences between the two tasks in the current study. Future studies could apply more advanced statistical modeling to address between-participant variability. We also did not account for respiratory function during speaking, which is known to be impaired in PD.[61] It is possible that the later utterances were more affected by decreased lung volume capacity compared to earlier utterances, and that this impacted the f_o results differentially between the two speech task types. Skodda and colleagues measured mean phonation time as a marker of respiratory capacity and did not find this measure correlated with f_o variability. However, the PD participants in the cohort had similar mean phonation time compared to controls, which suggests this may not be a sufficient marker to assess this relationship. Bowen and colleagues similarly were limited in conclusions they could draw about the respiratory impact on f_o measures as sound pressure level was not collected in their samples. Finally, the manual measurement of f_o may be technically difficult and subjective. Our work would have benefitted from additional raters of the picture description task to confirm consistency in our approach.

Strengths of this study include the analysis of spontaneous speech and a gold-standard approach to the examination of cognitive status. Spontaneous speech better reflects daily communication than repetition or reading tasks. Although the picture description task was relatively brief and may be limited in evoking certain linguistic characteristics, it requires the speaker to plan, initiate, and organize semantic and syntactic content under time constraints and to utilize naming and lexical retrieval processes. In comparison, when reading aloud, one is able to use the text and punctuation to plan pitch structure. By demonstrating different f_o patterns between picture description and reading, we highlight the importance of validating speech markers for specific types of speech tasks in PD. Furthermore, since f_o patterns differed by cognitive status, we recommend that a comparison of acoustic markers between speech tasks be performed to better capture both motor and non-motor features of PD.

Understanding how speech declines over the course of speaking in various contexts has important clinical implications for speech therapy interventions and novel technology that might assist people living with PD in improving and compensating for these declines. This area of research also has great potential to result in useful markers of cognitive status in PD that could be obtained easily and frequently in patients with PD using remote technology, leading to improved detection and monitoring of MCI.

CONCLUSION

Mean f_o and f_o variability, as well as CPPS, demonstrate speech motor instability over the course of speaking in PD during both reading and spontaneous speech tasks. Further speech marker research is needed to validate and expand these findings using approaches sensitive to time-based and task-dependent characteristics in PwPD. Analytical approaches that capture speech motor instability could lead to improved markers of motor and cognitive symptoms in PD.

Declaration of Competing Interest

The authors confirm that this manuscript has not been published elsewhere and is not under consideration by another journal. All authors have approved the manuscript and agree with its submission to Journal of Voice. All authors have no conflicts of interest to disclose.

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