RESEARCH ARTICLE

Expiratory Muscle Strength Training for Therapy of Pharyngeal Dysphagia in Parkinson's Disease

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ABSTRACT: Background: Pharyngeal dysphagia in Parkinson's disease (PD) is a common and clinically relevant symptom associated with poor nutrition intake, reduced quality of life, and aspiration pneumonia. Despite this, effective behavioral treatment approaches are rare.
Objective: The objective of this study was to verify if 4 week of expiratory muscle strength training can improve pharyngeal dysphagia in the short and long term and is able to induce neuroplastic changes in cortical swallowing processing.
Methods: In this double-blind, randomized, controlled trial, 50 patients with hypokinetic pharyngeal dysphagia, as confirmed by flexible endoscopic evaluation of swallowing, performed a 4-week expiratory muscle strength training. Twenty-five participants used a calibrated ("active") device, 25 used a sham handheld device. Swallowing function was evaluated directly before and after the training period, as well as after a period of 3 month using flexible endoscopic evaluation of swallowing. Swallowing-related cortical activation was measured in 22 participants (active: sham; 11:11) using whole-head magnetencephalography.
Results: The active group showed significant improvement in the flexible endoscopic evaluation of swallowing–based dysphagia score after 4 weeks and after 3 months, whereas in the sham group no significant changes from baseline were observed. Especially, clear reduction in pharyngeal residues was found. Regarding the cortical swallowing network before and after training, no statistically significant differences were found by magnetencephalography examination.
Conclusions: Four-week expiratory muscle strength training significantly reduces overall dysphagia severity in PD patients, with a sustained effect after 3 months compared with sham training. This was mainly achieved by improving swallowing efficiency. The treatment effect is probably caused by peripheral mechanisms, as no changes in the cortical swallowing network were identified. © 2021 The Authors. *Movement Disorders* published by Wiley Periodicals LLC on behalf of International Parkinson and Movement Disorder Society

Key Words: Parkinson's disease; FEES; oropharyngeal dysphagia; swallowing therapy; rehabilitation

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Relevant conflicts of interest/financial disclosures: Nothing to report. Full financial disclosures and author roles may be found at the end of this article.

Funding agencies: The study was supported by Deutsche Parkinson Vereinigung (dPV) (grant ID: #81).

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Received: 20 October 2020; **Revised:** 27 January 2021; **Accepted:** 8 February 2021

Published online 2 March 2021 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/mds.28552

Introduction

Pharyngeal dysphagia is a common and clinically relevant symptom in patients with Parkinson's disease (PD). Dysphagia affects up to 80% of PD patients during the course of their disease.[1] In later disease stages, severe dysphagia leads to complications in medication intake, dehydration, malnutrition, and aspiration pneumonia,[2] but critical swallowing dysfunction is often already present in earlier disease stages.[3] So far, only a few therapeutic options have been investigated, and more evidence of effectiveness and consistency of these methods is needed.[4,5]

Besides optimization of dopaminergic medication,[6,7] behavioral treatment strategies like swallowing exercises, compensatory maneuvers or bolus modification guided by

speech- and language therapists may be able to improve swallowing dysfunction.[8-11] Within the past years, few studies indicated a potential benefit in swallowing function by performing expiratory muscle strength training (EMST) with the goal of increasing force generation capacity of pharyngeal muscles.[12-14] Regarding swallowing dysfunction in PD, 1 randomized, controlled trial was able to show that a 4-week EMST could improve swallowing safety with positive, albeit mild effects on the penetration-aspiration scale,[15] measured by videofluoroscopic swallow study. Furthermore, a potential detraining effect was described.[16] Although these results suggest EMST training to be a good and cost-effective treatment candidate for PD patients,[4] more evidence is needed regarding the effects of EMST on other features of swallowing dysfunction, in particular, swallowing efficiency and possibly connected cortical swallowing processing pathways.[13]

Therefore, the aim of this double-blinded, randomized, placebo-controlled clinical trial was to evaluate if 4-week EMST results in a short- and long-term improvement of pharyngeal dysphagia. In addition, we explored the effect of EMST training on the cortical swallowing process using magnetencephalography (MEG).

Patients and Methods

Patients

Between May 2015 and August 2018, patients from our outpatient clinic at the Department of Neurology at the University Hospital of Muenster, Germany, were recruited. Inclusion criteria were diagnosis of PD following the established criteria,[17,18] modified Hoehn & Yahr stages II to IV, and flexible endoscopic evaluation of swallowing (FEES)–confirmed pharyngeal dysphagia following endoscopic standard criteria.[6,19-21] Pharyngeal dysphagia was defined by the presence of penetration and/or aspiration of any food consistency, relevant pharyngeal food residue after the swallow, or premature spillage with delayed initiation of the swallowing reflex.[6] Participants had to be on oral nutrition and on stable and sufficient medication at least 4 weeks before study inclusion. Exclusion criteria were the presence of other neurological diseases or conditions causing dysphagia, relevant dementia (Mini–Mental State Examination [MMSE] < 25 points, Montreal Cognitive Assessment [MoCA] < 26 points), severe depression (Beck Depression Inventory [BDI] > 19 points), and the presence of a percutaneous endoscopic gastrostomy.

