Voice Outcomes of Clear Speech Cueing in Individuals With Parkinson's Disease☆

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SUMMARY: Purpose. The purpose of this study was to investigate acoustic and auditory-perceptual voice outcomes of clear speech cueing in individuals with Parkinson's disease (PD).

Method. Speakers with PD completed speaking tasks (a spontaneous speech sample and a standard reading passage) in two speaking conditions: typical and clear speech. Acoustic measures of vocal intensity, fundamental frequency (f_o) variation, cepstral peak prominence (CPP), and low-to-high (L/H) ratio were calculated. Expert listeners completed auditory-perceptual ratings of the overall severity of dysphonia, breathiness, and strain of samples using visual-analog scales. Acoustic and auditory-perceptual measures were compared across speaking conditions and tasks.

Results. Intensity significantly increased in the clear speech condition compared with typical speech. When controlling for intensity, f_o variation increased, and L/H ratio decreased in the clear speech condition. Breathiness decreased from typical to clear speech. There were no condition differences in CPP when accounting for intensity and no condition differences in overall severity of dysphonia or strain.

Conclusions. Targeting the articulatory subsystem with clear speech cueing in PD elicits acoustic and auditory-perceptual changes that align with a louder voice, increased intonational variation, and reduced breathiness. Voice changes with clear speech are not fully explained by concomitant increases in intensity.

Keywords: Articulatory precision–Acoustic–Auditory-perceptual ratings–Voice therapy.

INTRODUCTION

Parkinson's disease (PD) is the second-most common neurodegenerative disease.[32] More than 90% of people with Parkinson's disease (PwPD) experience speech deficits [14,33,46] that are characteristic of a commonly co-occurring motor speech disorder called hypokinetic dysarthria.[12,21,60] Speech symptoms associated with hypokinetic dysarthria in PwPD often lead to communication breakdowns, and thus, reduced quality of life and communication participation.[37,54,61]

Speech impairments in PD are theorized to arise from changes to the respiratory, laryngeal, and articulatory subsystems of speech,[12] leading to respiratory,[51,70] phonatory,[21,33,8,83] and articulatory symptoms.[18,24,33,69,89,94] Voice changes are often identified in early-stage PD, and they tend to be the most frequently and severely affected features, compared with other aspects of speech.[33] Therefore, it is necessary to investigate acoustic and auditory-perceptual voice metrics in PwPD.

The most prominent voice symptoms in PwPD include reduced loudness (ie, hypophonia), impaired prosody, and atypical voice quality (ie, dysphonia[21,79]). Compared with speakers with typical voices, PwPD exhibit reduced vocal intensity[34] and reduced fundamental frequency (f_o) standard deviation (SD[11,80]), consistent with clinical and auditory-perceptual reports of reduced loudness and decreased intonational variation.[14,21] Laryngeal abnormalities, such as vocal fold bowing and glottal insufficiency, are also frequently observed upon videolaryngoscopic examination,[8,83] aligning with auditory-perceptual reports of breathiness[34] and consistent with a hypofunctional voice disorder.[93]

Evaluation of acoustic measures is recommended for objective voice assessment[58] and has been used to estimate voice quality in PwPD. It is important to assess voice acoustic metrics in running speech samples for PwPD because voice acoustic measures in PwPD are relatively unstable (ie, voice acoustics change across brief running speech tasks[82]). Cepstral peak prominence (CPP) is an acoustic measure of the "overall level of noise in the voice signal" and is one of very few acoustic estimates of voice quality that can be used to evaluate running speech.[49] Measurement of CPP is recommended for clinical evaluation of voice quality in people with voice disorders,[58] with lower CPP values indicative of greater dysphonia severity.[30,31,49] In the literature, CPP has been used to evaluate voice quality in PwPD; studies have found that PwPD have reduced CPP values, compared with speakers with typical voices.[20,63,78] Low-to-high (L/H) spectral energy ratio is another acoustic measure that can be paired with CPP to support the interpretation of speakers' voice quality

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in connected speech.[3,4] One study found that L/H ratio was increased in PwPD relative to controls,[20] which may be due to reduced periodic energy in the higher frequencies (ie, frequencies above 4000 Hz) and is indicative of a breathy or weak voice quality.

In addition to the evaluation of acoustic metrics, auditory-perceptual evaluation of voice quality is an important component of voice assessment in both clinical and research contexts.[40] Studies have found that PwPD have increased breathiness,[34,46,5,88] as well as increased overall severity of dysphonia,[5,88] compared with speakers with typical voices. There are conflicting findings on whether or not PwPD, as a group, exhibit elevated roughness[5,88] and strain,[34,5,53] which may be explained by the heterogeneity of clinical symptoms in PwPD.[100,92]

Several studies have recommended clear speech cueing to improve articulation in PwPD,[81,89,90,96] given the high prevalence of articulatory impairments in PwPD.[33] Articulation in PwPD has been described as "imprecise" and "irregular"[18] due to reduced range of motion and coordination of the articulators.[24,69,89,94] Clear speech cueing is a behavioral strategy often used in therapy for individuals with motor speech disorders that directly targets the articulatory subsystem[52]; patients are cued to articulate their words as clearly as possible. Articulatory outcomes of clear speech cueing in PwPD include increased vowel space area[44,81,89,90,95,96] and reduced articulatory rate.[16,28,89,90] Despite the primary focus on articulatory outcomes, it is possible that clear speech cueing in PwPD may also result in changes in *voice* measures.

