Journal of the International Neuropsychological Society (2023), 1–10
doi:10.1017/S1355617723000747

Research Article

Effects of facial biofeedback on hypomimia, emotion recognition, and affect in Parkinson's disease

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Abstract

Objectives: Facial expressions are a core component of emotions and nonverbal social communication. Therefore, hypomimia as secondary symptom of Parkinson's disease (PD) has adverse effects like social impairment, stigmatization, under-diagnosis and under-treatment of depression, and a generally lower quality of life. Beside unspecific dopaminergic treatment, specific treatment options for hypomimia in PD are rarely investigated. This quasi-randomized controlled trial evaluated the short-term effects of facial electromyogram (EMG) based biofeedback to enhance facial expression and emotion recognition as nonverbal social communication skills in PD patients. Furthermore effects on affect are examined. **Method:** A sample of 34 in-patients with PD were allocated either to facial EMG-biofeedback as experimental group or non-facial exercises as control group. Facial expression during posing of emotions (measured via EMG), facial emotion recognition, and positive and negative affect were assessed before and after treatment. Stronger improvements were expected in the EMG-biofeedback in comparison to the control group. **Results:** The facial EMG-biofeedback group showed significantly greater improvements in overall facial expression, and especially for happiness and disgust. Also, overall facial emotion recognition abilities improved significantly stronger in the experimental group. Positive affect was significantly increased in both groups with no significant differences between them, while negative affect did not change within both groups. **Conclusions:** The study provides promising evidence for facial EMG-biofeedback as a tool to improve facial expression and emotion recognition in PD. Embodiment theories are discussed as working mechanism.

Keywords: Parkinson's disease; emotion; hypomimia; biofeedback; quality of life; facial electromyography; depression; stereotyping

(Received 10 May 2023; final revision 23 August 2023; accepted 21 September 2023)

Introduction

Parkinson's disease (PD) is one of the most common and disabling neurological disorders in advanced age. Beside primary symptoms as tremor, bradykinesia, rigidity and postural instability, a growing body of research has addressed hypomimia, an important secondary symptom (Bologna et al., 2013). Two anomalies contribute to the mask-like appearance of patients with PD. Firstly, spontaneous facial activities are reduced, among them blinking, emotional and pain expressions (Agostino et al., 2008; Priebe et al., 2015; Simons et al., 2003). Secondly, voluntary facial movements are abnormally low, e.g., when instructed to pose an emotion (Bologna et al., 2016; Bowers et al., 2006).

Hypomimia is often regarded as pure motor symptom of PD, yet due to facial expression being inseparably involved in emotional processes, this symptom has many negative effects on patients' quality of life. Practitioners rated patients with facial masking more depressed, less sociable, and less cognitively competent (Tickle-Degnen et al., 2011). As depression and dementia are common in patients with PD (Riedel et al., 2016), hypomimia can, additionally to stigma, also lead to misdiagnoses. Furthermore, drastic consequences of hypomimia on social life were found. The more hypomimic an individual was, the less interest was shown by healthy adults in interacting with them (Hemmesch et al., 2009). Care partners' rating of how much they enjoyed interacting with the patients with PD was negatively correlated with their rating of the patients' facial masking (Gunnery et al., 2016).

Despite this evidence for the detrimental influence, clinical practice lacks treatment of hypomimia. Beside dopaminergic treatment, literature research revealed scarcity of evidence-based treatments. One study showed reduced hypomimia scores after a specialized treatment of hypomimia consisting of facial proprioception, emotion recognition, and mimicking tasks (Ricciardi et al., 2016). Furthermore, enhanced facial expression parameters were found as side benefits of Lee Silverman Voice Treatment (Dumer et al., 2014), group music therapy (Elefant et al., 2012), or orofacial physiotherapy (Katsikitis & Pilowsky, 1996). Generalization of treatment effects outside the study context or in daily life were not investigated in any of these studies. The findings suggest two

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Cite this article: Roßkopf S., Wechsler T.F., Tucha S., & Mühlberger A. Effects of facial biofeedback on hypomimia, emotion recognition, and affect in Parkinson's disease. *Journal of the International Neuropsychological Society*, 1–10, https://doi.org/10.1017/S1355617723000747

implications. Firstly, hypomimia seems to be treatable beside of pharmacological approaches, and secondly, further empirical research should be aimed on hypomimia treatment.

Hypomimia and deficits in mimicry among patients with PD has also been associated to distinct deficits in decoding emotions from other peoples' faces (Livingstone et al., 2016). While hypomimia is the general reduction of voluntary and spontaneous facial expressions, mimicry describes the mainly spontaneous, subconscious, and unintentional imitation of the opposite's facial expression (Blairy et al., 1999; Dimberg et al., 2000). Embodiment theories suggest that the perceiver mimics the facial expression of the counterpart and the corresponding motor, sensory, cognitive, and affective processes are triggered (Dimberg et al., 2000; Hess & Blairy, 2001; Wood et al., 2016). Deficits in mimicry could have a mediating role in emotion recognition deficits in PD patients (Livingstone et al., 2016). Two recent studies have investigated the association between emotion recognition and facial expression deficits in patients with PD (Livingstone et al., 2016). Contradicting results were reported. In the study in which voluntary facial expressions were investigated, no relation between the impairments in recognition and expression were found (Bologna et al., 2016), whereas in the study investigating mimicry, significant correlations with emotion recognition deficits were shown (Livingstone et al., 2016). Addressing the inconsistent findings and to contribute to embodiment theories, the proposed association is also examined in this study.

As a further aspect associated with hypomimia, facial muscle activity was shown to be a reliable part of the affective reaction (Cacioppo et al., 1986). In specific, patients with neuromuscular disorders were found to be more severely depressed when they show specific impairments in smiling (Van Swearingen et al., 1999). Reduced physiological feedback as well as impairment in social interactions are suggested as underlying factors (Gunnery et al., 2016). As also a considerable number of patients with PD are found to show depressive symptoms, enhancing the ability to smile is considered as supportive for (social) well-being (Yamanishi et al., 2013). Several studies in healthy subjects could already show that an activation of Musculus zygomaticus major (zygomaticus), associated with the expression of happiness, was linked to positive affect (Strack et al., 1988). Up to now, there are no specific treatments, targeting facial expression to improve neither positive affect nor emotion recognition in PD patients. In this regards, also trainings targeting the expression of negative affects like sadness, anger, fear, disgust, and the associated corrugator muscle (Cacioppo et al., 1986) seem of interest.