Age, sex, disease duration, Hoehn & Yahr stage, levodopa-equivalent dose, and Unified Parkinson's Disease Rating Scale (UPDRS) parts I to IV were documented in all subjects. Levodopa-equivalent dose was determined using an established schema.[22] Safinamide with its antiglutamatergic and monamine oxidase B–inhibitory effect was rated equivalent to amantadine.[23] Data acquisition and analysis were approved by the ethics committee of the medical association Westfalen-Lippe and the Westfälische Wilhelms-Universität Münster (AZ: 2014-438-f-S). Written consent was obtained from all participants. The trial was registered at ClinicalTrials.gov (identifier NCT02461082).

Study Design

The design is detailed in Figure 1.

Dysphagia Assessment

A FEES was performed in every patient at the baseline visit (M0) as well as immediately after a 4-week training period (M1) and a 3-month follow-up visit (M3) in accordance with our established protocol for PD patients,[6,19] based on the Langmore standard protocol.[20,21] In brief, after anatomic-physiologic assessment, all patients received 3 boluses of puree consistency (3 × 8 mL, IDDSI level 4), blue-dyed liquids (3 × 5 mL, IDDSI level 0), and soft solid food (white bread, size:

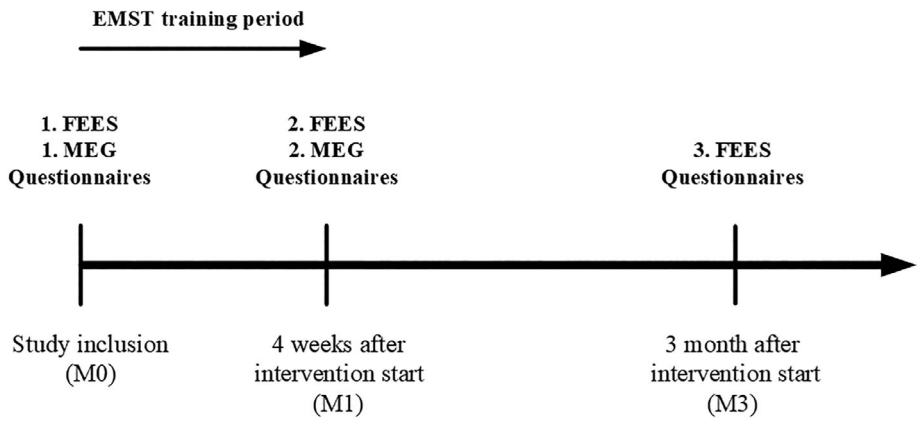

FIG. 1. Study time line. M0, month 0 (baseline study visit/point of study inclusion); M1, month 1 (second study visit after 4-week training period); M3, month 3 (3-month follow-up visit).

$3 \times 3 \times 0.5$ cm^3; International Dysphagia Diet Standardisation Initiative [IDDSI] level 7).[24] Each bolus was clinician-administered and noncued. FEES equipment consisted of a 3.5-mm-diameter flexible fiberoptic rhinolaryngoscope (Storz, 11,101 RP2, Karl Storz, Tuttlingen, Germany) with a video processor (CV-170, Olympus, Shinjuku, Japan) and processing software (rpSzene 10.7 g on Panel-PC-226/227; Rehder/Partner, Hamburg, Germany). Each examination was performed under regular medication intake in the clinical "on"-state condition using xylocaine gel (2%) for local anesthesia on the tip of the endoscope. FEES was always performed by a well-experienced SLP together with a trained neurologist, who were blinded for treatment group. All FEES examinations were video-recorded, anonymized, and independently scored offline in random order by 2 blinded raters with several years of experience with FEES examinations. The video analysis followed a previously published protocol. Three salient parameters of swallowing function were evaluated in each of 9 swallowing tasks. (1) In premature spillage materials spilled over the base of the tongue into the hypopharynx (including the valleculae, the lateral channels, and the piriform sinus) too early during the oral swallowing stage, meaning before the pharyngeal swallow was initiated. (2) In penetration-aspiration (P/A) events penetration material entered the laryngeal vestibule (defined by Langmore's epiglottis level 3[21]) but remained at or above the level of the vocal cords; aspiration material entered the airway below the vocal cords. (3) In residue, material was insufficiently cleared from the hypopharynx during swallowing and remained after swallowing. Residues were judged after final clearing swallow. The scoring of these parameters was done separately using 3 ordinal 5-point scales (0–4, from 0 = best to 4 = worst) for each swallow and condition. The respective points of single ratings were added during each patient's study visit (range from 0 to 108, with higher scores indicating worse functioning; see supplementary material Fig. S2) and afterward compared with each other.[6,25] Scoring was repeated by the 2 raters in a blinded fashion 4 weeks after the initial rating. The results of these ratings were used to assess inter- and intrarater reliability. For final scores used in the analysis, disagreements were discussed separately for premature spillage, P/A events, and residue until agreement was reached. Therefore, the scoring after joint discussion did not influence the results of reliability testing. In addition, at each study visit (M0, M1, M3), all participants were asked to complete German versions of 2 validated swallowing questionnaires for evaluation of presence and changes in subjective dysphagia symptoms: the Swallowing Quality of Life Questionnaire (SWAL-QOL), which consists of 11 single domains,[26,27] and the Swallowing Disturbance Questionnaire (SDQ), which was developed especially for patients with PD, with answers ranging from "never" (0 points) to "very frequently" (3 points).[28]

