

Respiratory Strength Training: Concept and Intervention Outcomes

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ABSTRACT

Respiratory muscle strength training (RMST) focuses on increasing the force-generating capacity of the inspiratory and expiratory muscles. The choice of respiratory muscles that are targeted using RMST depends on the outcome desired. For example, if an individual has reduced inspiratory muscle strength due to a neurogenic injury and is unable to ventilate the lungs, then inspiratory muscle strength training may be the chosen rehabilitation target. On the other hand, if a professional voice user is complaining of difficulty generating adequate vocal loudness during song production and is suffering from laryngeal dysfunction, then an expiratory muscle strength training paradigm may be the chosen rehabilitation target. Our most recent work with RMST has focused on increasing expiratory muscle force generation for those with Parkinson's disease who have difficulty with breathing, swallowing, and cough production. This difficulty typically worsens as the disease progresses. Highlights of these outcomes are summarized in this article.

KEYWORDS: Respiratory, strength, training

Learning Outcomes: As a result of this activity, the reader will be able to (1) describe the mechanisms associated with respiratory muscle strength training, and (2) define the outcomes of respiratory muscle strength training for persons with Parkinson's disease.

RESPIRATORY MUSCLE STRENGTH TRAINING CONCEPT

In 2004, McConnell and Romer¹ reviewed the rationale for specific respiratory muscle training

as well as several techniques used to accomplish respiratory muscle strength training (RMST), such as resistive loading and pressure threshold loading. The conclusions from this literature

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review supported the use of RMST as a treatment modality for respiratory muscle fatigue and improved exercise performance. Through the use of appropriate methods tested using randomized clinical trials in addition to the selection of valid and sensitive outcome measures, RMST has been transferred to many populations including those with chronic obstructive pulmonary disease, spinal cord injury, multiple sclerosis (MS), Parkinson's disease, sedentary elderly, and others.²⁻¹⁶ RMST continues to be investigated for its effects on breathing, with new applications to functions such as swallowing and cough production.^{9,17} Additionally, RMST has been used as preventative exercise in the elderly¹⁸ and as a mechanism for strengthening respiratory muscles in vocal performers and instrumentalists.¹⁴

Motor exercise paradigms like RMST, both inspiratory (IMST) and expiratory (EMST), require appropriate selection of intensity and duration of treatment. The prescribed duration for each of these treatments is based on knowledge adapted from the exercise physiology literature, indicating that muscular (or myogenic) changes and central (central to the nervous system) changes are greatly influenced by the amount of exercise performed over time. Thus, these treatments are often delivered over a period ranging from 4 to 8 weeks, 3 to 5 days per week, and one to three sessions per day. Within a daily session, 25 to 30 repetitions are typically completed.^{4,8,16,19,20}

The RMST treatment paradigm incorporates intensity levels designed to augment muscle strength, and thus targeted muscle groups may benefit from improved force-generating capability. It is the improved force-generating capacity that acts as a platform for improved breathing and cough production. Use of RMST, specifically EMST, for the improvement of swallow function relies on cross-training of the submental musculature as discussed by Wheeler et al.²¹ Some results of EMST on swallow function are covered here, but more detail can be found in Pitts et al,⁹ Troche et al,¹⁷ and Wheeler et al.²²

Quantifying increased force generation of the respiratory muscles can be done by measuring maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP). MIP

and MEP increase significantly with both IMST and EMST protocols for the inspiratory and expiratory muscles, respectively.² Strength training paradigms are not limited to respiratory muscles as training paradigms are also effective with skeletal muscle types.²³⁻²⁵ Clearly, strength gains achieved with concisely prescribed exercises, sustained over time, impact physiological and functional measures. Based on study findings of RMST specifically,^{2,5,7,9,17} it is likely that 2 weeks of treatment, delivered three to five times per week, should be recommended with reasonable expectation for improvement. Additionally, the development of a maintenance program is necessary to prevent detraining effects common to the cessation of strength training protocols (e.g., Baker et al,² Clark et al,²⁴ and Henwood and Taaffe²⁶).

