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Targeted exercise therapy for voice and swallow in persons with Parkinson's disease

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Abstract

Sensorimotor deficits affecting voice and swallowing ability can have a devastating impact on the quality of life of people with Parkinson disease (PD). Recent scientific findings in animal models of PD pinpoint targeted exercise therapy as a potential treatment to reduce neurochemical loss and decrease parkinsonian symptoms. Although there may be beneficial effects, targeted exercise therapy is not a standard component of therapy for the cranial sensiromotor deficits seen in PD. In this paper we review the scientific evidence for targeted training for voice and swallowing deficits. The literature search revealed 19 publications that included targeted training for voice and only one publication that included targeted training for swallowing. We summarize 3 main findings: 1) targeted training may be associated with lasting changes in voice behavior, 2) targeted training of sensorimotor actions with anatomical or functional overlap with voice and swallowing may improve voice and swallowing to some degree, but it is unknown whether these effects endure over time, and 3) evidence regarding cranial sensorimotor interventions for Parkinson disease is sparse. We concluded that targeted training for voice and swallow is a promising but under-studied intervention for cranial sensorimotor deficits associated with PD and posit that animal models can be useful in designing empirically based studies that further the science on targeted training.

Targeted Physical Exercise and Parkinson Disease

The concept of using physical exercise to treat Parkinson disease (PD) is not new. However, interest in exercise on both research and consumer levels has recently escalated because of promising new findings from clinical and animal research (Chen et al.,2005; Fisher et al., 2008; Kurtais et al.,2008; O'Dell et al.,2007; Protas et al.,2005; Toole et al.,2005). In the animal research arena, rodent models of Parkinson disease have been created using neurotoxins such as 6-OHDA (6-hydroxydopamine) and MPTP (1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine). These animal models allow preclinical manipulation of neural and behavioral signs of PD, as well as environmental and treatment variables in a systematic

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fashion. This review will cover the findings of studies of targeted physical exercise in human populations for Parkinson disease and discuss clinical implications from animal models.

We define targeted physical exercise, or targeted training, as the systematic, repeated and controlled activation of particular groups of muscles for particular sequences of goal-directed actions. The elicited behavior should closely represent the desired movement sequence. In other words, if improved motor function is the training goal, then targeted training may optimally involve activation of muscle groups for the particular movement sequences required for that function. For Parkinson disease, where a primary neural substrate is dopamine deficiency within the basal ganglia, the theoretical basis for targeted training is clear. First and foremost, there is evidence that the basal ganglia are somatotopically organized, as evidenced by segregation of leg, arm and face areas (Alexander and DeLong,1985a; Alexander and DeLong,1985b; Crutcher and Delong,1984; DeLong et al.,1986; Gerardin et al.,2003; Miyachi et al.,2006; Romanelli et al.,2005). As such, there may be limited expectation that exercise training of muscle groups uninvolved in the target action will generalize to improved sensorimotor control of the target movement sequence. Second, the classic motor deficits found in patients with Parkinson disease, such as poverty of movement, are manifested to different degrees within a particular patient based on the task performed (Connor and Abbs,1991; Gordon,1998). That is, the context of the movement matters, even within a prescribed set of muscle activations. If degree of motor impairment is variable based on task, as has been shown empirically, (Connor and Abbs, 1991) it follows that a particular task should be used in therapy to encourage improved performance of that task.

Importantly, animal studies have suggested that use of targeted training may reverse or slow disease progression (Anstrom et al.,2007; Cohen et al.,2003; Smith and Zigmond,2003; Tillerson et al.,2001). For example, in unilateral 6-OHDA models, rats show deficits in forelimb use (Allred et al.,2008; Calne and Zigmond,1991; Schallert et al.,2000) but forced use of an impaired forelimb yields behavioral sparing of that limb and may prevent the degeneration of dopaminergic neurons when training is initiated before or early enough after introduction of the neurotoxin (Anstrom et al.,2007; Cohen et al.,2003; Tillerson et al., 2001). However, if initiation of intervention is delayed by 7 days, then the effect is not apparent or as robust (Tillerson et al.,2001; Tillerson et al.,2002). Thus, since this behavior (forelimb use) is vulnerable to altering dopaminergic synaptic transmission and is rescued by targeted training, it seems reasonable that targeted training may involve enhanced activity of dopamine or related systems.