Magnetoencephalography

MEG data acquisition, preprocessing, and statistical analysis were performed as previously published according to a standard pipeline.[29-32] Data were collected using a 275-channel SQUID sensor array (Omega 275; CTF Systems, Coquitlam, BC, Canada) with a sample frequency of 600 Hz and a 150-Hz low-pass filter. Participants were seated in an upright position and instructed to swallow volitionally without external cueing during the 15-minute measurement. Using a plastic tube that was inserted in the oral cavity, water was continuously infused into the oral cavity with a flow of 10 mL/min. For event-related MEG data analysis, swallows were identified by surface electromyographic recordings from submental muscles. Subsequent MEG data processing and statistical analysis were carried out with custom-made MATLAB scripts (MathWorks, Natick, MA) based on FieldTrip (http://www.ru.nl/fcdonders/fieldtrip),[33] as previously published.[29-32] Briefly, MEG data were filtered within theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), low-gamma, (30–60 Hz), and high-gamma (60–80 Hz) frequency bands. In all frequency bands, source localization of each subject's swallowing-associated event-related desynchronization (ERD) of cortical rhythms was performed for the data from the first MEG before and the second MEG within 7 days after the end of 4 weeks of EMST by applying a linearly constrained minimum variance beamformer technique, which is capable of analyzing induced brain activity that occurs during complex sensorimotor tasks.[34] Individual source estimates were normalized to a template Montreal Neurological institute brain (T1) using SPM8 (http://www.fil.ion.ucl.ac.uk/spm). Grand averages of normalized and realigned source activation maps were separately computed for the data sets pre- and postintervention across all subjects. A cluster-based nonparametric randomization approach, built into FieldTrip, was applied to identify source locations that were modulated by EMST, considered significant at $P < 0.05$.

Study Intervention

The expiratory muscle strength training (EMST) was performed between M0 and M1 using a calibrated ("active"), or sham, handheld device (EMST 150; Aspire Products, Gainesville, FL; see supplementary material Picture S1) with a 1-way spring-loaded valve and an adjustable spring producing the most sufficient expiratory pressure to mechanically overload the expiratory and submental muscles.[15] For each patient, the optimal spring adjustment was evaluated individually using a special pressure manometer (FLUKE 713-30G)

for evaluation of the maximum expiratory pressure (MEP) as it is described in detail elsewhere.[15] Seventy-five percent of the MEP were set to the EMST device for subsequent training. The sham device was identical to the EMST device except the pressure release valve was made to be nonfunctional by removing the spring. Therefore, it was providing little to no physiological load to the targeted muscles. MEP adjustment of EMST devices was performed by an independent study member. During the first study visit, all patients got an introduction to performing the EMST training protocol. They were instructed to wear noseclips, take a deep breath, hold their cheeks lightly blow as hard as they could into the device, and identify that air was flowing freely through the device. In a consecutive training period, it was evaluated whether the patients were able to manage the task properly, and appropriate feedback was given. Written instructions were provided to each patient as well. All patients trained at home for 4 weeks, 5 days per week completing 5 sets of 5 repetitions per training episode, completed a training logbook,[15] and did a telephonic evaluation during the training period.

Device Allocation

Device allocation was created using computer-assisted rank randomization with Matlab (MathWorks Inc., Natick, MA) by an independent study member to guarantee for blinding of both clinician and participant.

Study Outcome Parameters

The primary outcome parameter was a change in the overall FEES dysphagia score after the 4-week EMST training (M0 vs M1). Secondary outcome parameters were changes in the FEES dysphagia score subscales (M0 vs M1 and M0 vs M3), changes in the overall FEES dysphagia score after a 3-month period (M0 vs M3), changes in the cortical reorganization of swallowing process as detected by MEG (M0 vs M1) and changes in patient subjective dysphagia symptoms as well as swallowing-related quality of life as measured by the mentioned questionnaires (M0 vs M1 and M0 vs M3).

Calculation of Sample Size

Based on literature findings and our expertise, we considered an improvement in the dysphagia severity score of 30% to be of clinical relevance.[6] In a sample size calculation, n = 21 patients would yield a power of 80% to detect a statistically significant difference ($\alpha = 0.05$, 2-sided) of 30% between the active and sham groups. Numbers were rounded up to 25 patients per study arm.

Statistical Analysis of Behavioral Data

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY). Bonferroni corrections were applied using SPSS software where applicable. A cutoff of $P < 0.05$ was used for all reported tests. To ensure the active and sham groups were comparable regarding clinical parameters, differences in age, UPDRS I to IV, levodopa-equivalent dose, MoCA, MMSE, and BDI scores (independent *t* test), sex, and Hoehn- and Yahr stage (chi-square test), and disease duration (Mann–Whitney *U* test) were analyzed, after testing the respective parameters for normal distribution (Kolmogorov–Smirnov test). A repeated-measures multivariate analysis of variance (MANOVA) was performed to compare FEES dysphagia total and subscores between the active and sham groups before (M0) and at 2 times after study intervention (M1, M3). The same analysis was run for the questionnaire scores (SWAL-QOL and SDQ). To test for interrater and intrarater reliability of the FEES dysphagia scores, 25% of the total data set was reanalyzed, and Cohen's *d* was calculated. Behavioral data from the pre-/post-intervention MEG measurements (head movement, number of swallows analyzed) were compared using a dependent *t* test for normally distributed variables or the Wilcoxon rank sum test for nonparametric data (indicated by an asterisk) to ensure comparable performance of the measurements.

