CHEST Original Research

COUGH AND ASPIRATION

Impact of Expiratory Muscle Strength Training on Voluntary Cough and Swallow Function in Parkinson Disease*

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Background: **Cough provides high expiratory airflows to aerosolize and remove material that cannot be adequately removed by ciliary action. Cough is particularly important for clearing foreign particles from the airway in those with dysphagia who may be at risk for penetration/aspiration (P/A). Expiratory muscle strength training (EMST) was tested to improve cough and swallow function.**

Methods: **Ten male participants, diagnosed with Parkinson disease (PD), with videofluorographic evidence of penetration or with evidence for aspiration of material during swallow of a thin 30-mL bolus, completed 4 weeks of an EMST program to test the hypothesis that EMST would improve cough and/or swallow function. Measured parameters from an airflow waveform produced during voluntary cough, pre-EMST and post-EMST, included inspiration phase duration, compression phase duration (CPD), expiratory phase peak flow (EPPF), expiratory phase rise time (EPRT), and cough volume acceleration (VA) [ie, the EPPF/EPRT ratio]. The swallow outcome measure was the degree of P/A during the swallow task.**

Results: **There was a significant decrease in the duration of the CPD and EPRT; the decrease in EPRT resulted in a significant increase in cough VA. Significant decreases in the P/A scores were found posttraining.**

Conclusions: **The results demonstrate that EMST is a viable treatment modality for a population of participants with PD at risk of aspiration.** ***(CHEST 2009; 135:1301–1308)***

Key words: airflow; cough; dysphagia; Parkinson disease; respiratory strength training

Abbreviations: CPD = compression phase duration; EMST = expiratory muscle strength training; EPPF = expiratory phase peak flow; EPRT = expiratory phase rise time; IPD = inspiration phase duration; P/A = penetration/aspiration; PD = Parkinson disease; PEmax = maximal expiratory pressure; VA = volume acceleration

Cough is a mechanism of airway clearance that adds to normal ciliary function.[1,2] Composed of three events, cough production contains an inspiratory effort that is followed by a rapid vocal fold adduction and a contraction of the expiratory muscles, including all abdominal muscles, with a majority of force production from the internal and external oblique muscles.[3–7] The dynamic narrowing of the airways and ballistic vocal fold adduction (via contraction of the thyroarytenoid and interarytenoid muscles) allows for the production of high expiratory airflow velocity. The high airflow velocity provides

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the force to aerosolize material and safely remove it from the lungs.[4,8] These events are followed by vocal fold opening to widen the glottis, releasing the high subglottic pressure.

Current treatments that have been promoted to assist airway clearance include postural drainage,[9,10] manually assisted cough,[2,11] incentive spirometry,[9,12] percussion and vibration (chest clapping/shaking),[2,13–15] a forced expiratory technique also known as *huffing*,[2] and an active cycle of breathing techniques.[9,16] Most of these training paradigms include forced expiratory maneuvers. Van Den Eeden et al[17] concluded that this forced expiratory maneuver is an effective component for airway clearance.

In those with Parkinson disease (PD), aspiration may occur during swallowing, potentially causing pneumonia,[3,18] a leading cause of death in the population with PD.[19–22] Given the high prevalence of morbidity and mortality due to aspiration in PD, treatments focusing on airway protection from aspiration while improving cough effectiveness are ideal.

Fontana et al[5] and Ebihara et al[3] reported significant decrement in cough function with PD, including decreased peak electromyogram amplitude of abdominal muscles during both reflexive and voluntary cough, and decreases in cough sensitivity necessary for activation of a reflexively induced cough. These changes represent the difficulty that the pulmonary and/or laryngeal systems may have reacting to and eventually removing foreign material from the airway. Furthermore, Pitts et al[23] demonstrated significant differences in the voluntary induced cough patterns of participants with PD who penetrated/aspirated compared with those with PD who did not. The cough pattern changes also were related significantly to the level of penetration/aspiration (P/A) during a 30-mL sequential swallow task.