The benefit of targeted training has been demonstrated in the appendicular system of humans. (Dibble et al.,2006; Farley and Koshland,2005) These training regiments incorporated multiple repetitions, a focus on intensity of movement, and complexity of tasks, as these elements contribute to neuroplasticity and brain reorganization in animal models of PD. (Fisher et al.,2004) Specifically, Farley and Koshland, 2005 found that multi-repetition, high amplitude reach training increased arm reach amplitude and speed in PD subjects. This evidence suggests that targeted training is a promising treatment of Parkinson disease in humans.

In general, exercise has been shown to improve motor performance (Miyai et al.,2000; Sunvisson et al.,1997), to increase daily activity (Miyai et al.,2000), and to decrease mortality.(Kuroda et al.,1992) Regular exercise may even delay the appearance of parkinsonian features in people diagnosed with PD(de Goede et al.,2001; Tsai et al.,2002). However, given the potentially beneficial effects of regular exercise on PD, it may seem surprising that exercise is not a standard component of therapy for PD. Of course, controlled studies should be carried out to confirm and determine optimal treatment strategies. Studies have shown that persons with PD actually reduce their level of physical activity, and only 12-15% of diagnosed individuals with PD are referred to physical therapy for an exercise intervention (Goodwin et al.,2008; Thacker et al.,2008). Further, deficits involving the cranial sensorimotor system (i.e.,. swallowing, facial expression, voice, and/or speech production) have a devastating impact on quality of life, yet only 3-4% of people with PD receive treatment from a speech-language pathologist (Trail et al.,2005). Perhaps this is because specifics on *how* to exercise the cranial sensorimotor systems to treat the myriad of symptoms affecting voice and swallow with PD is under-studied. Accordingly, in this paper we review the scientific evidence for targeted training in the cranial sensorimotor system with regard to treatment of voice and swallow deficits.

Systematic Review of the Clinical Literature Concerning Targeted Therapy

To identify relevant articles for inclusion in this review, a comprehensive search was undertaken involving four electronic databases: Pubmed (1980 to June 2009); Cinahl (1982 to June 2009); Web of Knowledge (1965 to June 2009); and Cochrane Library (1980- to June 2009). The following keywords were used in combinations: Parkinson's disease, Parkinson's disorder, swallowing, deglutition, dysphagia, therapy, exercise, exercise therapy, voice, voice disorder, task-specific, targeted-training, dopamine. Abstracts were reviewed and papers in English language were retrieved that reported primary research involving exercise as a treatment intervention of voice and swallow of people with PD. No restrictions were placed on study design. There were no limitations on disease duration or disease severity. In addition subjects of all ages were included. As papers were read, ancestral searching was used by examining reference lists for relevant studies.

A study was included if it met the following criteria: (1) The target population was people with PD; (2) The effects of an exercise/physical activity on voice and swallow were evaluated. Examples include Lee Silverman Voice training (LSVT) and swallowing exercises; (3) The outcomes included at least one of the following measures: phonation time, vocal intensity, vocal quality, swallow, swallow reflex, and aspiration; and (4) The paper was available in English. A study was excluded if: (1) The study included other treatment strategies such as deep brain stimulation and cueing strategies, and (2) The study included patients with neurological diseases other than PD.

General Findings

The search process identified 20 research articles concerning training therapy for voice and swallow in PD (Table 1). The following data were summarized: the number, sex and age of the patients, the state of the disease, the measures used, the kind of intervention used, and the study's outcomes. Nineteen of the twenty articles included targeted training therapy for voice, while five of the nineteen articles also included a non-targeted therapy (i.e., respiratory exercise therapy) as a control for voice. However, three articles were identified as using targeted training therapy for voice and included a swallowing parameter as one the outcomes (therefore was considered targeted therapy *related* to swallowing). There was only one article identified with targeted training for swallowing. Finally, there was one article that is included in Table 1 that used expiratory muscle training to improve swallowing outcomes that is also *related* to swallow training.

Voice Training

Most targeted training in the voice literature pertained to LSVT, with 13 of the 20 articles using this type of intervention (Baumgartner et al.,2001; Cannito et al.,2008; de Swart et al., 2003; El Sharkawi et al.,2002; Liotti et al.,2003; Narayana et al.,2009; Ramig et al.,1995;

Ramig et al.,1996; Ramig et al.,2001a; Ramig et al.,2001b; Sapir et al.,2002; Sapir et al., 2007; Spielman et al.,2007). Seven of the publications that comprised the 13 total LSVT articles were based upon two larger studies (Baumgartner et al.,2001; Ramig et al.,1995; Ramig et al.,1996; Ramig et al.,2001a; Ramig et al.,2001b; Sapir et al.,2002; Sapir et al., 2007). LSVT uses targeted training of the voice and an intensive therapy paradigm with multiple repetitions, a focus on intensity of movement, and sensory recalibration of effort of movement. LSVT leads to increased vocal intensity and improved vocal fold adduction and measures of respiration (Ramig et al.,1995). Follow-ups to this study demonstrated that vocal intensity was sustained at 12 and 24-months post treatment (Ramig et al.,1996; Ramig et al.,2001a). Cerebral blood flow measures show that LSVT causes a shift in cortical activity to the right hemisphere and which is more representative of a healthy state (Liotti et al.,2003; Narayana et al.,2009).