Binary Logistic Regression Analysis

To identify predictors of positive response to EMST (defined as improvement $\geq 30\%$ in the overall FEES dysphagia score) in the active group, binary logistic regression analysis was performed including age, disease duration, levodopa-equivalent dose, UPDRS III, SDQ, and SWAL-QOL as independent variables.

Results

Fifty-three of the 81 screened patients were included for study participation. Fifty patients finished the 4-week EMST training period, with 22 patients in addition performing MEG examination. Forty-five patients completed the full 3-month trial and were accessed for data analyzation (per protocol analysis). No relevant training side effects were observed. For a detailed description, see Figure 2.

Reliability

Both interrater (kappa, 0.82) and intrarater (kappa, 0.91) reliability were excellent ($P < 0.001$) for FEES dysphagia scores using Cohen's kappa.[35] Values were analyzed separately for residues, premature spillage, and P/A events.

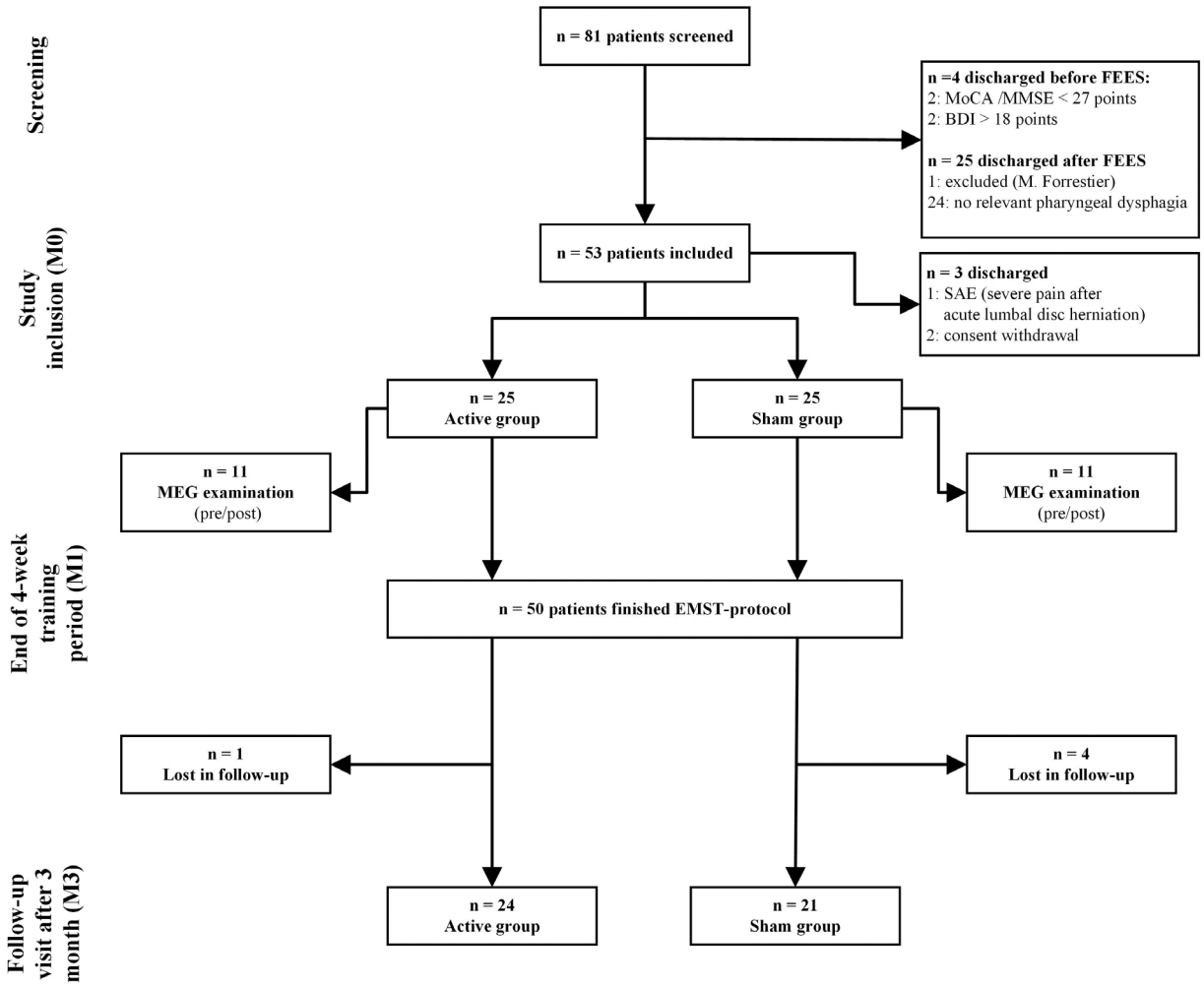

FIG. 2. Study participation and follow-up flow chart. The SAE was rated as not device-related.