Recently, the authors examined the use of expiratory muscle strength training (EMST) as a treatment for increasing maximal expiratory pressure (PEmax) generation. Evidence of its benefits following training comes from numerous studies, including persons with PD,[24–27] the sedentary elderly,[28] those with multiple sclerosis,[29,30] instrumentalists,[31] professional voice users,[32] and young healthy adults.[33]

EMST (EMST 150; Aspire Products; Gainesville, FL) uses a calibrated, one-way, spring-loaded valve to overload the expiratory muscles mechanically. The valve blocks the flow of air until a sufficient expiratory pressure is produced. Once the targeted pressure is produced, the valve opens, and air begins to flow through the device. The physiologic load on the targeted muscles can be increased or decreased depending on the device setting. When calibrated to a person's PEmax generation, the load can create a condition that results in peripheral adaptations to the muscle.[34–36]

By using the device to facilitate the development of greater PEmax values following training, the functional ability to develop higher expiratory airflows during cough should result. Preliminary evidence supporting this hypothesis comes from Chiara et al.[29,30] Compared with other positive expiratory pressure devices, the EMST device may provide additional benefits.[9,37] To achieve the preset pressure level and open the valve on the EMST device, the users must produce an isometric muscle contraction. With most other positive expiratory devices, the respiratory load is less, and the manner of the resistance allows users simply to alter their breathing in a compensatory manner to reach the target. The authors hypothesize that EMST operates by allowing task-specific training directed to the "ballistic nature" of voluntary and reflexive cough. This training activity may provide a major advantage in populations with diseases like PD who have difficulty performing high-velocity tasks.

It was hypothesized that the voluntary cough airflow pattern in those with PD with known P/A would improve significantly from pre-EMST to post-EMST. Specifically, the authors predicted that with training, there would be a decrease in the duration of the inspiratory and compression phases along with the expiratory phase rise time (EPRT) as measured from the cough airflow waveform. Additionally, the authors hypothesized that with training, there would be an increase in the peak expiratory flow and cough volume acceleration (VA) [a measure relating to the "shearing force" potential]. Third, it was hypothesized there would be a significant decrease in the P/A score, as measured from the videofluorographic examination of the sequential swallow (3 mL) task.

Materials and Methods

Ten male participants (60 to 82 years of age) with PD were included in the study. A neurologist who specializes in movement disorders, affiliated with the University of Florida Movement Disorders Center, provided the diagnosis of PD by UK Brain Bank Criteria, and he further provided the evaluation disease stage (Hoehn and Yahr scale, 1967). Only participants with midstage PD were used with Hoehn and Yahr scores between 2 and 3 (Table 1), and these participants had demonstrated videofluorographic evidence of P/A into the laryngeal vestibule during a thin 30-mL sequential swallow task. Participants were all oriented to person, place, and time, able to follow two- to three-step directions, and scored at least a 24 on the Mini Mental State Examination.[38]

All participants reported no history of being treated for pulmonary disease, stroke, tobacco use within the last 5 years, or a diagnosis of dementia as confirmed by neuropsychological testing. Review of the participants' self-reported medical history at the start of the study determined that all were on standard

Table 1—*Participant Demographics and P/A Scores Pretraining and Posttraining**

Participant	Sex	Age, yr	H & Y	P/A	
				Pretraining	Posttraining
1	M	72	3	5	3
2	M	77	2.5	5	2
3	M	72	3	3	3
4	M	74	3	5	5
5	M	78	2.5	8	1
6	M	70	3	3	2
7	M	77	3	2	1
8	M	82	3	7	5
9	M	67	3	3	3
10	M	60	3	5	2

*H & Y = Hoehn and Yahr score; M = male.

medications for treatment of PD, and none were taking any medications with a potential influence on cough production, such as codeine. All videofluorographic examinations and voluntary cough productions were sampled in a medication "on" phase. Medication "on" was defined as 60 min following the ingestion of the participants' medications. The institutional review board at the University of Florida approved the study (IRB No. 154–2003).

The participants completed one baseline session, trained with the EMST 150 device (Fig 1) for 4 weeks, and then they returned for a visit 1 week following completion of training. During the 4-week training period, the participants used the device 5 days per week at home, performing five sets of 5 breaths through the device for a total of 25 breaths per day. The sets were performed sequentially and at approximately the same time each training day for 4 weeks. The trainer was set at 75% of the participant's PEmax (discussed in task 2). The participants were provided with verbal and written instructions for the task.