Our work on RMST has most recently focused on EMST, and the primary outcomes in Parkinson's disease will be reviewed here. Recently, other research groups have used IMST to examine the physiological impact on amyotrophic lateral sclerosis,²⁷ with results suggesting a slowing respiratory function. A 10-week IMST program resulted in significantly increased inspiratory muscle strength. Generalized improvements in expiratory pulmonary function in participants with MS have been reported in those with minimal to moderate disability.²⁷ Finally, Chiara et al⁵ showed that EMST resulted in positive changes to breathing and cough production in persons with MS of similar disability levels.

RMST EFFECTS ON MAXIMUM EXPIRATORY PRESSURE FOR THOSE WITH PARKINSON'S DISEASE

Many individuals with Parkinson's disease suffer from obstructive or restrictive pulmonary disease,²⁸⁻³⁰ with MIP and MEP reduced by over 50%. The restrictive component of the disease is thought to be influenced by reduced respiratory muscle strength and by increased chest wall rigidity.²⁹ Given that persons with Parkinson's disease often succumb to pulmonary sequelae and pulmonary dysfunction at all stages of disease, management of pulmonary

compromise is a top management priority throughout the disease progression.^{28,31–35} There is mounting evidence suggesting that EMST improves ventilatory function in persons with neurodegenerative disease.^{5,7,11,12} As described above, the respiratory muscles respond well to strength training.^{5,7,11–13,15} EMST improves respiratory muscle pumping force capacity, which is important in ventilation. In fact, pilot testing revealed a 158% improvement in MEP with EMST training,¹⁰ suggesting that EMST is a viable treatment option targeting expiratory muscles and could also result in improvement to pulmonary function. We completed a 4-week randomized clinical trial testing the effects of EMST, a device-driven treatment to target increased force activation of the expiratory muscles on MEP and pulmonary function in those with Parkinson's disease.

METHOD

Participants

Sixty participants with idiopathic Parkinson's disease were recruited from the University of Florida and Malcom Randall Veterans Affairs Medical Center Movement Disorders Clinics in Gainesville, Florida. Table 1 contains the participant demographic information. Parkinson's disease severity assessment occurred prior to inclusion in the study. All participants were kept in a stable medication state throughout the entire duration of the experimental protocol. Other inclusion criteria were: (1) age between 55 and 85 years; (2) moderate clinical

disability level (II to III)^{36,37}; and (3) score of at least 24 on the Mini-Mental State Examination.³⁷ Participants were excluded if there was presence of: (1) other neurological disorders; (2) gastrointestinal disease; (3) gastroesophageal surgery; (4) head and neck cancer; (5) history of breathing disorders or diseases; (6) untreated hypertension; (7) heart disease; (8) history of smoking in the last 5 years; (9) failing the screening test of pulmonary functions (e.g., forced expiratory volume in one second [FEV₁]/forced vital capacity [FVC] < 75%); and (10) difficulty complying due to neuropsychological dysfunction (i.e., severe depression). The University of Florida and Malcom Randall Veterans Affairs Institutional Review Boards (154–2003 and 195–2005) approved the study.

In line with the requirements of a prospective, randomized, placebo-controlled, clinical trial, participants were randomly assigned to an intervention group. All participants took part in a baseline assessment of MEP and pulmonary function. This assessment was followed by 4 weeks of EMST or sham intervention. The sham treatment used the same device that was used in the EMST treatment. It was visually no different than the EMST device, but it did not produce a pressure threshold load during its use. Participants trained with either the experimental or sham device with the same frequency per week and logged their training in the same manner. The treatment regimen consisted of five sets of five repetitions of this procedure, completed 5 days of the week.² Compliance for all participants, regardless of treatment assignment, was tracked by having

Table 1 Demographic Information by Treatment Group

Measure	Experimental (SD)	Sham (SD)	<i>p</i> Value
Age	66.73 (8.90)	68.50 (10.31)	0.480
Sex	25 M, 5 F	22 M, 8 F	0.356
Hoehn and Yahr	2.67 (0.48)	2.75 (0.60)	0.554
UPDRS III Motor			
(total)	39.44 (9.15)	40.04 (8.51)	.404
Pre	38.92 (8.11)	41.50 (10.29)	.293
Post	1.74 (0.66)	1.86 (0.52)	.870
UPDRS III	1.71 (0.86)	1.88 (0.43)	.331
(Speech Pre Post)			

SD, standard deviation.



