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The Acoustic Voice Quality Index (AVQI) in People with Parkinson's Disease Before and After Intensive Voice and Articulation Therapies: Secondary Outcome of a Randomized Controlled Trial

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Abstract

Objectives. The majority of individuals with Parkinson's disease (PD) experience voice and speech problems during the course of the disease. Despite the importance of voice quality in communication and the documented disordered voice quality in PD, few studies have explored the effects of speech treatment on this variable.

Study Design/Methods. A parallel arm, unblinded randomized controlled trial (RCT) was conducted with two active comparators, LSVT LOUD (n = 23) and LSVT ARTIC (n = 20), and an inactive comparator group of untreated individuals with PD (n = 22). A group of 20 healthy adults was also included for pre-treatment analysis. Voice recordings were obtained pre-treatment, immediately post-treatment and at 6-month follow-up. The acoustic voice quality index (AVQI) is reported here as a secondary outcome measure of the RCT. Linear mixed-effects regression analysis was performed with AVQI and sound pressure level (SPL) as dependent variables. Pearson correlation coefficient analysis was also conducted to explore the relationship between voice quality and SPL.

Results. Statistically significant improvements in AVQI and SPL from pre-treatment to post-treatment and follow-up were only observed in the LSVT LOUD group. Voice quality significantly improved only from pre-treatment to follow-up in the LSVT ARTIC group, whilst significant improvements in SPL

were observed during maximum phonation only immediately post-treatment. No significant changes were observed in the untreated group.

Discussion. This study investigated the effects of intensive speech treatment targeting voice or targeting articulation on voice quality, as measured by the AVQI, in individuals with PD. Findings indicate that voice-focused treatment leads to greater improvements in voice quality in this population.

Keywords: AVQI, voice quality, RCT, Parkinson's disease, LSVT LOUD

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1. Introduction

It has been well established that the majority of individuals diagnosed with Parkinson's disease (PD) can expect to develop one or more significant voice and speech symptoms during the course of the disease [1]. These symptoms, which collectively describe the motor speech disorder of hypokinetic dysarthria, stem from changes to multiple speech subsystems affecting voice production, articulation, respiration, prosody, and resonance [2]. The impact of PD on one or more of these subsystems results in a characteristic profile of reduced vocal loudness [3,4], decreased pitch and loudness variability (monopitch and monoloudness), hoarse or breathy voice quality [5], imprecise consonants (heard as slurring or mumbling) [6], centralized vowels [7,8], and speech timing changes (eg, fast rate, dysfluencies) [9].

Voice and speech characteristics associated with PD are a reported concern by patients [10,11]. Deterioration of voice and speech function, coupled with reported deficits in language skills [12], frequently leads to decreased intelligibility, and self-reported changes in functional communication and social participation, which, ultimately, detrimentally affect quality of life [13,14]. Poor-quality voices, for example, have been shown to increase listener reaction time [15] and contribute to a speaker's overall self-perception of speech impairment.

Standard acoustic measures reflecting prosody, articulation and sound pressure level (dB SPL) stand in contrast to the historical challenges of studying voice quality in PD, which may revolve around problems in consistently identifying acoustic measures that clearly map to specific perceptual characteristics of "quality." Recently, several research groups have developed new acoustic measurements that appear to easily and reliably evaluate voice quality [16,17]. Among them is the acoustic voice quality index (AVQI v. 03.01) [16], an objective measure of dysphonia that is well-correlated to auditory-perceptual ratings of voice quality across a variety of languages [18]. The AVQI combines and weighs six different acoustic measures from connected speech and sustained phonation (smoothed cepstral peak prominence [CPPS], harmonic-to-noise ratio, shimmer local (SL), SLdB, general slope of the spectrum, and tilt), with the heaviest weighting given to CPPS. Measures such as the AVQI allow clinicians and researchers to begin to look more closely at changes in voice quality after speech treatment, and eventually at the relationships between voice quality, speech intelligibility, and social participation in individuals with PD.

There is a variety a variety of speech treatment approaches to managing communication deficits in individuals with PD [19,20], including recent approaches [21] and [22], only some of which directly target voice production. The behavioral approach with the highest amount of evidence to date is the Lee Silverman Voice Treatment (LSVT®LOUD) [23]. In brief, LSVT LOUD is an intensive dosage, high effort standardized voice treatment that targets the common deficits of reduced vocal loudness and disrupted sensory feedback in people with PD. Although decreased loudness may be a specific deficit in this population, increasing loudness is used as a global organizing principle—a way to increase amplitude by overriding hypokinesia throughout the speech motor system while working directly on one of the primary (and often earliest) voice symptoms in PD. LSVT LOUD is the only speech treatment for PD with randomized controlled trial (RCT) data; there are five published RCTs with short and long-term efficacy data funded by NIH-NIDCD [23,24,25,26,27,28,29].

LSVT LOUD targets voice and speech deficits in PD through high-effort exercises focused on increasing healthy vocal loudness, combined with daily activities designed to improve internal calibration of appropriate loudness levels. Voice quality is indirectly targeted through modeling and training of healthy sustained phonations, avoiding strained or pressed voice production. Clinicians are trained to demonstrate good voice quality and use modelling to reinforce healthy phonation behaviors. Reported outcomes include significant improvements in aerodynamics [30] and acoustics [31,32,33], articulation [8], intonation [25], vocal fold closure [34] as well as neural changes [29,35,36,37] and measurable improvements in self-reported functional communication [8,25,28,38,39].

