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Research Article

The Relationship Between Listener Ratings of Speech, Primary Motor Symptoms, and Global Cognitive Functioning in Idiopathic Parkinson's Disease

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Abstract

Purpose: While previously considered purely a motor disorder, Parkinson's disease (PD) is now recognized as a complex constellation of motor and non-motor symptoms. Specifically, converging evidence suggests an association between the presence of dysarthria and cognitive decline, and that this relationship may be mediated by primary motor phenotype.

Methodology: This pilot study utilized perceptual ratings of naturalness, articulatory precision, and intelligibility to examine the relationship between dysarthria, primary motor presentation, and cognition in 9 individuals with PD. Ten experienced SLPs used a visual analog scale to rate naturalness and articulatory precision. Orthographic transcription completed by naïve listeners was used to calculate intelligibility. Cognition was assessed with the Parkinson's Disease Cognitive Rating Scale and primary motor presentation was rated with the Unified Parkinson's Disease Rating Scale.

Results: Participants with increased non-tremor motor symptom severity had more impaired ratings of speech naturalness and articulatory precision. Furthermore, participants with mild cognitive impairment had more impaired speech ratings than individuals without cognitive impairment.

Conclusion: This pilot study highlights the interconnectedness of primary motor characteristics, secondary motor characteristics, and cognition in PD. Clinicians might anticipate a greater likelihood of cognitive challenges in clients with dysarthria and a non-tremor dominant motor phenotype.

Keywords: Parkinson; Motor; Cognition; Speech naturalness; Dysarthria

Introduction

Parkinson's disease (PD) is now recognized as a disorder that spans multiple motor and nonmotor systems. As a result of this increased breadth of characterization, attempts to elucidate the full range of motor and nonmotor features have emerged in recent literature [9,37,43,45,64] and contributed to an amplified focus on nonmotor features such as altered cognition, neuropsychiatric symptoms, sleep disorders, and fatigue [54,70]. More specifically, there has been increased attention given to cognitive changes that may be associated with well-known motor traits [8,22,26,42]. Emerging from this line of research are studies suggesting that

dysarthria may uniquely link to primary motor symptoms or cognitive impairment [8,13,17,36,49,53]. Dysarthria in PD typically presents as hypokinetic, which can lead to impairment across the range of speech subsystems, including the respiratory, laryngeal, velopharyngeal, and articulatory components [14,48]. The most evident perceptual characteristics of this dysarthria are impaired voice, articulation, and prosody. In particular, reduced loudness, monopitch, monoloudness, reduced stress, repeated phonemes, and rapid rate are considered distinguishing characteristics [10,14]. Although perceptual characteristics can vary across individuals, these speech changes often lead to reduced intelligibility [21,52] and naturalness [32,71], and can considerably impact communicative participation and quality of life [38,41]. Most germane to this study are the constructs of naturalness, articulatory precision, and intelligibility.

Naturalness of speech refers to the degree to which speech conforms to an expected or conventional speech pattern. This perceptual characterization is garnered from overall adequacy of prosodic properties such as rate, rhythm, intonation, and intensity, as well as voice quality [14,71,73]. Naturalness of speech is largely responsible for undertone signals that send additional cues related to a speaker's message. The monotonous quality associated with reduced naturalness can lead to negative connotations and mixed messages by reducing an individual's ability to signal emphatic meaning [14]. Naturalness is thus considered a useful functional outcome measure due to its value as an independent contributor to an individual's ability to communicate [1] as well as influence on communicative participation [15]. While aspects of naturalness can be measured acoustically with discrete variables (e.g., related to pitch or stress placement), it is often measured holistically via perceptual ratings, such as rating scales or a visual analog scale (VAS). VAS, in particular, has been shown to be valid and reliable in the perceptual judgments of dysarthric speech [71].