Based on the current literature, there is preliminary evidence that clear speech cueing for PwPD does elicit improvements in voice measures. Several studies show increased vocal intensity with clear speech cueing in PwPD[81,89,90]; Skrabal et al[81] found an average increase of 1.36 dB with clear speech cueing, and two others found an average increase of 3 dB.[89,90] To date, only two studies have investigated f_o SD changes with clear speech cueing. Both studies reported increases in f_o SD following clear speech cueing: one found an increase of 0.2 semitones (ST) in a reading passage and 0.1 ST in a spontaneous speech sample,[28] and the other found an increase of 0.4 ST for spontaneous speech.[81] However, the sample sizes in both studies were small (12 and 17 participants, respectively), and replication is warranted. Only one known study has investigated metrics related to voice quality following clear speech cueing in PwPD. Shin et al[77] cued 15 Korean speakers with PD to "speak to someone with a hearing impairment." They evaluated changes in acoustic measures (CPP, CPP SD, CPP f_o, CPP f_o SD, L/H ratio, and L/H ratio SD), as well as auditory-perceptual ratings of breathiness and loudness from inexperienced listeners using a visual-analog scale; CPP increased, CPP f_o SD and L/H ratio SD decreased, breathiness decreased, and loudness increased. However, additional work is needed. Firstly, this study had a small sample size and should be replicated with a larger cohort. Secondly, the study did not account for the impact of intensity on CPP and L/H ratio, despite the known relationship between these measures.[13,2] Lastly, the cue to "speak to someone with a hearing impairment" is one of several variants of clear speech instruction; however, the clear speech cue to "overenunciate" is associated with the greatest benefit to speech intelligibility compared with other clear speech cue variants.[43,84] Thus, it is critical to establish both acoustic and auditory-perceptual outcomes of clear speech cueing, particularly for cues to "overenunciate" in a larger group of PwPD.

Despite the lack of robust findings on voice outcomes of clear speech cueing in PwPD, we can theorize expected outcomes that may indicate voice improvement based on findings from more standardized and comprehensive behavioral voice intervention programs designed for PwPD.[62] The most common behavioral treatment program, Lee Silverman Voice Treatment (LSVT LOUD), has strong empirical support [62] and centers on clinician-provided cues for PwPD to "get louder".[66,67] Acoustic outcomes of LSVT LOUD include increased vocal intensity,[35,39,48,57,66,67,71,75,98] increased f_o variability,[64,65] and one report of increased CPP and decreased L/H ratio [1] and another with decreased acoustic voice quality index (AVQI), a weighted metric of cepstral and spectral measures.[55] Auditory-perceptual outcomes of LSVT LOUD include reduced breathiness[15,6,86] and reduced strain.[98] Although the evidence for other behavioral voice interventions in PwPD is limited,[62] SPEAK OUT! is a commonly used intervention program for PwPD with cues to "speak with intent" and "say it purposefully".[7] Only three studies have measured voice acoustic outcomes of SPEAK OUT!; two studies found increased vocal intensity and CPP[45,7] and increased f_o variability.[10,7] Only one study investigated auditory-perceptual voice outcomes of SPEAK OUT! using a binary judgment (ie, presence or absence) and found reduced presence of "hoarseness".[10] It could be argued that the clinician-provided cueing in SPEAK OUT! (ie, speak with intent) shares similarities with the "get loud" cue in LSVT LOUD in that they both target respiratory and/or phonatory power; however, "speak with intent" may also indirectly target the articulatory subsystem, which may make it more comparable to the clear speech cue.

A few studies investigated voice outcomes of intervention programs for PwPD that use an articulatory cue. Ramig et al[66] observed significant increases in vocal intensity for PwPD following a 1-month intensive articulation treatment course of LSVT ARTIC, which targets "enunciation" rather than loudness. In a recent study, researchers found a significant decrease in AVQI at 6 months after LSVT ARTIC.[55] In a perceptual study on this same dataset,[50] inexperienced listeners rated the voices pre and post LSVT ARTIC as either "typical" or "atypical"; there was no change in proportion of "typical" ratings post treatment. However, measuring perceptual voice quality in PwPD likely requires a method designed to detect smaller changes (ie, use of a visual-analog scale rather than a binary judgment) across multiple parameters (eg, overall severity of dysphonia, breathiness, and strain). Another pilot study investigated intensity changes in 15 PwPD following a "clear speech intervention program".[76] There was an increase in auditory-perceptual ratings of loudness but no objective increase in acoustic vocal intensity. However, interpretation of this finding is confounded by the fact that the intervention program only explicitly emphasized the clear speech cue during the first week of sessions.[76] Overall, outcomes of intervention studies are likely driven by multiple factors (ie, therapeutic dose, the role of the clinician). Before we can interpret these findings from intervention studies, additional work is needed to determine the voice outcomes of the clear speech cue in isolation.

Although clear speech cueing has not been identified in the literature as a voice therapy tool for individuals with hypofunctional voice disorders (like PwPD), it has been used to elicit vocal improvement in speakers with *hyperfunctional* voice disorders. In one study by Gillespie and Gartner-Schmidt,[27] a total of 114 patients with vocal fold nodules, muscle tension dysphonia, and vocal fold atrophy read aloud a standard reading passage using clear speech as a form of stimulability assessment; clear speech cueing resulted in an increase in vocal intensity and average airflow. Additionally, 57% of patients noticed an improvement in the way their voice sounded, and 46.1% reported an improvement in how voicing felt.[27] Further, clear speech has been used as a primary component of a recently developed voice therapy treatment protocol, called Conversation Training Therapy, which has documented improvements in voice symptoms for individuals with hyperfunctional voice disorders.[26] These findings suggest that clear speech cueing not only facilitates articulatory improvements, but that it can also elicit vocal improvements. However, it is unclear whether a treatment approach effective for individuals with excessive vocal effort— those with hyperfunctional voicing—would also benefit individuals with progressive speech subsystem decline (ie, PwPD), who typically exhibit insufficient vocal effort due to hypofunctional voicing.

Clear speech cueing may result in speakers increasing their attention to articulation, which may elicit upstream or upregulatory effects in the phonatory and respiratory subsystems for individuals with both hyper- and hypofunctional voice disorders. If clear speech cueing does indeed elicit upregulation of the phonatory subsystem in PwPD, we may expect to see elevated vocal intensity and increased f_o variation, aligning with acoustic findings from prior studies.[28,81,89,90] Further, we might observe changes in acoustic correlates of dysphonia (CPP and L/H ratio) that reflect "pressed" phonation with reduced breathiness,[91] and a strengthening of periodic energy in the higher harmonics.[47] These acoustic changes may be accompanied by decreased ratings of overall severity of dysphonia, breathiness, and strain.