Figure 1 Photograph of expiratory muscle strength trainer used in referenced studies.

participants keep a log of their success. A simple check mark on a form indicated the days they trained and the number of trials they completed each day. Following completion of the treatment arm, participants returned for a postintervention assessment.

Training

As described previously,^{7,9,10,12,17} the experimental training program used a calibrated, one-way, spring-loaded valve to mechanically overload the expiratory muscles (see Fig. 1). Prior to the training phase, each participant was shown how to use the device. To use the device (whether experimental or sham), nose clips

were put in place and participants were cued to take a deep breath, hold their cheeks (to reduce labial leakage), and blow as hard as they could into the device (see Fig. 2). Once the participant recognized that air was flowing freely through the device and they had reached threshold pressure, they were verbally cued to stop expiring. This training time took approximately 10 minutes and all participants demonstrated an independent ability to use the device to the clinician prior to being sent home with the device.

During the training phase of the study, participants were visited weekly at their homes by a clinician. The clinician spent ~20 minutes with the participant during the weekly visit to



Figure 2 Posture when using the expiratory muscle strength trainer to facilitate an increase in maximum expiratory pressure.

review the training protocol and answer questions. The same clinician completed all of the home visits, regardless of the treatment group. The time spent in the weekly visits varied minimally across participants. At the weekly visit, measures of MEP for assessment of expiratory muscle strength were made, and the EMST or sham device was set to 75% of the participants' average MEP. If the MEP increased or decreased from the previous week, the device was reset. If the MEP remained the same, the device setting remained the same. For the sham group, MEP never increased for any participant. Because the participants were blinded to group membership, the clinician "reset" the device at the weekly meeting to a higher setting, thereby deceiving the participant to believe they were improving with training.

Baseline/Post-Training Visits

During baseline visits, participants completed the measures of MEP and pulmonary function. The same protocol was completed following (post) training. All participants were consistently tested 1 hour after taking their medications to help ensure optimal medication activity for both the pre and post measurements. All participants verbally reported feeling "on" their medications. Detailed description of procedures used at assessment visits follows.

Maximum Expiratory Pressure

MEP was obtained using a standardized protocol at each assessment interval. Participants were instructed to stand and occlude the nose with nose clips provided for the study. Measurements of MEP were made using a pressure manometer (FLUKE 713-30G [Fluke Corp., Everett, WA]), which was coupled to a mouthpiece via 50-cm, 2-mm inner-diameter tubing, with an air-leak created by a 14-gauge needle. Once the mouthpiece was in place, the participants were instructed to inhale as deeply as possible and blow into the tube quickly and forcefully. Participants completed this task until three values within 5% of each other were achieved. The average of these three values was considered the participants' average MEP

score. The average score was used by the clinician to set the EMST device for training.^{2,5,7,9}

Pulmonary Function Tests

All participants completed a minimum of three standard pulmonary function test trials utilizing Spirovision 3+ (Futuremed, Granada Hills, CA). The maximum value of the three trials was used as the measure. The main pulmonary function outcome measures included FVC (in liters), FEV₁ (in liters), peak expiratory flow (in liters per second), and computed FEV₁/FVC. All testing was completed with participants seated upright and with nose clips in place.

Analysis and Methods

The individuals who gathered these data were unaware of participants' group assignment. Descriptive statistics characterize the demographics of each intervention group. Treatment effect was analyzed utilizing a repeated-measures analysis of variance (ANOVA), with time (two levels: pre and post) as the within-subjects variable and group (EMST and sham) as the between-subjects variable. The primary outcome variable was MEP for the EMST versus sham groups. Secondary outcome variables included pulmonary function measures compared across the EMST versus sham groups

RESULTS

Table 2 contains the means and standard deviation data for the dependent variables as a function of treatment group pre- and post-training. A repeated-measures ANOVA tested the effects of EMST on MEP by intervention group. A significant time by group interaction ($F = 24.23$, $p < 0.01$) was found when comparing the experimental and sham groups post-treatment. There was no difference in the baseline characteristics of the EMST group compared with the sham treatment group ($F = 1.383$, $p = 0.901$). However, after 4 weeks, the active treatment group had a significantly greater MEP than the sham group ($F = 3.214$, p