Two studies focused on training control of respiration and pitch variations that resulted in increased vocal intensity (Johnson and Pring,1990), and improvements in vocal quality, articulation, and intelligibility (Robertson and Thomson,1984). One targeted training method used a pushing technique to increase effort and therefore increase glottal closure to produce a louder more resonant voice (de Angelis et al.,1997). This training was effective in improving laryngeal airflow, valving and increasing vocal intensity during phonation (de Angelis et al.,1997). However, none of these studies measured functional voice changes or the duration that therapeutic effects lasted after treatment. From these studies it is unknown whether the specific targeted training techniques led to functional and long-term improvement to voice.

Investigations into music therapy, which we considered to be *related* to voice targeted training, have found improvements in vocal intensity, maximal sustained phonation, and intelligibility (Di Benedetto et al.,2009; Haneishi,2001). Voice choral singing therapy (VCST) increased measures of respiratory volumes and pressures and reduced vocal fatigue but no significant improvements in functional measures of vocal quality were found. Therefore, although singing therapy improved respiratory parameters, there was a lack of transference to improvements in vocal quality. Long-term effects of this type of treatment were not evaluated.

Respiratory exercise therapy (RET) was the most widely identified targeted training approach for a subsystem related to voice.(Baumgartner et al.,2001; Ramig et al.,1995; Ramig et al.,1996; Ramig et al.,2001a; Sapir et al.,2002) Treatment was found to increase vocal intensity, and maximal sustained vowel phonation.(Ramig et al.,1995) However, the treatments were not sustained during follow-up at 12 and 24 months.(Ramig et al.,1996; Ramig et al.,2001a) In addition, RET did not improve functional vocal quality (Baumgartner et al.,2001; Sapir et al.,2002).

Swallow Training

Studies to determine the effects of swallowing training in patients with PD are sparse (El Sharkawi et al.,2002; Nagaya et al.,2000; Pitts et al.,2009; Robertson and Thomson,1984). Specifically, only one article attempted targeted training of swallowing in PD by training patients for one 20 minute session of 5 different swallow-related exercises and measuring the duration of time from a visual cue to swallow to the first detected change in muscle activity in the submental region (Nagaya et al.,2000). A significant decrease in duration was observed after swallowing training. However, this study did not examine transference of the behavior to functional tasks or how long the treatment effects lasted.

Three specific methods of targeted training for systems *related* to swallowing including respiration, speech and/or voice have been shown to benefit swallowing. Expiratory muscle strength training (EMST) improved cough function and measures of airway compromise (Pitts et al.,2009). Intensive voice treatment (LSVT) led to improvement in oral tongue and tongue base movement during the swallowing that resulted in improvement in measures of swallow efficiency (El Sharkawi et al.,2002). In addition, intensive speech therapy led to improved swallow response time to solid food and liquid (Robertson and Thomson,1984). Although these treatments targeted different aspects of physiology and did not directly target swallowing, per se, they recruit many of the same muscles that are involved in swallowing. Therefore, the positive outcomes can likely be contributed to the recruitment of similar central and peripheral neural control elements during training. However, it is unknown whether these related training regimens provide any long-term beneficial effects for swallowing in PD patients.

Discussion

Our literature search of targeted training for parkinsonian voice and swallow deficits revealed 3 main findings: 1) targeted training is associated with lasting changes in voice behavior, 2) targeted training to systems that are *related* to (subserve or share similar muscles and nerves) voice and swallowing may improve voice and swallowing to some degree, but it is unknown whether these effects endure over time, and 3) evidence regarding cranial sensorimotor interventions for Parkinson disease is sparse. A commonality to the successful therapeutic interventions found in the review is that they employed task-specific training in an intensive manner to systems that serve or are related to voice and swallowing.