Given that reduced intensity is a key marker of hypofunctional voice disorders, investigation is needed not only on voice acoustic outcomes of clear speech in isolation but also on the role that vocal intensity plays in other voice acoustic changes associated with clear speech cueing. It is possible that f_o variation, CPP, and L/H ratio will change with clear speech cueing partially due to increased vocal intensity. Prior work has shown that elevated vocal intensity may be associated with increased f_o variation[17,59] and increased CPP.[13,2] Further, an increase in intensity may also influence the distribution of spectral energy,[25,85] resulting in a change in L/H ratio values as well. Of the few studies on acoustic correlates of dysphonia following clear speech cueing[77] or following voice intervention programs for PwPD,[1,45,7] none of them controlled for intensity change. Thus, a change in CPP or L/H ratio post therapeutic intervention does not necessarily indicate a voice quality improvement. To determine whether changes in CPP and L/H ratio following clear speech cueing in PwPD are related to a change in voice quality, it is crucial to account for intensity changes.

The purpose of this study was to investigate voice outcomes of clear speech in PwPD. This study aimed to 1) compare voice measures across two speech conditions (clear speech and typical speech) and 2) determine the portion of variance in changes in voice acoustic measures between conditions that could be explained by changes in vocal intensity. Speakers with PD completed speaking tasks (ie, spontaneous speech and a reading passage) across the two speech conditions. Voice measures included four acoustic parameters (vocal intensity, f_o variation, CPP, and L/H ratio) and auditory-perceptual ratings of overall severity of dysphonia, breathiness, and strain. We hypothesized that clear speech cueing would result in increased vocal intensity compared with typical speech. Additionally, we hypothesized that we would observe increased f_o variation, increased CPP, and decreased L/H ratio with clear speech cueing, even when controlling for intensity. We also hypothesized that clear speech cueing would lead to lower auditory-perceptual ratings of the overall severity of dysphonia, breathiness, and strain.

METHODS

Speakers

Thirty-two PwPD (20 cisgender men and 12 cisgender women) aged 55–80 years (M = 69.6 years; SD = 7.0 years) were recruited for this study. All speakers completed a virtual session (lasting ~1.5-2 hours) prior to the in-person recording session at Boston University. Virtual sessions took place no further in advance than 24 days. During the virtual session, the *Montreal Cognitive Assessment* (MOCA version 7) was completed as a cognitive screener; participants were required to score 23 or higher (out of 30 total points) to be included in this study. The mean score on the MOCA was 26.8 (SD = 2.3). Participants also reported no history of stroke or traumatic brain injury and no concurrent diagnoses of laryngeal disorders (eg, vocal fold nodules, laryngeal dystonia). If participants were taking dopaminergic medication, they were only included if they reported no changes to their prescription within the last 30 days. To be included, they were also required to have no participation in individual or group voice/speech therapy within the 6 months prior to completing the study.

During the virtual session, the experimenter also collected responses to interview questions and standardized questionnaires for descriptive reporting. Participants reported the number of years since their initial PD diagnosis (M = 8.0 years; SD = 4.7 years). Additionally, participants completed the Voice-Related Quality of Life measure; the mean score was 84.8 (SD = 13.6) out of a total of 100 points. Normative data suggest that those with self-reported voice symptoms in daily life score below 94.8 on this metric.[41] The Movement Disorder Society's Unified Parkinson's Disease Rating Scale (MDS-UPDRS) part III was conducted by a trained researcher (ie, a doctoral/postdoctoral researcher or a full-time research fellow) who had completed the MDS-UPDRS certificate program. Ratings were completed while participants were on their standard medication. The average UPDRS score was 62.1 (SD = 13.0), indicating mild-to-moderate levels of motor impairment for this group.[29] All participants were proficient speakers of North American English. All participants completed written consent in compliance with the Boston University Institutional Review Board.

The experimental tasks for this study were completed as part of a larger in-person session lasting 3 hours. During this in-person session, participants completed a pulsed-tone hearing screening (American Speech-Language and Hearing Sciences, 2018) using over-ear headphones on a Grason-Stadler (GSI) 18 audiometer (Grason-Stadler, Littleton, MA). Of the 32 participants, four participants reported regular use of hearing aids, but they were asked to remove them for the hearing screening. At lower frequencies (125, 250, 500, and 1000 Hz), 27 participants detected pulsed tones at or below 25-dB HL for 125-1000 Hz, and three of the five participants that failed this screening were individuals who typically wear hearing aids. At higher frequencies (2000 and 4000 Hz), 18 participants detected pulsed tones at or below 40-dB HL[74]; four out of the 14 participants who failed the screening at higher frequencies were individuals who typically wear hearing aids. For the 10 individuals without typical hearing aid use that failed the hearing screening, eight individuals failed in one ear at one or two frequencies or failed for both ears but only at 4000 Hz; two individuals failed in both ears across two frequencies. We did not exclude any participants based on unaided hearing loss since hearing ability, especially at higher frequencies, is expected to decline with age.[68,74] Further, we did not expect the inclusion of these speakers with hearing loss to significantly impact the present study findings.

Data collection

Acoustic recordings

Participants completed speaking tasks in a sound-attenuated booth, seated in front of a monitor. They wore an omnidirectional earset microphone (Shure MX153) placed 7 cm from the corner of the mouth at a 45-degree angle.[58] The microphone was connected to an RME Quadmic II amplifier and digitized via a soundcard (RME Fireface). The acoustic signal was recorded using Sonar Artist (Cakewalk, Boston, MA) with 16-bit resolution and at a sampling rate of 44.1 kHz. To calibrate the speech recordings, the experimenter used an electrolarynx positioned at the participants' lips (7 cm from the microphone) to record a reference signal while simultaneously measuring the intensity (dB SPL) of the electrolarynx signal using a sound-level meter (Checkmate CM-150) placed at the level of the microphone. This reference was used to convert the root-mean-square (RMS) of the microphone signal during the speaking tasks to its dB SPL equivalent.

Participants completed acoustic recordings for a spontaneous speech task and a reading passage across the two speaking conditions (typical and clear speech). Participants always completed the typical condition first. For both conditions, participants completed the spontaneous speech task first and then the reading passage. There were several additional speaking tasks that were part of a larger study, which were completed in between the speaking tasks used for this study, but the order in which the tasks were completed was consistent.

