The Effect of Lee Silverman Voice Treatment (LSVT®) on Parkinsonian Phonation: Nonlinear Dynamic, Perturbation, and Perceptual Analysis

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Background & Objectives: Lee Silverman Voice Treatment (LSVT®) has been widely accepted to improve Parkinsonian voice, speech, and swallowing. Acoustic analysis has been used to measure the treatment effectiveness for dysphonia. Unlike traditional perturbation analysis, a nonlinear dynamic approach has been applied to reliably quantify both periodic and aperiodic voice signals. The present study aims to investigate the effectiveness of LSVT® on Parkinsonian voice with acoustic and perceptual analysis for evidence-based practice (EBP) and to evaluate whether nonlinear dynamic methods can be used to quantify the aperiodic phonation which is frequently exhibited in Parkinsonian voice. ***Methods:*** Fifteen Idiopathic Parkinson's Disease (IPD) patients were enrolled and randomly assigned to a control (no treatment) (N=7) or treatment group (N=8). The standard LSVT® program was administered by a speech language pathologist four times a week for four weeks, for a total of 16 sessions with the experimental PD group. Nonlinear dynamic methods with traditional perturbation measures were used to test treatment effects for a clinical quantification of aperiodic Parkinsonian phonation. All acoustic and perceptual parameters with /a/ sustained vowels were obtained before and four weeks after the voice therapy in the experimental group and before and four weeks after no treatment in the control group. Three listeners rated general vocal impairments with sustained /a/ vowel segments from a randomly ordered dataset for the control and experimental group before and four weeks after voice therapy. ***Results:*** Results demonstrated that both % jitter (p=0.039) and D_2 (p=0.023) were significantly lower following voice therapy, whereas % shimmer values were not. For the PD control group (no treatment group), no significant differences were revealed before versus after four weeks in all acoustic parameters; % jitter (p=0.875), % shimmer (p=0.250), and D_2 (p=0.078). In addition, perceived voice quality was improved following voice therapy for the treated group, while no change was found between before and four weeks after in the control group. ***Discussion & Conclusions:*** LSVT® improves aperiodicity and supplements prior treatment outcomes. These findings suggest that the nonlinear measure of correlation dimension (D_2) can be applicable for the characterization of aperiodic Parkinsonian voice, and the treatment effects of LSVT® may provide useful information to clinicians for evidence-based decision making in Parkinsonian voices. (***Korean Journal of Communication Disorders*** 2011;16:335-345)

Key Words: Parkinson's voice, LSVT®, treatment effectiveness, randomized controlled trials, perturbation analysis, perceptual analysis, nonlinear dynamic analysis

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Ⅰ. Introduction

Parkinson's disease (PD) is a progressive and degenerative disease of the brain that results in a loss of motor and communicative skills. Signs of PD include tremor, rigidity and bradykinesia (slow/weak movement) which also often features voice and speech impairment as a secondary symptom (Hartelius & Svensson, 1994; Logemann et al., 1978). Parkinsonian voice was characterized by hypophonia (weakness /quietness), tremor, breathiness, monotone and monoloudness, and hoarseness (Hanson, Gerratt &

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Ward., 1984; Logemann et al., 1978; Ramig et al., 1988). Pharmacologic and surgical treatments such as Levodopa and Deep brain stimulation (DBS) lead to concurrent speech improvement, but these benefits may not occur consistently in voice (Gentil et al., 2003; Hoffman-Ruddy et al., 2001; Jiang et al., 1999; Lee et al., 2008; Sanabria et al., 2001; Schulz, 2002; Schulz & Grant, 2000; Wang et al., 2003).