Tasks

1. Videofluorographic examination of swallow. Participants were seated in an upright position and asked to swallow a 30-mL thin bolus (Varibar; E-Z-EM; Lake Success, NY) in a continuous manner. A qualified speech-language pathologist, blinded to the experimental condition, measured degree of P/A from the videofluorographic examination of the sequential swallow task using the P/A scale (Table 2).[39] The P/A scale is a standard measure developed and used by speech pathologists for the evaluation of pharyngeal dysphagia.[39–44] The judge had > 20 years of experience in dysphagia. All of the videofluorographic examinations were archived using the Digital Swallow Station (model 7200; Kay Elemetrics Corp; Lincoln Park, NJ).
2. PEmax. As an indirect measure of expiratory muscle strength, PEmax was determined for each participant. PEmax was measured using a pressure manometer (FLUKE 713-30G; Fluke Corporation; Everett, WA) coupled to a mouthpiece by a 50 cm × 2 mm inner diameter tubing, with an air leak achieved with a 14-gauge needle. Participants were asked to stand, a nose clip was used to occlude the nose, and they were then asked to breathe in to total lung capacity and blow hard into the tubing. Three measures of PEmax were made until three values were obtained within ± 5% of one another. The average of the three values was used as the average measure of PEmax.
3. Voluntary cough measures. Airflow produced during voluntary cough production was sampled using an oral pneumotachograph (MLT 1000; ADInstruments, Inc; Colorado Springs, CO), connected to a spirometer (ML141, ADInstruments, Inc.). A nose clip was used to occlude nasal airflow during the cough maneuver. The airflow signal was measured and digitized at 1 KHz and displayed using appropriate software (Chart, version 5, for Windows; Microsoft Corp; Redmond, WA). Each sample was low-pass filtered at 150 Hz within the program (*ie*, Chart software).

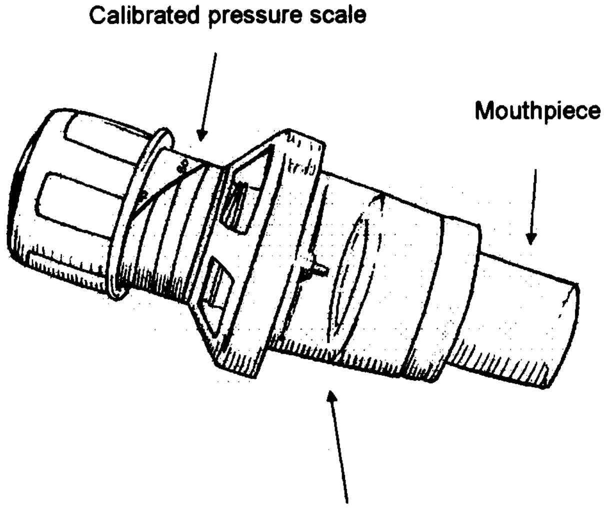

FIGURE 1. EMST device.

The instruction given to each participant included the following (1) relaxing and breathing into the pneumotachograph tube (held by the researcher); (2) following three tidal volume breaths, breathing deeply and then coughing hard; and (3) completing three trials of the voluntary cough.

The following measures were made from the cough flow waveform (Fig. 2):

1. Inspiration phase duration (IPD): the onset of inspiration, following tidal volume breathing, to the end of inspiration prior to the compression phase;
2. Compression phase duration (CPD): the time from the end of the inspiratory phase to the beginning of the expiratory phase;

Table 2—*P/A Scale Developed by Rosenbek et al*[39]

Score	Contrast	P/A
1	Contrast does not enter the airway	No penetration
2	Contrast enters the airway; remains above the vocal folds	Penetration
3	Contrast remains above the vocal folds with visible residue	Penetration
4	Contrast contacts vocal folds; no residue	Penetration
5	Contrast contacts vocal folds; visible residue	Penetration
6	Contrast passes glottis; no subglottic residue	Aspiration
7	Contrast passes glottis; visible subglottic residue despite response	Aspiration
8	Contrast passes glottis; visible subglottic residue; absence of response	Aspiration

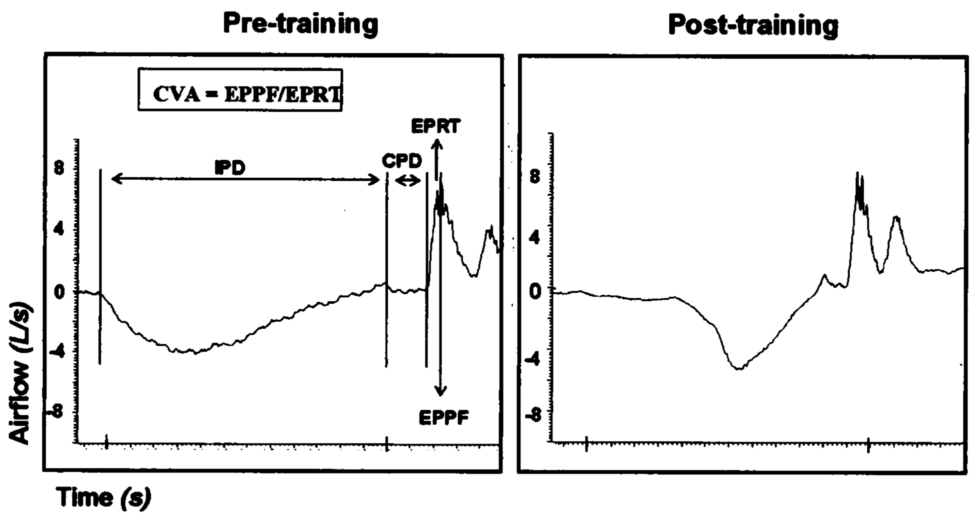

FIGURE 2. Examples of airflow waveforms during a voluntary cough task from group 1 and group 2. The vertical lines within the group 2 waveform denote the phases of the cough waveform as described in the text. CVA = cough VA.