While there is ample evidence that LSVT LOUD improves a variety of voice and speech characteristics believed to affect intelligibility (eg, increased loudness, reduced vowel centralization, pitch variability), less is known about the effects of intensive voice-focused treatment on voice quality. Baumgartner et al. [40] reported statistically significant improvements in listener judgments of hoarseness and breathiness following LSVT LOUD compared to participants receiving a treatment targeting the respiratory system. More recently, Cannito et al. [41] reported improvements in perception of voice quality, favorable redistribution of harmonic energy, and improved intelligibility following LSVT LOUD in 24 subjects with PD from two different studies [27,42]. Of note, intelligibility was judged on sentences with normalized loudness in the presence of noise, suggesting that factors such as voice quality, intonation and articulation were potentially driving perceived intelligibility changes. Similarly, Alharbi et al. [43] reported improvements in cepstral peak prominence along with a decrease in cepstral/spectral index of dysphonia, in sustained phonation following treatment with LSVT LOUD, suggesting improved voice quality in speakers with PD.

Given the potential impact of voice quality on intelligibility, as well as the role of dysphonia in communicative participation, research is needed to evaluate the effects of intensive voice treatment on voice quality in larger groups of individuals with PD. The purpose of this study was to compare the impact of treatments (LSVT LOUD and LSVT ARTIC) matched on intensive dosage with different treatment targets (voice or articulation) on a measure of voice quality. Results were compared to individuals with PD receiving no treatment (UNTXPD) as well as to healthy controls at pre-treatment (HC).

Voice quality was measured through the AVQI [16]. Sound Pressure Level, an acoustic correlate of perceived vocal loudness, was measured to evaluate short and long-term changes in vocal intensity— reflecting both the effects of intensive dosage of treatments and long-term changes in participants receiving no treatment—and to examine the relationship between voice quality and SPL.

Voice quality was expected to improve following LSVT LOUD, as increases in SPL have been documented to improve this voice dimension [40,41,43]. The LSVT ARTIC treatment group was also expected to demonstrate voice quality changes, albeit to a lesser extent than the LSVT LOUD group, given that its target is articulation and not the glottal source. However, targeting the articulatory speech subsystem directly, hence eliciting clear speech, has been shown to increase SPL in speakers with PD [44], potentially contributing to an improvement in voice quality. Additionally, with the clinical concern that training increased loudness could result in increased vocal tension and, subsequently, also negative effects on vocal quality, the authors deemed this additional study justified to evaluate the impact of training increased vocal loudness on voice quality in PD. No changes were expected in the untreated group.

2. Methods

This study was approved by the Institutional Review Boards at the University of Colorado-Boulder and the University of Colorado Health Sciences Center-Denver, with written informed consent obtained from all participants.

2.1. Participants

Data for this study were collected as part of a large NIH-NIDCD funded RCT comparing the effects of two speech treatments on communication in Parkinson's disease. All participants were compensated for their time and fully debriefed after completion of the study. Those with PD receiving no treatment were offered complementary treatment following completion of their participation in the study.

Following an initial successful phone screening, 106 participants from the Denver, Colorado area took part in an in-clinic screening for vocal function, cognitive status (Mini Mental State Examination) [45] and depression (Beck depression inventory-III) [46] to confirm eligibility. Eighty-five individuals passed this screening and participated in this study: 65 people with PD and 20 age- and gender-matched healthy controls. Individuals with PD were within stages I-IV of the Hoehn and Yahr Scale [47] and had a stable anti-parkinsonian medication schedule. Exclusion criteria to participate in the study included a medical diagnosis of atypical parkinsonism, a voice or speech impairment not related to PD, laryngeal surgery or pathology, neurosurgery intervention, prior LSVT LOUD therapy, any intensive speech treatment within 2 years, or a swallowing impairment requiring immediate attention [28]. Participants were screened by a laryngologist using a comprehensive protocol designed for the study [28]. Voice conditions unrelated to PD, and resulting in exclusion, included the presence of vocal fold masses or lesions (cysts, nodules, polyps, etc.), vocal hemorrhage, unilateral or bilateral vocal fold paresis or paralysis, severe reflux, laryngeal papillomatosis, or other pathological changes to the vocal fold tissue. Table 1 presents demographic and clinical characteristics of participants at pre-treatment.

Participants were randomly assigned to one of two treatment groups (intensive voice treatment LSVT LOUD [N = 23], intensive articulation treatment LSVT ARTIC [N = 20]), or a no-treatment group (UNTXPD [N = 22]), using a minimization procedure to incorporate various inclusion and exclusion criteria (see Ramig et al. [28] for details). There were no significant differences in gender, age, time since diagnosis, stage of disease, cognitive status, or depression among the groups with PD at pre-treatment. Perceived voice quality severity ranged from mildly to severely dysphonic across groups. The control group without PD (HC) was matched for age and gender, and used for pre-treatment comparison. Two participants in the LSVT LOUD group and one participant in the Untreated group were excluded from data analysis for this study due to a posterior diagnosis of atypical parkinsonism. An additional participant from the Untreated group was excluded from analysis due to the presence of severe palilalia. In order to minimize bias, participants were not disclosed treatment information from the other groups, nor did they interact with participants from the other groups. As discussed in van der Kolk and colleagues [48] "masking in nonpharmacological studies is virtually impossible because the intervention is obvious to those who receive it" (p. 1006), and patients are aware of different intervention options when they read the Human Subject Protocol. Participants in the two treatment groups

completed a rating scale at the end of the study asking, "Out of all the treatment groups you could have been randomized into, do you feel you had the best treatment?." Responses were comparable between the two groups (100% for LSVT LOUD and 95% for LSVT ARTIC) [28].

Table 1. Demographic and Clinical Characteristics Pre-Treatment for Participants by Group.