Targeted training is defined as the activation of a particular group of muscles in a task that closely represents the desired movement. For voice, training such as LSVT/LOUD employs voice-targeted tasks which may mediate beneficial transference and long-term carry-over for improved communication (Ramig et al.,1996; Ramig et al.,2001a). It is likely that the therapy that most closely resembles the desired behavioral outcome has a greater chance of transferring to that behavior. For example, when treating a swallowing disorder the most benefit may occur if the treatment involves targeted training of swallowing rather than an associated behavior, such as voicing. This concept was demonstrated in a study of electromyographic signals within a muscle that protects the airway during swallowing (i.e., the thyroarytenoid muscle in the larynx) during various tasks: voicing, valsalva, and swallowing (McCulloch et al.,1996). It is important to note, however, that evaluation of laryngeal muscle behavior during swallowing was performed in healthy participants and not part of a training paradigm. The magnitude of thyroarytenoid muscle contraction was the greatest for swallowing. Thus, the behavior that elicits the most functional closure of the airway during a swallow, therefore, is a swallow. Perhaps the task-specific target of speech and voice in LSVT leads to long-term functional changes in communication.

On the other hand, training voice and respiratory muscles also leads to improved swallow outcomes (Baumgartner et al.,2001; Pitts et al.,2009; Ramig et al.,1996). These findings may be explained by a “cross-systems” view (McFarland and Tremblay,2006). Muscles of voice and swallowing share many similar central and peripheral neural control elements as well as a cross-system interaction with respiratory functions (Kawasaki et al.,1964; McFarland and Lund,1993) that may interact with the target behavior. The idea of cross-system interactions is further supported by evidence for the co-occurrence of swallowing and voice/speech disorders within individuals (Martin and Corlew,1990; Nishio and Niimi,2004). Therefore, any training that would target one element of an oral-facial-laryngeal system may theoretically manifest beneficial effects across the entire cranial sensorimotor system. It is possible that the effects would be more robust if a targeted training paradigm was employed for swallow-specific tasks. Nevertheless, the findings demonstrate that target-specific training to voice, swallowing and/or systems that share or subserve the voice and swallow sensorimotor systems may be beneficial to parkinsonian deficits.

A question that remains unanswered from this review is *how specific* does the task need to be in order to show a positive behavioral change? That is, can exercise be employed in a general manner or does it need to be task specific? This has been partially addressed in the limbs with rodent models. In these models, there is some discrepancy as to the benefits on both brain function and behavioral outcomes with general exercise, such as treadmill running and environmental enrichment. Some studies show treadmill or wheel running leads to neurogenesis, angiogenesis, increased neurotrophic factors, and increased levels of nigrostriatal dopamine (Cohen et al.,2003; Faherty et al.,2005; Mabandla et al.,2004; O'Dell et al.,2007; Swain et al.,2003; Tillerson et al.,2003; van Praag et al.,2005), improves limb deficits and can protect against striatal dopamine loss following 6-OHDA lesions. (Cohen et al.,2003; Smith and Zigmond,2003; Tillerson et al.,2001). However, voluntary running and combinations of forced and voluntary running have not always shown apparent sparing of dopamine terminals or nigral tyrosine hydroxylase immunoreactivity even though behavioral recovery occurred (O'Dell et al.,2007). Thus, exercise can lead to behavioral recovery without neuroprotection in some instances. Inversely, treadmill running has also been shown to attenuate dopamine loss in the striatum, while not alleviating the locomotor deficits (Poulton and Muir,2005). Some of these discrepancies in the literature could be due to methodological differences, such as the amount and timing of exercise (Gerecke et al.,2010), but this controversy raises an important point. Perhaps with goal-directed and skilled movements, targeted training of dopamine-dependent movement may be required for consistent neuroprotective and positive behavioral outcomes and this may be true for the cranial sensorimotor system as well.

The body of animal research on exercise and neuroprotective effects suggests that animal models are an excellent way to examine the effects of targeted training on brain and behavior outcomes in PD. These models have the potential to be expanded to the vocalization and swallowing sensorimotor systems. Models of oromotor function have been used to study limb and oromotor skills in terms of feeding behavior among rat species (Whishaw et al.,1998) and in a rat model of stroke (Gonzalez and Kolb,2003). Oral and pharyngeal dysphagia have been assessed in murine models of amyotrophic lateral sclerosis (Lever et al.,2009). Tongue function associated with aging (Connor et al.,2009) and during altered dopaminergic synaptic transmission have been examined in rats (Ciucci and Connor, 2009; Fowler and Mortell,1992; Fowler and Das,1994). Unilateral infusions of 6-OHDA to the medial forebrain bundle leads to deficits in 50-kHz ultrasonic vocalizations (Ciucci et al.,2007; Clucci et al.,2009) and in the capacity to clear excessive saliva in rats (Schallert et al.,1978)(Tongue extension, biting strength and fine digit use also can be quantified in rats using simple and reliable methods (Allred et al.,2008; Whishaw et al.,1981) Thus, methods are available to test hypotheses regarding the effects of targeted training in animal models that can be easily translated to human clinical trials given appropriate study design, execution and careful interpretation of results.

