Clinical Focus

Effects of Intensive Voice Treatment (the Lee Silverman Voice Treatment [LSVT]) on Ataxic Dysarthria: A Case Study

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This study examined the effects of intensive voice treatment (the Lee Silverman Voice Treatment [LSVT®]) on ataxic dysarthria in a woman with cerebellar dysfunction secondary to thiamine deficiency. Perceptual and acoustic measures were made on speech samples recorded just before the LSVT program was administered, immediately after it was administered, and at 9 months follow-up. Results indicate short- and long-term improvement in phonatory and articulatory functions, speech intelligibility, and overall communication and job-related activity following LSVT. This study's findings provide initial support for the application of LSVT to the treatment of speech disorders accompanying ataxic dysarthria. Potential neural mechanisms that may underlie the effects of loud phonation and LSVT are addressed.

Key Words: ataxia, dysarthria, voice treatment, voice disorders, neurologic disorders

Ataxic dysarthria is a motor speech disorder associated with cerebellar dysfunction. The dysarthria appears to be related to a disturbance in the neural mechanisms that underlie the coordination, temporal regulation, and quasi-automatic control of respiratory, phonatory, and articulatory movements for speech. The symptoms of ataxic dysarthria vary, and may include any, or a combination, of the following abnormalities: imprecise articulation, momentary irregular articulatory breakdowns, slow rate of speech, excess and equal stress, monoloudness, monopitch, prolonged syllables, irregular intrasyllabic voice fundamental frequency (F0) inflections, and breathy, weak, or unstable voice. Physiologic studies of ataxic dysarthria have documented slow movements, temporal dysregulation, errors of direction and range of movements, impaired ability to increase muscular forces in order to produce rapid movements, and reduced or exaggerated range of movements involving the respiratory, phonatory, or articulatory systems. These abnormalities may be accompanied by other signs of cerebellar dysfunction, such as hypotonia, broad-based stance and gait, truncal instability, dysmetria, tremor, and dysdiadochokinesis (Duffy, 1995; Kent et al., 2000).

Past studies of the treatment of ataxic dysarthria have reported only modest or limited improvement in speech intelligibility or naturalness when treatment was geared

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toward teaching the patient to change and monitor specific parameters such as articulatory precision, rate, stress patterning, or pitch inflection (Duffy, 1995; Yorkston, Hammen, Beukelman, & Traynor, 1990). This lack of improvement may be related to the important role the cerebellum plays in motor learning and control. Based on recent studies (e.g., Blakemore, Frith, & Wolpert, 2001; Topka, Massaquoi, Benda, & Hallett, 1998), it appears that (a) the acquisition of a motor skill involves learning an internal model of the dynamics of the task; (b) such learning is achieved in part by the cerebellum, which makes use of predicted and actual sensory consequences of movements to detect and correct errors and to automatize and store the neural patterns of the newly mastered movements; (c) the cerebellum also plays a major role in the coordination and stability of movements; and (d) these functions are performed in concert with other neural structures, such as the striatum, limbic system, and prefrontal cortex, although each structure plays a different role in these functions.

The cerebellum, alone or in combination with the other neural structures mentioned above, appears to play a similar role in motor speech control and learning, including learning associated with treatment (Bloom & Ferrand, 1997). One might argue that lesions to any of these neural structures may prevent or impede motor learning, thus rendering behavioral treatment ineffective. However, Topka et al. (1998) and Schultz, Dingwall, and Ludlow (1999) provided evidence to suggest that limb, speech, and oral motor learning in individuals with ataxic dysarthria may not be impaired, although such learning seems to depend on the nature of the task. For example, Topka et al. found that patients with cerebellar degeneration were able to exhibit almost normal performance in limb motor skill learning, but this was true only for slow, nonballistic movements. They interpreted these findings to suggest that individuals with cerebellar dysfunction may have difficulty in the refinement of motor execution, which is more of a requirement for fast movements than for slow movements. Topka et al.'s findings, and the fact that speech movements are typically very fast, may partially explain why individuals with ataxic dysarthria find it difficult to modify (improve) articulatory movements during speech.

Another reason why motor learning might be problematic for individuals with ataxic dysarthria is that premorbid movement patterns are difficult to de-automatize, and new movement patterns, such as those practiced in therapy, are difficult to habituate and automatize. This difficulty probably relates to the need to constantly monitor and control the execution of intended movements. During speech, this task becomes even more taxing due to the added cognitive and linguistic demands associated with the formulation of ideas and sentences.

The foregoing discussion indicates a need to explore new clinical methods that may help individuals with ataxic dysarthria overcome their speech problems. A method that might be especially useful is one that does not require conscious effort to de-automatize premorbid speech patterns. Also, to be effective, treatment should be of relatively short duration and should not impose high cognitive demands on the part of the treated individual. One such method might be the Lee Silverman Voice Treatment (LSVT®) program (Ramig et al., 1988). This program has been proven effective in the treatment of dysarthria in individuals with Parkinson's disease (PD; Ramig, Sapir, Countryman, et al., 2001; Ramig, Sapir, Fox, & Countryman, 2001) and has resulted in positive, long-term effects on vocal function in individuals with multiple sclerosis (MS; Sapir et al., 2001). In this 4-week program, individuals are taught to "think loud" and are trained daily and intensively to produce high-effort loud phonation while constantly monitoring their vocal loudness and effort. These tasks are practiced during sustained vowel phonation, while reading simple texts aloud, and during conversation. These tasks are cognitively simple, as the patients are not asked to modify specific speech patterns, but rather to simply amplify their speech output.

Studies of normal speakers and individuals with other types of dysarthria have also provided evidence of the positive effects of loud phonation on speech production (see Dromey & Ramig, 1998). These findings have been collectively interpreted to suggest that loud phonation may serve as a global variable, affecting multiple systems and upscaling the output of these systems (Dromey & Ramig, 1998).

Loud phonation has also been shown to improve phonatory and articulatory stability in individuals with normal speech (e.g., Dromey & Ramig, 1998) and in individuals with PD (e.g., Kleinow, Smith, & Ramig, 2001). Acoustically, the impact of loud phonation on voice and speech may be reflected in an overall increase in sound pressure level (SPL), and in the range and accuracy of SPL, F0, and vowel formant modulations. Perceptually, speech should sound clearer and louder, with more precise articulation of phonemes, more natural intonation, and greater intelligibility and acceptability.

The LSVT has been shown to produce long-term improvement in individuals with PD and MS (Ramig, Sapir, Countryman, et al., 2001; Ramig, Sapir, Fox, & Countryman, 2001; Sapir et al., 2001), suggesting that these individuals were able to internalize what they learned and perhaps automatize the new mode of speech. We do not know to what extent the effects of the LSVT are specific to hypokinetic dysarthria and to what extent they are applicable to other types of dysarthria. The purpose of the present study was to obtain preliminary information on the potential effects of the LSVT program on ataxic dysarthria secondary to cerebellar dysfunction. To this end we chose to study changes in acoustic and perceptual measures of speech, as well as functional outcomes of employment satisfaction and overall communicative ability, in an individual with ataxic dysarthria treated with the LSVT.