Demographic and Clinical Characteristics	LSVT LOUD (N = 23)	LSVT ARTIC (N = 20)	Untreated (N = 22)	HCs (N = 20)
Males (0.5)				
N	16	15	14	13
%	69.6	75	63.6	65
Females (0.5)				
N	7	5	8	7
%	30.4	25	36.4	35
Age in y (0.5)				
Mean	67.7	68.2	64.2	64.2
SD	8.1	9.3	9	8.7
Years since diagnosis (0.5)				
Mean	5.1	5.0	4.6	–
SD	6.6	5.1	4.0	–
Hoehn and Yahr stage with medication (0.5)				
Mean	2.2	2.2	2.0	–
SD	0.6	0.7	0.5	–
Swallow (1)				
Mean	1.4	1.2	0.9	0.3
SD	1.0	0.9	0.6	0.6
Voice severity (1)				
Mean	2.3	2.5	2.2	0.6
SD	1.1	1.3	0.9	0.7
Articulation severity (1)				
Mean	0.9	0.9	1.0	0.0
SD	1.0	0.6	1.3	0.1
BDI-II (0.25)				
Mean	9.6	9.1	8.3	2.9
SD	5.5	5.6	5.7	3.3
MMSE (0.25)				
Mean	28.8	28.7	28.9	29.3
SD	1.3	1.2	0.8	0.9

Note. Numbers in parentheses represent weights. Voice and articulation severity were measured on a scale from 0-5 (0 = no disorder and 5 = severe disorder). Randomization ratio was 1:1:1 conducted using a minimization algorithm based on variables and weights selected a priori [28]. BDI-II = Beck depression inventory-II); LSVT = Lee Silverman voice treatment; MMSE = mini mental status examination.

2.2. Treatments: LSVT LOUD and LSVT ARTIC

Twenty-three individuals with PD received LSVT LOUD in 16 consecutive sessions over a 1-month period. A further 20 participants received speech treatment targeting articulation—LSVT ARTIC—which was developed as part of the RCT to evaluate whether the intensive *mode* of treatment is the driving factor behind improvements reported following LSVT LOUD, or if the *target* of treatment is of primary importance. LSVT ARTIC was designed to duplicate LSVT LOUD in all aspects of delivery mode (increased effort, number and frequency of sessions, sensory calibration, and homework) but with a target on articulatory effort and precision, using the cue "enunciate" instead of "loud." The description of the complete treatment protocols can be found in Levy et al. [49], Ramig et al. [28] and Schulz et al. [50]. Treatments were delivered by three speech-language pathologists (including the second author) with expertise in the treatment of individuals with PD who were also instrumental in helping to develop and pilot LSVT ARTIC. These clinicians were not involved in the data collection of the participants they treated.

In order to ensure equipoise during the treatment phase of the study, and given that clinicians were unblinded to treatment assignment, they were also carefully trained to avoid bias when delivering treatment, and understood their role in maintaining treatment fidelity [28]. Clinicians provided participants with the same type of positive reinforcement during sessions and reported equal investment in both treatments in a post-treatment interview, as well as equal belief in the effectiveness of either speech approach.

2.3. Procedure

2.3.1. Recording. Participants were recorded in an Industrial Acoustics Company sound-treated booth twice in the week immediately before treatment (pre1 and 2), twice in the week immediately after treatment or a 1-month waiting period (post1 and 2), and twice in the week 6 months after the post-treatment recording (fu1 and 2). Recording within each week took place on separate days. Data were collected through a head-mounted condenser microphone (AKG 420) positioned 8 cm from the lips [51] at a 45-90-degree angle [52], and calibrated to a type 1 sound level meter (SLM, Brüel, and Kjaer 2239). Data were recorded onto a hard drive using the Kay Pentax Computerized Speech Lab, with a separate digital audiotape backup. Data collectors (highly trained research staff and clinicians) read instructions from a standardized, written protocol and were blinded to the treatment each participant received. Participants read the Rainbow Passage [53] from a computer monitor at a fixed distance, and sustained six maximum-duration phonations on the vowel "ah" as part of a larger protocol. They were not prompted to modify their speech in any way. Items from the first recording of each time period ("day 1") were used for the main analysis (pre1, post1, and fu1).

3. Data Analysis

3.1. Acoustic Analysis

3.1.1. Acoustic Voice Quality Index (AVQI v 03.01). Analysis was completed using the AVQI v 03.01 [16]. The AVQI algorithm is designed to calculate a value between 0 and 10, although values outside that range are theoretically possible. The algorithm can be found below, where CPPs = smoothed cepstral peak prominence; HNR = harmonics-to-noise ratio; Shim =

shimmer local; ShdB = shimmer local dB; Slope = general slope of the spectrum, and Tilt = tilt of the regression line through the spectrum [18].

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AVQI 03.01 = (4.152 − (0.177 × CPPs) − (0.006 × HNR) − (0.037 × Shim) + (0.941
             × ShdB) + (0.01 × Slope) + (0.093 × Tilt)) × 2.8902
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Values below 2.43 reflect non-dysphonic phonation and values above 2.43 indicate dysphonia on samples of continuous speech in Dutch, although the measure has also been demonstrated to be well-correlated to perceptual ratings of voice quality across a variety of languages [18].

The AVQI was developed to include the acoustic properties of both sustained phonation and connected speech. The present study made use of recommendations for specific length of material yielding the greatest sensitivity, and the first 34 syllables of the Rainbow Passage and the middle 3 seconds from the third sustained phonation were submitted to acoustic analysis [18]. A total of 251 measurements from the first data collection point at pre-treatment, post-treatment, and follow-up were calculated (pre1, post1, and fu1). Sixteen percent of these measures were also compared to tokens from the second data collection point at pre-treatment, post-treatment, and follow-up (eg, post1 v. post2), across all groups to assess test-retest reliability.

3.1.2. Sound Pressure Level (SPL dB). SPL dB was measured for all groups at all times to evaluate the effects of treatment or no treatment on vocal intensity levels, and test for correlations with changes in the AVQI. SPL is reported for both reading (ie, first 34 syllables of the Rainbow Passage) and maximum phonation (ie, middle 3 seconds from the third sustained phonation) tasks. The calibrated acoustic recording was cleaned of any throat clearing, coughing, laughing or other artifacts and then submitted to SPL analysis using a fully automated program designed to emulate a type I sound level meter (see Ramig et al. [28] for details).