Baseline Characteristics

The patients' main clinical characteristics and descriptive statistics are shown in Table 1. No pretreatment differences in the active and sham groups existed. In addition, no statistically significant differences were found comparing Hoehn & Yahr stage, UPDRS I to IV scores, and levodopa-equivalent dose of the active and sham groups at M1 and M3 compared with at M0.

FEES Results

None of the FEES scores (total or subscores) violated the assumption of sphericity (Mauchly's test: total FEES: $\chi^2_2 = 0.82$, $P = 0.66$; residues: $\chi^2_2 = 0.38$, $P = 0.83$; premature spillage: $\chi^2_2 = 0.01$, $P = 0.99$; P/A: $\chi^2_2 = 2.81$, $P = 0.25$). The repeated-measures MANOVA revealed a significant interaction effect between experimental group (real, sham) and the testing phase (M0, before intervention; M1, after intervention; M3, follow-up), $F_{8,36} = 4.30$, $P < 0.005$; Wilk's $\Lambda = 0.51$, partial $\eta^2 = 0.49$. Specifically, significant intervention effects in the active group were found for total FEES total score ($F_{2,86} = 11.70$, $P < 0.001$, partial $\eta^2 = 0.21$) and residues ($F_{2,86} = 13.62$, $P < 0.001$, partial $\eta^2 = 0.24$). In contrast, no significant effect of the intervention was found for premature spillage ($F_{2,86} = 1.48$, $P = 0.23$, partial $\eta^2 = 0.03$) and P/A ($F_{2,86} = 0.39$, $P = 0.68$, partial $\eta^2 = 0.01$). Pair-wise follow-up comparisons showed significantly improved residue scores in the active but not in the sham group after study intervention (M0–M1; $F_{1,43} = 25.2$, $P < 0.001$, partial $\eta^2 = 0.37$) and continued improvement at follow-up (M0–M3; $F_{1,43} = 7.11$, $P < 0.05$, partial $\eta^2 = 0.14$). The effect on residue scores also led to significantly improved FEES total scores in the active but not in the sham group after study intervention (M0–M1; $F_{1,43} = 26.8$, $P < 0.001$, partial $\eta^2 = 0.38$) and continued improvement at follow-up (M0–M3; $F_{1,43} = 4.62$, $P < 0.05$, partial $\eta^2 = 0.10$). For detailed data presentation, see Figure 3 and supplementary material Table S2.

Questionnaire Results

The Swallowing Disturbance Questionnaire evaluation showed significant score improvement after

TABLE 1. Main clinical characteristics of EMST patients (mean ± standard deviation [SD] and [Min–Max values])

Patient characteristics	"Active" group	"Sham" group	*P*
Subjects (n)	24	21	
Age (y)	67.3 ± 9.5 (54–83)	67.1 ± 7.7 (49–82)	0.22
Sex (women/men)	5/19	3/18	0.57
Disease duration (y)	6.6 ± 2.8 (2–12)	6.5 ± 4.1 (2–20)	0.45
Stage (H&Y):	2.5	2.6	0.12
2	8	9	
2.5	8	2	
3	7	8	
4	1	4	
UPDRS (points)			
I	0.8 ± 0.7 (0–2)	0.9 ± 0.9 (0–2)	0.19
II	7.2 ± 3.2 (3–18)	7.3 ± 4.4 (3–18)	0.11
III	20.3 ± 7.6 (10–33)	20.6 ± 7.7 (9–40)	0.99
IV	1.9 ± 1.1 (0–5)	2.1 ± 1.2 (0–5)	0.63
Levodopa-equivalent dose (mg)	687.1 ± 285.8 (100–1400)	692.4 ± 353.5 (225–1450)	0.26
MoCA (points)	29.0 ± 1.0 (27–30)	28.5 ± 1.2 (27–30)	0.06
MMSE (points)	28.8 ± 1.1 (27–30)	28.5 ± 2.1 (27–30)	0.92
BDI (points)	6.5 ± 4.0 (1–15)	8.1 ± 4.8 (1–15)	0.2

H&Y, Hoehn & Yahr; UPDRS, Unified Parkinson's Disease Rating Scale; MoCA, Montreal Cognitive Assessment; MMSE, Mini–Mental State Examination; BDI, Beck Depression Inventory.

intervention in the active but not in the sham group ($F_{2,88}$ = 15.41, $P < 0.001$, partial η^2 = 0.26). Score improvement was observed directly after intervention (M0–M1; $F_{1,44}$ = 32.65, $P < 0.001$, partial η^2 = 0.43), as well as a prolonged intervention effect (M0–M3; $F_{1,44}$ = 13.95, $P < 0.05$, partial η^2 = 0.24). No significant intervention effect was found using the SWAL-QOL questionnaire total score or subdomains ($F_{2,88}$ = 0.82, P = 0.45, partial η^2 = 0.02). For detailed data presentation, see supplementary material Table S3.

Predictors of Treatment Response

No significant predictors of treatment response between M0 and M1 including age, disease duration, levodopa-equivalent dose, UPDRS III, SDQ, and SWAL-QOL could be identified.