In the typical speech condition, participants were prompted to complete the speaking tasks in their "typical speaking voice." For the spontaneous speech task in the typical speech condition, participants were instructed to talk about their upcoming or past travel plans to elicit a 1-minute speech sample. For the reading passage, participants read aloud two paragraphs of the Rainbow Passage.[22] In the clear speech condition, participants were asked to "use clear speech by over-enunciating each word" before each task. To obtain a comparable but distinct spontaneous speech sample in the clear speech condition, participants were instructed to respond to a second open-ended prompt. We used a protocol designed to elicit a 2-3-min speech sample about an upcoming trip to New York.[23] For the reading passage in the clear speech condition, participants read the two paragraphs of the Rainbow Passage again. Mean duration for the spontaneous speech sample was 1.27 minutes (SD = 0.25 minutes) in the typical speech condition and 2.37 minutes (SD = 0.40 minutes) in the clear speech condition.[1] Mean duration for the Rainbow Passage was 1.14 minutes (SD = 0.18 minutes) in the typical speech condition and 1.47 minutes (SD = 0.40 minutes) in the clear speech condition.

Listening experiment

Ten speech-language pathologists with at least 3 years of clinical voice experience completed the listening experiment.

[1] The total durations of the spontaneous speech samples in the clear speech condition were longer than the samples in the typical speech condition. We do not expect this difference to influence results for this project. Firstly, we only analyzed the first ~120 syllables from each sample (see Data Analysis Section 2.3). Secondly, the clear speech condition was always completed after the typical speech condition, so any fatigue effects during the clear speech condition would not influence our analysis.

These listeners included six cisgender women and four cisgender men aged 29 to 40 years (M = 33.7 years; SD = 3.7 years) with no history of relevant communication disorders (eg, self-reported hearing loss, cognitive, or comprehension impairments that would negatively impact completion of the listening experiment). Duration of clinical voice experience ranged from 3 to 13 years (M = 6.3 years; SD = 3.5 years). All listeners were fluent speakers of American English. All listeners completed written consent in compliance with the Boston University Institutional Review Board.

Listeners completed the experiment via the virtual behavioral research platform called Gorilla Experiment Builder (gorilla.sc). They completed the experiment from a quiet environment. They wore either headphones (wired or wireless) or wireless earbuds throughout the session and were required to use a desktop computer or laptop. We did not expect headphone type to impact auditory-perceptual results. A researcher provided instructions and supervision via teleconference throughout the session. Prior to initiating the experiment, the listeners were instructed to listen to an audio sample and set their volume to a comfortable level. This volume was maintained throughout the experiment. The experiment included two blocks of stimuli derived from the two speaking tasks described above: the spontaneous speech and Rainbow Passage samples. The order of these task blocks was counterbalanced. Within each block, the typical and clear speech samples were randomly presented to minimize listeners' awareness of the speech condition differences.

In preparation for the listening experiment, stimuli were manually cropped in Praat.[9] For the spontaneous speech sample stimuli, samples were cropped from the onset of the speech sample to a standardized syllable length of ~20 syllables. If the 20th syllable was mid-word or mid-phrase, the stimulus was either shortened or extended to maintain word and phrasal boundaries (M = 20.2 syllables; SD = 2.1 syllables; Range = 16-24 syllables). For the reading passage stimuli, samples were cropped to include the second sentence of the Rainbow Passage ("The rainbow is a division of white light into many beautiful colors"), which contains 20 syllables. Given that the speech rate differed across typical speech and clear speech conditions, the durations of the stimuli varied. The spontaneous speech stimuli in the typical speech condition had a mean duration of 6.1 seconds (SD = 1.0 seconds). In the clear speech condition, the mean duration was 5.9 s (SD = 1.2 seconds). Rainbow Passage stimuli in the typical condition had a mean duration of 4.1 s (SD = 0.7 seconds), and in the clear speech condition, the mean duration was 5.7 s (SD = 1.7 seconds). All audio files were RMS amplitude-normalized. Each of the two blocks contained 72 total stimuli comprising 32 spontaneous speech samples, 32 Rainbow Passage samples, and an additional 8 repeated samples for intra-rater reliability.

Listeners rated each sample on three parameters (overall severity of dysphonia, breathiness, and strain) using three visual-analog scales with custom anchors on each side; the left-sided anchors were labeled "0 (Not dysphonic/breathy/strained)" and the right-sided anchors were labeled "100 (Severely dysphonic/breathy/strained)." They were instructed to base their ratings on the "degree of perceived deviance from normal" for each parameter. Participants were allowed to play each audio recording up to two times. They were required to listen to the entire audio sample at least once. On average, the experimental duration was 45.9 minutes (SD = 7.5 minutes). Participants were offered a 5-minute break between the two experimental blocks.

Data analysis

Acoustic

For acoustic analysis, audio files from both the typical and clear speech conditions were manually cropped in Praat to include the first 120-130 syllables of the spontaneous speech sample[2] (M = 126.2 syllables) and the first paragraph of the Rainbow Passage (127 syllables). We chose these syllable lengths to replicate clinical recommendations for acoustic analysis of running speech samples.[59] A trained researcher used a semiautomated script to remove pauses from each audio file. Pauses were removed to reduce their influence on all acoustic measures. Mean duration for the pause-removed spontaneous speech files was 29.0 seconds (SD = 4.3 seconds) in the typical speech condition and 29.6 s (SD = 5.7 seconds) in the clear speech condition. Mean duration for the pause-removed Rainbow Passage files was 27.4 s (SD = 4.0 seconds) in the typical speech condition and 34.3 s (SD = 8.1 seconds) in the clear speech condition.