3.2. Statistical analyses

Data were analyzed using linear mixed-effects regression analysis [54]. Independent variables consisted of group (LSVT LOUD, LSVT ARTIC, UNTXPD, and HC), time (pre-treatment, post-treatment, and follow-up), and their interaction. The effects of age and gender were examined but not retained, as they did not alter the patterns of results. The analysis was repeated for each of the three dependent measures, AVQI, SPL for reading, and SPL for maximum phonation. The dependent measures showed approximately normal distributions and, therefore, were kept in their original scale. The presence of outliers was examined by looking at average performance by subject and dependent measure; only one subject with absolute standardized values greater than 3, corresponding to 1.2% of the data, was excluded from the analysis ($z = 3.5$, $z = 4.2$, and $z = -3.1$ for AVQI, SPL for reading, and SPL for maximum phonation, respectively).

Mixed-effects regression was adopted because it allows flexible modeling of within- and between-subject effects, and it has been shown to be superior and less biased than traditional approaches, such as analysis of variance (ANOVA) [54,55]. All models included random intercept for subjects. Random slopes for the within-subject predictor, time, were examined but never retained, either because of convergence failure or because they did not improve the model fit (as assessed by the likelihood-ratio test), and did not change the fixed effects component of the models significantly.

Data were analyzed with R version 4.1.1 [56] using the *lmer* function from the **lme4** package (version 1.1.27.1) [57]. To facilitate the interpretation of the results, we reported type-III ANOVA tables generated from the mixed-effects models estimates using the *joint_tests* function from the **emmeans** package [58]. Post-hoc Tukey adjusted comparisons were completed using the **emmeans** package [58]. Cohen's d effect sizes were computed using the *eff_size* function from the **emmeans** package [58]. Effects were considered statistically significant for $p < 0.05$.

3.3. Reliability

Intra-rater reliability was examined using the intraclass correlation coefficient (ICC), and was carried out by dependent variable (AVQI, SPL for reading, and SPL for maximum phonation) and time (pre-treatment, post-treatment, and follow-up). Data for the reliability analyses were randomly selected for a subset of participants: 13 subjects for the pre-treatment session (LSVT LOUD = 4, LSVT ARTIC = 3, UNTXPD = 3, and HC = 3), 14 subjects for the post-treatment session (LSVT LOUD = 3, LSVT ARTIC = 4, UNTXPD = 4, and HC = 3), and 11 subjects for the follow-up session (LSVT LOUD = 2, LSVT ARTIC = 3, UNTXPD = 2, and HC = 4). Given the small N, ICC was computed by time, rather than by time and group. Overall, reliability for all variables was good to excellent, supporting the stability of the measures. Table 2 provides information on reliability results.

Table 2. Intraclass Correlation Coefficient (ICC) by Dependent Variable and Time.

Variable	Pre-Treatment	Post-Treatment	Follow-Up
AVQI	0.953 [0.847; 0.986]	0.962 [0.881; 0.988]	0.768 [0.139; 0.938]
SPL reading	0.917 [0.927; 0.975]	0.833 [0.48; 0.946]	0.952 [0.822; 0.987]
SPL max phonation	0.921 [0.741; 0.976]	0.949 [0.84; 0.984]	0.844 [0.421; 0.958]

Note. Mean dB SPL is reported at a reference distance of 30 cm. In square brackets, 95% confidence interval (CI). AVQI = acoustic voice quality index; SPL = sound pressure level.

4. Results

4.1. Acoustic Voice Quality Index

Table 3 shows descriptive statistics (mean and standard deviation) for the AVQI for the healthy controls, LSVT LOUD, LSVT ARTIC, and untreated groups. Although no significant difference in the AVQI score was found between healthy controls and the combined PD group ($t(78) = -1.16$, $p = 0.247$) at pre-treatment, all three groups with PD tended to have higher AVQI values pre-treatment. Furthermore, there were no statistically significant differences in the AVQI scores among the three PD groups at pre-treatment. However, the AVQI was higher in the LSVT ARTIC group than in the other two.

Mixed-effects regression analysis revealed significant main effects for group ($F(3,84.03) = 3.95$, $p = 0.011$) and time ($F(2,164.42) = 21.86$, $p < 0.001$), as well as a significant interaction between group × time ($F(6,164.42) = 6.57$, $p < 0.001$). Significant pre-to-post treatment effects for the LSVT LOUD group were observed ($t(164) = 8.13$, $p < 0.001$), with a large effect size ($d = 2.57$) and gains maintained at follow-up ($t(165) = 6$, $p < 0.001$). In contrast, no significant pre-to-

post difference was found for the LSVT ARTIC group ($t(164) = 2.13$, $p = 0.087$), although a significant decline in the AVQI score was noted between pre-treatment and follow-up ($t(165) = 2.45$, $p = 0.041$), with a large effect size ($d = 0.83$). Still, AVQI scores were outside normal limits across all data collection points for this group. No statistically significant differences were observed in the untreated group. Descriptive statistics for treatment effects across groups can be found in Appendix A.

Table 3. Descriptive Statistics (Mean and Standard Deviation) for the AVQI for the Healthy Controls (N = 20), LSVT LOUD (N = 21), LSVT ARTIC (N = 19), and Untreated (N = 20) Groups.

Group	Pre-Treatment	Post-Treatment	Follow-Up
Healthy controls	2.16 (0.96)	1.88 (0.93)	1.74 (0.93)
LSVT LOUD	2.35 (1.17)	1.03 (1.03)	1.44 (0.78)
LSVT ARTIC	2.91 (1.37)	2.55 (1.06)	2.50 (1.31)
Untreated PD	2.31 (1.19)	2.33 (1.30)	2.23 (1.33)

Note. AVQI = acoustic voice quality index; LSVT = Lee Silverman voice treatment; PD = Parkinson's disease.

4.2. Sound Pressure Level

Table 4 shows descriptive statistics (mean and standard deviation) for reading SPL (in dB) at 30 cm for the healthy controls, LSVT LOUD, LSVT ARTIC, and untreated groups.