So far, no previous study examined the effects of facial biofeedback on hypomimia. Biofeedback is a technique to assess and to provide feedback on usually involuntary physiological signals, and therefore seems to be a promising approach to improve PD patients' facial expressivity. We furthermore investigated potential effects on emotion recognition and affect. Owing to the positive influence on social interactions and affect we decided to focus on the training of happiness and the associated zygomaticus. Additionally, the expression of sadness, anger, fear, disgust, and the associated corrugator muscle are trained to examine broad effects. The effects of biofeedback are being compared to those of non-facial gymnastics, as a reliable intervention to improve mobility in PD patients. We hypothesize, that facial EMG-feedback in comparison to non-facial gymnastics achieves a significantly higher pre to post increase in (a) facial expressions, (b) facial emotion recognition, and (c) positive affect. Further exploratory research questions address effects on negative affect, emotion-specificity of training, and correlations between emotional expressions, recognition, and affect.

Methods

Experimental procedures were in line with the Declaration of Helsinki and approved by the ethical review committee of the University of Regensburg (Ref-No.: 17-739-101). The study is reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) statement (Schulz et al., 2010).

Participants

Thirty-four participants were recruited from inpatients of a neurological hospital. The hospitalization followed a planned admission for multimodal treatment for patients with movement disorders. Eligibility criteria included a clinical diagnosis of idiopathic PD, and hypomimia defined by a score > 0 on item 19 of the Unified Parkinson's Disease Rating (UPDRS; Goetz et al., 2008). Patients were excluded for cognitive impairment, defined by a Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) score < 20, language unfamiliarity (<8 years experience of speaking German), facial botulinum toxin treatment in the last six months (assuming a reduced facial motility), and facial hyper- and dyskinesia as side effect of medication (to avoid EMG artifacts).

Study design, outcomes, and randomization

Within this quasi-randomized-controlled trial with a within-between-subject design, participants were assigned in equal number either to facial EMG biofeedback (experimental group) or non-facial gymnastics (control group). Group allocation was based on the order in which people were recruited, with alternating assignment to the experimental and control group by a person blind to the experimental design. As primary outcome for testing the hypotheses, the patients' (a) overall facial expression, (b) overall emotion recognition, and (c) positive affect were assessed pre and post treatment. As secondary outcomes, the facial expression during posing of and recognition of the emotions happiness, surprise, sadness, disgust, fear, and anger, as well as negative affect were assessed at pre and post treatment. The required sample size was calculated via an a-priori statistical power analysis using G*Power 3.1 (Faul et al., 2009). Because no literature on EMG-changes in the treatment of hypomimia was found, we referred to the feasibility study on hypomimia treatment (Ricciardi et al., 2016) which found medium to big effect sizes and expected a medium effect. Power was set to 80%, alpha to .05, r to .50 and the effect size was estimated as $f = 0.25$. The Analysis indicated a sample size of 34 patients to detect an interaction effect of Group × Time within a repeated-measures ANOVA. There was no blinding realized.

Materials and measures

Apparatus

All stimuli were presented with the BioTrace+ Software (V2017A, Mind Media, Herten, Netherlands) on a notebook with a 17-in. LCD display. The NeXus-10 system (also Mind Media) was used for measuring and amplifying the surface EMG signal. Two bipolar electrodes were placed on two emotion specific facial muscles (Cacioppo et al., 1986), and as ground electrode on the clavicle to reduce effects of ground electrode placement on facial expressivity (Fridlund & Cacioppo, 1986). Signals were bandpass filtered (20–500 Hz), and acquired at 1,024 samples per second. For further

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analyses as well as for the biofeedback training, the EMG amplitudes, in terms of root mean square-voltage were calculated with 32 samples per second. To smooth the visual signal, the feedback-parameter was the averaged amplitude over the last epoch, sized 1/4 s.

Facial expression

For measuring facial expressivity, the muscular activity during an expression posing task was assessed via EMG. Zygomaticus activity was recorded to analyze the expression of happiness. Corrugator activity was recorded for the expression of anger, sadness, surprise, and fear; for being involved in the expression of negative valence (Cacioppo et al., 1986; Topolinski & Strack, 2015). As approximation to measure disgust, the mean amplitude of zygomaticus and corrugator was computed. The zygomaticus is located nearby the Musculus levator labii, which is the main contributor to the expression of disgust, and crosstalk can be expected (Fridlund & Cacioppo, 1986). We validated this procedure as proxy to measure disgust in healthy subjects before. During the task, the patients were presented words of emotions ("happy", "disgusted", "angry", "surprised", "sad", and "fearful") and were instructed to pose the facial expression for 10 s. All emotions were presented once, and in the same order in every participant. The mean EMG amplitude of the 10 s period was used as measured variable for each facial expression, for overall expression the mean over all emotions was used.

Emotion recognition

The patients' ability to recognize emotions from facial stimuli was assessed with a modified version of the Ekman 60 Faces Test (Ekman, 1976), shortened to 48 faces depicting the six basic emotions happiness, surprise, sadness, disgust, fear, and anger. A review on facial emotion recognition in PD indicates that differences in emotion recognition ability can be found using shortened versions of the 60 Faces Test (Assogna et al., 2008). After an exemplary screen and assuring the patients' comprehension of the task, each face was presented for three seconds, response time was limited to 30 s, and the patients were instructed to respond preferably fast. The response format was a six forced-choice identification task. The order of emotions was pseudorandomized in favor of no consecutive repetition and was the same for every participant. For overall emotion recognition the mean percentage of correct answers over all six emotions is used.