3. Expiratory rise time (EPRT): the time from the beginning of the expiratory phase to the peak expiratory flow;
4. Expiratory phase peak flow (EPPF): the peak airflow during the expiratory phase of the cough; and
5. Cough VA: expiratory peak flow/EPRT.

Means and SDs were calculated from the three trials of the cough. Intrameasurer reliability was calculated on 100% of the data set for the assessment of P/A and 20% of the data set for the measures of the voluntary cough parameters. Pretraining and posttraining differences for P/A scores, PEmax, and the cough measures were tested using the Wilcoxon signed rank test. Significance was set at $p = 0.05$ for P/A score and PEmax but adjusted for the number of comparisons for the cough airflow waveform parameters using the Bonferroni correction procedure because significant relationships existed between the dependent variables ($p = 0.05/5 = 0.01$).

Results

Intrameasurer reliability for the P/A scores and the measurements made from the cough flow signals was assessed using intraclass correlation coefficients. The ratings were significant for reliability for the P/A scores ($\alpha = 0.56$; $p = 0.001$) and the measurements from the cough flow signals ($\alpha = 0.70$; $p < 0.001$).

Videofluorographic Evaluation of Swallow

P/A scores before and after training significantly decreased ($Z = 2.388$; $p = 0.01$) [Table 1].

PEmax

There was a significant increase in PEmax ($Z = 2.803$; $p = 0.005$) due to training. The mean PEmax before training was 108.2 ± 23.2, and the mean PEmax following training was 135.9 ± 37.5.

Voluntary Cough

Pretraining and posttraining differences were found for particular parameters of the cough waveform. Table 3[1] shows the means and SDs. There was a reduction (insignificant) in the IPD ($Z = 2.090$; $p = 0.04$). There was a significant reduction in the CPD ($Z = 2.803$; $p = 0.005$) and EPRT ($Z = 2.492$; $p = 0.01$) following the EMST training (Fig 3). Due to the decrease in EPRT, there was a significant increase in cough VA ($Z = 2.497$; $p = 0.01$) [Figs 3 and 4]. There was no significant training effect for IPPF ($Z = 1.376$; $p = 0.17$) or EPPF ($Z = 0.459$; $p = 0.65$).

Discussion

This study examined the effects of 4 weeks of EMST on voluntary cough function and the occurrence of P/A in a group of persons with PD. The overall effectiveness of the participants' voluntary cough increased, as indicated by the increase in cough VA, which relates to the ability of the cough to

Table 3—*Voluntary Cough Measures Pretraining and Posttraining**

Measure	Pretraining	Posttraining
IPD	1.02 (0.30)	0.75 (0.27)
CPD	0.32 (0.03)	0.15 (0.01)
EPRT	0.10 (0.04)	0.06 (0.03)
EPPF	6.54 (0.84)	6.77 (1.09)
Cough VA	80.63 (28.3)	165.35 (87.7)

*Values are given as the mean and (SD).

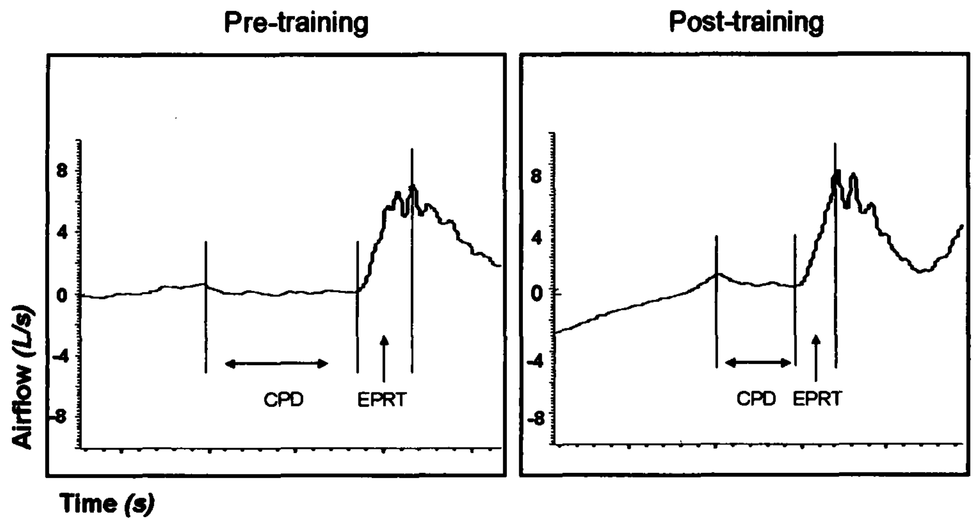

FIGURE 3. Portions of the cough waveform demonstrating differences in CPD and EPRT from before training to after training in one participant.