Table 4. Descriptive Statistics (Mean and Standard Deviation) for Reading SPL (in dB) at 30 cm for the Healthy Controls (N = 20), LSVT LOUD (N = 20), LSVT ARTIC (N = 20), and Untreated (N = 20) Groups.

Group	Pre-Treatment	Post-Treatment	Follow-Up
Healthy controls	73.0 (2.22)	73.4 (2.51)	73.1 (2.19)
LSVT LOUD	71.9 (2.86)	78.0 (2.85)	75.7 (2.14)
LSVT ARTIC	72.9 (3.12)	73.6 (3.34)	73.2 (3.05)
Untreated PD	71.5 (3.23)	72.3 (2.81)	71.8 (3.16)

Note. LSVT = Lee Silverman voice treatment; PD = Parkinson's disease; SPL = sound pressure level.

Table 5 shows descriptive statistics (mean and standard deviation) for maximum phonation SPL (in dB) at 30 cm for the healthy controls, LSVT LOUD, LSVT ARTIC, and untreated groups.

Table 5. Descriptive Statistics (Mean and Standard Deviation) for Maximum Phonation SPL (in dB) at 30 cm for the Healthy Controls (N = 20), LSVT LOUD (N = 21), LSVT ARTIC (N = 19), and Untreated (N = 20) Groups

Group	Pre-Treatment	Post-Treatment	Follow-Up
Healthy controls	76.2 (5.25)	75.7 (4.61)	76.4 (4.50)
LSVT LOUD	75.5 (5.50)	85.4 (4.17)	83.5 (4.91)
LSVT ARTIC	72.9 (4.69)	75.5 (5.52)	74.2 (6.18)
Untreated PD	75.8 (6.10)	75.7 (5.41)	75.8 (4.94)

Note. LSVT = Lee Silverman voice treatment; PD = Parkinson's disease; SPL = sound pressure level.

Although no significant difference in SPL was found between healthy controls and the combined PD group for reading SPL ($t(78) = 1.27$, $p = 0.201$) or maximum phonation SPL ($t(78) = 1.01$, $p = 0.318$) at pre-treatment, all three groups with PD tended to have lower SPL across both tasks pre-treatment. No significant differences were found in either measure of SPL between the three groups with PD at pre-treatment. Of note, SPL values only reflect the first 34 syllables of the Rainbow passage and the middle 3 seconds from the third sustained phonation.

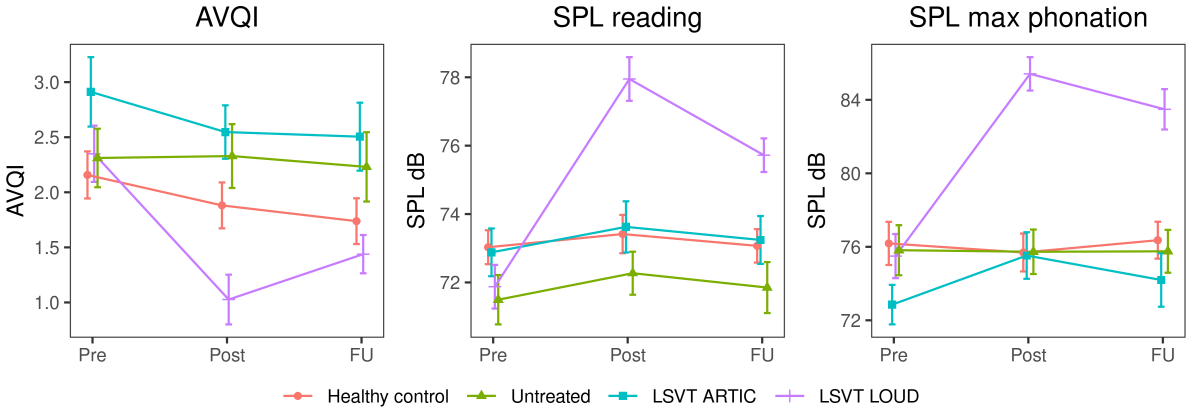

Figure 1. Pre-to-post treatment and follow-up results for the AVQI, reading SPL (in dB), and maximum phonation SPL (in dB) for the healthy controls, LSVT LOUD, LSVT ARTIC, and Untreated groups. LSVT, Lee Silverman voice treatment; PD, Parkinson's disease; SPL, sound pressure level.

Mixed-effects regression analysis for reading SPL showed a significant main effect for group ($F(3,84.01) = 5.528$, $p = 0.002$) and time ($F(2,164.43) = 40.455$, $p < 0.001$), together with a significant interaction between group × time ($F(6,164.43) = 19.168$, $p < 0.001$). Results were replicated for SPL during maximum phonation (significant main effects for group ($F(3,83.87) = 10.202$, $p < 0.001$) and time ($F(2,164.42) = 19.489$, $p < 0.001$) and a significant group × time interaction ($F(6,164.42) = 13.172$, $p < 0.001$). Post hoc Tukey adjusted comparisons yielded a

significant pre-to-post treatment increase in SPL with a large effect size for the LSVT LOUD group for both passage reading ($t(164) = -13.494$, $p < 0.001$, $d = -4.38$) and maximum phonation ($t(164) = -10.081$, $p < 0.001$, $d = -3.19$), with gains also maintained at follow-up in both conditions ($t(165) = -8.896$, $p < 0.001$, and $t(165) = -7.943$, $p < 0.001$, respectively). SPL significantly increased for the LSVT ARTIC group pre-to-post treatment for maximum phonation only, with a large effect size ($t(164) = -2.585$, $p = 0.029$, $d = 0.86$). No significant changes in SPL were found for the untreated group in either condition.

Figure 1 shows pre-to-post treatment and follow-up results for the AVQI, reading SPL, and maximum phonation SPL for all groups.

Post hoc Tukey adjusted comparisons after mixed-effects regression for AVQI, reading SPL, and SPL for maximum phonation can be found in Appendix B. Appendix C contains tables indicating percent change in all groups across data collection points and percent of individuals who improved in all variables in each group.