To date, Lee Silverman Voice Treatment® (LSVT®) is a four-week intensive program and the loud and effortful phonatory tasks has been considered as the most effective behavioral treatment for Parkinson's voice, speech, and swallowing (El Sharkawi et al., 2002; Fox et al., 2002; Ramig et al., 1994; 1996; 2001a; Sapir, Ramig & Fox, 2008; Smith et al., 1995; Spielman et al., 2007). Generally, the effects of LSVT® on PD voice have been reported with voice quality using perceptual analysis only emphasized on hoarseness and breathiness (Baumgartner, Sapir & Ramig, 2001) or vocal function measured by means of acoustic analyses of voice loudness (measured as sound pressure level, or SPL) and inflection in voice fundamental frequency (Ramig et al., 2001b); or perceptual ratings with acoustic analysis which focus on vocal loudness (Sapir et al., 2007); or vocal loudness with perceptual rating and Voice Handicap Index (VHI) (Spielman et al., 2007); or vocal loudness or vocal intensity only (El Sharkawi et al., 2002; Ramig et al., 2001a; 2001b). Another studies for effectiveness have been used phonatory stability in sustained phonation (Countryman & Ramig, 1993; Dromey, Ramig & Johnson, 1995), articulatory acoustic parameters (vowel and whole word duration, transition duration, extent and rate, and frication duration and rise time) in single-word productions (Dromey, Ramig & Johnson, 1995), and maximum phonation time, open quotient in electroglottography analysis, laryngeal resistance (Dromey, Ramig & Johnson, 1995) to evaluate its effects.

A number of studies for effectiveness of LSVT® have demonstrated some benefits on voice, speech, and swallowing in individuals with PD but majority of studies have evaluated the effectiveness of single intervention before and after therapy (El Sharkawi et al., 2002; Fox et al., 2002; Sapir, Ramig & Fox, 2008; Smith et al., 1995; Spielman et al., 2007; Ramig et al., 1994; 1996; 2001a) or compared with normal age-matched control not with PD control without treatment (Ramig et al., 2001b). Therefore, our concern of this study is non-intervention should also be rigorously evaluated before and 4 week after (same dosage of LSVT®) to test the effectiveness of this intervention. From this perspective, randomized controlled trials are scientific experimental, prospective studies, widely accepted as the most reliable method of determining effectiveness of treatment for evidence-based practice (EBP) (Dollaghan, 2004; Sackett et al., 1996) because participants are randomly allocated into control group (non intervention), experimental group (treatment group), different types of intervention (alternative treatment group) or placebo and outcomes of interest can be followed up over time and compared them to investigate if there is an effect on a certain intervention.

Acoustic perturbation analysis had been used to measure the therapeutic effect of levodopa on vocal function in PD (Sanabria et al., 2001). Recently nonlinear dynamic approach such as correlation dimension (D_2) has been applied to reliably quantify both periodic and aperiodic voice signals (Giovanni, Ouaknine & Triglia, 1999; Hertrich & Ackermann, 1995; Lee et al., 2008; Maccallum et al., 2009; Rahn et al., 2005; Zhang et al., 2004; 2005a ; Zhang, Jiang & Rahn, 2005b; 2005c).

Basically, hoarseness of voice has been previously linked to aperiodic patterns of fundamental vocal frequency (f_o) that often exists in severe vocal pathology (Herzel, 1993; Herzel et al., 1994; Toner, Emanuel & Parker, 1990). Traditional acoustic methods of voice analysis (e.g. %jitter, %shimmer, and signal-to-noise ratio (SNR)) in routine clinical assessments rely on extraction of a stable f_o to calculate phonatory impairment, making them invalid for describing aperiodic phonation (Karnell et al., 1997; Titze, 1995) and reliable %jitter and %shimmer in a typical clinical voice task can be influenced by vowel, gender, vocal intensity, and fundamental frequency (Brockmann et al., 2008; 2011). Nonlienar dynamic methods, including phase space and correlation dimension (D_2), have been considered as new acoustic methods to describe aperiodic and chaotic activities and can predict period-doublings, bifurcations, deterministic chaos or nonlinear dynamic system rather than stochastic chaos. (Zhang et al., 2004; 2005a; Zhang, Jiang & Rahn, 2005b; 2005c). Phase space can be portrayed graphically as a trajectory of vocal fold vibration with time evolution to describe their vibratory characteristics and the correlation dimension (D_2) is a quantitative measure that may quantify a dynamic vibratory system which can differentiate a low dimensionality with number of freedom from an infinite dimensional system such as random white noise. Thus, the correlation dimension (D_2) can quantify the complexity or irregularity of a trajectory in phase space based on the estimation ; a zero-dimensional fixed point (static states), a one-dimensional limit cycle (periodic oscillations), a two-dimensional quasi-periodic torus (superposition of two or more oscillations), or a fractal dimensional chaotic trajectory (aperiodic oscillations) (Herzel et al., 1994; Jiang, Zhang & McGilligan, 2006). Many studies have been applied these nonlinear dynamic methods to see the possibility of clinical utility and recent study found that PD voices showed higher D_2 compared to normal voices (Hertrich & Ackermann, 1995; Rahn et al., 2005).