create shearing forces and remove unwanted material from the airway.[45] Specifically, CPD and EPRT, as measured from the voluntary cough airflow waveform, from before training to after training, significantly decreased. The significant decrease in the EPRT led to a significant increase in the cough VA. This may be due to the nature of the training task, which includes a short duration and isometric contraction of the expiratory muscles to generate the maximum pressure to open the pressure release valve on the device. Specifically, to complete a trial with the EMST device, participants were required to achieve 75% PEmax repeatedly on the trainer by producing an expiratory maneuver forcefully. If the task was performed at slower speeds, producing decreased force generation, an inadequate amount

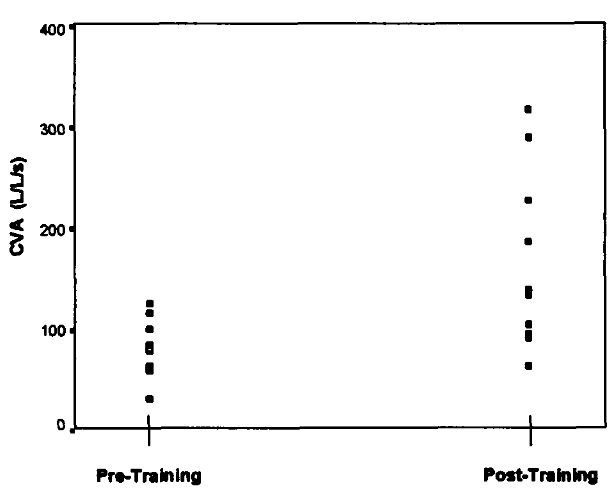

FIGURE 4. Cough VA differences from before training to after training.

of flow would result and the device's valve would not release. The release of the valve with air moving through the trainer is the signal that the trial was successful.

There was no significant increase in EPPF. Rather than simply examining cough magnitude, analysis of the cough pattern provides more information as to the viability of airway clearance because EPPF is highly dependent on pulmonary function[46] and not entirely on the participant's effort or strength.[47] Moreover, a productive cough relies on all three phases to generate the necessary pressures and an acceleration of the gases within the pulmonary system to achieve shearing forces. Pulmonary function testing revealed that 80% of the participants in this study presented with restrictive lung disease, which is well known in PD.[48,49] A post hoc comparison of pulmonary function before to after training revealed no significant training effect on the measures of pulmonary function FEV_1 ($t = -1.115$; $p = 0.29$) or FVC ($t = 1.702$; $p = 0.12$). Thus potential change in EPPF is limited by the restrictions of the pulmonary system regardless of the participant's effort.

The P/A scores, obtained from the videofluorographic examination of participant's 3-mL sequential swallow task, significantly decreased. P/A scores reflect a clinician's evaluation of the depth of material penetrated into the airway, and whether there is a cough or throat clearing response to assist in the removal of the material. Table 2 describes the defined criteria used for judging the degree of penetration or aspiration. For example, when P/A scores reach a value of 8, it indicates a severe degree of threat to the airway because the material has passed below the level of the vocal folds and was not removed with a reflexive cough. A decrease in the score from before to after training indicates a decrease in the severity of the material entering the laryngeal vestibule or airway, and this improvement hypothetically decreases participant risk.

Wheeler et al[50] describe the biomechanical events that occur with EMST beyond the exercise of expiratory muscles that could be contributing to reduced P/A scores, including increased vertical elevation of the hyoid bone via increased activation of the submental muscles. Vertical elevation of the hyoid bone is important for the pharyngeal phase of swallowing, and lack of coordination or muscle weakness in the submental group results in changes in laryngeal elevation and the opening of the upper esophageal sphincter, all leading to P/A of the bolus into the airway.[50–52] It is speculated that the decrease in the P/A scores is due in part to a strengthening of the submental muscles that are responsible for elevating the hyoid bone, and thus the larynx, which is necessary to close off the airway during the swallow.