Method

Participant

The participant was a 48-year-old woman with a 16-year history of cerebellar dysfunction secondary to iatrogenically induced (gastric repartitioning surgery) thiamine deficiency encephalopathy. She had been stable on medication

(L-5-hydroxytryptophan) since her encephalopathy and throughout this study period. At the time of this study her language, cognitive, and hearing functions were normal by self-report, and there were no observable deficits during interaction with the patient. She had not received speech therapy before beginning the LSVT program.

Just before the LSVT program, an otolaryngologist and a speech-language pathologist examined the patient. Speech showed irregular articulatory breakdowns and a slow rate. Oral motor examination revealed difficulty with lip movement and coordination, as reflected in the patient's difficulty in repetitively moving her lips rapidly and consistently from a pucker to a smile-like gesture. The tongue showed mildly reduced range of motion. Alternating motion rates (AMR) and sequential motion rates (SMR) tasks with the syllables /pa/, /ta/, and /ka/ were performed with slowed rate, weak closure, and some breakdown in rhythmicity. The patient complained that she tended to slur her speech and that her voice tended to "overmodulate" and "undermodulate," with the voice sometimes being "heavy" and other times "breathy." The speech-language pathologist who examined her noted an overall weak voice, frequently with intermittent increases or decreases in breathiness or hoarseness, and occasionally with intermittent increases in loudness, giving rise to the perception of an unstable voice that is often observed in individuals with dysphonia secondary to cerebellar dysfunction. The speech-language pathologist also characterized the voice as low in pitch, with reduced and inappropriate prosodic pitch inflection. These speech and voice abnormalities were judged mild to moderate, leaning more towards a moderate impairment. The patient reported that these abnormalities had a negative impact on her ability to communicate effectively.

Given that the patient's abnormal voice and speech patterns were somewhat atypical of the ataxic dysarthria described by Darley, Aronson, and Brown (1975), but were still consistent with the heterogeneity of the symptoms of ataxic dysarthria (Kent & Kent, 2000; Kent et al., 2000), we had another speech-language pathologist (an expert with nearly 20 years of experience in motor speech disorders) independently and blindly diagnose the patient's speech abnormality. The expert diagnosed it as ataxic dysarthria.

At the time of the study, the participant was working as a volunteer 4 hr per day, 4 days per week, conducting interviews, answering telephone calls, and organizing volunteer programs at an outpatient rehabilitation center. Before her enrollment in the LSVT program she had indicated that her speech and voice deficits had affected her ability to communicate and work effectively. She had frequently been asked to repeat herself before her message could be understood. Her employer had indicated that she had been difficult to understand, because of her "slurred speech."

Treatment

The LSVT was administered to the participant in 16 individual sessions during a 4-week period. Treatment techniques were focused on training the global variable "loud" to achieve optimal coordinative effects throughout the speech mechanism. The techniques used were designed to maximize phonatory efficiency and loudness, improve vocal fold adduction and respiratory support, increase self-monitoring of vocal effort and loudness, and promote carryover of increased loudness into daily speech communication. Details of the LSVT program are provided elsewhere (Ramig, Pawlas, & Countryman, 1995) and are summarized below.

Treatment sessions consisted of successive repetitions of activities such as maximum duration sustained vowel "ah" phonation, generation of highest and lowest F0 levels while sustaining vowel phonation, and speech production tasks using high-effort healthy loud phonation. The participant was encouraged to maintain use of her loud voice throughout the session, yet at no point was use of a strained or pressed voice advocated. Improved vocal loudness with healthy quality was the training target. Furthermore, no attention was directed to altering or in any way changing the participant's speaking rate or articulation during treatment.

Data Collection

Acoustic Measures. Baseline data were collected on 3 consecutive days before treatment (Pre 1, Pre 2, Pre 3). Posttreatment data were collected on 2 consecutive days after treatment (Post 1, Post 2). Follow-up data were collected in one recording session (FU) at 9 months after treatment. Across all recording sessions, data were collected by the same experimenter (one who did not administer LSVT to the participant) at approximately the same time of day (between 12:00 noon and 12:30 p.m.).

The acoustic data were collected while the participant was seated in a sound-treated booth. A head-mounted microphone (AKG C410) was fitted to her head, with a mouth-to-microphone distance of 6 cm, which remained constant throughout each session. A Brüel & Kjær 2236 sound-level meter (SLM) was placed 30 cm from the participant's lips and maintained at that distance throughout the recording session. The microphone and SLM signals were recorded onto a digital audio tape (DAT) 8-channel recorder (Sony PC-208AUC). In addition, during all speaking and voice tasks, the experimenter hand-recorded the peak vocal SPL measures that were continuously displayed at 1-s intervals from the digital output of the SLM. Calibration signals (tone generator and sustained phonations) were recorded onto the DAT tapes for the participant before the speech and voice tasks were recorded and after any adjustments of input levels on the DAT recorder. Standard procedures for recording calibration signals were followed (Ramig, Countryman, Thompson, & Horii, 1995).

Acoustical data were collected while the participant performed the following tasks: maximum duration sustained vowel "ah" phonation, reading the Rainbow Passage (Fairbanks, 1960), describing the "cookie theft" picture (Goodglass & Kaplan, 1972), producing a 30-s monologue, and reading six phrases for articulatory acoustic analysis (Weismer, 1984).

Sound Pressure Level (SPL). SPL, the acoustic correlate of vocal loudness (Holmberg, Hillman, & Perkell, 1988), was measured during (a) sustained vowel phonation, (b) reading aloud the Rainbow Passage, (c) describing a picture, (d) a monologue, and (e) producing standard sentences. These SPL measures were obtained by transcribing the peak decibel level displayed at 1-s intervals from the digital display of the SLM. Such measures have been shown to be highly reliable and comparable to those obtained with a software program (Fox & Ramig, 1997; Ramig et al., 1995). Pauses in speech were not included in this analysis.

Voice Fundamental Frequency. Given that the patient's speech was characterized by low pitch and reduced and inappropriate pitch inflection, it was important to measure the acoustic correlate of pitch—the F0— in terms of its average (reflecting overall pitch level) and standard deviation (reflecting the magnitude of pitch inflection; the higher the standard deviation, the greater the pitch inflection). In addition, F0 was measured to determine whether changes in phonatory and respiratory effort and vocal loudness generalized to other aspects of the participant's speech. Changes in F0 often accompany changes in vocal loudness (Linville & Korabic, 1987). Mean F0 and F0 standard deviation in semitones (STSD) for the Rainbow Passage, the picture description, the monologue, and the standard sentences were obtained using GASP interactive signal processing software (Terry, Sparks, & Obenchain, 1994). GASP operates using a combination of cepstral and time-domain peak-picking techniques that attempt multiple-stage smoothing and tracking operations. Interactive features allow the user to visualize the tracked signal, remove any noise or mistracked portions and hand-track any portions of the signal missed by the automated tracking system. Voiced consonants were included as well as vowels to provide a realistic pitch contour of connected speech. When tracking the standard sentences for mean F0, original uncut versions of each sentence were used rather than the versions used for formant analysis (from which all consonants had been removed).