Conclusion

A systematic review of the literature revealed that targeted training for voice and swallow is a promising but under-studied intervention for cranial sensorimotor deficits associated with Parkinson disease. Questions remain as to the nature of the exercise (task-specificity) and how this leads to long-term carry-over to functional tasks. Animal models afford the opportunity to explore some of the basic questions that remain largely unanswered in the human literature.

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Table 1

Results of identified articles for task-specific exercise for voice and swallow

Study	Design	Number Gender (M/F) Mean Age (yrs)	Disease State	Methods & Measures	Intervention	Outcomes
Robertson et al. 1984(Robertson and Thomson,1984)	Case Control **1** PD treated **2** PD not treated	n=18 (17/1) 63 years	NA	Phonation, Respiration, prosody articulation, swallowing	40 hours over 2 weeks. Intense speech therapy	Significant improvements in swallowing, phonation, articulation and swallowing following intense voice therapy
De Angelis et al. 1997(de Angelis et al., 1997)	Observational	n=20 63 years	H&Y : I-V	maximal phonation time, airflow	45 minute sessions × 13 over 4 weeks. Routine voice therapy	Increased maximal phonation times, airflow decrease and vocal intensity
Nagaya et al. 2000(Nagaya et al., 2000)	Case Control **1** PD **2** No PD	n=10 (5 / 5) +12 72 years	H&Y: III-IV	Flurography, EMG	one 20 min session 5 exercises for swallowing	Swallow training improved the initiation of the swallowing reflex in patients with PD and dysphagia.
Haneishi et al. 2001(Haneishi,2001)	Observational	PD (n=4) 73 years	NA	Vocal Intensity, Fundamental frequency, MVR, MDPh	60 minute × 12 or 14 over 4 weeks MTVP	MTVP was successful in increasing vocal intensity. There was also an increase in speech intelligibility.
deSwart et al. 2003(de Swart et al.,2003)*	Observational	n=32 (17/15) 60 years	NA	Loudness, Pitch, Duration, Jitter	one 30 min session LSVT & PLVT	Both treatments produced the same increase in loudness, but PLVT limits an increase in vocal pitch and prevents a strained or pressed voicing.
Cannito et al. 2008 (Cannito et al.,2008)	Observational	1-male 67 years	NA	Harmonics & Intelligibility	60 minute sessions × 16 over 4 weeks LSVT	The speaker with PD produced more intelligible words and sentences following intensive voice treatment than preceding it.
Johnson et al. 1990(Johnson and Pring, 1990)	Case Control **1** PD treated **2** PD not treated **3** No PD, not treated	n= 16 (13/3) 64 years	NA	Vocal Intensity, fundamental frequency, pitch	10 × 1 hour over 4 weeks dysarthric speech whilst	Treatment group improved dysarthria and volume, range, and pitch relative to controls
El Sharkawi et al. 2002 (El Sharkawi et al.,2002)	Observational	n= 8 (6/2) 66 years	H&Y: II-IV	Videoflurograp hy & SPL	60 minute sessions × 16 over 4 weeks LSVT	Increased vocal intensity during prolonged vowel phonation and reading. LSVT improved the oral and