4.3. Relationship between AVQI and SPL

Pearson correlation coefficient analysis between treatment effects was conducted to explore the relationship between changes in AVQI scores and SPL across sessions. Significant correlations were found between AVQI and reading SPL between pre-treatment and post-treatment ($r = -0.42$, $p < 0.001$) as well as between pre-treatment and follow-up ($r = -0.26$, $p = 0.024$). Significant correlations were also found between AVQI and SPL during maximum phonation between pre-treatment and post-treatment ($r = -0.53$, $p < 0.001$) and between pre-treatment and follow-up ($r = -0.43$, $p < 0.001$).

5. Discussion

This RCT investigated the effects of two intensive speech treatments (active comparators), LSVT LOUD and LSVT ARTIC, on voice quality in individuals with PD. The two treatment approaches were identical in dosage and effort but differed in their treatment target (voice vs articulation, respectively). Additionally, an untreated group of individuals with PD served as an inactive comparator and healthy controls were included to examine differences in voice quality at pre-treatment.

Voice quality, as measured by an objective measure of dysphonia, the AVQI, significantly improved pre-to-post treatment in the LSVT LOUD only. The large effect size obtained and the large gain difference in treatment effects across data collection points underscores the clinical significance of this voice-focused treatment to reduce dysphonia in individuals with PD. Furthermore, the fact that the two speech treatments were matched on all variables with the exception of target, ie, voice vs articulation, demonstrated that the observed benefits in voice quality, as measured by the AVQI, were not solely due to the intensive nature of treatment. This result, therefore, expands previous evidence of positive effects of LSVT LOUD on voice quality in this population [41,43]. Most importantly, in the current study improvements in voice quality were maintained at the 6-month follow-up, suggesting long-term benefits of this treatment approach. Interestingly, immediately post-treatment and at follow-up, the AVQI scores for the LSVT LOUD group remained lower than those for healthy controls (1.03 vs 1.88 and 1.44 vs 1.74, respectively). This finding, however, is in agreement with former studies documenting the positive impact of this voice-focused treatment on the aging voice [59]. The LSVT ARTIC group

did not experience significant changes in their AVQI scores immediately post-treatment, nor did the untreated group. Of note, however, a significant improvement in voice quality was observed from pre-treatment to the six-month follow-up in the LSVT ARTIC group, with a large effect size. Upon inspection of individual performance, it was noted that 60% of people in the LSVT ARTIC group experienced improved voice quality immediately post-treatment (compared to 95.2% of individuals in the LSVT LOUD group), and 57.9% did so at follow-up. Nonetheless, and despite this observed improvement, the AVQI scores still remained above the cut-off point of 2.43, used to separate dysphonic from non-dysphonic voices, across all data collection points. It could be hypothesized that phonatory, but not articulatory, effects may drive more immediate changes in voice quality in individuals with PD. While there were no significant differences among the three PD groups pre-treatment, it is clear that the LSVT ARTIC had the highest AVQI values pre-treatment. This may be a spurious finding and provides the LSVT-ARTIC group more "room for change." It is important to point out that there were no differences post-treatment to follow-up in this group. Having said this, the authors also hypothesize that this seemingly surprising (pre-treatment to follow-up) result may underscore the longer-term impact of intensively treating articulation, although results should be viewed with caution. Recent developments in voice therapy have also demonstrated that "clear speech"—with an initial focus on sensory awareness of producing "crisp, clear consonants" and "precise articulation" without excessive tension—can be a primary component for successful voice therapy and yield continued improvement following treatment. These authors hypothesize that improvement following therapy could be a result of "ongoing skill acquisition," which would require some time for more complex motor tasks [60]. It is known that a cue to enunciate, which is elicited by LSVT ARTIC, also increases SPL [61], thus improving glottal source function. Improvement in the glottal source function as a result of increased SPL has been reported in various papers [30,34].

The lack of statistical significance at pre-treatment between speakers with PD and healthy controls could have been due to several factors: 1) the healthy controls were age matched to speakers with PD, and it is not uncommon for aged speakers to have reduced loudness and disordered voice quality [59], and 2) AVQI and SPL were both sampled from a smaller section of phonation in the current study than in previously reported studies of PD and healthy aged speakers, such as Ramig et al. [28]. Of importance is the contrast of the groups at post-treatment and follow-up.

Results on SPL replicate findings from previously published studies on the effects of voice-focused treatment on SPL [28]. Only the LSVT LOUD group significantly increased SPL from pre-treatment to post-treatment and follow-up across both tasks, passage reading and maximum phonation. Vocal intensity significantly increased for the LSVT ARTIC group pre-to-post treatment for maximum phonation only. This result was expected, however, considering the nature of the task, ie, maximum effort, and the treatment target in LSVT ARTIC, ie, increasing articulatory precision and maximizing enunciation. Of note, SPL has been extensively reported to be significantly lower in individuals with PD than in healthy controls pre-treatment [3,4,28]. The fact that SPL measures did not significantly differ between the combined PD group and healthy controls in this study reflects the nature of the current analysis, which was focused on the AVQI. SPL was measured on the first 34 syllables of the Rainbow passage and the middle 3 seconds from the third sustained phonation. Based on the limited sample for SPL analysis, therefore, these results are not surprising.

Correlations between the AVQI and SPL were significant and strong, which suggests that changes in SPL were associated with changes in voice quality. This was an expected finding as well, as voice quality partly relies on loudness [62,63]. The strongest correlation was 0.53 in this study, which was 28% of the shared variance, hence supporting the notion that the two variables were closely related to each other without measuring the same construct. This correlation is also particularly meaningful to establish a beneficial side effect of targeting healthy loudness using LSVT LOUD.