Thirty percent of all connected speech samples were selected at random and reanalyzed by the same experimenter for mean F0 and STSD. The standard error of measurement (*SEM*) for mean F0 was 2.05 Hz, with a Pearson product–moment correlation coefficient of $r = 1.0$. For STSD, *SEM* = 0.12 semitones and Pearson product–moment correlation coefficient $r = .99$. An additional 30% of randomly selected samples were analyzed by a second investigator for inter-rater reliability. Mean F0 measures yielded *SEM* = 4.17 Hz ($r = 1.0$), and STSD yielded *SEM* = 0.27 semitones ($r = .97$).

Formant Frequency Dynamics. Given that the patient's speech sounded intermittently "slurred" and imprecise, as though it were produced with reduced articulatory movements, we anticipated that these articulatory abnormalities would be reflected in more centralized vowels and, acoustically, by less separation between the first and second formants (F1 and F2) representing these vowels (see discussion by Turner, Tjaden, & Weismer, 1995; Weismer, Martin, Kent, & Kent, 1992; Ziegler & von Cramon, 1983). Thus, to examine the effects of LSVT on articulatory movements, we elected to analyze the center frequency of the first two vowel formants (F1 and F2) in continuous speech, because these formants reflect both articulatory positions and dynamics and because they provide a valid and reliable index of articulatory impairment and improvement (e.g., Weismer et al., 1992). Formant analysis was completed for all vowels on multiple productions of three of the six phrases (*The potato stew is in the pot*, *The blue spot is on the key*, and *When sunlight strikes raindrops in the air*). These three phrases were selected because they incorporate a variety of vowels that would allow assessment of vowel formant dynamics. Because the patient's speech was characterized primarily by what appeared to be reduced articulatory movements and centralized vowels, we anticipated that improvement with the LSVT would be reflected in both a general increase in formant triangle area (see below) and vowel formant dynamics (Weismer et al., 1992), the latter expressed in terms of increased standard deviation of the formant frequencies (SDF1 and SDF2) from their respective means.

Each of these three sentences was elicited several times as follows: nine times before treatment (three times at each of the Pre 1, Pre 2, and Pre 3 recording sessions), six times immediately after treatment (three times at each of the Post 1 and Post 2 recording sessions), and three times at FU (on the day of the FU recording session). Thus, for the three sentences combined, there were 27 pretreatment tokens, 18 posttreatment tokens, and 9 FU tokens. Only a single pretreatment token of the "raindrops" sentence was found unanalyzable for formant frequency information. This token was excluded from analysis.

Consonants were identified through spectrographic display using MATLAB 5.3 (The Mathworks, Inc., 1999) software. The voiceless and aspirated portions of the consonants were removed from each sentence by means of a mouse-activated cursor. The first two formants were then tracked using a linear predictive coding (LPC) technique (autocorrelation method) with a window length of 50 ms and an overlap of 12.5 ms to generate a pseudoformant spectrum at 12.5-ms intervals. The frequency locations of the first two formants were determined by peak-picking and parabolic interpolation (Titze, Horii, & Scherer, 1987). Numerical data (frequency in Hz) representing (F1, F2) pairs were transferred to an Excel spreadsheet for further processing and statistical analysis. Erroneous data points that could not be deleted through MATLAB procedures were also removed at this point.

For intrarater reliability of dynamic formant measurements, 100% of the phrases were reanalyzed. A complete reanalysis of the phrases for formant information was undertaken because of the amount of human judgment required during several different stages of the analysis process. Intrarater *SEM* was 23.07 Hz ($r = .88$) for mean F1, and *SEM* = 16.08 Hz ($r = .89$) for SDF1; *SEM* = 38.38 Hz ($r = .95$) for mean F2, and *SEM* = 38.17 ($r = .93$) for SDF2. Thirty percent of the phrases were also reanalyzed for interrater reliability (two experimenters both extracting and measuring formant data). Interrater *SEM* was 41.11 Hz ($r = .81$) for mean F1, and *SEM* = 22.45 Hz ($r = .88$) for SDF1; *SEM* = 52.75 Hz ($r = .90$) for mean F2, and *SEM* = 66.08 ($r = .82$) for SDF2.

Vowel Formant Space. A more detailed analysis of mean F1 and F2 frequencies was also completed to assess whether increases and decreases in the formants were related to individual vowels and reflected an overall increase in formant triangle area (also called "vowel space"), indicating improved articulatory function (Ziegler & von Cramon, 1983). For this analysis, the vowels /i/, /u/, and /a/ were chosen to represent the most extreme values of a vowel triangle and extracted from multiple productions of three of the six recorded phrases; /i/ was selected from the word *key* in the phrase *The blue spot is on the key*, /u/ from the word *stew* in the phrase *The potato stew is in the pot*, and /a/ from the word *Bobby* in the phrase *Buy Bobby a puppy*.

The target vowel was isolated through visual/auditory inspection of the waveform in MATLAB and a spectrogram was produced. An (F1, F2) track for that vowel was then created as described above and the computer was programmed to calculate either the minimum (for /u/ and /a/) or the maximum (for /i/) distance between the F1 and F2 frequencies, depending on the expected relationships between the formants for each vowel. For example, a clearly articulated /u/ vowel would ideally show a relatively small distance between F1 and F2, whereas a large distance would be expected between F1 and F2 in the vowel /i/ (Peterson & Barney, 1952). This minimum or maximum (F1, F2) pair was then taken as the set of points representing the best production for that particular vowel token and entered into a spreadsheet, where it was eventually averaged with the other (F1, F2) pairs extracted from additional tokens of that vowel. Each vowel was represented by nine pretreatment (F1, F2) pairs, six posttreatment pairs, and three FU treatment pairs. Averages were then plotted onto an F1–F2 graph and represented as a vowel triangle.

Perceptual Measures

Perceptual Ratings of Articulatory Precision and Pitch Intonation. Increased inflections in F0 and formant frequencies, expressed here in terms of increased STSD, SDF1, and SDF2, may be interpreted either to reflect improved phonatory and articulatory dynamics (Ziegler & von Cramon, 1983) or to reflect worsening of phonatory and articulatory stability (Zwirner & Barnes, 1992). Perceptual ratings of articulatory precision and pitch intonation can therefore help disambiguate the changes in STSD, SDF1, and SDF2. To evaluate the impact of LSVT on perceptual aspects of speech production, 26 speech-language pathology graduate students listened to the speech samples (see above) and rated the samples with respect to intonation or articulatory precision. Raters were members of a first-year graduate class in research methods and were sufficiently proficient in English to attend a department of speech and hearing sciences at an American university. Hearing acuity was not tested; however, all students confirmed that they were able to clearly hear and understand the recordings used in the study.