Values for vocal intensity (RMS) were extracted from the pause-removed audio files using an automated Praat script. Intensity values (RMS) from Praat were converted to dB SPL using the calibration procedure described in Section 2.1.1. To measure f_o variation, a trained researcher manually adjusted f_o settings in Praat[9] to optimize tracking for each sample, and mean f_o and f_o SD (Hz) were extracted. These values were used to convert f_o SD to ST using a formula (see Equation 1). The trained researcher then repeated manual analysis of f_o for 15% of the samples to calculate an intraclass correlation coefficient (ICC) for intra-rater reliability. A second trained researcher completed manual analysis of f_o for the same 15% of repeated samples to calculate an ICC for inter-rater reliability. For intra- and inter-rater reliability of f_o SD (ST), ICC (2,1) values for agreement were 0.94 and 0.98, respectively, indicating excellent intra- and inter-rater reliability.

$$ST = 12 \times \log_2 \frac{fo\,(Hz) + fo\;SD\,(Hz)}{fo(\mathrm{Hz})} \tag{1}$$

To calculate acoustic correlates of dysphonia, CPP (dB) and L/H ratio (dB) were extracted from the pause-removed audio files using an automated Praat script. The procedure

[2] The reported syllable lengths for spontaneous speech samples ranged from 120 to 130 syllables to closely match the syllable length of the Rainbow Passage while preserving word and phrasal boundaries of each sample.

described in prior work was used to calculate CPP[93]; first, we selected "Analyze periodicity" and chose "To Power-Cepstrogram." The following parameters were then selected: Pitch floor = 60 Hz, Time step = 0.002 seconds, Maximum frequency = 5000 Hz, Pre-emphasis from = 50 Hz. From the program window, we then selected "Query" and "Get CPPS." The next parameters were set as follows: "Subtract tilt before smoothing" was unchecked, Time-averaging window = 0.01 seconds, Quefrequency averaging window = 0.001 seconds, Peak search pitch range = 60-330 Hz, Tolerance = 0.05, Interpolation = Parabolic, Tilt line quefrequency range = 0.001-0.0 seconds, Line type = Straight, and Fit method = Robust. Values represent the degree of periodicity in the vocal signal measured by the relative amplitude of the peak in the cepstrum (ie, the Fourier transform of the power spectrum). The L/H ratio was calculated with a 4000-Hz cutoff; values represent the ratio of low (< 4000 Hz) to high (> 4000 Hz) spectral energy in the signal.

Auditory-perceptual ratings

Auditory-perceptual ratings of the overall severity of dysphonia, breathiness, and strain for each stimulus were averaged across the ratings from all ten listeners. Intra-rater reliability was calculated for each listener using ratings from the repeated samples as ICC(2,1), and inter-rater reliability was calculated for ratings across the listeners as ICC(2,k) for the three parameters. For intra-rater reliability, average ICC(2,1) values were 0.96 for overall severity of dysphonia, 0.97 for breathiness, and 0.92 for strain, indicating excellent intra-rater agreement for all three parameters. For inter-rater reliability, ICC(2, k) values were 0.95 for overall severity of dysphonia, 0.96 for breathiness, and 0.91 for strain, indicating excellent agreement across raters for all three parameters.[38]

Statistical analysis

Statistical analyses were completed in *R statistical software* (RStudio Team, 2020). Significance was set a priori at $\alpha = 0.05$. To reduce the risk of false positives, we first constructed a multivariate analysis of variance (MANOVA) to test the effects of condition, task, and their interaction on all seven voice measures (intensity, f_o SD, CPP, L/H ratio, overall severity of dysphonia, breathiness, and strain). The model specifications were the following: manova(cbind(intensity_dBSPL, f_o_SD, CPP, LH_ratio, overall_severity, breathiness, strain) ~ Condition * Task + Error(SpeakerID). Based on the results of the MANOVA, seven *post hoc* linear mixed-effects models were constructed using the **lmer** function in RStudio to compare each acoustic measure (intensity, f_o SD, CPP, and L/H ratio) and auditory-perceptual rating measure (overall severity of dysphonia, breathiness, and strain) of clear speech to typical speech. Fixed effects were condition (typical and clear speech) and task (spontaneous speech and reading passage). To account for the role of intensity in the effect of clear speech cueing on the other three acoustic measures (f_o SD, CPP, and L/H ratio), intensity was included as a covariate. Participant was included as a random effect. For intensity and the auditory-perceptual measures, the model specifications were the following: VoiceMeasure ~ SpeakingCondition + Task + (1|Participant). For f_o SD, CPP, and L/H ratio, the model specifications were the following: VoiceMeasure ~ SpeakingCondition + Task + Intensity_dBSPL + (1|Participant). If the covariate of intensity significantly accounted for a portion of the variance in the other acoustic measures, we calculated the partial R^2 values between intensity and the dependent variable using the **r2glmm** package in RStudio. Effect sizes for all significant fixed effects were measured via partial squared curvilinear correlations (n_p^2) and designated as small (0.01), medium (0.09), and large (0.25[99]).

Results

The results of the MANOVA revealed a significant main effect of condition, $F(7,77) = 7.24$, $P < 0.001$, and task, $F(7,77) = 4.73$, $P < 0.001$, on the voice measures. There was no significant interaction of condition and task on the voice measures, $F(7,77) = 1.03$, $P = 0.416$. Thus, linear mixed-effects models for each acoustic and auditory-perceptual measure included only condition and task as main effects with participant as a random factor. Results for acoustic measures and auditory-perceptual measures are visualized in Figures 1 and 2, and results of the seven *post hoc* linear mixed-effects models are listed in Table 1. Additionally, descriptive statistics for acoustic and auditory-perceptual measures in both speech conditions and tasks are listed in Supplemental Table 1.

Acoustic measures

There was a significant main effect of condition on intensity with a large effect size ($n_p^2 = 0.22$). At the group level, mean intensity significantly increased in clear speech condition as compared with the typical speech condition; mean intensity increased by 0.76-dB SPL in the spontaneous speech task (from 83.42-dB SPL to 84.18-dB SPL) and 1.43-dB SPL in the Rainbow Passage (from 83.40-dB SPL to 84.83-dB SPL). There was no significant effect of task on intensity.

There were significant main effects of both condition and task on f_o SD with small-medium and medium effect sizes ($n_p^2 = 0.04$ and 0.09, respectively), even when statistically controlling for intensity as a covariate. There was no significant effect of the covariate of intensity on f_o SD. At the group level, f_o SD was significantly greater in the clear speech condition as compared with the typical speech condition. In the clear speech condition compared with typical speech, f_o SD increased by 0.16 ST in the spontaneous speech task (from 1.93 ST to 2.10 ST) and 0.11 ST in the Rainbow Passage (from 2.12 ST to 2.23 ST).