Affect

The patients' current affect was assessed with the German paper-and-pencil version of the Positive and Negative Affect Schedule (PANAS) in the state version (Watson et al., 1988). It consists of two independent and internally consistent scales for positive and for negative affect (Krohne et al., 1996). Ten items (adjectives describing either positive or negative affect *at the moment*) are rated on a five-point scale.

Intervention

Facial EMG-biofeedback training

The experimental group training consisted of an imitation task, which was assisted by facial EMG Biofeedback. Zygomaticus amplitude was assessed to feedback facial expressivity for happiness, corrugator amplitude for sadness, fear, and anger (displayed via bar chart); and the amplitude of both muscles for disgust (two bar charts). Starting with brief psychoeducation screens about reciprocity of communication, followed by instruction screens, patients' comprehension of the task was ensured. Figure 1 shows an exemplary screen. Facial stimuli were depicted from the Montreal Set of Facial Displays of Emotion (Beaupré & Hess, 2005). Caucasian models' pictures in the 100% intensity were used. A training sequence started with the participant mimicking the displayed emotional expression. A slow running average was used to determine the adaptive threshold. Whenever the amplitude surpassed the threshold (yellow marked at the bar chart) for more than 500 ms, a rewarding sound rang out. The participants were instructed to relax for a short moment, then try to reach the threshold again, until the period of 30 s was over. The threshold was consequently adaptively determined in relation to the individual participants' muscular tension during the interval. Three training blocks lasting on average 8–10 minutes with breaks of 2–4 minutes between were conducted. The whole training session including instructions and examples lasted about 40 minutes. Within each block happiness was trained eight times; sadness, anger, fear, and disgust respectively one time. Surprise was not included, because for the expression of a recognizable surprised facial reaction we considered corrugator amplitude as not sufficiently specific. For the assessment of surprise we used the muscle activity in the region of corrugator muscle as an approximation since raising and/or lowering of brow is mainly involved (Topolinski & Strack, 2015).

Physical training (control)

The control group training consisted of mild physical activation and stretching exercises (amplitude oriented therapy – LSVT-BIG, 2018) for non-facial muscles suggested for patients with PD. Starting with brief psychoeducation about the importance of physical activation, the training included torso mobilization, arm-shoulder-finger mobilization, and leg-feet mobilization. In line with the experimental training, the control treatment consisted of three blocks and breaks, resulting in a comparable length.

Procedure

Figure 1 illustrates the study procedure. Initial screening was conducted within the standard diagnostic procedure on the inpatient ward. The study took place in an examination room of the clinic and was applied by the same trainer in all participants. The patients were fully enlightened about the purposes of the study and gave written informed consent. Sociodemographic and clinical variables, among others depression screening (Lehr et al., 2008) and medication status (Table 1), were examined. Pre-test, intervention, and posttest were all conducted within one session.

Statistical analyses

Baseline differences in demographic and clinical variables, as well as in outcome variables were assessed using *t*-tests for continuous variables and χ^2-tests for categorical variables. Mixed-design ANOVAs were conducted to test the three hypotheses, defining significant time × group interaction effects as confirmatory. Therefore, facial EMG data were standardized as *z*-scores within time series and electrode sites so that analysis across muscle sites is allowable. For better legibility we furtherly used *T*-scaled values. Alpha was set to .05. For tests of primary outcomes, no correction had to be applied. For secondary outcomes, Bonferroni's correction was applied to multiple comparisons (six comparisons: $p = .05/6 = .008$). As effect size, partial eta-squared (η_p^2) values and Cohen's *d* were calculated. For further exploratory analyses,

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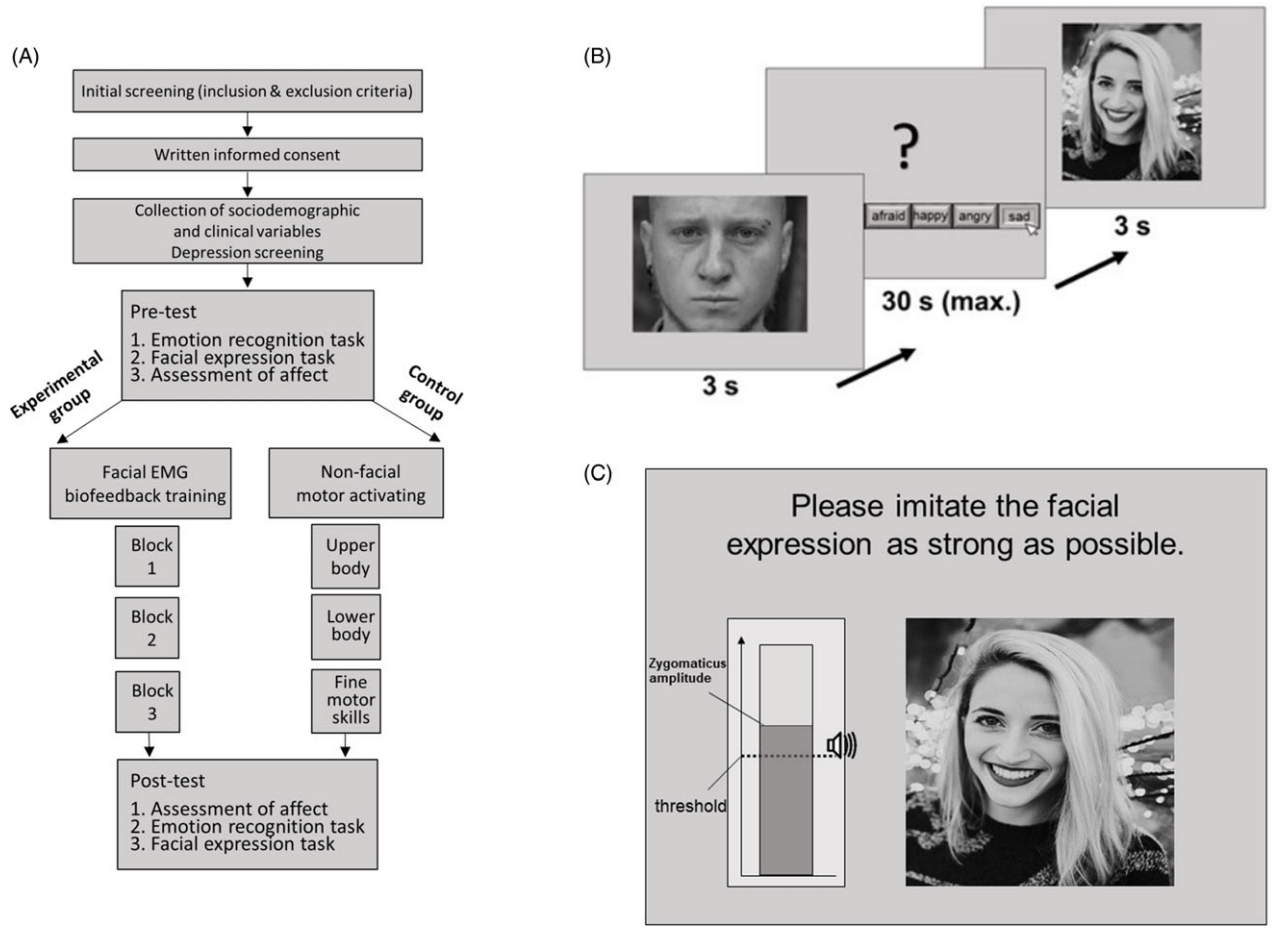