The Rainbow Passage was used to rate intonation. The phrases *The blue spot is on the key*, *The potato stew is in the pot*, and *When sunlight strikes raindrops in the air* were used to rate articulatory precision. These speech samples were presented via speakers in a quiet classroom. Because the intensity of a sample can influence judgments of intonation and articulatory precision, all samples were presented to each listener at the same normalized SPL level (approximately 70 dB). The samples were presented in six types of pairs (pretreatment–posttreatment, pretreatment–FU, posttreatment–FU, posttreatment–pretreatment, FU–pretreatment, FU–posttreatment), and these pairs were presented in random order. The listener's task was to indicate whether the first or the second sample in the pair sounded "better," or whether the two samples sounded the "same" on the parameter being judged (intonation or articulatory precision). The listener was not informed of the time (pretreatment, posttreatment, or FU) when each of the samples in a pair was recorded.

For rating intonation the listener was provided with these instructions:

> You will be hearing pairs of audio segments. You will be deciding which segment, the first or the second, has better or more normal intonation. On your paper you will print the letter A for the first segment, the letter B for the second segment, or the word "same" if you don't think that there is any difference in the quality or normalcy of intonation between the two samples. Intonation is not intensity or pitch of the speaker's voice, but rather the variability of a person's pitch and the appropriateness of the variability in pitch.

For rating articulatory precision, the listener was provided with these instructions:

> You will be deciding which of the two segments, A or B, has better articulatory precision. On your paper, you will write the letter A or B for the better segment, or the word "same" if you feel there is no difference in articulatory precision between the two samples.

> In both cases the listeners were instructed:

> Remember, you are only comparing two segments. Do not compare one segment to any previous or future audio segments you will hear. Approach each pair of sentences with a "fresh" ear.

All listeners received training before the actual study to familiarize themselves with the procedures for rating the samples. The instructions were explained thoroughly and terminology was defined and explained to each of the listeners. The perceptual study itself took approximately 30 min for each of the two variables. Intrajudge reliability was determined by repeating three pairs at random within each rating (intonation or articulatory precision) and measuring the agreement for each rater. Analysis of the listeners' ratings indicated 96% intrajudge and 98% interjudge agreement for the intonation rating, and 71% intrajudge and 80% interjudge agreement for the articulatory precision rating. A .71 intrajudge reliability is considered "fairly accurate" (Kerlinger, 1973, p. 452). Percent agreement was calculated as the number of paired comparisons in which the majority of raters agreed with each other, divided by the number of all paired comparisons possible.

Speech Intelligibility. We elected to use three indices of speech intelligibility—one involving a measure of percent intelligible words (PIW) in noise, one involving a measure of ease of intelligibility (EI) by means of a rating scale (1 = *easy* to 5 = *difficult*), and one involving a ratio of these two indices (PIW/EI). The greater the ratio, the better the intelligibility. The details of these indices and how they were obtained are provided below.

Three additional female raters were recruited to evaluate the participant's speech intelligibility before and after treatment. Listeners were upper level undergraduate speech-language pathology majors with normal hearing (by self-report).

A total of 18 sentences were extracted from multiple pretreatment, posttreatment, and FU productions of the Rainbow Passage, the picture description, and spontaneous conversation. For the monologue and picture description, the first sentence of each production was chosen because all were significantly different in content and very general in nature. The Rainbow Passage was divided into 10 grammatically complete sentences/phrases and 6 of these were picked at random. Sentences were divided into two groups: nine sentences reflecting three pretreatment data collection sessions and nine sentences representing the two posttreatment and one FU sessions. Sentences were computer-digitized and SPL normalized, then mixed with noise (babble) at a 5 dB signal-to-noise ratio. Sentences ranged in length from 5 to 16 words, with a mean length of 11 (*SD* = 3.6) words for pretreatment sentences and 10.6 (*SD* = 2.2) words for the posttreatment/FU treatment sentences. There were a total of 99 words for the pretreatment condition and 95 words for the posttreatment/FU condition.

The sentences were played in random order over headphones at a comfortable loudness to the 3 listeners, who were asked to write down exactly what they heard. They were also asked to rate each sentence for EI on a scale of 1 to 5 (1 = *easy to understand* and 5 = *difficult to understand*). Listeners were aware that the participant had ataxic dysarthria but did not know she had received any kind of treatment. The study took approximately 10 min per listener. Interjudge agreement on the 5-point scale ratings was assessed by calculating intraclass correlation using absolute agreement. The average measure correlation among the three raters yielded a reliability coefficient of alpha = .77.

The rates of speech for the sentences before and after (post and FU) treatment were also calculated. This was done by dividing the number of words in a sentence into the duration of the entire sentence.

Social Measures

In order to assess the impact of the LSVT on communication and in the workplace, the patient's supervisor was administered the Minnesota Satisfactoriness Scales (MSS) before and after the administration of the LSVT (Gibson, Weiss, Dawis, & Lofquist, 1970). This was done with the consent of both the patient and supervisor. The MSS is a 28-item questionnaire completed by an employer, designed to evaluate the employee in the following five domains: performance, conformance, dependability, personal adjustment, and general satisfactoriness. The general satisfactoriness score is considered an overall index of job performance. Raw scores were calculated for the five categories of the MSS and then converted into percentile ranks based on the type of work. Scores ranked above the 75th percentile are considered highly satisfactory, whereas those ranked below the 25th percentile are considered unsatisfactory. All scores in between are considered average. Confidence bands equal to 1 *SD* from the mean are also reported for each scale. In addition to the MSS, the patient was interviewed before and after LSVT to get her impression of her speech status and its effect on her ability to communicate, work, and socialize. The work-related questionnaires for the employer and employee were administered by an independent observer/interviewer who was not the speech-language pathologist providing treatment and was not involved in other aspects of this study.

Measurements of Significant Changes Associated With LSVT

Given the limitations of a single-case study with relatively small samples, inferential statistics were often considered inappropriate, and for these cases a comparison of means was made across tasks and treatment conditions (Dromey, Ramig, & Johnson 1995). A difference in mean beyond 1 *SD* was considered significant when comparing the three pretreatment means to the two posttreatment means and the FU mean for each task. This method has been used in the past to measure differences within a limited sample (Kratochwill & Levin, 1992) and may indicate large size effects (Cohen, 1988). For the perceptual judgments by the 26 graduate students, we used chi-square statistics to assess significant trends in judgment, as described below.

Results

Acoustic Analyses

Table 1 shows the means and standard deviations (in parentheses) for SPL (dB at 30 cm) and F0 (Hz) measures for sustained phonation (SPL only), the Rainbow Passage, picture description, and the monologue. As can be seen, the SPL and F0 measurements for the repeated recordings (Pre 1, Pre 2, and Pre 3; or Post 1 and Post 2) are consistent, showing marked increases from pretreatment to posttreatment and from pretreatment to FU for all tasks.