Articulatory precision refers to how accurately speech sounds are produced or, rather, the extent of agreement between expected and observed phonetic contrasts [3]. Articulatory precision is often captured perceptually as phoneme distortions, deletions, additions, and/or substitutions. Individuals with hypokinetic dysarthria, in particular, often demonstrate articulatory undershooting, resulting in indistinct speech sound production or syllable boundaries [14]. Phonetic complexity plays an important role in articulatory precision, such that articulatory decrement is increased as greater demands are placed on articulators [34]. Articulatory precision has been recognized as an independent contributor to communicative participation, a reflection of the significant impact of this variable on intelligibility [3,39].

Intelligibility of speech, defined as speech clarity or the extent to which a listener can understand a speaker's message, is a perceptual measurement influenced by respiration, phonation, articulation, resonance, and prosody [21,52]. Transcription-based intelligibility is considered a reflection of the acoustic signal created by the speaker [14,30,31] and conveys the accuracy with which the speaker's intended message was received by the listener [6]. It is most reliable when derived from the average of multiple raters [72]. Intelligibility is considered an important outcome measure particularly in individuals with neurodegenerative conditions such as PD as it can directly inform treatment planning [40] and has been shown to influence participation in life situations [60].

Taken together, listener ratings of naturalness and articulatory precision, and transcription-based intelligibility, can serve as valid and holistic measurements of speech function [72]. The use of multiple global speech measures, across multiple listener groups, is anticipated to capture group-level changes to prosody and precision that may be missed by more restricted, discrete measures, such as pitch, rate of speech, or presence of dysfluencies. When examining dysarthria in complex, heterogeneous populations, such as those with PD, global measures may be beneficial as they are less influenced by the individual variability associated with discrete measures [4,65,66,67].

Previous research has supported a link between dysarthria and primary motor presentation, although the link is typically examined through discrete motor symptoms. For example, Cantiniaux et al. (2009) demonstrated that individuals with more impaired gait also showed reduced speech velocity [57]. Dias et al. [12] reported worsening of axial symptoms (e.g., postural instability and gait disturbance) with prosodic changes, as did Goberman (2005) [23]. Conversely, some speech characteristics have been associated with both tremor-dominant and non-tremor phenotypes. For example, increased pause time in reading tasks, and decreased speech rate, imprecise articulation, and increased pause time in monologue tasks have been shown to correlate with variables associated with both tremor and non-tremor subtypes [23]. Thus, the relationship between speech and primary motor presentation remains unclear and a more holistic examination of speech as related to primary motor presentation is warranted.

In addition to an association between dysarthria and primary motor symptoms, an intriguing link has been posited between the presence of dysarthria and worsened cognitive decline in PD. For example, individuals with PD and cognitive decline were found to have more severe speech disruption compared to those who did not have cognitive impairment [17]. These findings were supported by a follow-up study [13], although the authors used a composite score of speech and facial expression (termed bulbar score) to examine speech and cognition. Additionally, Bugalho and Viana-Baptista [5] explored predictors of cognitive decline in individuals with PD and found that more impaired speech was significantly associated with a decline in cognitive performance. More recently, Schneider, Sendek and Yang [53] examined the relationship between speech and cognition in participants with PD and reported significant associations between the bulbar composite score and numerous cognitive measures.

Also probing an association between dysarthria and cognitive decline in PD, Rektorova and colleagues [49] conducted a longitudinal study to assess whether baseline acoustic speech parameters would predict cognitive decline across two years. The authors found the speech index of rhythmicity to significantly predict cognitive decline at a 2-year follow-up with 73.2% accuracy [49]. Thus, a lower speech index of rhythmicity (suggestive of less

natural speech) indicated an increased probability of worsening cognitive status. These results provide insight into potential links between dysarthria and cognitive dysfunction, specifically as related to disruptions to discrete, often highly specific, components of naturalness, but do not provide a more global examination of naturalness as related to dysarthria. Furthermore, methodological limitations, such as the use of a speech and facial expression composite score, highlight the need for further research examining this purported link.