The objectives of this study are to investigate if there is the treatment effect of LSVT® on parkinsonian voice as Level I efficacy data and to evaluate if nonlinear dynamic measure such as correlation dimension (D_2) can quantify the aperiodicity which was frequently exhibited in PD voices because nonlinear dynamic analysis can provide more reliable acoustic outcomes both periodic and aperiodic voice signals than traditional acoustic perturbation measures.

Ⅱ. Method

1. Participants

The University of Wisconsin IRB approved the protocol and consent procedure for this study. Fifteen PD patients (12 males and 3 females: mean age=66 yrs) were recruited based on their diagnosis of IPD at the UW hospital and randomly assigned to treatment versus control group. Eight PD patients (7 males and 1 female: mean age=67) for experimental group (treatment group); seven control PD patients (5 males and 2 females: mean age=65 yrs) in control (no treatment) group. All participants in both groups had taken antiparkinsonian medications during this study and were able to complete all evaluation and treatment independently.

T-test was used to examine the age, Unified Parkinson's Disease Rating Scale (UPDRS), stage of disease (Hoehn & Yahr, 1967) to compare between groups <Table - 1> and no significant differences were found for any of the variables between groups (p >.05). Group characteristics in the baseline for both groups were shown in <Table - 1>.

<Table – 1> Mean (SD) values of characteristics for pre-treatment conditions in control (no treatment) PD group and experimental (treatment) PD group.

	Control (N=8) (non- LSVT®[a])	Experimental (N=7) (LSVT®)	p-Value
Age(yr)	67.3(11.6)	65.4 (7.8)	$p > 0.05$
UPDRS[b]	27.8(13.0)	25.2(15.1)	$p > 0.05$
H & Y[c]	2.2 (0.8)	2.6 (0.6)	$p > 0.05$

[a] LSVT® = Lee Siverman Voice Treatment; [b] UPDRS = Unified Parkinson's Disease Rating; [c] H & Y = H & Y stage = Hoehn & Yahr stage

2. Voice Therapy

Standard LSVT® program was administered by the same speech language pathologist 4 times a week for 4 weeks, sixteen-session with experimental PD group (Ramig et al., 1994). During the voice therapy, individuals with PD practiced increasing their maximum vocal effort and loudness, maximum duration of sustained vowel production, maximum fundamental frequency range, maximum functional speech loudness during production of words, phrases, sentences, conversation and reading. Moreover, LSVT® was structured to ensure that patients are not pushed to effort levels harmful to the voice mechanism.

3. Sampling

Samplings were conducted twice a day before the first session of LSVT® and within one day after the last session of LSVT® (four weeks later) in both control and experimental group. As described in previous study (Spielman et al., 2007), participants were stable on their medications and all data were collected consistently across sessions, typically 1 hour after taking medications.

At each time period, several sustained /a/ vowel phonations were recorded in a sound-attenuated room using a head-mounted microphone (AKG Acoustics, Vienna, Austria) positioned at a distance of 15cm from the mouth. Audio files were recorded at a sampling rate of 44.1kHz using Multi-speech software (Kay Elemetrics, Lincoln Park, NJ). One-second segments were cut from the middle of these sustained vowels and processed using perturbation, nonlinear dynamic and perceptual analysis.

4. Perturbation Acoustic Analysis

The one-second segments of sustained phonation were analyzed using CSpeech 4.0 software (Milenkovic, 1992). % jitter and % shimmer were obtained for the nearly periodic phonations. It has been previously determined that values of % jitter and % shimmer are only reliable for nearly periodic voices and are invalid for clearly aperiodic samples (Titze, 1995). Consequently, 10 aperiodic phonation segments (2 pre-LSVT® and 2 post-LSVT® from the treatment group, 3 pre- and 3 post-without LSVT® from the control group) were eliminated from the perturbation analysis.