Tables 2 and 3 show the means and standard deviations (in parentheses) of the acoustic measures for each of the three utterances (*The blue spot is on the key*, *When sunlight strikes raindrops in the air*, and *The potato stew is in the pot*). The pretreatment data are pooled (i.e., Pre 1, Pre 2, and Pre 3 combined), as are the posttreatment data (i.e., Post 1 and Post 2 combined). As can be seen, all acoustic measures (mean SPL, mean F0, STSD, mean F1, mean F2, SDF1, and SDF2) show an increase beyond 1 *SD* from pretreatment to posttreatment and from pretreatment to FU for each of the three utterances. The only exception is the

TABLE 1. Means and standard deviations for sound pressure level (dB SPL at 30 cm), and fundamental frequency (Hz) for sustained phonation (SPL only), the Rainbow Passage, picture description, and monologue.

	Pre 1		Pre 2		Pre 3		Post 1		Post 2		FU	
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sustained phonation /a/												
Sound pressure level	66.78	3.09	69.99	2.27	68.84	1.42	89.66	1.21	92.87	1.47	88.95	1.76
Rainbow Passage												
Sound pressure level	71.08	2.77	73.17	2.25	72.37	2.66	82.73	2.07	83.54	4.96	80.64	2.12
Fundamental frequency	167.53	14.65	176.52	17.68	172.49	15.42	243.26	40.30	266.95	48.84	231.67	39.00
Picture description												
Sound pressure level	72.56	2.19	73.73	2.62	76.25	2.76	82.09	2.54	81.23	2.16	79.77	3.48
Fundamental frequency	172.42	14.07	188.25	25.66	196.39	35.53	267.12	55.32	233.10	63.56	231.12	41.85
Monologue												
Sound pressure level	71.75	5.14	72.07	2.21	73.75	3.02	79.85	2.14	81.46	2.93	78.05	1.86
Fundamental frequency	174.04	16.99	175.24	14.52	192.49	31.69	241.46	54.32	252.47	52.18	222.75	29.60

Note. Pre = pretreatment; Post = posttreatment; FU = follow-up.

variable SDF1 in the phrase *The potato stew is in the pot*, which decreased from pretreatment to posttreatment and from pretreatment to FU.

The significance of changes to both F1 and F2 can be seen in Figure 1 by comparing Panel A, an F1–F2 formant plot for a single token of the sentence *The blue spot is on the key*, before treatment, to Panel B, a plot of the same sentence following treatment. Comparison of the two formant trajectory plots illustrates frequency (Hz) increases in both formants, as well as a shift in the concentration of data points away from the center of the plot and towards the periphery. A spectrographic display with vowel formants tracked over time for *The potato stew is in the pot*, is shown in Figure 2, displaying a similar increase in formant excursion.

Figure 3 shows three vowel triangle areas, one before LSVT (solid lines), one immediately after LSVT (broken lines), and one at FU (dotted line). These triangles were created by plotting the mean frequencies of F1 against the mean frequencies of F2, calculated as described above for each of the vowels /i/, /u/, and /a/. As can be seen, the

TABLE 2. Means and standard deviations comparing treatment conditions for sound pressure level (SPL), fundamental frequency (F0), and F0 variability (standard deviation in semitones [STSD]) for individual utterances

	Treatment Condition					
	Pre		Post		FU	
	M	*SD*	*M*	*SD*	*M*	*SD*
The blue spot is on the key						
SPL dB	74.04	2.61	84.85	1.47	85.33	3.21
F0 Hz	184.03	4.86	267.95	6.47	254.89	26.04
STSD	1.43	0.30	3.79	0.59	3.78	0.48
When sunlight strikes raindrops in the air						
SPL dB	71.88	1.36	84.92	0.92	84.33	1.53
F0 Hz	179.74	2.72	266.36	11.78	251.98	7.77
STSD	1.23	0.36	3.13	0.34	3.16	0.25
The potato stew is in the pot						
SPL dB	73.52	1.39	84.77	2.14	82.0	2.0
F0 Hz	185.7	7.26	277.51	11.20	251.8	1.35
STSD	1.54	0.41	3.4	0.53	2.81	0.43

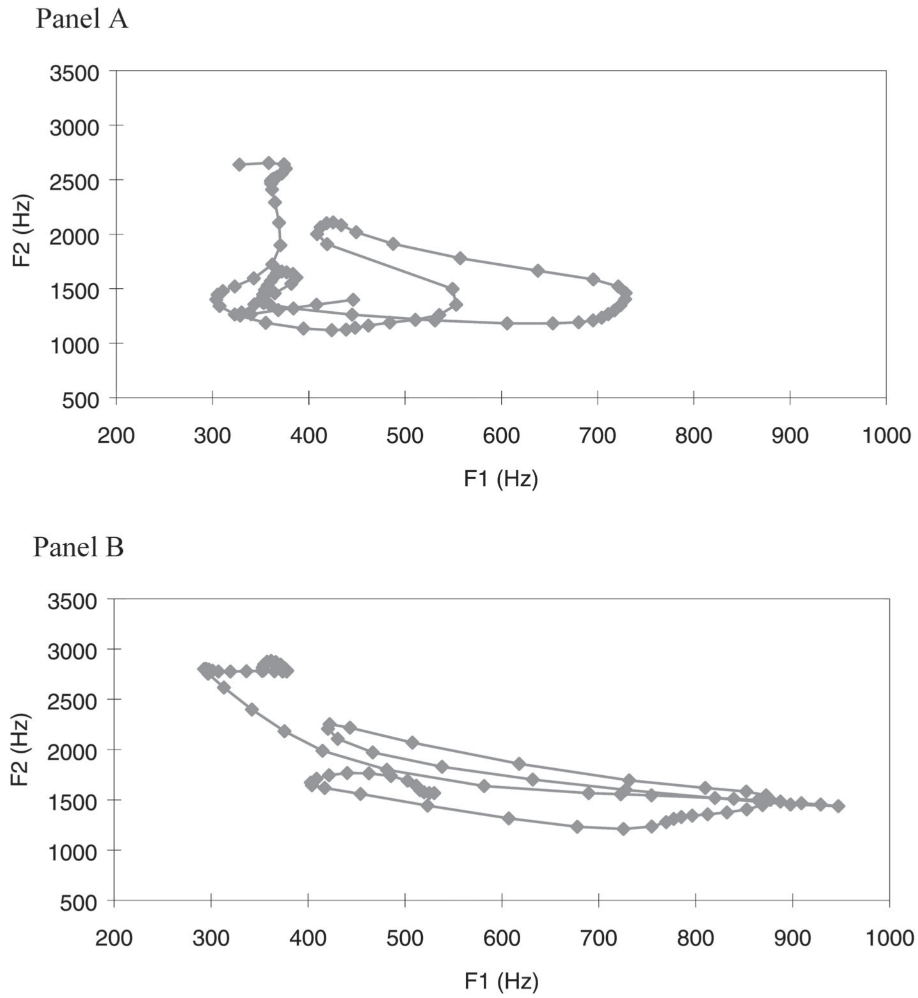
Note. STSD is in semitones. All posttreatment and 9 month follow-up values are greater than 1 *SD* compared to pretreatment values. Pre = pretreatment; Post = posttreatment; FU = follow-up.