In sum, extant literature provides limited support for a link between discrete measures of speech and the primary motor characteristics and cognitive abilities of individuals with PD. These relationships have not yet been comprehensively studied using a more holistic approach to dysarthria characterization. Thus, the goal of this pilot study was to examine the relationship between cognitive performance, tremor and non-tremor symptom severity, and global measures of dysarthria (ratings of speech naturalness and articulatory precision, combined with transcription-based intelligibility) in PD. It was hypothesized that reduced speech intelligibility, articulatory precision, and naturalness would be associated with poorer performance on a measure of global cognition as well as greater severity of non-tremor symptoms.

Methods

Speakers

This study was approved by the Institutional Review Board and all participants provided informed consent. A total of 9 participants were recruited from the Washington State Parkinson's Disease Registry and the University of Washington speech pathology clinic. Speaker demographics can be found in Table 1.

Inclusion criteria were (1) diagnosis of idiopathic PD by neurologist (per self-report), (2) native speaker of American English, (3) typical speech, language, and cognitive developmental history, (4) adequate vision (able to read line 20/30 at 2.3 feet from the Snellen chart) and hearing (thresholds < 50 dB at 500, 1000, and 2000 Hz in one ear).

All speakers presented with hypokinetic dysarthria. Presence of hypokinetic dysarthria was based on determination of pertinent perceptible characteristics of speech disruption by two independent investigators during the initial telephone screening/interview and speech recordings. Exclusion criteria were (1) history of any surgical procedure to treat PD, (2) diagnosis of atypical Parkinsonism, (3) severe depression per Beck Depression Inventory II (BDI-II) score > 29 (Beck, 1996), (4) neurologic compromise beyond PD (e.g., stroke, traumatic brain injury), (5) alcohol or drug dependency, (6) currently taking sedatives or tranquilizers, and (7) severe cognitive impairment such that an individual was unable to make informed consent. No participants were excluded based on these criteria. Participants were assessed while remaining on their current medication routine, approximately 1-2 hours after ingestion of anti-Parkinsonian medications.

Listeners

Ten Speech-Language Pathologists with a minimum of five years of clinical experience working with individuals with dysarthria from PD were recruited to serve as experienced listeners (see Table 2).

Clinically experienced listeners were chosen over untrained listeners given their specialized training related to this population and the metrics of intelligibility and naturalness. Experienced listeners completed perceptual ratings of naturalness and articulatory precision. Three research assistants completed intelligibility calculations. All listeners were native speakers of American English with no history of hearing impairment per self-report.

Speaker Session

Information specific to participant disease history was collected in an interview format. Speech samples were obtained via monologue during a covert recording in order to attain a sample reflective of typical speech performance [71]. A three-minute speech sample was obtained by the experimenter asking open-ended questions. A conversational speech sample was chosen over reading or repetition tasks as disruption to speech is more apparent and accurately represented in individuals with PD with conversational speech than with speech that is externally guided with a reading or repetition task [29,56,69]. Additionally, it has been demonstrated that speech naturalness in particular is enhanced when individuals with PD are cued with a reading task, and thus not reflective of typical speech performance [71]. Sounds files were clipped and processed in sound editing software (Adobe Audition 9.0). The first 30 seconds of continuous speech that met extraction criteria were used for the listener rating task and were also transcribed by naïve listeners for the objective measure of intelligibility. Extraction criteria were based on Sidtis, Cameron, Bonura, & Sidtis [56]; samples were free of proper nouns, low frequency words, formulaic expressions, and specialty vocabulary. To preserve naturalness, samples were clipped to the nearest sentence's end; thus, sample length varied negligibly.

The Parkinson's Disease Cognitive Rating Scale (PD-CRS) was administered to participants to examine cognition. The PD-CRS is a PD specific cognitive scale designed to capture and measure functional changes across the continuum of cognitive severity, including subtler mild impairments [55]. The PD-CRS uses a broad range of tasks and is recommended as a global cognitive measure for individuals with PD [25].