MEG Results

In the sham group (n = 11) number of swallows (pre, 55.92 ± 17.85; post, 50.27 ± 17.47; P = 0.518) as well as movement during MEG before and after intervention (pre, 0.691 ± 0.339 cm; post, 0.683 ± 0,364 cm; P = 0.954) did not differ significantly. Mean age in this subgroup was 65.18 ± 7.67 years. In the intervention group (n = 11), number of swallows was 64.64 ± 25.21 before intervention and 67.45 ± 25.67 after intervention (P = 0.603). With regard to head movement, no significant difference was observed at P = 0.424 (pre, 0.646 ± 0.252 cm; post, 0.675 ± 0.257 cm). Mean age was 65.18 ± 11.82 years and would not differ significantly between the subgroups analyzed in the MEG (P = 0.643). Activation was mainly localized in the bilateral pericentral cortex, conforming to primary and secondary sensorimotor areas, as previously described[28-30] and was centered in the alpha- and beta-frequency range with expansion into adjacent frequency bands. An example of source distribution of group-wise averaged swallowing-associated ERD in cortical oscillatory activity before and after 4 weeks of EMST intervention is presented in Figure 4 for the beta-frequency band (13–30 Hz). Regarding cortical activation, no significant differences between the 2 conditions were identified during swallowing in either of the 5 frequency bands (8–80 Hz) analyzed.

Discussion

This double-blind, randomized, placebo-controlled trial was able to show statistically significant improvement of the endoscopic FEES dysphagia total score in our active group after 4 weeks of EMST

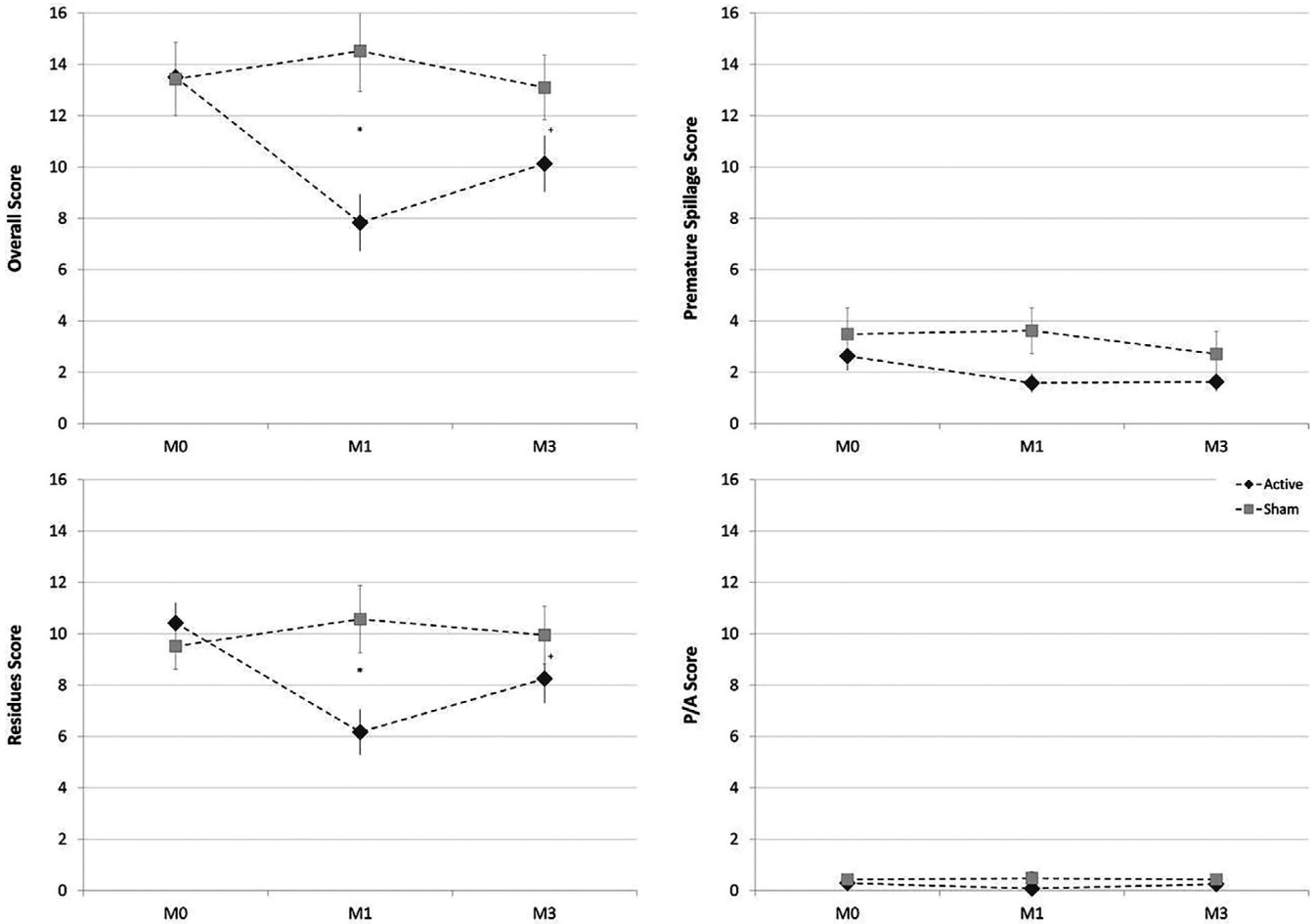

FIG. 3. Results of FEES video rating scores in EMST "active" and "sham" group (mean ± standard error [SE]) over time at different study visits (M0, M1, M3). *Statistically significant (interaction time active vs sham between M0 an M1; overall score, $P < 0.001$; partial $\eta^2 = 0.38$; residue score, $P < 0.001$; partial $\eta^2 = 0.37$); +statistically significant (interaction time active vs sham between M0 and M3; overall score, $P < 0.05$; $\eta^2 = 0.1$; residue score, $P < 0.05$; partial $\eta^2 = 0.14$).