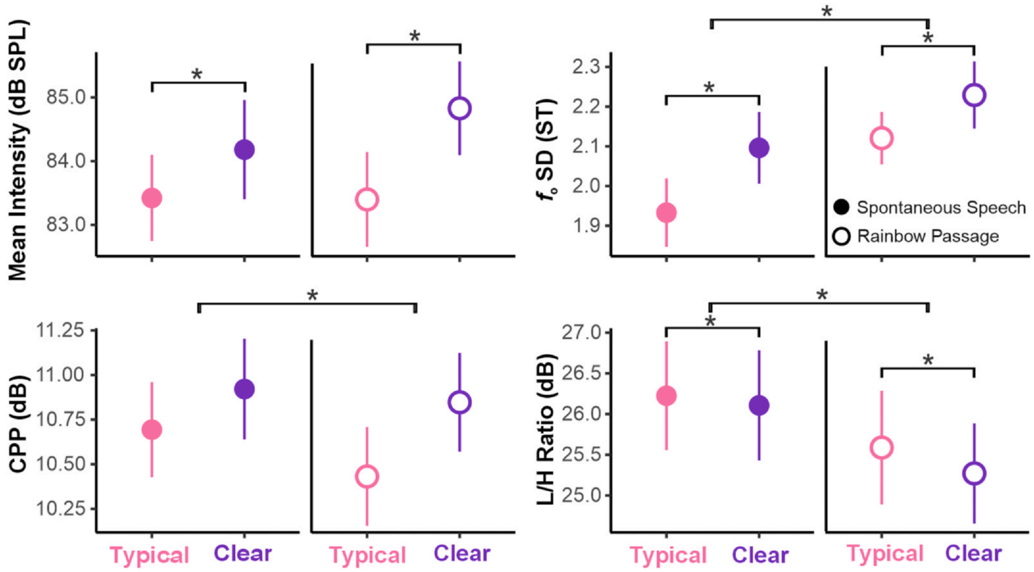

FIGURE 1. Interval plots comparing effects of condition (typical and clear speech) and task (spontaneous speech and Rainbow Passage) on acoustic voice measures. The four acoustic voice measures include intensity (dB SPL), fundamental frequency standard deviation (f_o SD) in semitones (ST), cepstral peak prominence (CPP; dB), and low-to-high (L/H) ratio (dB). Dots represent means, and vertical lines represent standard errors of the mean. The typical speech condition is depicted in pink, and the clear speech condition is depicted in purple. The spontaneous speech task is represented with filled circles, and the Rainbow Passage task is represented with open circles.

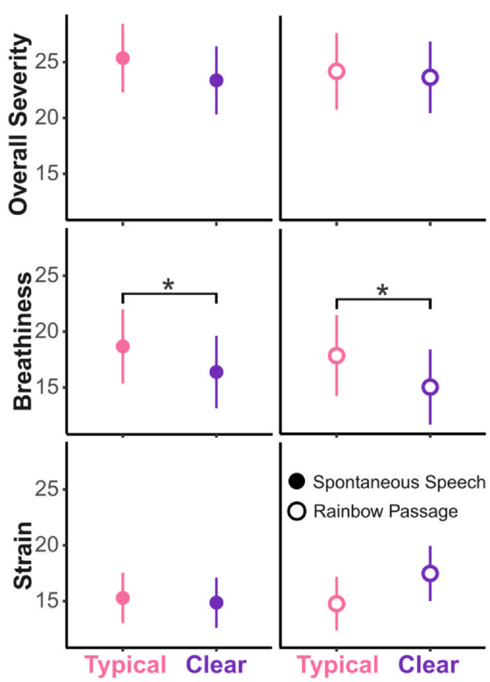

FIGURE 2. Interval plots comparing effects of condition (typical and clear speech) and task (spontaneous speech and Rainbow Passage) on auditory-perceptual voice measures. The three auditory-perceptual measures include overall severity of dysphonia, breathiness, and strain. Dots represent means, and vertical lines represent standard errors of the mean. The typical speech condition is depicted in pink, and the clear speech condition is depicted in purple. The spontaneous speech task is represented with filled circles, and the Rainbow Passage task is represented with open circles.

Additionally, f_o SD was significantly greater in the Rainbow Passage task as compared with the spontaneous speech task.

For the acoustic correlates of voice quality, there was no main effect of condition on CPP after statistically controlling for intensity. The covariate of intensity was significantly associated with CPP ($P < 0.001$) and accounted for 46% of the variance in CPP (partial $R^2 = 0.46$). There was a significant effect of task on CPP ($P < 0.001$) with a medium effect size ($n_p^2 = 0.11$). CPP was significantly greater in the spontaneous speech task compared with the Rainbow Passage. There were significant main effects of condition ($P = 0.02$) and task ($P < 0.001$) on L/H ratio with small-medium ($n_p^2 = 0.05$) and medium ($n_p^2 = 0.10$) effect sizes, respectively, even when controlling for intensity as a covariate. Intensity was significantly associated with L/H ratio ($P < 0.001$) and accounted for 21% of the variance in L/H ratio (partial $R^2 = 0.21$). L/H ratio was significantly lower in the clear speech condition compared with typical speech and significantly lower in the Rainbow Passage compared with spontaneous speech. Figure 3 compares intensity differences between speaking conditions with differences in CPP and L/H ratio.

Auditory-perceptual measures

There was a significant main effect of condition on breathiness ratings with a medium effect size ($n_p^2 = 0.11$). In the clear speech condition, compared with typical speech, breathiness ratings significantly decreased by 2.3 units on the visual-analog scale (“0” left anchor = not breathy; “100” right anchor = severely breathy) for the spontaneous speech task (from 18.7 units to 16.4 units),

TABLE 1.
***Post Hoc* Linear Mixed-Effects Models for Each Voice Measure. Fixed Effects of Condition (Typical and Clear) and Task (Spontaneous Speech and Rainbow Passage) and the Covariate of Intensity Are Listed. Participant was included as a random effect**

Measure Type	Measure	Effect	*F*	*P*	n_p^2	Effect size
Acoustic	Intensity	Condition	26.30	< 0.001*	0.22	Large
		Task	2.15	0.146	—	—
	f_o variation	Condition	4.33	0.040*	0.04	Small-medium
		Task	8.93	0.004*	0.09	Medium
		Intensity	2.58	0.113	—	
	CPP	Condition	0.04	0.845	—	
		Task	11.35	0.001*	0.11	Medium
		Intensity	87.24	< 0.001*	0.42	Large
	L/H ratio	Condition	5.83	0.017*	0.05	Small-medium
		Task	10.85	0.001*	0.07	Medium
		Intensity	20.40	< 0.001*	0.17	Medium
Auditory-perceptual	Overall severity	Condition	1.92	0.169	—	—
		Task	0.25	0.617	—	—
	Breathiness	Condition	11.56	< 0.001*	0.11	Medium
		Task	2.08	0.153	—	—
	Strain	Condition	2.03	0.158	—	—
		Task	1.70	0.196	—	—

— = not applicable for nonsignificant findings.
Abbreviations: *fo*, fundamental frequency; CPP, cepstral peak prominence; L/H ratio, low-to-high ratio.
* Significant at $P < 0.05$.