5. Nonlinear Dynamic Analysis

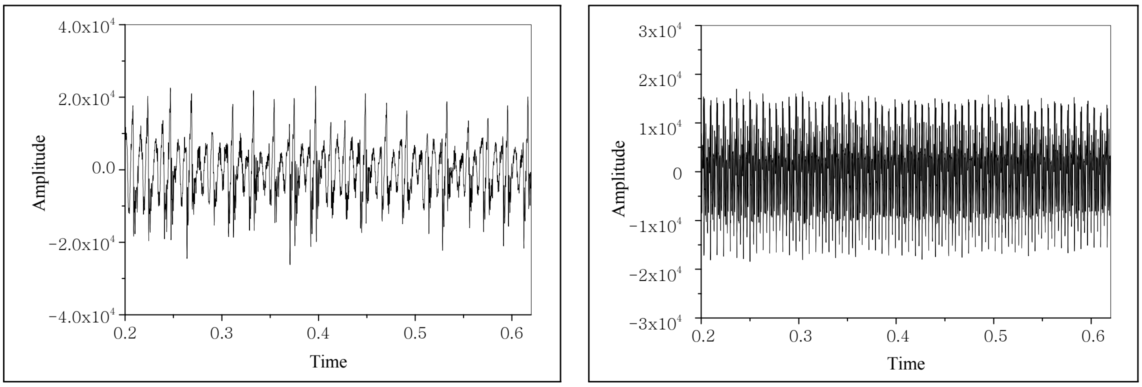
Nonlinear dynamic methods have been used the same as described previous literature (Jiang, Zhang & Ford, 2003; Kumar & Mullickm 1996; Narayanan & Alwan, 1995; Titze, Baken & Herzel, 1993). Dimension estimates yield a quantitative calculation of the number of degrees of freedom needed to describe a dynamic system, where higher dimensionality (D_2) may indicate higher irregularity or aperiodicity (Grassberger & Procaccia, 1983). In this study, D_2 calculations were performed using custom nonlinear dynamic analysis software developed by the Laryngeal Physiology Laboratory at the University of Wisconsin School of Medicine and Public Health. Signals were downsampled to 25 kHz prior to nonlinear dynamic analysis using GoldWave 5.1 (GoldWave, St. John's, NL, Canada). To analyze the parkinsonian voices in this study, the equations were used to estimate dimension as previous studies (Jiang, Zhang & Ford, 2003; Jiang, Zhang & McGilligan, 2006). Nonlinear dynamic analysis can be used with not only regular oscillation but also aperiodic oscillation, all voice segments were used to calculate D_2 values.

6. Perceptual Ratings

The one-second segments were rated general vocal impairment on a scale from 1 to 5 (with anchors of 1= absolutely none present, and 5= most severe possible) by 2 laryngologists and 1 speech-language pathologist (3 females: ages ranging from 34 to 42) with 4~6 years of voice experience. None of the raters had a history of hearing difficulties. All voice segments were combined in a randomized order and presented to each rater through headphones (Targus Inc., Anaheim, CA) in a quiet isolated room. The raters had relatively higher inter-rater agreement with Cronbach's alphas of 0.83.

7. Statistical Analysis

SigmaStat 3.0 and SigmaPlot 8.0 software (Jandel Scientific San Rafael, CA) was utilized to statistically compare and graph the data from the individuals with PD. Wilcoxon signed rank tests were used to compare the objective variables (D_2, jitter and shimmer) as well as each rater's perceptual judgment of general vocal impairment before and after LSVT® in experimental group and before and after 1month with no treatment in control group. Statistical significance was set at the 0.05 level.