(primary outcome) as well as a sustained effect 8 weeks after the end of the intervention. Following SDQ results, a positive effect on subjective dysphagia symptoms could have been shown as well, but these effects were not driven by modulation of the supramedullary swallowing network.

Clinical Value of Observed Effects

The most important and clinically relevant finding of our study was the significant improvement of swallowing function after a 4-week training period of EMST, which resulted from a reduction of pharyngeal residues only in the active but not the sham group. Former studies already indicated that EMST training strengthens the pharyngeal muscles in patients suffering from pulmonary and neurological diseases.[36] Regarding PD patients, preliminary data suggest improvement of speech breathing, maximum expiratory pressure, and peak cough flow after EMST training.[37-41] One larger placebo-controlled, randomized trial including PD patients reported a positive, albeit very mild effect on swallowing safety, measured as a reduction in penetration-aspiration severity and improvement in cough function.[15] Several mechanistic studies in healthy adults employing electromyography and high-resolution pharyngeal manometry have shown an EMST training effect on suprahyoid muscles and velopharyngeal closing pressure.[42-44] Hence, it is assumed that EMST leads to suprahyoid muscle activation, resulting in improvement of swallowing function for different food consistencies.[14] Even physiologic changes seen in PD might be positively affected by the EMST: compared with healthy older adults, significant pharyngal muscle atrophy was found in PD, being a source for swallowing dysfunction as well and leading to worse swallowing safety and efficiency.[45] In addition, quantitative changes in pressure generation of the velopharynx were found in former studies[46] being a potential treatment target for swallowing rehabilitation via EMST as well.

Apart from a direct effect on muscle strength, EMST may also impact bradykinesia of swallowing, which has been shown to be a hallmark of PD-related

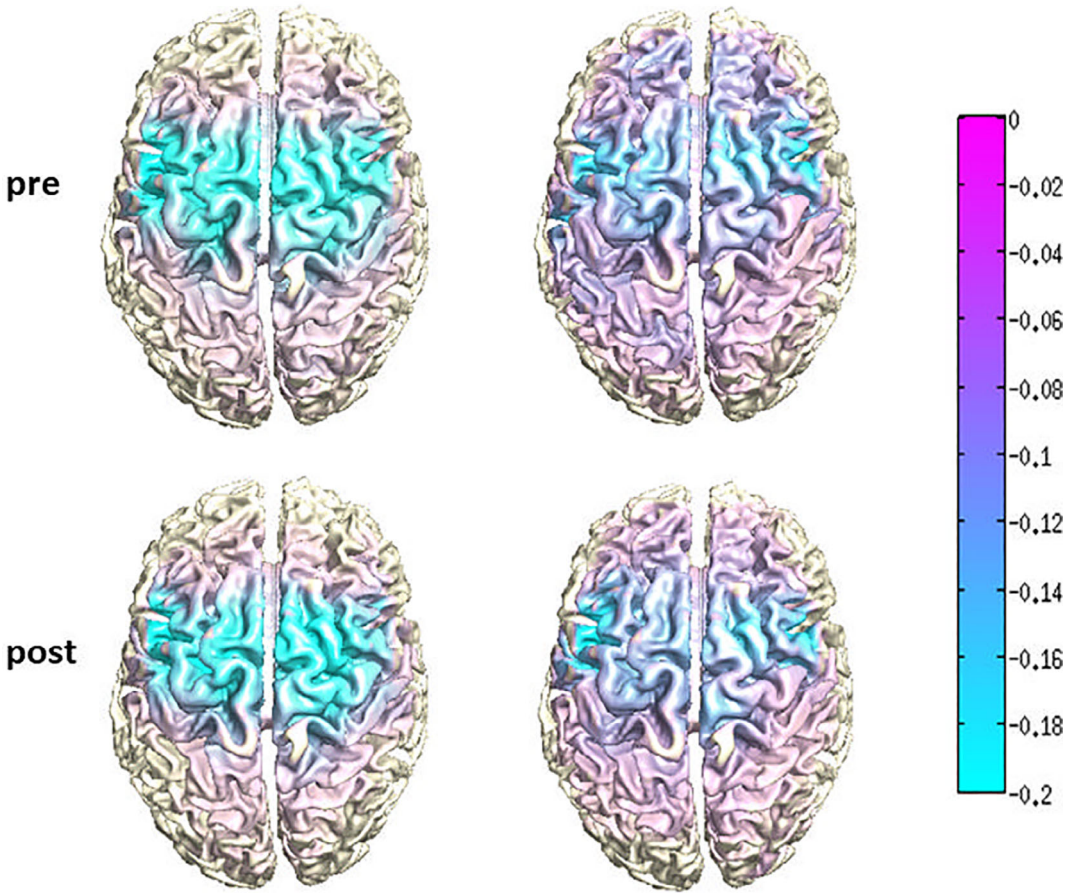

FIG. 4. Average cortical activation of active and sham groups in the beta-frequency band (13–30 Hz) before (pre) and after (post) intervention (4-week EMST training period). [Color figure can be viewed at wileyonlinelibrary.com]