Table 2 Mean (SD) Values for the Experimental versus Sham Groups for Each Outcome Measure

	Experimental		Sham	
	Pre	Post	Pre	Post
MEP	105.29 (28.81)	133.26 (35.53)	103.65 (24.82)	99.23 (27.46)
PFT				
FEV ₁ /FVC	77.09 (4.53)	76.91 (4.42)	77.03 (5.50)	77.09 (5.88)
FVC (L)	3.64 (0.96)	3.65 (0.96)	3.20 (0.78)	3.23 (0.78)
FEV ₁ (L)	2.80 (0.71)	2.81 (0.75)	2.47 (0.63)	2.58 (0.85)
PEF (L/s)	7.33 (1.67)	7.44 (1.79)	6.61 (1.81)	6.55 (1.80)

MEP, maximum expiratory pressure (cm H₂O); FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; PEF, peak expiratory flow; PFT, pulmonary function test; SD, standard deviation.

< 0.01). MEP significantly improved following EMST in the active treatment group ($t = -4.993$, $p < .01$), but not for the sham group ($t = 1.463$, $p = 0.154$).

Secondary outcome of the pulmonary function tests were also assessed using a repeated-measures ANOVA with a within-subject factor of time and between-subject factor of intervention. Dependent measures included: FEV₁/FVC, FVC, FEV₁, and peak expiratory flow. There was no significant main effect of time, and there were no significant time by intervention group interactions for any of the pulmonary function outcomes.

DISCUSSION

The results of this study support the hypothesis that a 4-week expiratory muscle strength training paradigm targeting increased MEP was functionally effective in Parkinson's disease. Participants in the EMST group demonstrated a 27% increase in MEP on average, and persons in the sham group averaged a 4% decrease in MEP. Importantly, EMST targets the development of active expiratory pressure. Increased MEP reflects the increased and voluntary control of the expiratory muscles, generating the force critical for adequate ventilation and airway defense. Note that the potential effect of EMST on pulmonary function may be limited by the degree of change that can be obtained in expiratory flow rates because the resistance of the airways actually limits airflow in an effort-independent manner reference. Although the individual airway resistance increases as the airway diameter decreases, the total resistance decreases because of the large increase in

surface area of the airways. The smallest airways, the bronchioles, are surrounded by smooth muscle but because they do not contain cartilage, they are susceptible to collapse with an external compressing force. Likewise, the cartilaginous airways are not fully collapsible as are the bronchioles, but will decrease their diameter in response to an external compressing force.

So although it appears that EMST may not modify lung volumes and maximal expiratory airflow rates, it does positively increase MEP. In addition, cross-system effects on functions less task-specific to EMST have been recorded and seem to be particularly related to airway defense mechanisms. Results from studies of EMST in have observed improvements in both swallow function and cough function.⁹ Following 4 weeks of training, persons who trained with the EMST device had a reduced incidence of aspiration/penetration and an increased peak expiratory flow as compared with the sham group.^{9,17} Thus, although EMST does not alter lung mechanics, it does improve expiratory muscle function and may prove critical to protecting the lung from aspiration-related pulmonary complications.

More specifically, our research group analyzed acquired swallow function data in this same participant pool following the 4 weeks of the EMST program. The results showed a significant improvement in swallow function. The data strongly supported the hypothesis that those trained with the EMST device would perform superiorly to a sham EMST device treatment group in physiological measures of swallow function. The most important

finding of this study was the significant reduction in the primary outcome variable of Penetration-Aspiration (P-A) score³⁸ pre- to post-EMST treatment compared with sham treatment.¹⁷ Improvements in P-A score reflect a reduction in the presence of penetration/aspiration events, a finding with potentially critical implications for aspiration risk, which is the leading cause of death in Parkinson's disease.^{39–41} Also, the EMST group maintained the duration of hyoid elevation over time, and the sham group experienced a decreased duration. Therefore, the mechanisms underlying the improvement in P-A score with EMST are likely rooted in physiological changes in the actual swallow. The EMST group maintained the duration of hyoid excursion, increased hyoid displacement at the three key swallow events, and also maintained coordination of events over the 4 weeks of treatment.¹⁷