TABLE 3. Means and standard deviations for formant frequency (F1, F2) and variability (SDF1, SDF2) in Hz for individual utterances.

	Treatment Condition					
	Pre		Post		FU	
	M	*SD*	*M*	*SD*	*M*	*SD*
The blue spot is on the key						
F1	465	19.23	562.32	30.70	623.82	28.27
F2	1672.87	35.91	1935.05	24.32	1869.77	55.57
SDF1	131.15	11.03	192.56	12.09	202.59	3.88
SDF2	434.3	36.48	532.67	38.20	528.32	61.46
When sunlight strikes raindrops in the air						
F1	556.41	29.07	626.21	23.76	604.88	9.34
F2	1718.16	35.13	1920.39	61.23	2000.58	43.52
SDF1	101.28	21.71	152.43	19.70	167.33	1.63
SDF2	328.45	58.96	473.11	42.48	512.54	21.41
The potato stew is in the pot						
F1	500.32	25.19	549.95	30.22	561.3	8.72
F2	1690.61	22.53	1813.37	27.17	1802.1	38.71
SDF1	177.99	17.81	168.6	29.85	173.89	10.86
SDF2	245.62	21.65	303.97	38.83	293.95	9.64

Note. All posttreatment and 9 month follow-up values are greater than 1 *SD* compared to pretreatment values, except for SDF1 for *The potato stew is in the pot*. Pre = pretreatment; Post = posttreatment; FU = follow-up.

FIGURE 1. Static F1–F2 formant plot of vowels in *The blue spot is on the key,* before treatment (Panel A) and after (Panel B). Note movement of formant frequencies towards the periphery.



vowel triangle area representing the post-LSVT means is larger than that of the pre-LSVT means, due to specific increases and decreases in vowel formant frequencies. The vowel triangle area for the FU data is also larger than the vowel triangle area for the pretreatment data.

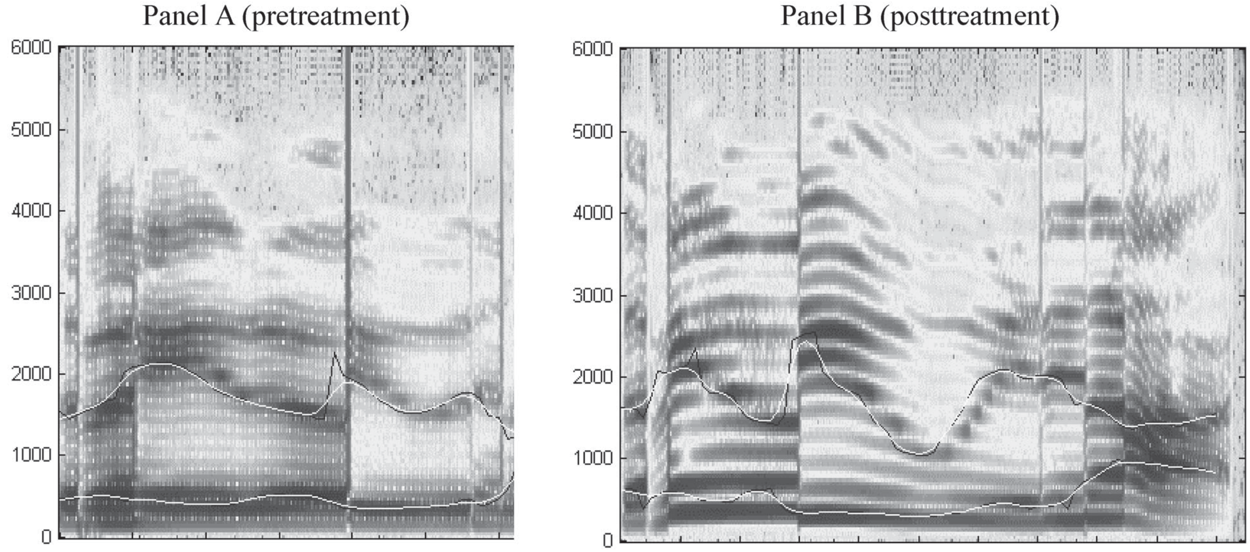
Perceptual Ratings of Articulatory Precision

Table 4 summarizes the perceptual ratings of articulatory precision across the three utterances presented (*The blue spot is on the key*, *When sunlight strikes raindrops in the air*, and *The potato stew is in the pot*). As can be seen, of the 285 pairs comparing articulatory precision pre- versus post-LSVT, 205 posttreatment were rated better, 30 pretreatment were rated better, and 50 pairs were rated "same." The frequency of "better posttreatment" (205/285, 72%) is significantly higher than the frequency of both "better pretreatment" and "same" (80/285, 28%), $\chi^2(1, N = 285) = 54.83$, $p < .001$. For the pretreatment versus FU pairs, the frequency of "better FU" (165/234, 71%) was significantly higher than the frequency of both "better pretreatment" and "same" (69/234, 29%), $\chi^2(1, N = 234) = 38.40$, $p < .001$. These findings indicate that both the posttreatment and FU samples were significantly more likely to be rated as having better articulatory precision than were the pre-LSVT samples.

Rating of Intonation

Table 5 summarizes the perceptual ratings of intonation for the Rainbow Passage. For the pretreatment versus posttreatment pairs, the great majority of listeners (25/26, 96%) rated the posttreatment samples as having better or more normal intonation, whereas only one listener rated the pretreatment sample as having better or more normal intonation (1/26, 4%). This difference is significant, $\chi^2(1, N = 26) = 22.15$, $p < .001$. For the pretreatment versus FU pairs, the majority of the listeners (20/26, 77%) rated the pairs as same. Three listeners (3/26, 11.5%) rated the pretreatment samples better or more normal, and three other listeners (3/26, 11.5%) rated the FU samples better or

FIGURE 2. Spectrographic display with F1 and F2 traces for vowels in *The potato stew is in the pot*, before treatment (Panel A) and after (Panel B). Note greater excursion of vowel formants following treatment.



more normal. For the posttreatment versus FU pairs, the great majority (25/26, 96%) rated the posttreatment samples as better or more normal than the FU samples. These findings indicate that intonation significantly improved from pretreatment to posttreatment, but that this improvement was not maintained at FU.

Intelligibility Ratings and Rate Measurements

Findings from the intelligibility study are presented in Table 6. On average, the percentage of intelligible words increased from pretreatment to posttreatment conditions by 16%. This improvement was evident for all three individual raters, who transcribed 10%, 14%, and 22% more words correctly from the posttreatment and FU items than from the pretreatment utterances. All three listeners also judged the participant's speech as easier to understand for the posttreatment items (mean scale rating of 2.13, *SD* = 0.77) compared to before treatment (mean scale rating of 3.29, *SD* = 1.12), indicating significant improvement from pretreatment to posttreatment. The ratio of the PIW to EI rating also improved significantly, $t(8) = 2.92$, $p = .0097$ (one-tailed, paired comparison) from pretreatment to posttreatment and FU measurements.