<Figure - 1> The acoustic phonatory signal from one parkinsonian voice before and after LSVT®

Ⅲ. Results

<Figure - 1> exhibits the typical waveforms of a parkinsonian voice before and after LSVT®, respectively. Acoustic perturbation measures, %jitter and %shimmer are summarized in <Table - 2> and <Table - 3>. A Wilcoxon signed rank test revealed that % jitter and %shimmer had no significant changes between before- and 4-week after- without LSVT® ($p = 0.375$, $p = 0.250$, respectively). In contrast, <Table - 3> demonstrated that % jitter was significantly lower after-LSVT® (M = 0.34, SD =0.33) than before-LSVT® (M =1.28, SD =1.44) ($p = 0.039$).

<Table - 2> % jitter, % shimmer, and estimated dimension (D2) in acoustic voice data before and four-week after no intervention in control PD group.

	Before Without LSVT®	After 4-week Without LSVT®	p-Value
% jitter	M=0.53 SD=0.08	M=0.40 SD=0.12	0.375
% Shimmer	M=2.79 SD=1.63	M=1.44 SD=0.41	0.250
D_2	M=1.75 SD=0.31	M=1.61 SD=0.33	0.078

* $p < 0.05$

No significant differences in %shimmer were represented between before- (M=3.58, SD=1.25) vs. after- (M= 3.27, SD=1.54) LSVT® (p=0.654) <Table - 3>. On the other hand, control (no treatment) PD group did not demonstrate any differences during the same time dose (four-week) in D_2 ; before (M=1.75, SD=0.31) and four-week after (M=1.61, SD=0.33) without LSVT® (p=0.078) <Table - 2> while D_2 values were significantly decreased following intensive voice therapy in the individuals with PD (M=1.82, SD=0.55) than before voice therapy (M=2.73, SD=0.88) (p=0.023) <Table - 3>.

<Table - 3> % jitter, % shimmer, and estimated dimension (D_2) in acoustic voice data before and four-week after Lee Silverman Voice Treatment® (LSVT®) in experimental PD group.

	Before-LSVT®	After-LSVT®	p-Value
% jitter	M=1.28 SD=1.44	M=0.34 SD=0.33	0.039
%Shimmer	M=3.58 SD=1.25	M=3.27 SD=1.54	0.654
D_2	M=2.73 SD=0.88	M=1.82 SD=0.55	0.023

* $p < 0.05$

The perceptual ratings of vocal impairment by 3 raters were shown in Fig. 2. A summary of the Wilcoxon signed rank comparisons for the perceptual data from the three raters is shown in <Table - 4> and <Table - 5> for control and experimental group, respectively. No significant differences was observed across all raters between before- and 4-week after without LSVT® ($p > 0.05$). In contrast, perceived voice quality was improved after voice therapy by rater 1 ($p = 0.020$) and rater 3 ($p = 0.007$).

<Table - 4> Mean grade of vocal impairment before and 4-week after in PD group without Lee Silverman Voice Treatment® (LSVT®).

	Score	p Value
Rater 1	Before=3.14 After=3.29	0.846
Rater 2	Before=2.86 After=3.14	0.726
Rater 3	Before=3.42 After=3.00	0.534

* $p < 0.05$

<Table - 5> Mean grade of vocal impairment before and after Lee Silverman Voice Treatment® (LSVT®).

	Score	p Value
Rater 1	Before=2.25 After=1.50	0.020**
Rater 2	Before=3.13 After=3.00	0.685
Rater 3	Before=2.75 After=1.63	0.007**