Motor presentation was characterized using three self-report scores from the Unified Parkinson's Disease Rating Scale (UPDRS) Part II and thirteen ratings by a trained examiner (author KB) from Part III [24]. Motor characterization aligned with the approach of Jankovic et al. (1990), updated using the most recent UPDRS version [24,61], where total tremor score (TD) was calculated as a sum of tremor-related items, and total non-tremor score (NT) was calculated as a sum of non-tremor items.

Listener Session

Experienced listeners listened to speech samples and rated them on the constructs of naturalness and articulatory precision using two 100-point visual analog scales (VAS). VAS has been used

to successfully identify and characterize changes to speech from PD [63,68,71]. Due to in-person restrictions related to COVID-19 closures, the VAS was created to be a specific interface designed for listeners to access from their personal computers. Using the Gorilla Experiment Builder perceptual interface, naturalness and articulatory precision continuous scales were developed with numerical values from 0-100 (see Figure 1).

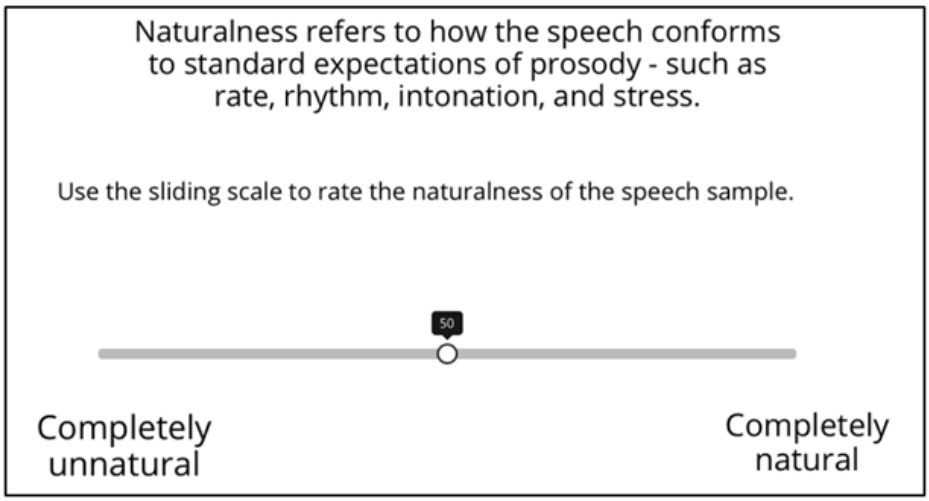

Figure 1: Visual Analog Scale (VAS) for rating speech naturalness.

Each speech sample was rated by each listener with counterbalanced presentation of naturalness and articulatory precision VAS. Listeners completed all ratings of one speech construct before completing the second set. Each listener heard a random order of samples and could not pause or replay samples during the rating task.

Participants were instructed to be seated in a quiet location in their home where they would be free of distractions and to best minimize ambient noise. Prior to rating speech samples, listeners were presented with instruction screens to familiarize them with the scale and definitions. The following definitions were provided to the experienced listeners: Naturalness – "how speech conforms to standard expectations of prosody- such as rate, rhythm, intonation, and stress," – with VAS anchors of "completely unnatural" and "completely natural" and Articulatory Precision – "how accurately speech sounds are produced…" – with VAS anchors of "completely imprecise; speech is fully degraded from articulation errors" and "completely precise; no perceived articulation errors." Definitions were available to the listeners throughout the listening session.

Intelligibility of the speech sample was scored via transcription by three research assistants, with familiarity in orthographic transcription, to provide a mean intelligibility calculation. Listeners produced a written transcription of each speech sample. Intelligibility calculations were determined by counting the number of correctly identified words and dividing by total number of words in the 30-second sample elicited from the covert monologue.

Statistical Analyses

SPSS 26 was used for the analyses. Reliability was measured using a point-to-point approach and intraclass correlations. Next, correlations between ratings of naturalness, articulatory precision, intelligibility and global cognition were conducted. To reduce the likelihood of Type II error in this pilot study, the p-value was maintained at 0.05 for significance [18] and supplemented with effect size [62].