Study	Design	Number Gender (M/F) Mean Age (yrs)	Disease State	Methods & Measures	Intervention	Outcomes
						pharyngeal stages of swallowing.
Ramig et al. 2001 (Ramig et al.,2001b)	Case Control **1** PD treated **2** PD not treated **3** No PD not treated	n=14 (7/7) + 15 (7/8) + 14 (7 / 7) 68 years, 71 years, 70 years	H&Y: I-V	Vocal intensity (dB SPL)	60 minute sessions × 16 over 4 weeks LSVT	Voice intensity (dB SPL) improved in treated group by 8 dB post treatment and 6 dB at 6 month follow up.
Sapir et al. 2007 (Sapir et al.,2007)	Case Control **1** PD treated **2** PD not treated **3** No PD not treated	n=14 (7/7) + 15 (7/8) + 14 (7 / 7) 68 years, 71 years, 70 years	H&Y: I-V	Vocal Intensity (dB SPL) & vowel assessment	60 minute sessions × 16 over 4 weeks LSVT	Vocal intensity increased significantly with LSVT. Along improvements in the goodness of vowels
Sapir et al. 2002 (Sapir et al.,2002)*	RCT **1** PD treated **2** PD attention controls	n=35 (22/13) 64 years	H&Y: I-V	Voice loudness, Voice quality	60 minute sessions × 16 over 4 weeks LSVT & RET	Perceptual increases in loudness and voice quality are maintained after 1yr LSVT and wasn't with RET treatment.
Ramig et al. 2001 (Ramig et al.,2001a)*	RCT **1** PD treated **2** PD attention controls	n=33(21/12)	H&Y: I-IV	Vocal Intensity, Vocal fold adduction & Respiration	60 minute sessions × 16 over 4 weeks LSVT & RET	LSVT maintained vocal intensity and frequency after 24 months
Ramig et al. 1996 (Ramig et al.,1996)*	RCT **1** PD treated **2** PD attention controls	n=35 (22/13) 64 years	H&Y: I-IV	Vocal Intensity, Vocal fold adduction & Respiration	60 minute sessions × 16 over 4 weeks LSVT & RET	Only LSVT sustained improvement in vocal intensity after 12 months
Ramig et al. 1995 (Ramig et al.,1995)*	RCT **1** PD treated **2** PD attention controls	n=45 (26/19)	H&Y: I-IV	Vocal Intensity, Vocal fold adduction & Respiration	60 minute sessions × 16 over 4 weeks LSVT & RET	Both groups improved but LSVT improved by a greater amount
Narayana et al. 2009 (Narayana et al.,2009)	Observational	n=10 (8/2)	NA	CBF & vocal intensity (dB SPL)	60 minute sessions × 16 over 4 weeks LSVT	Vocal Intensity increased significantly with LSVT. LSVT treatment results in a

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Study	Design	Number Gender (M/F) Mean Age (yrs)	Disease State	Methods & Measures	Intervention	Outcomes
						shift in cortical activity to the right hemisphere.
Lioti et al. 2003 (Liotti et al.,2003)	Case Control **1** PD **2** No PD	n=5 (4/1) + 5 (2/ 3) 61 years	H& Y: II-III	cerebral blood flow, voice level	60 minute sessions × 16 over 4 weeks LSVT	Effective improvement of IPD hypophonia following voice treatment with VT was accompanied cerebral blood representative of healthy condition.
Spielman et al. 2007 (Spielman et al.,2007)	Observational	n=15 (10/5)	II-III	Vocal Intensity	60 minute sessions × 16 over 8 weeks LSVT –X	Significant increase in vocal intensity (dB SPL) pre and post treatment. No difference from traditional 4 week LSVT program. No difference after 6-months
Baumgartner et al. 2001 (Baumgartner et al., 2001)*	Case Control **1** LSVT **2** RET	n=20 (16 /4) 66 years	H&Y II-IV	Perception of hoarseness & Breathiness	60 minute sessions × 16 over 4 weeks RET & LSVT	LSVT significantly improved hoarseness and breathiness but not RET.
Pitts et al. 2009	Observational	n=10 (10/0) 73 years	H&Y: II-III	Videofluroscop y &PEMAX	EMST 5 sets of 5 breaths (25) × 20 sessions over 4 weeks	Significant increase in PEMAX following training. Significantly decreased the P/A scores
Di Benedetto et al. 2009(Di Benedetto et al., 2009)	Observational	n=20 (13/7) 66 years	H & Y: I-III	FRC, MIP, MEP, MDPh	VSCT Speech therapy:60 minute sessions × 20 over 10 weeks Choral singing: 2 hrs sessions × 13 over 13 weeks	VCST significantly improved FRC, MIP, MEP, MDPh in patients with PD

LSVT, Lee Silverman Voice Training; MTVP, music therapy voice protocol; PLVT, pitch limiting voice treatmen; H&Y, Hoehn & Yahr's disability scale; VCST, Voice and Choral Singing Treatment; FRC, functional residual capacity ; MIP, maximal inspiratory pressure; MEP, maximal expiratory capacity; MDPh, maximal sustained vowel phonation; PEMAX, maximum expiratory pressure; P/A, penetration aspiration; SPL, sound pressure level; CBF, cerebral blood flow.