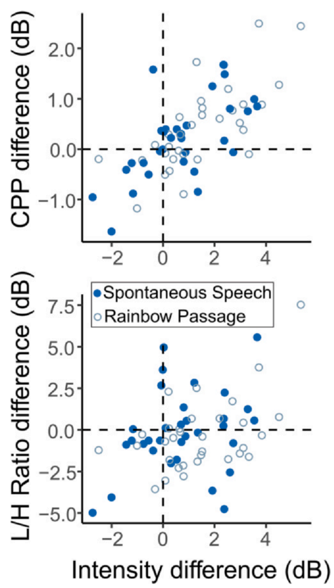

FIGURE 3. Scatterplots to compare intensity differences (dB) between the speech conditions (ie, clear speech-typical speech) with differences in cepstral peak prominence (CPP; dB), and low-to-high (L/H) ratio (dB) between conditions. The spontaneous speech task is represented with dark blue-filled circles, and the Rainbow Passage task is represented with light blue open circles.

and 2.8 units for the Rainbow Passage task (from 17.9 units to 15.0 units). There was no effect of condition or task on the overall severity of dysphonia or strain ratings.

DISCUSSION

This study investigated the acoustic and auditory-perceptual voice outcomes of clear speech cueing in PwPD. In the clear speech condition, intensity was significantly increased as compared with the typical speech condition. There was a significant effect of clear speech cueing on f_o variation and L/H ratio, but not CPP, when accounting for differences in intensity. In the clear speech condition, f_o variation increased, and L/H ratio decreased compared with typical speech. Intensity was significantly associated with both CPP and L/H ratio, accounting for 46% and 21% of the variance in the outcomes, respectively. For auditory-perceptual measures, there was a significant decrease in breathiness in the clear speech condition, compared with typical speech. However, there was no effect of the overall severity of dysphonia or strain across conditions. These findings suggest that targeting the articulatory subsystem via clear speech cueing may result in upstream effects on the phonatory subsystem.

Acoustic voice outcomes

As hypothesized, acoustic measures of intensity and f_o variation were significantly increased with clear speech cueing, as compared with typical speech. These findings align with prior work on clear speech cueing in PwPD.[28,81,89,90] Intensity differences did not significantly account for the variance in f_o SD, which suggests that the observed increase in f_o variation with clear speech cueing is not associated with the increase in intensity at the group level; instead, these two outcomes are independent of one another. That is, a speaker who increases their vocal intensity with clear speech cueing may not also increase their f_o variation, and vice versa. The results of increased intensity and f_o variation following clear speech cueing in the present study align with findings of voice outcomes from comprehensive behavioral voice treatment programs for PwPD. Following LSVT LOUD, many studies have also found an increase in intensity,[35,39,48,57,66,67,71,75,98] and two studies have found increased f_o variation.[64,65] The present study findings also align with the increased intensity and f_o variability observed in the two studies on acoustic outcomes following SPEAK OUT! [10,7] and the observed increase in intensity at 1 month after LSVT ARTIC.[66]

There was no significant effect of clear speech cueing on CPP when accounting for intensity; this finding differed from our hypothesis, suggesting that intensity is a key factor in interpreting CPP change in both the present study and in the prior study that found an increase in CPP with clear speech cueing (H.-B. [77]). Intensity accounted for 46% of the variance in CPP (partial $R^2 = 0.46$). As intensity increased, CPP also increased; this finding aligns with prior studies that found a relationship between intensity and CPP.[13,2] Descriptively, in this study, CPP changed in the expected pattern following clear speech cueing; CPP increased by 0.23 dB in spontaneous speech (from 10.69 dB to 10.92 dB) and 0.42 dB in the Rainbow Passage (from 10.43 dB to 10.85 dB). An increase in CPP has also been observed as a posttreatment outcome for LSVT LOUD[1] and SPEAK OUT!.[7] On the surface, an increase in CPP in PwPD who have a hypophonic or weak voice quality could be related to increased periodicity of harmonics or decreased aperiodic noise of the signal.[56,58,91] However, CPP increases in this study and in related work may not be representative of an improvement in voice quality and are likely driven instead by the increase in intensity.

There was a significant difference in L/H ratio values across conditions, even when controlling for intensity differences. As expected, we observed a decrease in L/H ratio, potentially due to an increase of periodic energy in the higher frequencies (> 4000 Hz) during the clear speech condition.[47] Intensity accounted for 21% of the variance in L/H ratio ($R^2 = 0.21$). A decrease in L/H ratio has also been observed as an outcome of LSVT LOUD[1]; however, the role of intensity was not accounted for in this prior work. The relationship between intensity and L/H ratio was somewhat unexpected. Increased intensity was associated with *increased* L/H ratio. Perhaps, this increase in L/H ratio is due to a subset of speakers reducing the amount of high-frequency aperiodic noise as they increased their loudness in the clear speech condition, which would align with the observed group-level reduction in breathiness ratings in the clear speech condition.