Reliability

Approximately 20% of speech samples were repeated for each experienced listener for the calculation of intra-rater reliability of naturalness and articulatory precision ratings. Thus, each of the experienced listeners heard and rated 11 speech samples (9 novel samples, 2 randomly-selected repeated samples) when rating both naturalness and articulatory precision. Intra-rater reliability was determined by the percent of repeat ratings that fell within a predetermined range on the VAS [2,59]. Of the 20 repeat ratings (10 listeners x 2 repeated files) for articulatory precision, 85% were within 10 units on the 100-point VAS scale, and 100% were within 20 units. No raters were inconsistent (> 20-point difference) in their perception of articulatory precision. For naturalness, 70% of repeat ratings were within 10 points, and 90% were within 20 points. Two ratings (10%) were inconsistent (> 20-point difference). Inter-rater reliability was assessed using intraclass correlation coefficient (ICC), two-way mixed-effects model. Excellent overall inter-rater reliability was achieved for ratings of naturalness (ICC = 0.904, range = 0.77–0.97) and articulatory precision (ICC = 0.934, range = 0.84-0.98) (Koo & Li, 2016).

Results

Speech Constructs and Cognition

Mean ratings of experienced listener's judgments of naturalness

and articulatory precision are shown in Table 3 along with intelligibility scores (also reported in Table 1). Pearson Product-Moment correlations were conducted to examine the relationship between cognitive and speech variables. Correlation coefficients between PD-CRS scores and ratings of naturalness, articulatory precision, and intelligibility can be found in Table 3 and Table 4.

Table 1: Characteristics of speakers with Parkinson's Disease.

Speaker	Sex	Age	Years of Education	Years Since Diagnosis	H&Y	Motor Subtype	PD-CRS	Intelligibility (percent)
S01	F	72	16	10	3	Non-Tremor	99	97
S02	M	79	20	14	4	Non-Tremor	79	82
S03	M	83	18	13	3	Non-Tremor	105	94
S04	M	76	18	3	2	Tremor	93	99
S05	M	62	16	6	2	Tremor	113	94
S06	M	65	16	6	3	Non-Tremor	94	98
S07	M	80	18	3	3	Non-Tremor	62	98
S08	M	75	14	4	3	Non-Tremor	78	88
S09	F	79	18	6	3	Non-Tremor	93	98
Mean	--	74.56	17.11	7.22	2.89	--	90.67	94
SD	--	7.06	1.76	4.15	0.6	--	15.47	6

Note. PD-CRS = Parkinson's Disease Cognitive Rating Scale (134 = total score; 81 = cutoff for PD Mild Cognitive Impairment (Pagonabarraga et al., 2008; Rosca & Simu, 2020). H&Y = Hoehn and Yahr Parkinson's Disease Severity Rating Scale (1967).

Table 2: Characteristics of experienced listeners.

Listener	Sex	Age	Years of Practice	Primary Setting
L01	F	34	8	Academic Medical Center
L02	F	35	10	Acute / rehab
L03	F	45	21	Outpatient
L04	F	33	9.5	Acute / Rehab
L05	F	52	29	Academic Medical Center
L06	F	37	9	Acute
L07	F	29	5	Acute
L08	F	31	7	Acute / Rehab
L09	F	42	15	Academic
L10	F	40	17	Academic
Mean	--	37.8	13.05	--
SD	--	7.04	4.47	--

Table 3: Mean listener ratings across speech constructs for nine speakers with Parkinson's disease.

Speaker	Naturalness	Articulatory Precision	Intelligibility
	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
S01	79.3 (23.69)	94.2 (4.44)	97 (0.96)
S02	32.5 (16.31)	43.1 (25.40)	82 (9.85)
S03	73.5 (13.79)	77.5 (24.61)	94 (1.14)
S04	77.8 (17.50)	92.1 (7.46)	99 (0.00)
S05	85.5 (10.23)	88.9 (14.48)	94 (1.75)
S06	84.4 (15.54)	96.1 (3.93)	98 (2.55)
S07	63.0 (27.46)	86.9 (12.31)	98 (1.52)
S08	65.0 (20.05)	56.9 (25.21)	88 (4.41)
S09	61.7 (27.38)	84.3 (19.69)	98 (2.78)
Mean	**69.2 (16.40)**	**80.0 (18.21)**	**94 (5.72)**

Table 4: Pearson Product-Moment correlations coefficients (r) between global cognition (PD-CRS) and speech variables.