Figure 1. Study procedure (A), exemplary screen of the recognition task (B), exemplary screen of the biofeedback training (C).

Table 1. Baseline sociodemographic and clinical sample characteristics

Variable	Total sample ($N = 34$)	Experimental group ($n = 17$)	Control group ($n = 17$)	Group differences	
				t or χ^2	p
Age, years, *M* (*SD*)	66.9 (9.8)	69.4 (8.5)	64.5 (11.1)	−1.44	.159
Sex, male, *n* (%)	22 (65)	11 (65)	11 (65)	0.00	1.000
Disease duration, years, *M* (*SD*)	8.5 (5.4)	7.1 (4.3)	9.8 (6.4)	1.44	.747
Education, years, *M* (*SD*)	9.4 (1.6)	9.4 (1.7)	9.5 (1.5)	0.33	.159
Cognitive function (MoCA), *M* (*SD*)	26.6 (2.8)	25.9 (2.5)	27.2 (3.2)	1.33	.192
UPDRS part III, *M* (*SD*)	37.3 (13.0)	36.6 (9.1)	38.7 (16.9)	0.46	.653
Hypomimia subscore (UPDRS-III), *M* (*SD*)	1.4 (0.6)	1.4 (0.6)	1.4 (0.5)	−0.31	.761
Depression screening (ADS-K), *M* (*SD*)	11.7 (5.4)	10.9 (5.7)	12.5 (5.2)	0.85	.401
Dopamine replacement, yes, *n* (%)	33 (97)	16 (94)	17 (100)	1.03	1.000
LED (mg/day), *M* (*SD*)	505.5 (250)	418 (312)	593 (188)	0.86	.397
Facial expression, mV, *M* (*SD*)	47.8 (6.0)	46.0 (4.2)	49.7 (7.0)	1.84	.075
Emotion recognition, % correct (SD)	63.6 (13.67)	62.4 (14.7)	64.8 (12.9)	0.52	.609
Positive affect (PANAS), *M* (*SD*), [10–50]	30.6 (6.5)	32.2 (5.7)	29.1 (7.0)	−1.43	.163
Negative affect (PANAS), *M* (*SD*), [10–50]	13.9 (4.1)	14.3 (4.3)	13.6 (3.9)	−0.50	.618

Abbreviations: MoCA, Montreal Cognitive Assessment; UPDRS-III, Unified Parkinson's disease rating scale III (motor subscale); ADS-K, Allgemeine Depressionsskala – Kurzversion [English: General Depression Scale – Short Version]; LED: Levodopa dose equivalent. PANAS: Positive and Negative Affect Schedule. Facial expression are reported as *T*-scores. χ^2-test was conducted for categorial data, *t*-tests were conducted for continuous variables.

descriptive statistics, Pearson correlation coefficients as well as repeated-measures ANOVAs were calculated. All analyses were conducted in SPSS 26 (IBM Corporation, 2019). There was no missing data in any outcome variable.

Results

Sample

Figure 2 shows the flow of participants through each stage of the study. The baseline sociodemographic and clinical variables of the

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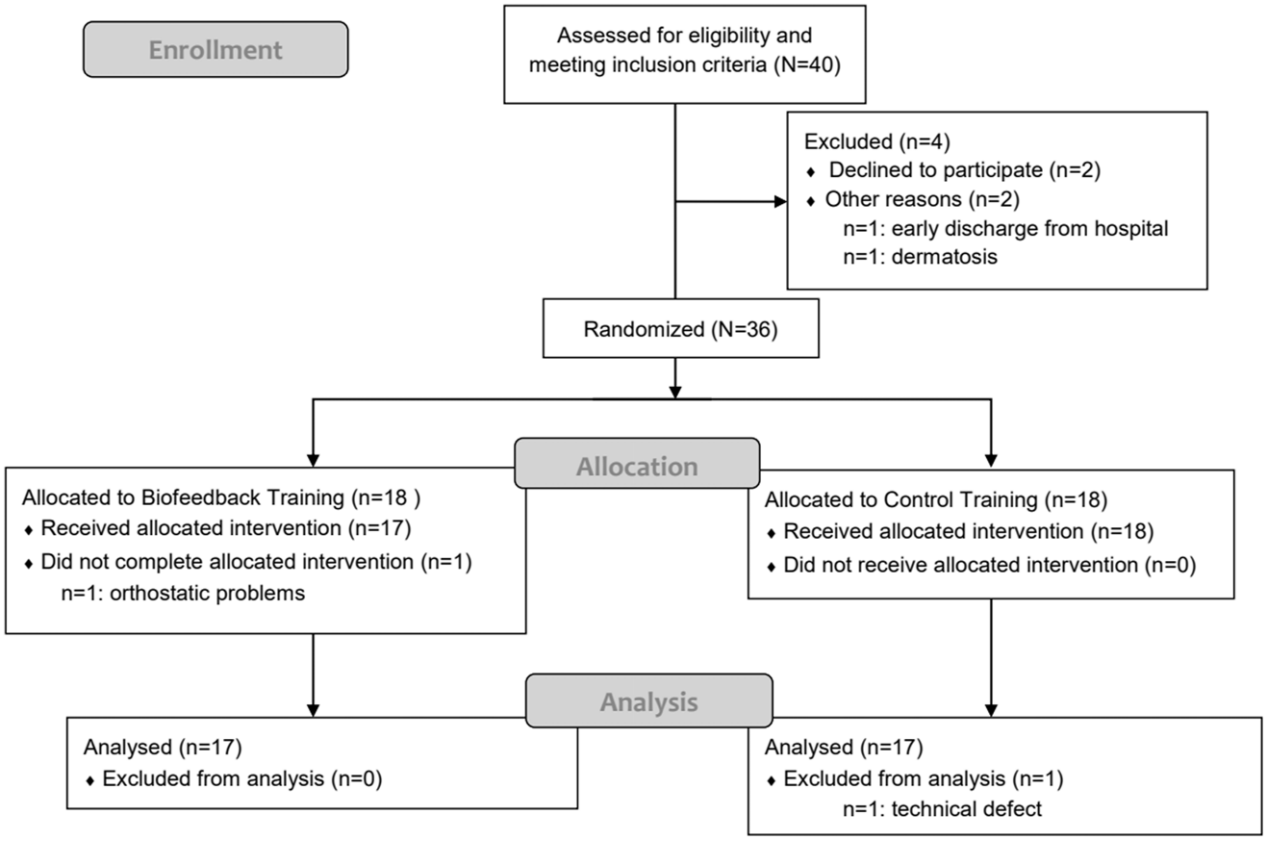