6. Limitations of this study

This study compared the effects of two intensive speech treatments on a secondary outcome measure from a previously published RCT [28]. One limitation of this study is that, given the nature of the two treatment approaches, clinicians and participants were not blinded to either condition. Nonetheless, strict measures were implemented to ensure equipoise during treatment training and implementation, as well as to minimize bias during data collection and analysis. In this study, no significant differences were found between speakers with PD and healthy controls for either AVQI or SPL at pre-treatment; however, these variables were sampled from a smaller section of phonation than in Ramig et al. [28]. Additionally, this RCT was powered on SPL as its primary outcome variable, with voice quality being a secondary variable of analysis. However, statistical analysis of within group performance showed a large effect size and a significant improvement of the AVQI scores immediately post-treatment and at the 6-month follow up for the voice-focused treatment only, suggesting shorter- and longer-term gains in voice quality in this population when targeting the glottal source directly.

7. Conclusions

Intensive voice-focused treatment improves voice quality, as measured by the AVQI, in individuals with PD. Additionally, these results add to the growing body of research supporting the validity and clinical responsiveness of the AVQI for a variety of clinical populations.

8. Acknowledgments

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9. Disclosure Information

Dr. Gemma Moya-Galé is employed by Long Island University, and has no relevant financial or nonfinancial relationships to disclose.

Jennifer Spielman has been a paid consultant for LSVT Global since 2012. She currently receives consulting fees for research and training projects. She has a preference for the LSVT LOUD treatment protocol in her clinical practice.

Dr. Lorraine Ann Ramig is employed as Chief Scientific Officer and has ownership interest in the for-profit company LSVT Global, Inc. She is in full compliance with Federal Statute 42 C.F.R. Part 50, Subpart F (see

https://grants-nih-gov.libdata.lib.ua.edu/grants/policy/coi/index.htm). She has disclosed any conflict of interest and her conflict of interest management plan has been approved by the Office of Conflict of Interest and Commitment at the University of Colorado, Boulder and she is in full compliance. Dr. Lorraine Ann Ramig reports funding from the National Institutes of Health and National Institute of Deafness and other Communicative Disorders (NIH-NIDCD) R01 DC 01150 during the conduct of the study.

Dr. Luca Campanelli is employed by the University of Alabama, and has no relevant financial or nonfinancial relationships to disclose.

Dr. Youri Maryn is employed by the Department of Otorhinolaryngology & Head and Neck Surgery, Sint-Augustinus Hospital (Wilrijk, Belgium); serves as professor at University College Ghent, University of Ghent and Université Catholique Louvain, for which he receives salaries. He is executive board member of Vlaamse Vereniging voor Logopedisten (Flemish Association of Speech-Language Therapists) for which he also receives a salary. He owns Phonanium (Lokeren, Belgium) and receives royalty payments from the sale of voice analysis products. He is post-doctoral researcher at University of Antwerp and received no compensation for this project.

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Appendix A

Table A.1. Descriptive statistics for the treatment effects across groups.

Variable	Difference	Group	Mean	SD	Min	Max
AVQI	Post-Pre	hc	-0.276	0.77	-1.53	1.5
AVQI	Post-Pre	lsvta	-0.365	0.884	-1.82	1.38
AVQI	Post-Pre	lsvtl	-1.323	0.713	-2.89	0.07
AVQI	Post-Pre	untx	0.018	0.928	-1.09	2.14
AVQI	FU-Pre	hc	-0.42	0.727	-1.74	0.61
AVQI	FU-Pre	lsvta	-0.396	0.627	-2.05	0.48
AVQI	FU-Pre	lsvtl	-0.999	0.701	-2.38	0.37
AVQI	FU-Pre	untx	-0.071	0.843	-1.17	1.42
AVQI	FU-Post	hc	-0.143	0.745	-1.44	1.46
AVQI	FU-Post	lsvta	-0.099	0.731	-1.31	2.09
AVQI	FU-Post	lsvtl	0.311	0.541	-0.6	1.63
AVQI	FU-Post	untx	-0.054	0.656	-1.48	1.3
SPL max ph	Post-Pre	hc	-0.495	4.968	-9.9	7.7
SPL max ph	Post-Pre	lsvta	2.674	3.878	-2.4	13.3
SPL max ph	Post-Pre	lsvtl	9.919	4.426	2.5	20.2
SPL max ph	Post-Pre	untx	-0.085	3.393	-8.6	7.3
SPL max ph	FU-Pre	hc	0.175	5.894	-9.8	11.7
SPL max ph	FU-Pre	lsvta	1.528	3.666	-4.6	7.5
SPL max ph	FU-Pre	lsvtl	7.945	5.385	-0.6	17.4
SPL max ph	FU-Pre	untx	-0.239	5.476	-11.2	8.7
SPL max ph	FU-Post	hc	0.67	4.1	-5.1	10.4
SPL max ph	FU-Post	lsvta	-1.172	4.213	-14.3	4.7
SPL max ph	FU-Post	lsvtl	-1.99	4.156	-9.5	6.5
SPL max ph	FU-Post	untx	-0.233	3.965	-11	7.8
SPL reading	Post-Pre	hc	0.385	1.571	-2.9	3.9
SPL reading	Post-Pre	lsvta	0.745	1.982	-3.1	3.8
SPL reading	Post-Pre	lsvtl	6.075	3.39	0.6	13.4
SPL reading	Post-Pre	untx	0.775	1.516	-1.7	4.5
SPL reading	FU-Pre	hc	0.04	1.862	-2.9	4.1
SPL reading	FU-Pre	lsvta	0.558	1.799	-2.6	4.6
SPL reading	FU-Pre	lsvtl	3.926	2.351	-0.2	8.3
SPL reading	FU-Pre	untx	0.678	1.927	-3.4	3.7
SPL reading	FU-Post	hc	-0.345	1.584	-2.9	2.9
SPL reading	FU-Post	lsvta	-0.268	1.2	-2.7	1.9
SPL reading	FU-Post	lsvtl	-1.763	2.001	-6.7	0.7
SPL reading	FU-Post	untx	-0.161	1.732	-3.6	3.2

Note: SPL max ph = SPL maximum phonation

Appendix B

Table B.1. Post-hoc Tukey adjusted comparisons after mixed-effects regression for AVQI.