PD-CRS	*r*	*p*
Speech variables		
Naturalness	0.6	0.086
Articulatory Precision	0.4	0.288
Intelligibility	0.23	0.557

***Note.** PD-CRS = Parkinson's Disease Cognitive Rating Scale.

Correlations did not reach significance (p values = 0.086, 0.288, and 0.557, respectively).

Next, independent samples t-tests were used to test for group differences on speech constructs between individuals with MCI and those without. A PD-CRS score of 81 (out of 134) has been shown to be an optimal cutoff score for detection of MCI in PD [19,20,51]. Three participants (S02, S07, S08) fell below the cut-off. Results from the independent samples t-test indicated that individuals with MCI, as determined via the PD-CRS, were rated as having speech that was significantly less natural than individuals with cognitive scores above the MCI cutoff (t(7) = 2.72, p = 0.029). The effect size for this analysis (d = 1.65) exceeded Cohen's (1988) convention for a large effect (d = 0.80). Welch's t-test indicated that speech ratings of articulatory precision did not differ significantly between MCI and individuals with cognitive scores above the MCI cutoff, although there was a large effect size (d = 1.60). Similarly, intelligibility did not differ between MCI and those with scores above the MCI cutoff, but the effect size was large (d = 1.24). Results are summarized in Table 5.

Table 5: Independent samples t-test examining speech constructs between MCI and normal cognition groups.

	MCI	**No-MCI**					
	(*n* = 3)	**(*n* = 6)**					
Speech Construct	Mean (SD)	Mean (SD)	Diff	*df*	*t*	*p*-value	*d*
Naturalness	53.50 (18.21)	77.03 (8.71)	23.53	7	2.72	**0.029***	1.65
Articulatory Precision	62.30 (22.39)	88.85 (6.95)	26.55	2.2	2	0.171	1.6
Intelligibility	89.33 (8.08)	96.67 (2.16)	7.34	2.14	1.54	0.254	1.24

Note. * = $p \leq 0.05$; MCI = mild cognitive impairment; No-MCI = cognitive performance above MCI cutoff (> 81) on Parkinson's Disease Cognitive Rating Scale.

Speech Constructs and Motor Presentation

Pearson-Product Moment correlations were calculated for tremor severity, non-tremor severity, and speech constructs of naturalness, articulatory precision, and intelligibility. Results can be found in Table 6.

Table 6: Pearson Product-Moment correlations coefficients (r) between primary motor profile and speech.

	Primary Motor Characteristic			
Speech Construct	**Tremor Severity**		**Non-Tremor Severity**	
	r	***p***	**r**	***p***
Naturalness	0.53	0.14	**-0.75**	**0.020***
Articulatory Precision	0.37	0.334	**-0.72**	**0.028***
Intelligibility	0.13	0.749	-0.62	0.076

Note. * = $p \leq 0.05$

Non-tremor severity, calculated as the sum of non-tremor items on the UPDRS, was significantly negatively correlated with listener ratings of naturalness (p = 0.020) and articulatory precision (p = 0.028), but not intelligibility. Correlation coefficients indicated that the strength of this relationship is strong. Thus, an increase in non-tremor symptom severity was strongly associated with decreased ratings of naturalness and decreased ratings of articulatory precision. Tremor severity, which represents the sum of all tremor items on the UPDRS, was not significantly correlated with speech constructs.

Discussion

This study was motivated by extant literature that suggests non-tremor symptoms, such as postural instability or gait

disturbance, may be associated with different patterns of speech disruption [7,23,58] and cognitive dysfunction [28,49] than tremor-dominant symptoms. The goal of this experiment was to examine these associations using the speech constructs of intelligibility, articulatory precision, and naturalness.