Figure 2. Consort flow diagram.

final sample consisting of 34 inpatients with idiopathic PD are shown in Table 1. No significant differences between groups were found among those variables. Within the outcome variables, only in one out of 16 tests a significant pretest difference was found, zygomaticus amplitude while imitating happiness was lower in the experimental group than in the control group, $t(32) = 2.369$, $p = .029$, $d = 0.81$. After correction for multiple testing, no significant pretest differences remain. To conclude, the pretest difference of zygomaticus amplitude lies within the chance probability range. In Supplementary Table 1, the outcome variable values at pretest are reported separately by sex. Briefly summarized, while there were no differences in other primary variables, female participants perform significantly better in facial emotion recognition, $t(32) = 2.51$, $p = .009$, $d = 0.89$.

Main results

Facial expression

Over all emotions, a significant time × group interaction effect for facial expression as primary outcome was found concerning changes from pre- to posttest between the facial EMG-feedback and the control group, $F(1,32) = 10.07$, $p = .003$, $\eta_p^2 = 0.24$., see Figure 3 for an overview. Regarding the specific emotional expressions, significant time × group interaction effects were found for the muscular activity during the expression of happiness and disgust (Table 2). With respect to the mean values at pre- and posttest for both groups, this indicates a greater overall increase in muscular activity, and specifically during the expression of happiness and disgust in the experimental group in contrast to the control group. Including sex as a covariate has no significant influence. For the expressions of sadness, fear, anger, and surprise, no significant group*time interaction effects were found. In an additional analysis, in which the negative facial expressions are grouped into one category, significant group*time interaction was found, $F(1,32) = 11.08$, $p = .002$, $\eta_p^2 = 0.26$.

Facial emotion recognition

For facial emotion recognition over all emotions as primary outcome, we found a significant time × group interaction effect, $F(1,32) = 8.18$, $p = .007$, $\eta_p^2 = 0.20$, for an overview see Figure 3. Facial emotion recognition improved significantly stronger in the facial EMG-biofeedback than in the control group. Regarding the recognition of specific emotional expressions, no significant time × group effects were found. Including sex as a covariate has no significant influence. In an additional analysis, in which the negative emotion recognition values are grouped into one category, a significant group × time interaction was found, $F(1,32) = 6.49$, $p = .02$, $\eta_p^2 = 0.17$, indicating a stronger improvement in the facial EMG-feedback group for the recognition of negatively valenced expressions in comparison to the control group.

Positive and negative affect

For positive affect, we found a significant effect of time, $F(1,32) = 11.40$, $p = .002$, $\eta_p^2 = 0.26$, but no significant time × group interaction effect, $F(1,32) = 3.16$, $p = .085$, $\eta_p^2 = 0.09$, indicating that positive affect increased in both groups, with no significant difference between groups (for an overview see

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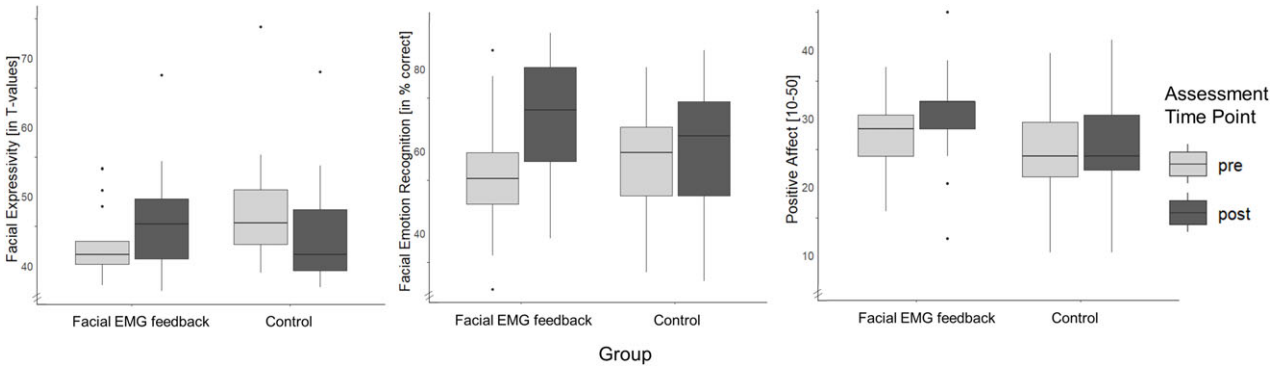

Figure 3. Primary outcome variables as a function of time point of assessment (pretest vs. posttest) and intervention group (facial EMG-feedback group vs. control group).