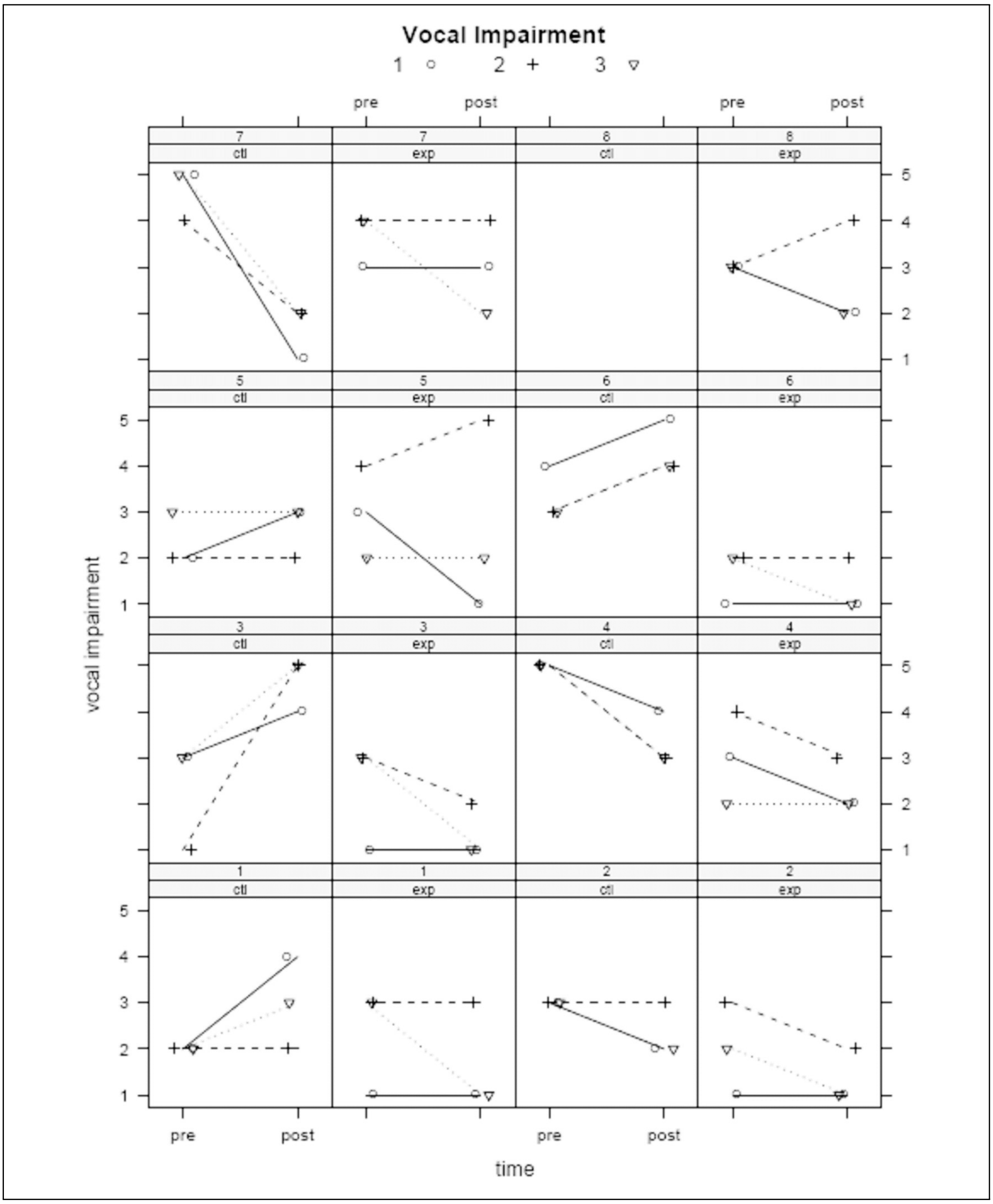
* $p < 0.05$

Ⅳ. Discussion and Conclusion

LSVT LOUD practice focuses on single motor control parameter amplitude (vocal loudness) and recalibration of self-perception of vocal loudness which can be a key of underlying treatment success for parkinsonian voice and may work across diverse motor systems (Fox et al., 2006). PD patients were taught to think loud and increase their vocal effort in order to improve the loudness and intelligibility of their speech by increasing vocal fold adduction and subglottal pressure (Ramig et al., 1994). In comparison with a respiratory therapy program, LSVT® has been represented to yield consistent improvements in vocal loudness that persists over 2 years (Ramig et al., 1994; 1995; 1996; 2001a) and to decrease hoarseness in PD voice (Baumgartner, Sapir & Ramig, 2001; Ramig et al., 1995). Increased vocal effort has been an effective method in improving vocal loudness and voice quality in patients with PD (Ramig et al., 1994).