Rate of speech decreased from an average of 198.5 words per minute (WPM) pretreatment to 161.4 WPM at posttreatment and FU.

Employer Satisfaction Scale

Table 7 shows the patient's job satisfactoriness ratings by her supervisor on the MSS. The table also shows the percentiles and confidence bands for each of the scales on

FIGURE 3. Vowel triangles before, immediately after, and 9 months after intensive voice treatment, created with multiple tokens of /i/, /u/, and /a/ extracted from running speech.

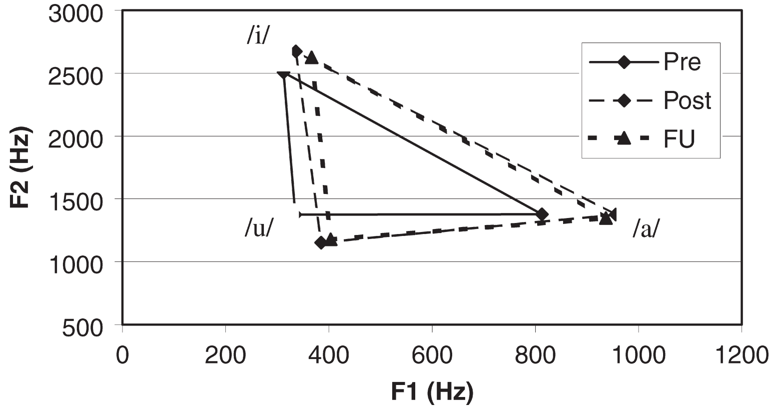


TABLE 4. Listener ratings of articulatory precision comparing pretreatment versus posttreatment, pretreatment versus follow-up, and posttreatment versus follow-up treatment pairs of multiple repetitions of three sentences (*The blue spot is on the key, When sunlight strikes raindrops in the air*, and *The potato stew is in the pot*).

Treatment Condition	*N*	Pre "Better"	Post "Better"	FU "Better"	"Same"
Pre vs. Post	285	30	205	NA	50
Pre vs. FU	234	24	NA	165	45
Post vs. FU	312	NA	36	103	173

Note. Listeners were asked to choose the sentence with "better articulatory precision" or to indicate whether the two sentences sounded the same. Pre = pretreatment; Post = posttreatment; FU = follow-up; NA = not applicable.

the MSS. The patient's scores increased in all but one category from pre- to post-LSVT. Specifically, performance rating increased from the 40th to the 60th percentile, conformance rating increased from the 45th to 75th percentile, personal adjustment rating increased from the 30th to the 50th percentile, and general satisfactoriness rating increased from the 32nd to the 55th percentile. The dependability rating remained constant at the 35th percentile. Confidence bands indicate that all gains exceeded 1 *SD* for each category. Thus, although none of the pretreatment ratings would be considered unsatisfactory, the patient made substantial gains in most areas, indicating higher levels of satisfaction from her supervisor.

Self-Assessment

Before LSVT the patient complained of difficulties speaking clearly and projecting her voice, a tendency for the voice to fatigue easily, and a reluctance to initiate communication and to engage in social activities, but after LSVT she reported marked improvement in these areas.

TABLE 5. Listener ratings of intonation for pretreatment versus posttreatment, pretreatment versus follow-up, and posttreatment versus follow-up treatment pairs of the Rainbow Passage.

Treatment Condition	Pre "Better"	Post "Better"	FU	"Same"
Pre vs. post	1	25	NA	0
Pre vs. FU	3	NA	3	20
Post vs. FU	NA	25	1	0

Note. Twenty-six listeners were asked to choose the passage with "better or more normal intonation" or to indicate whether the two passages sounded the same. NA = not applicable.

Discussion

The improvement observed in the present case study and the improvement observed in previous case studies of 2 individuals with multiple sclerosis who were treated with the LSVT program (Sapir et al., 2001) collectively suggest that the effects of the LSVT may not be restricted to a particular dysarthria, such as that associated with idiopathic Parkinson's disease (IPD).

We do not know why this patient improved speech and communication, nor do we know what physiologic mechanisms might have caused such improvement. Previous physiologic studies of normal speakers speaking loudly and of individuals with IPD treated with the LSVT (Dromey & Ramig, 1998; Dromey et al., 1995; Kleinow, Smith, & Ramig, 2001; Schulman, 1989) have demonstrated an increase in respiratory drive, glottic closure, vocal fold motion, subglottal pressure, maximum flow declination rate, laryngeal muscle activity, articulatory kinematics (range and velocity of movements), articulatory muscle activity, velopharyngeal closure function, and overall phonatory and articulatory stability associated with loud phonation. We suspect that similar physiologic changes may have contributed to the acoustic

TABLE 6. Percent intelligible words (expressed as a fraction), ease of intelligibility (expressed by a rating, with 1 = *easy*, 5 = *difficult*), and ratio of intelligibility/ease for the sentences prescribed pretreatment versus posttreatment or follow-up.

Pre	% Intelligible Words	Ease of Intelligibility	Intelligibility/ Ease	Post/FU	% Intelligible Words	Ease of Intelligibility	Intelligibility/ Ease
Pre 1 pic	.63	3	.21	FU rain	.81	1	.81
Pre 3 pic	.95	3.3	.29	Post 1 pic	.79	2.7	.29
Pre 2 con	.46	2.3	.20	Post 2 con	1.00	3.3	.30
Pre 2 pic	.64	2.7	.24	Post 1 rain	.70	1.3	.54
Pre 2 rain	.96	4.3	.22	Post 2 pic	.88	2.7	.33
Pre 3 con	.46	2	.23	FU pic	.97	2.3	.42
Pre 3 rain	1.00	2.3	.43	FU con	.83	2.3	.36
Pre 1 rain	.52	4.7	.11	Post 1 con	.87	2.3	.38
Pre 1 con	.78	5	.16	Post 2 rain	1.00	1.3	.77
M	.71	3.29	.23	*M*	.87	2.13	.47
SD	.22	1.12	.09	*SD*	.10	0.77	.20

Note. The difference in this ratio between pretreatment and posttreatment/follow-up is significant at $p = .0097$; t test, one-tailed, paired comparisons, $t(8) = 2.92$. A higher ratio value indicates better intelligibility. Pre = pretreatment; Post = posttreatment; FU = follow-up; pic = picture description; con = conversation; rain = Rainbow Passage.

TABLE 7. Percentiles and confidence bands (in parentheses) for the Minnesota Satisfactoriness Scales as rated by the participant's supervisor pretreatment to posttreatment.