dysphagia.[5,47] The significant reduction of overall FEES dysphagia scores in our study was mainly caused by a decrease in pharyngeal vallecular residues, especially with solid consistency, which is a typical FEES finding of PD-related bradykinetic pharyngeal dysphagia[25,48] Given that bradykinesia might be positively affected by EMST, recent findings from the field of physiotherapy improvement in PD patients could be taken into account.[49,50] Using progressive resistance training (PRT) in PD, a significant decline in bradykinesia with an increase in muscle strength including activation of agonist and antagonist muscles and reduction of agonist/antagonist coconstruction was found,[49,50] which might be a possible explanation model for the benefit of EMST to peripheral laryngeal muscles as well. Therefore, considering our study results, we postulate that the main effect of our EMST training is explained by peripheral mechanisms on bradykinesia of pharyngolaryngeal muscles. Anyway, our measured EMT effects go — as was similarly shown for PRT in physiotherapy — beyond dopaminergic effects, as all examined patients performed the training period under stable and sufficient medication intake for at least 4 weeks. A possible additional influence on subcortical regions was not assessed in our study. Nevertheless, regarding modulation of higher cortical control mechanisms of swallowing, we found no evidence for an EMST effect as depicted below.

Insights from MEG

Although the role of the cortical swallowing network in the pathophysiology of PD-related dysphagia has not been completely understood yet, dopaminergic and nondopaminergic mechanisms are suggested to be involved.[5] On the one hand, a lack of dopamine in the basal ganglia system of PD patients seems to impair the supramedullary control of swallowing. On the other hand, according to Braak staging, Lewy bodies appear in different nondopaminergic brain stem and cortical areas that are involved in the coordination of swallowing.[5] Furthermore, PD-specific adaptive cortical changes in swallowing processing were demonstrated using MEG[29] as well as changes of functional brain connectivity by magnetic resonance imaging[51] when comparing dysphagic with nondysphagic PD patients. The MEG results of our patient subgroup (n = 22) analysis showed no significant changes in

activation in the cortical swallowing network in the active or sham group comparing pre- and posttraining. Therefore, our study results lead to the conclusion that the positive EMST training effect in the active group is achieved rather by peripheral neuromuscular strengthening mechanisms and not from additional modulation of the cortical swallowing network, which has recently been shown for specific neurostimulation treatment modalities like transcranial direct current stimulation.[32]

Detraining Effects

Furthermore, our study results implicate an ongoing training effect for at least 8 weeks after finishing the EMST, which is in line with previous studies in this field[16] and adds the novel observation that improvement in swallowing efficacy shows a long-term effect after intensive 4-week EMST training. This supports the conclusion, that the EMST training effects might be comparable to those of the LVST-BIG training[52] but restricted to treatment of bradykinesia of the pharynx. Objective FEES findings were paralleled by an increase in the SDQ scores, confirming a subjective improvement in swallowing function in PD patients after intervention and with a sustained effect after 8 weeks of detraining, as it was shown in several other studies, supports its usefulness in the field of swallowing therapy in PD.[15,40,41]

Limitations and Further Directions

Based on the study design, only patients with stable and sufficient dopaminergic medication motivated to perform a 4-week training program were included. Therefore, our findings cannot be extrapolated to all PD patients. Although a standardized double-blinded randomization was performed, slight blinding effects cannot be excluded completely in a single-center study. Furthermore, detailed monitoring of each training session could not be given. Our study did not show clear improvement in premature spillage and P/A events, which might result from the only mild impairment of these 2 parameters at baseline examination, leading to a possible flooring effect on rehabilitation potential. In particular, the severity code of P/A events was lower in our cohort compared with the previous randomized, controlled EMST PD trial,[15] and a slightly modified rating score was used. Therefore, further studies should assess EMST effects on swallowing efficiency and safety in severe forms of dysphagia, especially in the advanced and late stages of PD. The option of using other forms of EMST devices (ie, $EMST_{75}$ with lower pressure ranges) should also be taken into account for more severely affected patients.

In conclusion, the 4-week EMST is a valid and easy-to-perform method for improvement of swallowing efficacy in PD patients and therefore an adjunct serious treatment option for patients with PD-related bradykinetic dysphagia. However, further investigations are necessary to develop guidelines for clinical practice and better identification of suitable patients in the treatment of PD-related dysphagia. ■

Acknowledgments: We gratefully thank Deutsche Parkinson Vereinigung (dPV) for financial support (grant 81). We are also very thankful to all patients, speech and language therapists, and physicians who have contributed to the success of this study.

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Supporting Data

Additional Supporting Information may be found in the online version of this article at the publisher's web-site.