Table 2. Analyses of the interaction of intervention and time on emotional expression, emotion recognition, and affect

	Experimental group ($n = 17$)				Control group ($n = 17$)								
	Pre		Post		Pre		Post		Time effect		Time × group interaction		
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F (1,32)*	*p*	*F (1,32)*	*p*	η_p^2
Facial expression[a]													
Overall	46.0	4.2	53.5	8.7	49.7	7.0	50.8	8.9	18.97	<.001	10.07	**.003**	0.24
Happiness	44.7	2.8	53.7	11.8	51.5	11.4	50.1	9.8	7.92	.008	14.84	**.001**	0.32
Anger	47.2	11.3	55.3	10.5	47.5	5.7	50.1	10.2	10.57	.003	2.69	.111	0.08
Disgust	46.0	4.5	53.7	9.3	49.9	7.8	50.4	10.9	14.19	.001	11.27	**.002**	0.26
Fear	45.8	4.4	53.3	14.1	48.8	6.1	53.3	14.2	8.52	.006	1.20	.281	0.04
Surprise	46.0	4.9	52.4	12.2	50.0	10.1	51.6	10.9	8.07	.008	3.03	.091	0.09
Sadness	46.4	5.3	52.8	12.1	50.2	11.8	50.6	9.1	4.90	.034	3.79	.061	0.11
Emotion recognition[b]													
Overall	62.4	14.7	74.6	13.8	64.8	12.9	68.9	15.7	32.22	<.001	8.18	**.007**	0.20
Happiness	94.2	7.8	98.5	4.2	95.6	15.3	94.9	1.2	2.67	.112	5.23	.029	0.14
Anger	55.9	25.8	65.4	22.3	59.6	23.2	69.9	23.8	12.82	.001	0.02	.895	0.00
Disgust	59.6	28.5	73.5	25.0	59.6	24.4	61.0	31.8	3.72	.063	2.44	.128	0.07
Fear	40.44	22.3	53.7	24.5	47.0	22.8	48.5	23.8	2.57	.119	1.64	.209	0.05
Surprise	77.2	18.9	86.0	13.2	72.0	14.3	73.5	18.2	2.11	.156	1.08	.307	0.03
Sadness	47.1	31.4	70.6	27.6	55.2	25.4	65.4	27.1	17.74	<.001	2.72	.109	0.08
Affect[c]													
Positive	32.2	5.7	35.6	7.4	29.1	7.0	30.1	7.7	11.40	.002	3.16	.085	0.09
Negative	14.3	4.3	12.8	3.9	13.6	3.9	13.2	4.0	2.89	.099	1.13	.296	0.03

Note. $N = 34$ PD patients. *F*-values, *p*-values for time and time × group interactions within a mixed repeated ANOVA are reported, η_p^2 are additionally supported for the tests of hypotheses (group*time interactions). Bold values indicate significant results of hypothesis tests, Bonferroni-corrected, $p < .008$.

[a]Mean facial muscle amplitude while posing different emotions during the facial expression task (assessed in mV; *z*- and *T*-transformed for analyses). The average amplitude over all emotions and the single amplitudes for the specific emotions were assessed (Zygomaticus for happiness; Corrugator for anger, fear, surprise, and sadness; the average of Zygomaticus and Corrugator for disgust).

[b]Mean scores of facial emotion recognition were measured with a shortened version of the Ekman 60 Faces test. The scores are reported in percentage of correct responses [range 0–100%]. A total emotion recognition score over all emotions, and sub scores for the specific emotions were assessed.

[c]Mean scores for affect were measured using the PANAS (Positive and Negative Affect Schedule) subscales for Positive Affect and for Negative Affect (both range 10–50).

Figure 3). For negative affect, no significant time effect and no significant time × group effect was found (Table 2). Including sex as a covariate has no significant influence.

Exploratory analyses

Emotion-specificity of training

To show that the biofeedback training was emotion specific, we analyzed if only the relevant muscle (see Methods) responded. The dataset of one participant was removed, for exhibiting artifacts in the second training block. As expected, the amplitude of the emotion specific muscle (e.g., zygomaticus for happiness) was above the opponent muscle for all trained emotions (Figure 4). For disgust, the amplitude of corrugator was higher than of zygomaticus, although both were trained/displayed. Also mixed-design ANOVAs proved a significant main effect of the factor Muscle over all three blocks of the training, indicating that the training specifically addressed the expected muscle (Supplementary Table 2).

Correlations of facial expression and emotion recognition

To examine associations between muscular facial expression and emotion recognition as suggested by embodiment theories, correlations between sociodemographic and clinical variables at pretest were computed (Supplementary Table 3). Facial expression and emotion recognition scores were positively correlated at pretest, even when controlling for age and cognitive impairment (Supplementary Table 4). Age and cognitive impairment were correlated to emotion recognition. This means that patients with a higher muscle amplitude in the facial expression task at pretest also showed better facial emotion recognition abilities at pretest.