Another possible mechanism for the change in the P/A scores after training is an increase in subglottic air pressure during the swallow. Various studies examining participants with tracheotomy tubes[53–55] demonstrate that closure of the tube during swallow results in a general decrease in the depth of penetration and/or aspiration of the bolus compared with a condition in which the tube was open. The current results demonstrated a significant increase in the PEmax from before training to after training, and this increase in respiratory pressure generation capacity could have assisted the participants in generating higher subglottal pressures during swallow. However, the amount of pressure needed during a swallow at tidal volume is very low. Gross et al[56] demonstrated (in one healthy participant) that a swallow at tidal volume uses approximately 2 cm H_2O. A swallow at total lung capacity requires approximately 7 to 10 cm H_2O. It may be that an increase in the magnitude of PEmax does not influence the generation of subglottal pressure needed during swallow in these participants but induces better coordination in generating subglottal pressure for the swallow task. Strength training, in general, alters the way in which motor units are recruited, the total number of motor units recruited, and the coordination of recruitment. These changes in neural activation are observed clinically not only as an improvement in force production but also in the coordination and precision of movement.[35,57]

In the future, it would be interesting to determine the relationship between P/A scores and timing events such as laryngeal course during swallow and how they relate to changes in voluntary cough pattern with EMST, particularly the relationship between laryngeal closure during swallow and laryngeal compression phase during cough. Wheeler et al[58] demonstrated that those with PD who had P/A produced a significantly later maximum laryngeal closure during a single 5-mL swallow. Unfortunately, voluntary cough was not measured in this cohort of participants.

One conclusion from the results could be that the positive effects were due to a practice effect. Early researchers believed that any therapeutic interventions focusing on speech or laryngeal function with PD would fail because of the progressive nature of the disease.[59,60] Sarno[60] studied > 300 PD participants attempting to develop methods to rehabilitate speech volume, facial mobility, speed of speech, and accuracy of articulation. He was able to demonstrate effects within a treatment session (which lasted 2 h). However, even with 2 h/wk for 6 weeks, he was unable to establish significant carryover effects to any of these areas. Later work done by Ramig et al[61] into PD demonstrated positive treatment effects when the participants were treated for 50 to 60 min four times a week, citing significant changes in speech including vocal loudness and articulation. Based on this prior literature, the evaluation time (1 h and then repeated 4 weeks later) does not meet the minimum time threshold to elicit a practice effect. Therefore a larger/longer research protocol would be necessary to achieve this effect.

Conclusion

This study demonstrates clear improvement in cough and swallow, as measured by P/A scores, following EMST training, and it shows it is a viable treatment option for participants with PD who are at risk for aspiration. Future studies should examine larger cohorts and also a more diverse group of participants, including those in different disease stages and of a different gender.

In future studies we aim to establish the relationship between P/A scores and timing events. These events may include the laryngeal course during a swallow and the relationship to changes in voluntary cough pattern with EMST. We are particularly interested in the relationship between laryngeal closure during swallow and laryngeal compression phase during cough. If findings from these studies can be related to delaying the morbidity and mortality from aspiration in PD and correlated with validated measures of quality of life, the EMST approach may be an appealing approach for participants with PD who exhibit evidence of aspiration.