Acoustic, aerodynamic, electroglottographic, and endoscopic studies have all found evidence that LSVT® achieves these physiologic changes (Fox et al., 2002). Pathologically high levels of jitter and shimmer have been observed in patients with PD (Ramig et al., 1988), but LSVT® has been represented to reduce these characteristics in some case study (Countryman & Ramig, 1993; Dromey, Ramig & Johnson, 1995). To investigate the effectiveness of this intensive voice therapy as a higher evidence-based treatment for this population with voice problems, this study design employed randomized assignments to the two groups (treatment versus non-treatment group) and all acoustic and auditory-perceptual data were collected before and after voice therapy in the treatment group and before and 4-week after without voice therapy in control PD group. Because all PD patients have routinely taken antiparkinsonian medications (i.e., levodopa) throughout this study, this can influence treatment outcomes. Thus, the parallel comparison with intensive voice therapy and non-voice therapy during the same period (4-week) may provide more reliable treatment outcome comparisons for powerful clinical trials.

Further, nonlinear dynamic analysis with traditional perturbation measures was used to quantify the aperiodicity of PD voice. Percent Jitter and shimmer values were selected with less than 10 Err value in CSpeech in this study because percent jitter and shimmer values can be only reliable when nearly periodic voice signals can be used. In some previous studies, %Jitter and/or %shimmer levels in PD patients have been demonstrated to decrease after pharmacologic and surgical treatments for the primary symptoms of PD, though these results, too, have not been consistently observed (Gentil et al., 2003; Hoffman-Ruddy et al., 2001; Sanabria et al., 2001; Wang et al., 2003). In the current study, LSVT® could make the improvement for hoarseness with decreased D2 and % jitter. No significant difference, however, was exhibited in %shimmer following LSVT®. Some studies of effectiveness of LSVT® reported increased loudness (measured as sound pressure level, or SPL) following voice therapy, SPL was not measured in the present study. Recent



<Figure - 2> Perceptual ratings of Grade by 3 raters in control PD group (N=7) before and 4-week after no intervention and before and after LSVT® experimental PD group (N=8).

study showed that voice SPL has the single biggest impact on jitter and shimmer (Brockmann et al., 2011) and may affect %jitter or % shimmer or both. Current study demonstrated only % jitter values significantly decreased following LSVT® as enhancing vocal loudness. It can be expected that LSVT® can be more effective on improving the hoarseness in parkinsonian voice since jitter can be associated with an objective measurement of hoarseness (Jones et al., 2001). In addition, as in other studies (Ramig et al., 1995; Baumgartner, Sapir & Ramig, 2001), a majority of raters in the present study found improved voice quality following LSVT®.

Compared to nonlinear methods the perturbation analyses required voice recordings of longer signal lengths, higher sampling frequency, and lower noise levels (Zhang et al., 2005a). When the signal is periodic or nearly periodic, perturbation and nonlinear dynamic methods are both capable of voice analysis. However, if a signal is aperiodic or chaotic, measurements errors increase with the traditional perturbation measures. Nonlinear dynamic methods do not require determination of a pitch period, which is a component of the algorithms used in perturbation analysis. Nonlinear dynamic methods have been used to measure the effectiveness of treatments for voice disorders (Zhang et al., 2004). By simulating the physiologic effects of LSVT®, a recent mathematical model of PD vocal function predicted that LSVT® would decrease aperiodic phonation in this vocal pathology (Zhang, Jiang & Rahn, 2005b). The results from the present study compliment the prediction in this model. That is, given that the individuals with PD in this investigation exhibited lower dimensionality in acoustic phonatory signal following LSVT®. The present results support the hypothesis that LSVT® may be helpful to reduce phonation irregularity in PD. This outcome suggests that nonlinear dynamic methods may be useful to clinicians who are using LSVT® to treat aperiodic parkinsonian voices.

%Jitter and correlation dimension (D_2) represented two distinct and potential predictors for measuring the effectiveness of LSVT® for PD voice in this study. Thus, current study indicated that nonlinear dynamic methods could quantify both aperiodic and periodic PD voice signals and would be more capable than perturbation parameters such as % jitter and %shimmer for reliable measurement of the aperiodic PD voice and may be useful to clinicians because it seems to be a valid and diagnostically specific method of detecting aperiodic phonation. The objective and perceptual outcomes presented here lend further support to the efficacy of LSVT®. This study encourages applications combining nonlinear dynamic methods with other methods used in clinical diagnosis and treatment of voice disorders. This research is also meaningful as Level I efficacy data in terms of EBP to evaluate the treatment effectiveness. In future study, long-term follow-up is essential to ensure that long-term treatment effects will be able to be achieved and gain additional evidence of treatment effectiveness on the pathophysiology of PD voice at the clinical trials.