Scale	Pretreatment Percentiles	Posttreatment Percentiles
Performance	40 (30–55)	60 (50–75)
Conformance	45 (40–55)	75 (65–80)
Dependability	35 (25–50)	35 (25–50)
Personal Adjustment	30 (15–40)	50 (40–55)
General	32 (25–38)	55 (45–65)

Note. Higher scores indicate greater employer satisfaction.

and perceptual improvement observed in the present study.

Perceptual ratings in the present study indicated improved intonation and articulatory precision—as well as improved speech intelligibility—suggesting that the increases in STSD, SDF1, and SDF2 following LSVT may have reflected increased phonatory and articulatory dynamics and stability. Other studies have documented improved phonatory and articulatory dynamics and stability with loud phonation in normal and dysarthric speakers (Dromey & Ramig, 1998; Schulman, 1989). The only puzzling finding in this study is the lack of improvement in the rating of intonation at FU compared to pre-LSVT, in spite of an increase in STSD at FU. This incongruity is difficult to explain without further exploration.

The speech rate of this patient decreased considerably from approximately 200 WPM before treatment to 160 WPM after treatment and at follow up. Normal speaking rate during conversation varies from about 150 to 250 WPM (Goldman-Eisler, 1968), and during sentence and paragraph reading from about 150 to 200 WPM (Fairbanks, 1960; Yorkston & Beukelman, 1981). Thus, the patient's speech rates before and after treatment were within the normal range. Importantly, before treatment, the patient tended to truncate the end of words and blend words together. She also tended to speak without pauses. After treatment, she uttered her words without truncating them, and she added pauses more frequently. These pauses were linguistically appropriate and did not reflect difficulty in breathing or in articulating speech. Thus, one can view the decrease in rate of speech as another positive consequence of the LSVT program, inasmuch as it allowed the patient to articulate speech more accurately and pause more appropriately. One can, of course, argue that the slower rate of speech was a by-product of improved articulation and pausing. Similar changes in rate have been reported following LSVT applied to individuals with PD (Ramig, Countryman, et al., 1995).

The neural mechanisms underlying the effects of loud phonation in general, and LSVT in particular, are yet to be delineated (Liotti et al., 2003). In humans, lesions to different parts of the central nervous system, especially the limbic system (LS), the anterior cingulate cortex (ACC), the thalamus, and the basal ganglia (BG) in PD produce hypophonia, hypoprosodia, and hypokinetic articulatory movements (Ho, Bradshaw, Iansek, & Alfredson, 1999; Jurgens & von Cramon, 1982; Meissner, Sapir, Kokmen, & Stein, 1987; Sapir & Aronson, 1985). Studies in animals suggest that the LS, ACC, thalamus, and BG are involved in the regulation of vocal intensity associated with emotive vocalization (Davis, Zhang, Winkworth, & Bandler, 1996; Jurgens & Zwirner, 1996; West & Larson, 1995). Brain stimulation and cell recordings in animals indicate that emotive vocalization is associated with coactivation of the respiratory, phonatory, and orofacial muscles (Davis et al., 1996; Larson, 1988; West & Larson, 1995). The periaqueductal gray (PAG), which receives input from most of the areas of vocalization mentioned above, as well as sensory input from the vocal periphery, is also involved in the regulation of vocal intensity (see Davis et al., 1996). Taken together, these findings suggest that the global effects of loud phonation on speech and nonspeech functions as described above may be mediated via common, phylogenetically old, neural mechanisms.

The effects of the LSVT program may also be mediated via reflex mechanisms. Studies in animals have shown that loud phonation is associated with activation of mechanoreceptors in the respiratory, laryngeal, and orofacial structures, and that this activation is likely to reflexively augment motor neuronal activity in the speech musculature, especially in muscles that are typically involved in loud phonation (Davis et al., 1996). Such a positive feedback servomechanism may be useful for phonatory and speech motor control, as has been demonstrated in the limb system, where reflexogenic mechanisms improve the intrinsic properties (e.g., stiffness and linearity) of muscles; coordinative actions of muscles; and the range, precision, and stability of movements (e.g., McIntyre, Mussa-Ivaldi, & Bizzi, 1996; Muller, Abbs, & Kennedy, 1981; Prochazka, Gillard, & Bennett, 1997). Because the speech system is endowed with various sensorimotor mechanisms, including positive feedback loops (Gracco & Abbs, 1989; Muller et al., 1981; Sapir, Baker, Larson, & Ramig, 2000), it is possible that the beneficial effects of positive feedback loops as observed in the limb system may also apply to the speech system, thus yielding better phonatory and articulatory stability as well as range and precision of movements. There is, of course, the danger that such feedback mechanisms might result in excessive vocal impedance and excessive stiffness of the respiratory, phonatory, and articulatory muscles, which could result in cessation of phonation and impaired articulatory movements. However, these ill effects may be prevented by higher neural centers, especially the BG, through a process of sensorimotor gating (Izdebski, 1992; Ludlow, Schultz, Yamashita, & Deleyiannis, 1995).

Importantly, the central neural mechanisms that regulate loud vocalization appear to participate in cognitive and executive functions such as drive, goal-directed activity, attention to action, self-regulation, internal cueing, and motor learning (e.g., Devinsky, Morrell, & Vogt, 1995; Ho et al., 1999; Meissner et al., 1987; Sapir & Aronson, 1985). Thus, the use of loud phonation to improve voice and speech production may also result in improved vocal learning and maintenance of learned vocal behaviors through stimulation of these central mechanisms. We suggest that the long-term improvement in the speech of this study's participant may have been related to such stimulation.

There are many missing parts to the puzzle of why the LSVT produces positive, long-term improvement in speech and nonspeech functions in dysarthric individuals. Obviously, more research is needed to understand the neural mechanisms underlying the effects of the LSVT in individuals with lesions to the BG, cerebellum, or other parts of the nervous system. As for the present findings, without comparing this patient to other patients with ataxic dysarthria we cannot be sure that the same effects seen here would generalize to other individuals with ataxic dysarthria. This is especially true given the heterogeneity of ataxic dysarthria. Thus, it is possible that LSVT was effective here because the patient's voice was weak and breathy. Individuals with other types of ataxic dysarthria, especially those characterized by excessive loud phonation, may not benefit as much from this treatment as the present patient, although this must be tested empirically. Furthermore, without studying individuals with other types of dysarthria we cannot be sure that the LSVT is applicable to all types of dysarthria. These concerns, the fact that this study had only one participant, and the lack of direct physiologic measures, are obvious methodological shortcomings that necessitate more extensive investigation to assess the impact of LSVT on ataxic dysarthria. Furthermore, without comparing the effects of LSVT with those of alternative methods of treatment, we cannot be sure that the present findings were treatment-specific. Finally, the lack of experimental control, the borderline acceptability of intrajudge reliability (71%) for the articulation ratings, and the inability to unambiguously attribute the observed changes to the treatment must be kept in mind when evaluating the findings in this study. These limitations notwithstanding, the present findings are encouraging and add to other studies suggesting that the LSVT may be a promising method for treating various forms of dysarthria

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