There was a task difference for three out of the four acoustic measures: f_o SD was significantly higher, and both CPP and L/H ratio were significantly lower in Rainbow Passage task compared with the spontaneous speech task. It is unsurprising that we observed elevated f_o SD in the Rainbow Passage task, as this result aligns with prior findings of increased intonational changes when speakers read aloud, as opposed to when they produce a spontaneous speech sample.[42] As for CPP and L/H ratio, it is less clear why these values were both lower in the Rainbow Passage than in the spontaneous speech. One notable task-related difference was observed in the descriptive analyses of the speech samples used in this study. Prior work suggests that clear speech cueing results in slower speech rates[16,28]; therefore, we expected longer speech sample durations in the clear speech condition compared with the typical speech condition. As expected, Rainbow Passage samples showed longer durations in the clear speech condition for both the pause-removed acoustic recordings (average clear speech duration was 34.3 seconds, and typical speech duration was 27.4 seconds) and the auditory-perceptual experiment stimuli (average clear speech duration was 5.7 seconds, and typical speech duration was 4.1 seconds). In contrast, the average speech durations of the spontaneous speech samples were similar across the two speech conditions; for the pause-removed acoustic recordings, average clear speech duration was 29.6 seconds, and typical speech duration was 29.0 seconds. One explanation for these task differences may be related to the role of cognitive load in implementing the clear speech cue.[97] Clear speech cueing during spontaneous speech may require more cognitive effort compared with implementing the cue during a reading passage, leading participants to make differing motor adjustments in response to the cue across the two tasks. Further work is needed to clarify the extent to which speech task type influences how speakers respond to clear speech cueing.

Auditory-perceptual voice outcomes

This study investigated three auditory-perceptual voice outcomes of clear speech cueing in PwPD. There was a significant decrease in auditory-perceptual ratings of breathiness in the clear speech condition, compared with typical speech. This finding supports our hypothesis and aligns with our finding of decreased L/H ratio with clear speech cueing. This finding is also similar to the results from the prior clear speech cueing study that found reduced breathiness in PwPD following cues to “speak to someone with a hearing impairment”.[77] Decreased breathiness has also been observed following LSVT LOUD.[15,6,87] Only one study has investigated auditory-perceptual outcomes of SPEAK OUT![10]; in this study, the authors tested for change in presence/absence of “breathy,” “hoarse,” “harsh,” and “strained/strangled” voice quality, and they only found reduced presence of “hoarseness” following SPEAK OUT!. Similarly, the prior study on auditory-perceptual outcomes of LSVT ARTIC did not find a greater proportion of “typical voices” after the intervention.[50] However, because these prior studies used a method of binary judgments on nonstandardized perceptual voice parameters,[101] future work is needed to more closely investigate auditory-perceptual voice outcomes of other interventions for PwPD before comparing to the present study.

There was no effect of overall severity of dysphonia or strain across conditions. These findings did not support our hypotheses; we expected clear speech cueing to result in decreased overall severity of dysphonia and strain. However, compared with breathiness, these two auditory-perceptual outcomes are less supported by evidence in other behavioral voice interventions for PwPD. Only one study on LSVT LOUD found reduced strain.[98] Another study investigated outcomes of LSVT LOUD when administered via teletherapy.[19] This study found improvements in perceptual voice quality, as measured by a limited 4-point Likert scale. However, to our knowledge, there is no evidence reporting reduced overall severity of dysphonia as measured by a visual-analog scale following LSVT LOUD. In the present study, the lack of significant differences for overall severity of dysphonia and strain could have been due to conflicting patterns at the individual level, given the individual variability of voice symptom expression in PwPD.[12] Additionally, although not statistically significant, the mean strain ratings in the clear speech condition did increase numerically from typical speech for the Rainbow Passage task (see Figure 2 and Supplemental Table 1). It is possible that the trending increase in strain in the clear speech condition for the Rainbow Passage is driving the lack of reduced overall severity of dysphonia. However, additional work is needed to extrapolate further.

Limitations and future directions

In this study, several participants' voice qualities were rated as having severe overall dysphonia. However, the majority of participants in this sample were rated in the mild range (see Supplemental Table 1 for descriptive statistics). Further, to be included in this study, participants were required to have a diagnosis of PD, but they were not required to have voice complaints. Thus, this sample of speakers with PD may differ from the population of PwPD who seek behavioral voice services. Future work should consider how clear speech cueing may impact a sample of participants with more severe voice symptoms and complaints.

Additionally, this project was designed to observe voice changes as a result of a standard clear speech cue in a lab-based setting during a single session. The goals, and therefore, the methodology, of the present study were not representative of those of a therapeutic setting. Clinical use of clear speech cueing involves an iterative process of providing augmented feedback to elicit improvement of patients' vocal status and symptoms.[26] Future studies should examine clear speech in a more ecologically valid context. More work is needed to examine the influence of clinician-driven external feedback and shaping and determine the appropriate therapeutic dosage to reach retention of voice outcomes beyond a single session.

The spontaneous speech tasks in the typical versus clear speech conditions used different open-ended prompts. In the typical speech condition, participants were asked to discuss their upcoming or past travel plans, and in the clear speech condition, they were asked to imagine and discuss an upcoming trip to New York. We chose to use two prompts that were not identical but were closely related (ie, both questions elicited a speech sample on the topic of travel plans). However, one potential limitation is that the two prompts may have elicited minor differences in speech patterns across the conditions for some participants.

This project focused specifically on group differences across the speaking conditions. However, there is substantial variability of broad motor[36,73] and voice symptoms[12,72] in PwPD. This individual variability can be observed in the present study's distribution of acoustic values and auditory-perceptual ratings both from the typical speech condition (ie, individual variability at baseline) and in the distribution of differences across the two speech conditions (ie, individual variability in the direction and magnitude of change from baseline during clear speech). Participants may be responding to clear speech cueing to varying degrees or via differing strategies. For example, if a participant is unable to isolate greater oral constriction associated with overarticulating, they might incorporate maladaptive constriction at the laryngeal level. Future work should investigate voice measures that better reflect distinct patterns of voice change following clear speech cueing across the speech subsystems, such as respiratory and articulatory kinematic measures.

CONCLUSIONS

In this study, acoustic and auditory-perceptual voice outcomes of clear speech cueing in PwPD included increased intensity, increased f_o variation and decreased L/H ratio after controlling for intensity, and reduced breathiness as compared with the typical speech condition. There was no difference in CPP after controlling for intensity, and there was no difference in overall severity of dysphonia or strain across the speaking conditions. Intensity accounted for 46% of the variance in CPP and 21% of the variance in L/H ratio. Intensity was not associated with f_o SD. These findings suggest that targeting the articulatory subsystem via clear speech cueing for PwPD can elicit both acoustic and auditory-perceptual voice outcomes that align with a louder voice with increased intonational variation and reduced breathiness.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to commitments to protect participant confidentiality but are available from the senior author through formal mechanisms on reasonable request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jvoice.2025.11.020.

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