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References

1 McCool FD. Global physiology and pathophysiology of cough: ACCP evidence-based clinical practice guidelines. Chest 2006; 129(suppl):48S–53S
2 McCool FD, Rosen MJ. Nonpharmacologic airway clearance therapies: ACCP evidence-based clinical practice guidelines. Chest 2006; 129(suppl):250S–259S
3 Ebihara S, Saito H, Kanda A, et al. Impaired efficacy of cough in participants with Parkinson disease. Chest 2003; 124:1009–1015
4 Fontana GA, Lavorini F. Cough motor mechanisms. Respir Physiol Neurobiol 2006; 152:266–281
5 Fontana GA, Pantaleo T, Lavorini F, et al. Defective motor control of coughing in Parkinson's disease. Am J Respir Crit Care Med 1998; 158:458–464
6 Mahajan RP, Singh P, Murty GE, et al. Relationship between expired lung volume, peak flow rate and peak velocity time during a voluntary cough manoeuvre. Br J Anaesth 1994; 72:298–301
7 Fontana GA, Widdicombe J. What is cough and what should be measured? Pulm Pharmacol Ther 2007; 20:307–312
8 Macklem PT. Relationship between lung mechanics and ventilation distribution. Physiologist 1973; 16:580–588
9 Pryor JA. Physiotherapy for airway clearance in adults. Eur Respir J 1999; 14:1418–1424
10 Tucker B, Jenkins S. The effect of breathing exercises with body positioning on regional lung ventilation. Aust J Physiother 1996; 42:219–227
11 Braun SR, Giovannoni R, O'Connor M. Improving the cough in participants with spinal cord injury. Am J Phys Med 1984; 63:1–10
12 Hall JC, Tarala R, Harris J, et al. Incentive spirometry versus routine chest physiotherapy for prevention of pulmonary complications after abdominal surgery. Lancet 1991; 337: 953–956
13 Bauer ML, McDougal J, Schoumacher RA. Comparison of manual and mechanical chest percussion in hospitalized participants with cystic fibrosis. J Pediatr 1994; 124:250–254
14 Gallon A. Evaluation of chest percussion in the treatment of participants with copious sputum production. Respir Med 1991; 85:45–51
15 Mazzocco MC, Owens GR, Kirilloff LH, et al. Chest percussion and postural drainage in participants with bronchiectasis. Chest 1985; 88:360–363
16 Pryor JA, Webber BA, Hodson ME, et al. Evaluation of the forced expiration technique as an adjunct to postural drainage in treatment of cystic fibrosis. BMJ 1979; 2:417–418
17 Van Den Eeden SK, Tanner CM, Bernstein AL, et al. Incidence of Parkinson's disease: variation by age, gender, and race/ethnicity. Am J Epidemiol 2003; 157:1015–1022
18 Nakashima K, Maeda M, Tabata M, et al. Prognosis of Parkinson's disease in Japan: Tottori University Parkinson's Disease Epidemiology (TUPDE) Study Group. Eur Neurol 1997; 38(suppl 2):60–63
19 Fernandez HH, Lapane KL. Predictors of mortality among nursing home residents with a diagnosis of Parkinson's disease. Med Sci Monit 2002; 8:CR241–CR246
20 Gorell JM, Johnson CC, Rybicki BA. Parkinson's disease and its comorbid disorders: an analysis of Michigan mortality data, 1970 to 1990. Neurology 1994; 44:1865–1868
21 Schiermeier S, Schafer D, Schäfer T, et al. Breathing and locomotion in participants with Parkinson's disease. Pflügers Arch 2001; 443:67–71
22 Shill H, Stacy M. Respiratory function in Parkinson's disease. Clin Neurosci 1998; 5:131–135
23 Pitts T, Bolser D, Rosenbek J, et al. Voluntary cough production and swallow dysfunction in Parkinson's disease. Dysphagia 2008; 23:297–301
24 Saleem A, Sapienza C, Rosenbek J, et al. The effects of expiratory muscle strength training program on pharyngeal swallowing in patients with idiopathic Parkinson's disease. Paper presented at: 9th International Congress of Parkinson's Disease and Movement Disorders; September 28–October 1, 2005; New Orleans, LA
25 Saleem AF, Sapienza CM, Okun MS. Respiratory muscle strength training: treatment and response duration in a participant with early idiopathic Parkinson's disease. NeuroRehabilitation 2005; 20:323–333
26 Saleem AF, Sapienza C, Rosenbek J, et al. The effects of expiratory muscle strength training program on pharyngeal swallowing in participants with idiopathic Parkinson's disease. Paper presented at: 57th Annual Meeting of the American Academy of Neurology; April 9–16, 2005; Miami, FL
27 Sapienza C. Strength training implications for swallowing. Paper presented at: Pre-ASHA seminar; November 18–20, 2004; Philadelphia, PA
28 Kim J, Sapienza CM. Implications of expiratory muscle strength training for rehabilitation of the elderly: tutorial. J Rehabil Res Dev 2005; 42:211–224
29 Chiara T, Martin AD, Davenport PW, et al. Expiratory muscle strength training in persons with multiple sclerosis having mild to moderate disability: effect on maximal expiratory pressure, pulmonary function, and maximal voluntary cough. Arch Phys Med Rehabil 2006; 87:468–473
30 Chiara T, Martin D, Sapienza C. Expiratory muscle strength training: speech production outcomes in participants with multiple sclerosis. Neurorehabil Neural Repair 2007; 21:239–249
31 Sapienza CM, Davenport PW, Martin AD. Expiratory muscle training increases pressure support in high school band students. J Voice 2002; 16:495–501
32 Wingate JM, Brown WS, Shrivastav R, et al. Treatment outcomes for professional voice users. J Voice 2007; 21:433–449
33 Baker S, Davenport P, Sapienza C. Examination of strength training and detraining effects in expiratory muscles. J Speech Lang Hear Res 2005; 48:1325–1333
34 Lieber RL. Skeletal muscle structure, function, and plasticity. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002
35 Powers SK, Howley ET. Exercise physiology: theory and applications to fitness and performance. 5th ed. Boston, MA/Toronto, ON, Canada: McGraw-Hill, 2004
36 Adams GR, Hather BM, Baldwin KM, et al. Skeletal muscle myosin heavy chain composition and resistance training. J Appl Physiol 1993; 74:911–915
37 Falk M, Kelstrup M, Andersen JB, et al. Improving the ketchup bottle method with positive expiratory pressure, PEP, in cystic fibrosis. Eur J Respir Dis 1984; 65:423–432
38 Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": a practical method for grading the cognitive state of participants for the clinician. J Psychiatr Res 1975; 12:189–198
39 Rosenbek JC, Robbins JA, Roecker EB, et al. A penetration-aspiration scale. Dysphagia 1996; 11:93–98
40 Daggett A, Logemann J, Rademaker A, et al. Laryngeal penetration during deglutition in normal subjects of various ages. Dysphagia 2006; 21:270–274
41 Kelly AM, Drinnan MJ, Leslie P. Assessing penetration and aspiration: how do videofluoroscopy and fiberoptic endoscopic evaluation of swallowing compare? Laryngoscope 2007; 117:1723–1727
42 Troche MS, Sapienza CM, Rosenbek JC. Effects of bolus