Despite the small sample size, an emerging relationship between speech and cognition in PD was present, and the hypotheses were partially supported. Of the speech variables, the construct of naturalness had the strongest relationship with cognition. Previous investigations linking more impaired speech with poorer cognitive performance [5,13,17] have discussed shared neuropathological mechanisms that are purported to underlie dysarthria and PD-related cognitive changes. For example, the amygdala has been posited as a central regulator of pitch control, a salient component of naturalness [35,49] suggesting a role in modulating and interpreting prosodic elements. The amygdala is functionally connected to the medial prefrontal cortex and is innervated by cholinergic projections stemming from the basal forebrain [16]. Degeneration of the basal forebrain, and the resulting acetylcholine depletion, has been implicated as a predictor of subsequent dementia in PD [46], thus serving as an anatomical link between observed cognitive and speech changes.

Participants with increased non-tremor symptom severity had more impaired ratings of speech naturalness and articulatory precision. The pattern of an association between non-tremor motor symptoms and disrupted speech is consistent with previous studies linking these characteristics [12,57]. These findings may be explained by the cholinergic breakdowns which are implicated in more severe non-tremor symptom presentation in PD [47], particularly postural instability and gait disturbance [27,50]. Moreover, results are consistent with the notion that speech disruption is an axial motor sign, aligning with other axial characteristics such as postural instability and freezing of gait [7,11,44,58].

Across the speech measures, perceptual ratings of naturalness and articulatory precision appeared more sensitive to disruption of speech, compared to intelligibility scores which were similar across many of the speakers. Thus, VAS ratings of naturalness and articulatory precision might uniquely capture a wider breadth of changes to speech in PD than intelligibility measures alone. This finding may be of particular importance when assessing speech changes in individuals with mild hypokinetic dysarthria, where intelligibility ratings may not suitably capture initial speech changes. This is consistent with the notion that naturalness is a distinct construct that serves as an independent contributor to an individual's ability to communicate [1]. Similarly, perceptual ratings of articulatory precision extend beyond traditional intelligibility measures by allowing nuanced detection of changes to speech patterns (e.g., distortions that may not impact intelligibility).

Clinical Implications

The results of this study highlight the interconnectedness of primary motor characteristics, secondary motor characteristics, and cognition in PD. This line of research may inform clinical practice, as clinicians might anticipate a greater likelihood of cognitive challenges in clients with dysarthria and a non-tremor dominant motor phenotype. Converging evidence, and the results of the present experiment, support this premise. The findings of this study also suggest that clinicians should not rely on the single speech metric of intelligibility to determine level of speech functioning—a common clinical approach. Rather, rating scales that capture naturalness/prosody, in particular, would allow for a more comprehensive representation of the severity and impact of dysarthria in PD. In addition, it is important for clinicians to consider measures of naturalness in their measurement of speech outcomes over time given the influence of prosody on communicative participation and quality of life. As noted in Anand & Stepp [1], changes to naturalness likely account for negative listener- and self-perception of speech in PD, and these changes may be significantly limiting even when intelligibility is relatively unaffected [1,74].

Limitations and Future Directions

The small sample size resulted from premature study shutdown pursuant to COVID-19 restrictions. Thus, generalization from this study sample is limited; a larger sample size across severity levels is particularly warranted when investigating subgroup differentiation. Proper nouns, low frequency words, formulaic expressions, and specialty vocabulary words were removed to standardize the speech samples [56], making the samples less natural than in typical conversation. Future investigations of the relationship between speech, cognition, and motor phenotype would benefit from longitudinal investigation to determine whether associations change with disease progression. Improved understanding of clinical symptoms that are more likely to cluster, such as cognitive changes and dysarthria, can aid clinicians in managing PD symptoms as well as working to provide more individualized care when recommending supports or systems for proactive care.

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Conflict of Interest

No conflict of interest.

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