Finally, we have been studying the effects of EMST on voluntary cough function. Cough plays an important role in expelling foreign substances, or excessive mucus, from the intrathoracic airways through the production of forced expiratory airflows.^{40,42–45} Cough is intricately controlled by coordinated activity of various respiratory muscles. The inspiratory muscles contract to increase lung volume

needed to augment the high velocity of expiratory flow. The vocal folds adduct to allow for the buildup of tracheal pressure, during which the expiratory muscles contract to build up high positive intrapleural and intra-airway pressures for development of peak expiratory flow rates.^{43,46} Weakness of the inspiratory or expiratory muscles greatly affects an individual's ability to generate the forces essential for cough, decreasing the airway pressure critical for generating the essential cough expiratory airflow rates and velocity. Impaired airway clearance leads to recurrent chest infections and respiratory deterioration particularly in individuals with neurodegenerative disease processes.^{40,45,47–49} Assessment tools are available to measure the different aerodynamic and physiological components of cough. Cough is a separate and distinct measure of airway protection, providing additional diagnostic information to the measures of swallow function briefly discussed earlier. Swallow measures are commonly employed to determine an individual's ability to protect the airway during eating. However, should an aspiration event occur, cough measures assess the *corrective* means of the system. Measures of voluntary cough production complement measures of swallow function and assist in defining swallow safety pre- and posttreatment(s).

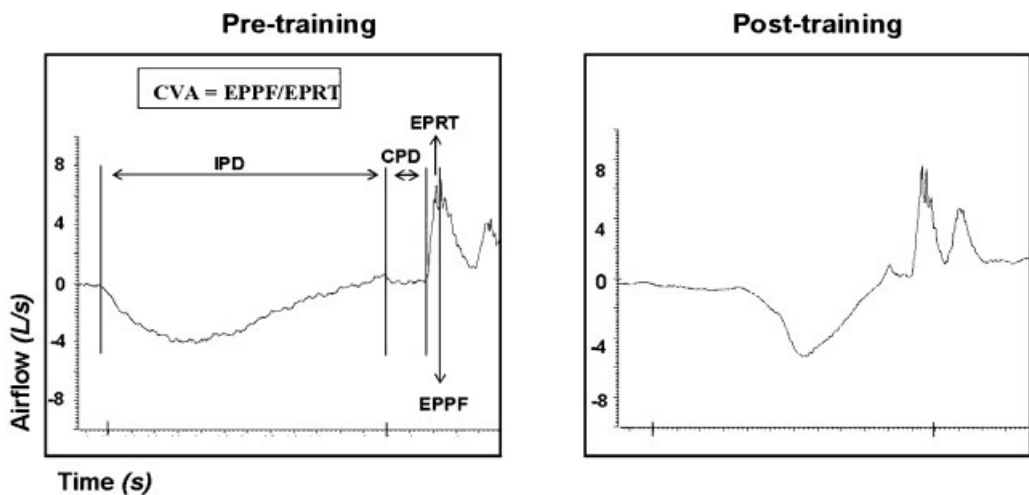


Figure 3 Examples of airflow waveforms during a voluntary cough task from pre-EMST to post-EMST. IPD, inspiratory phase duration; CPD, compression phase duration; EPRT, expiratory phase rise time; EPPF, expiratory phase peak flow; CVA, cough volume acceleration; EMST, expiratory muscle strength training.

We have completed studies using EMST to improve cough airflow production.^{9,17} This work has been completed in individuals with Parkinson's disease. The results demonstrate that following 4 weeks of EMST, there was a significant decrease in the compression phase duration and expiratory rise time as well as a significant increase in the cough volume acceleration (Fig. 3). Cough volume acceleration is an indirect measure of a cough's effectiveness. This coupled with a significant decrease in P-A scores after the 4 weeks of EMST implies that the training protocol may be a viable one for individuals "at risk" for aspiration.

CONCLUSIONS

RMST represents the use of a short-term treatment that can be quantified and translated into functional outcomes that may directly improve functions related to breathing, cough, and swallow. The impact is high because its cost-effectiveness and its ability to minimize direct therapist time required to rehabilitate the deficits. Furthermore, because it was developed as a home-based program, RMST reduced the need for both clinical resources and travel time.

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