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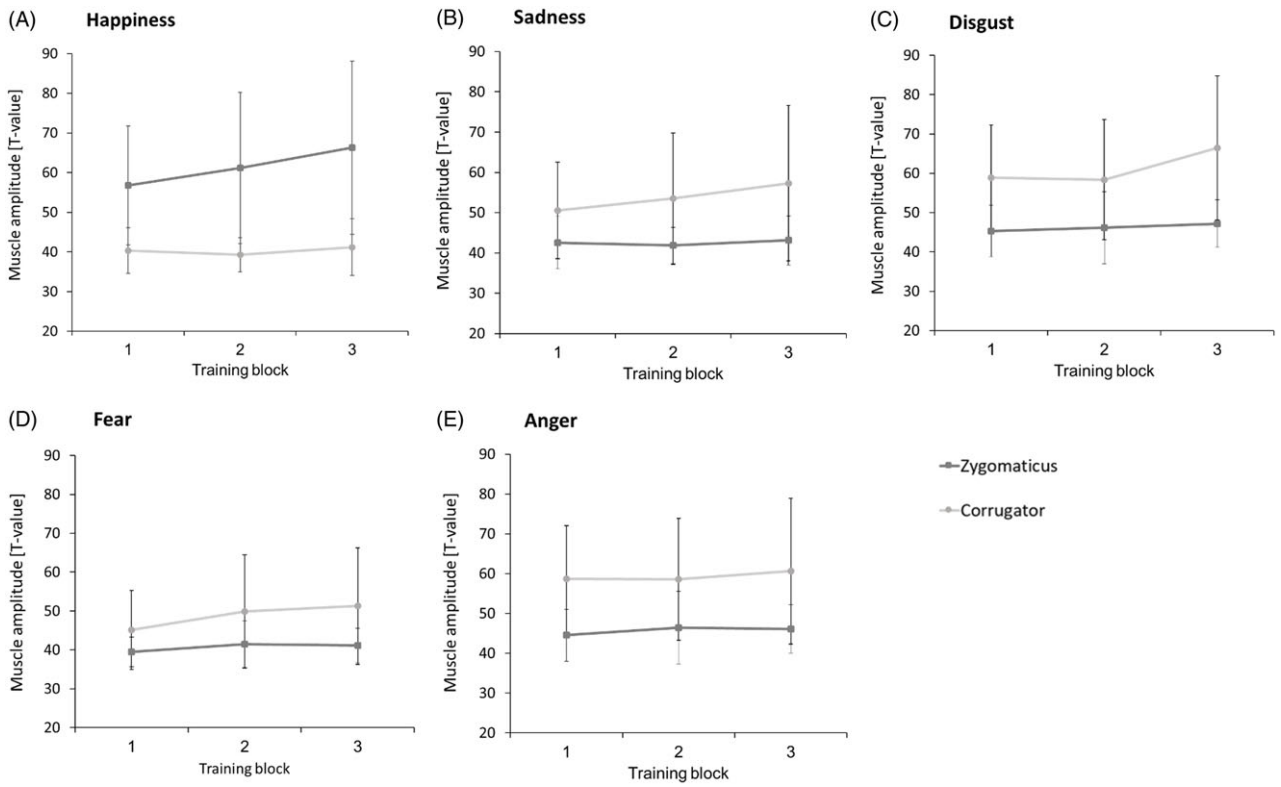

Figure 4. Mean muscle amplitudes for Zygomaticus and Corrugator in PD patients from to the biofeedback training group ($N = 16$) during the training blocks (T1–T3), assessed in mV and z- and *T*-transformed for analyses. Error bars indicate the standard deviation. The training was expected to specifically target zygomaticus during the expression of happiness; corrugator during anger, fear, and sadness, and both muscles during disgust.

Correlations of outcome variables and PD related clinical variables

To examine whether facial expression, facial emotion recognition, and positive and negative affect are related to PD severity, correlations between years since diagnosis, UPDRS-III scale, levodopa dose equivalent, and facial expressivity at pretest were computed. No significant correlations between PD related clinical variables and outcome variables at pretest were found (see Supplementary Table 5). Not surprisingly, years since diagnosis correlated with levodopa dose equivalent and UPDRS-III scale.

Discussion

This quasi-randomized-controlled trial examined facial EMG-biofeedback training as clinical approach to reduce hypomimia in patients with idiopathic PD. The facial EMG-biofeedback compared to non-facial gymnastics as control condition resulted in significantly greater improvements concerning facial muscular activity during the expression of emotions, and emotion recognition abilities. Positive affect significantly increased in both groups, with no significant differences between them. In regard to the single emotional expressions, greater improvements from pre to post measure were specifically confirmed in facial muscular activity during the expression of happiness and disgust. The findings suggest that our one-session biofeedback training is feasibly and effective concerning voluntary emotional facial expressions. Regarding single emotional expressions, greater improvements from pre to posttest were specifically confirmed for the expression of happiness and disgust. Exploratory analysis showed that the biofeedback training specifically addressed the emotion-related facial muscles (Figure 4). The feasibility of a specific hypomimia rehabilitation program was only examined in one prior study (Ricciardi et al., 2016). This training focusing on facial proprioception training resulted in a stronger reduction of hypomimia scores (UPDRS-III, item 19), and a stronger increase in facial expression of fear (but not the other basic emotions) measured via a computerized video analysis, both in comparison to DVD-guided facial physiotherapy and no treatment. Changes in emotion processing and recognition were not examined. As happiness and therefore zygomaticus was trained eight times per block, whereas all other emotions were trained only once per block, this indicates a stronger effect for happiness that might result from it's more frequent training. This could also serve as explanation for the result concerning disgust. As the only emotion beside happiness, zygomaticus was also trained in the expression of disgust, in addition to corrugator. Alternatively, or additionally, one might speculate that zygomaticus is easier to be trained than corrugator. Future studies could examine a more frequent training for sadness, anger, and fear, and could develop possibilities to include a training for surprise.

As potential working mechanisms of the effects of facial EMG-biofeedback training on facial expressivity, enhanced self-perception, and improvements in motor extent planning can be suspected. There is evidence that the basal ganglia network, which is known to be dysfunctional in PD, plays a part in the planning of the extent of movements (Desmurget et al., 2004). Dysfunctional feedback loops while executing motions are therefore hypothesized in PD. Thus, monitoring the patient's amplitude while mimicking an expression is suggested as supportive for motor extent planning. The hypothesized dysfunctional feedback loop could then partly be

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compensated by the visual presentation of the actual motion (Desmurget et al., 2004). Whether the reinforcement used in this study helped to increase motivation or treatment success cannot be disentangled with our study. Nonetheless, the emotion-specific amplitude increased over the course of the blocks (see Supplementary Table 2). This can be seen as an indication that the adaptive threshold may have supported a continuous increase in muscle effort. However, those expected mechanisms behind the effect of facial EMG biofeedback should be examined and validated in future studies. We suggest to use dismantling studies to further investigate necessary and sufficient parts of the facial EMG-feedback training. Furthermore, it would be helpful to know whether there are subgroups of patients who differentially benefit from biofeedback training or also from facial expression training. With a larger sample size interindividual differences, e.g. regarding predominance of either tremor or rigidity and Hoehn- & Yahr stages on treatment outcome should be investigated. Nonetheless, the focus of this study was on feasibility and efficacy of facial EMG-feedback training. First evidence is provided that facial EMG-feedback training can be used to improve facial expressivity in patients with idiopathic PD.