Group	Contrast	Estimate	SE	*df*	*t*	*p*-value	Effect size[a]
hc	Pre-Post	0.2765	0.167	164	1.658	0.2247	0.5382
hc	Pre-FU	0.4195	0.167	164	2.515	0.0342	0.8165
hc	Post-FU	0.143	0.167	164	0.857	0.6679	0.2783
lsvta	Pre-Post	0.3647	0.171	164	2.131	0.0867	0.7099
lsvta	Pre-FU	0.4271	0.175	165	2.447	0.0407	0.8313
lsvta	Post-FU	0.0624	0.175	165	0.357	0.9321	0.1214
lsvtl	Pre-Post	1.3229	0.163	164	8.127	<.0001	2.5748
lsvtl	Pre-FU	0.9936	0.166	165	5.997	<.0001	1.9338
lsvtl	Post-FU	-0.3293	0.166	165	-1.987	0.1185	-0.6409
untx	Pre-Post	-0.0175	0.167	164	-0.105	0.994	-0.0341
untx	Pre-FU	0.0571	0.173	165	0.329	0.942	0.1111
untx	Post-FU	0.0746	0.173	165	0.43	0.903	0.1452

Note. [a]Cohen's *d*.

Table B.2. Post-hoc Tukey adjusted comparisons after mixed-effects regression for SPL reading.

Group	Contrast	Estimate	SE	*df*	*t*	*p*-value	Effect size[a]
hc	Pre-Post	-0.385	0.45	164	-0.855	0.6693	-0.2776
hc	Pre-FU	-0.04	0.45	164	-0.089	0.9957	-0.0288
hc	Post-FU	0.345	0.45	164	0.766	0.7242	0.2488
lsvta	Pre-Post	-0.745	0.45	164	-1.655	0.2259	-0.5372
lsvta	Pre-FU	-0.495	0.459	165	-1.079	0.5281	-0.357
lsvta	Post-FU	0.25	0.459	165	0.545	0.8492	0.1802
lsvtl	Pre-Post	-6.075	0.45	164	-13.494	<.0001	-4.3809
lsvtl	Pre-FU	-4.08	0.459	165	-8.896	<.0001	-2.9422
lsvtl	Post-FU	1.995	0.459	165	4.35	0.0001	1.4386
untx	Pre-Post	-0.775	0.45	164	-1.721	0.2003	-0.5589
untx	Pre-FU	-0.604	0.468	166	-1.292	0.4018	-0.4357
untx	Post-FU	0.171	0.468	166	0.365	0.9292	0.1231

Note. [a]Cohen's *d*.

Table B.3. Post-hoc Tukey adjusted comparisons after mixed-effects regression for SPL maximum phonation.

Group	Contrast	Estimate	SE	*df*	*t*	*p*-value	Effect size[a]
hc	Pre-Post	0.495	1.008	164	0.491	0.8757	0.1594
hc	Pre-FU	-0.175	1.008	164	-0.174	0.9835	-0.0564
hc	Post-FU	-0.67	1.008	164	-0.665	0.7844	-0.2157
lsvta	Pre-Post	-2.674	1.034	164	-2.585	0.0285	-0.8609
lsvta	Pre-FU	-1.474	1.054	165	-1.398	0.3442	-0.4746
lsvta	Post-FU	1.2	1.054	165	1.138	0.4921	0.3863
lsvtl	Pre-Post	-9.919	0.984	164	-10.081	<.0001	-3.194
lsvtl	Pre-FU	-7.949	1.001	165	-7.943	<.0001	-2.5598
lsvtl	Post-FU	1.97	1.001	165	1.968	0.1234	0.6342
untx	Pre-Post	0.085	1.008	164	0.084	0.9961	0.0274
untx	Pre-FU	0.227	1.046	166	0.217	0.9744	0.0731
untx	Post-FU	0.142	1.046	166	0.136	0.9899	0.0457

Note. [a]Cohen's *d*.

Appendix C

Table C.1. Treatment effects in percentage change for healthy controls (hc), LSVT LOUD, LSVT ARTIC, and Untreated PD groups.

Difference	Group	AVQI	SPLah	SPLra
Post-Pre	hc	-16.2	-1.2	0.6
Post-Pre	lsvta	-14.8	2.7	1.2
Post-Pre	lsvtl	-54.4	12.9	8.9
Post-Pre	untx	2	0	0.8
FU-Pre	hc	-18.6	1.3	-0.4
FU-Pre	lsvta	-13.1	3.7	0.4
FU-Pre	lsvtl	-36.6	11.2	5.5
FU-Pre	untx	-7.6	-1.8	1.6
FU-Post	hc	-7.8	0.7	-0.3
FU-Post	lsvta	-4.8	0.1	0
FU-Post	lsvtl	18.2	-2.7	-1.9
FU-Post	untx	-4.3	0.6	0.1

Note: SPLah = maximum phonation SPL; SPLra = reading SPL.

Table C.2. Percentage of participants who improved across data collection points for healthy controls (hc), LSVT LOUD, LSVT ARTIC, and Untreated PD groups.

Difference	Group	AVQI	SPLah	SPLra
Post-Pre	hc	70	65	45
Post-Pre	lsvta	60	60	70
Post-Pre	lsvtl	95.2	100	100
Post-Pre	untx	45	70	50
FU-Pre	hc	65	35	55
FU-Pre	lsvta	57.9	63.2	63.2
FU-Pre	lsvtl	95	95	95
FU-Pre	untx	55.6	66.7	38.9
FU-Post	hc	70	45	55
FU-Post	lsvta	63.2	42.1	47.4
FU-Post	lsvtl	20	15	35
FU-Post	untx	55.6	50	55.6

Note: SPLah = maximum phonation SPL; SPLra = reading SPL.