consistency on timing and safety of swallow in participants with Parkinson's disease. Dysphagia 2008; 23:26–32
43 Colodny N. Interjudge and intrajudge reliabilities in fiberoptic endoscopic evaluation of swallowing (FEES) using the penetration-aspiration scale: a replication study. Dysphagia 2002; 17:308–315
44 Robbins J, Coyle J, Rosenbek J, et al. Differentiation of normal and abnormal airway protection during swallowing using the penetration-aspiration scale. Dysphagia 1999; 14:228–232
45 Smith Hammond CA, Goldstein LB, Zajac DJ, et al. Assessment of aspiration risk in stroke participants with quantification of voluntary cough. Neurology 2001; 56:502–506
46 Ross BB, Gramiak R, Rahn H. Physical dynamics of the cough mechanism. J Appl Physiol 1955; 8:264–268
47 Loudon RG, Shaw GB. Mechanics of cough in normal subjects and in participants with obstructive respiratory disease. Am Rev Respir Dis 1967; 96:666–677
48 Pal PK, Sathyaprabha TN, Tuhina P, et al. Pattern of subclinical pulmonary dysfunctions in Parkinson's disease and the effect of levodopa. Mov Disord 2007; 22:420–424
49 Sathyaprabha TN, Kapavarapu PK, Pall PK, et al. Pulmonary functions in Parkinson's disease. Indian J Chest Dis Allied Sci 2005; 47:251–257
50 Wheeler KM, Chiara T, Sapienza CM. Surface electromyographic activity of the submental muscles during swallow and expiratory pressure threshold training tasks. Dysphagia 2007; 22:108–116
51 Kendall KA, Leonard RJ. Hyoid movement during swallowing in older participants with dysphagia. Arch Otolaryngol Head Neck Surg 2001; 127:1224–1229
52 Schultz JL, Perlman AL, VanDaele DJ. Laryngeal movement, oropharyngeal pressure, and submental muscle contraction during swallowing. Arch Phys Med Rehabil 1994; 75:183–188
53 Dettelbach MA, Gross RD, Mahlmann J, et al. Effect of the Passy-Muir Valve on aspiration in participants with tracheostomy. Head Neck 1995; 17:297–302
54 Gross RD, Mahlmann J, Grayhack JP. Physiologic effects of open and closed tracheostomy tubes on the pharyngeal swallow. Ann Otol Rhinol Laryngol 2003; 112:143–152
55 Muz J, Mathog RH, Nelson R, et al. Aspiration in participants with head and neck cancer and tracheostomy. Am J Otolaryngol 1989; 10:282–286
56 Gross RD, Steinhauer KM, Zajac DJ, et al. Direct measurement of subglottic air pressure while swallowing. Laryngoscope 2006; 116:753–761
57 Burkhead LM, Sapienza CM, Rosenbek JC. Strength-training exercise in dysphagia rehabilitation: principles, procedures, and directions for future research. Dysphagia 2007; 22:251–265
58 Wheeler K, Troche MS, Rosenbek JC, et al. Physiologic aspects of swallow function in participants with idiopathic Parkinson's disease with and without penetration and/or aspiration. Paper presented at: Dysphagia Research Symposium; March 5–8, 2008; Charleston, SC
59 Allan CM. Treatment of non fluent speech resulting from neurological disease: treatment of dysarthria. Br J Disord Commun 1970; 5:3–5
60 Sarno MT. Speech impairment in Parkinson's disease. Arch Phys Med Rehabil 1968; 49:269–275
61 Ramig LO, Countryman S, Thompson LL, et al. Comparison of two forms of intensive speech treatment for Parkinson disease. J Speech Hear Res 1995; 38:1232–1251