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파킨슨씨 병 음성에 대한 리실버만 음성치료의 효과: 비선형의 역동적, 섭동적, 청지각적 분석

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대구가톨릭대학교 의료과학대학 언어청각치료학과와 생체모방감각제어연구소

배경 및 목적: 리실버만 음성치료는 파킨슨씨병 환자의 음성, 말, 삼킴 장애를 개선하는 것으로 알려져 왔으며, 음향학적 분석은 음성 장애의 치료 효과를 측정하는데 사용되어져 왔다. 많은 연구들이 리실버만 음성치료법에 대한 효과성을 보고하였음에도 불구하고, 대부분 리실버만 음성치료법 중재 전후의 단순 비교만을 보고하였다. 무작위 통제 실험연구는 가장 최선의 임상 중재를 위하여 치료의 효과에 대한 증거를 제공하는데, 이러한 통제 실험 연구는 거의 시도되지 않았다. 전통적인 섭동적 분석과 달리, 주기적 신호와 비주기적 음성 신호를 신뢰성 있게 모두 정량화하기 위하여 최근 비선형 역동적 분석법이 사용되고 있다. 본 연구는 증거 참조 중재를 위하여 파킨슨씨병 환자의 음성에 대한 1단계 수준의 치료 효과를 조사하고, 비선형 역동적 음향학적 접근법이 파킨슨씨병에서 흔히 관찰되는 비주기적인 음성을 정량화할 수 있는 지 평가하는 데 목적을 두고 있다. **방법:** 특발성파킨슨씨병으로 진단받은 15명의 환자를 통제군(치료 받지 않은 집단, 7명)과 치료 집단(8명)에 무작위로 할당하였다. 한 명의 언어치료사에 의해 실험군의 파킨슨씨병 환자군은 일주일에 4회, 4주 동안 총 16회의 집중적인 리실버만 음성치료를 받았다. 비선형 역동적 분석법이 비주기적인 파킨슨씨병 음성을 분석하기 위해 사용되었다. 연장 모음 /아/를 사용하여 실험군은 치료 전과 치료 4주 후에, 통제군은 치료 없이 4주 후에 비선형 역동적 분석, 전통적 섭동적 음향학적 분석과 청지각적 분석을 실시하였다. 3명의 측정자에 의해 /아/ 연장 모음으로 전반적인 음성장애의 정도를 치료 전・후에 통제군과 치료군의 음성을 측정하였으며 통계학적으로 분석되었다. **결과:** 주기간 주파수 변동률 (p=0.039)와 상관지수(D2, p=0.023)는 음성치료 후 유의미하게 감소하였으나, 주기간 진폭 변동률은 차이가 없었다. 반면, 치로 받지 않은 통제군은 4주 후 모든 음향학적 지수; 주기간 주파수 변동률((p=0.875), 주기간 진폭 변동률 (p=0.250), 상관지수((p=0.078)에 모두 유의미한 차이가 없었다. 게다가 청지각적으로 관찰된 음질은 치료군에서는 음성 치료 후 개선되었으나, 통제군에서는 4주 전후 유의한 차이가 없었다. **논의 및 결론:** 리실버만 음성치료 후 비주기성이 개선되었으며, 이전에 보고된 음성 치료 결과를 지지하였으며 비선형 역동적 분석 파라미터인 상관지수(D2)는 비주기적인 파킨슨씨병 음성의 특성을 정량화할 수 있었다. 따라서 리실버만 음성치료는 효과적으로 파킨슨씨병 환자의 음성을 개선시킬 수 있음을 증명하였으며, 이는 증거 참조 중재를 위한 의사결정 시 임상가들에게 유용한 정보를 제공할 것으로 보인다. 『**언어청각장애연구**』, 2011;16:335-345.

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