To our best knowledge, this is the first study to use an intervention approach to shed further light on embodiment theories, which claim that emotion processing is multimodal and that the activation of one component (i.e. vision processing of an emotional face) often leads to co-activation of other components (i.e. emotion expression or also affect itself; Wood et al., 2016). As one indication, emotion recognition improved significantly stronger in the facial biofeedback in comparison to the control group. Nonetheless, no definite reply can be made whether this results from enhanced facial expressivity or from other explanations, such as an added value of processed emotional faces. However, in line with embodiment theories, our exploratory correlations over all participants revealed a robust association between facial expression and emotion recognition at pretest. As further point for discussion, only overall emotion recognition showed stronger improvements, while no significant time × group interaction effect was found for the single expressions. Additionally, with recognition rates of 94% for happiness, this sub value may underlie a ceiling effect. To clarify whether we could not find a training effect on happiness recognition due to nonexistence of effect or due to the ceiling effect, future studies could use happiness recognition items with higher level of ambiguity and therefore more difficult items. Nonetheless, the greatest effect sizes of the intervention on emotion recognition were found for happiness, supposable due to the more frequent training of zygomaticus. Causal relations between emotion recognition and facial expression in patients with PD could be tested in future studies using a dismantling design.

The increase in positive affect in both groups, but no stronger increase in the EMG-biofeedback group could be due to unspecific factors as activation, care, and social interaction. Alternatively, two different mechanisms specific for the respective intervention are possible. The control group received physical exercises, which have constantly found to enhance mood (Berger & Motl, 2000). Zygomaticus training showed to improve mood via triggering the affective component of smiling (facial feedback hypothesis; Strack et al., 1988). Negative affect did not significantly change in both groups, which however can be interpreted as an indication that neither the biofeedback nor the control training had an aversive effect.

In general, the investigation of mid- and long-term effects of a more frequent facial EMG training should be examined in future studies. Since PD is a progressive degenerative disease, the research questions could rather target the stability of impairments over a limited period of time instead of improvements, and could examine effects on the social environment. In this study, emphasized training of smiles was applied due to several reasons. A considerable amount of patients with PD were found to show depressive symptoms, which are related to their quality of life (Yamanishi et al., 2013). Patients with neuromuscular disorders were found to be more severely depressed, when they show specific impairments in smiling (Van Swearingen et al., 1999). This was suggested to be due to reduced physiological feedback as well as impairment in social interactions. Therefore, enhancing especially the ability to smile is considered as most supportive for (social) well-being in patients with PD. Furthermore, enhanced physiological feedback loops while smiling as well as social reciprocity and improved social interactions could be possible (Hess & Blairy, 2001; Van Swearingen et al., 1999). Therefore, systematic investigation of possible changes in external evaluation by relatives and care partners should be endeavored. While mood improvements and alleviation of depressive symptoms would be generally desirable for PD patients, also improvements in the perception and expression of situation-adequate negative emotions might be supportable (Likowski et al., 2011; Seibt et al., 2015). Reduced emotional reactivity and recognition abilities, concerning negative affects might equally impair patients' social integration and well-being like it is true for positive affect. Therefore, future studies could also target the impact of EMG-biofeedback training on situation specific affective states.

Limitations

As outlined above, one limitation concerns the absence of clinical assessments of effects of the treatment and of follow-up assessments, therefore, further research is demanded to examine long-term effects. A further limitation concerns the external validity of the operationalization of facial expressions via the conducted EMG measurement. In the often-used coding system for facial expressions, emotional expressions are characterized by many interacting facial movements (Ekman & Friesen, 1978). Due to our biofeedback device, the measurement and training was restricted to two muscles (zygomaticus and corrugator), which can only represent a rough approximation to the complex patterns of emotional expression. Especially our approach to measure disgust, which is characterized by activation of levator labii muscle, which was not recorded in this study, has to be reflected critically. In prior studies, computer algorithm-based video observations were used to measure facial expressions (Bandini et al., 2017; Bologna et al., 2016; Wu et al., 2014). In future trials, this technology could be used for facial biofeedback, and online therapy using webcams could be considered. Besides, future assessment of the trainings' effects should include external valid measures also for hypomimia. As our study only measured muscular activity while posing expressions, no prediction can be made regarding spontaneous expressions or appropriate application in social interactions. In this regards, also effects on the patients' social integration and quality of life should be examined. However, in this study emotional faces were used as training stimuli, whereas in the facial expression task emotional words were presented. This indicates that patients in the experimental group were able to carry over

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what they trained with facial stimuli (imitating) to the expression task (posing). Finally, it should be considered that it was no double-blind randomized controlled trial. Participants were fully enlightened about the purposes of the study. Future studies could conceptualize a double-blind study for example with sham-biofeedback as control treatment to rule out nonspecific factors for improvement. In a next step, the treatment should also be validated in outpatients and patients with stronger cognitive impairment. Nonetheless, the focus was on validation of feasibility and efficacy of facial biofeedback training. Furthermore, all assessments were computer-guided and also objective data (muscle amplitude) was collected. Hence examiner effects can be assumed to have been small.

Conclusion

This quasi-randomized, controlled trial provides first evidence on the feasibility and efficacy of facial EMG-feedback training in terms of improved facial expressivity and emotion recognition in patients with idiopathic PD. Furthermore, positive affect increased from pre- to posttest, yet also in the control group (unspecific muscular activation). Additionally, emotion recognition and facial expression capabilities of participants were robustly correlated. Overall, these results provide preliminary evidence that facial EMG-feedback training might provide a valuable component of multimodal treatment in patients with idiopathic PD and hypomimia.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355617723000747

Funding statement. Nothing to declare.

Competing interests. None.

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