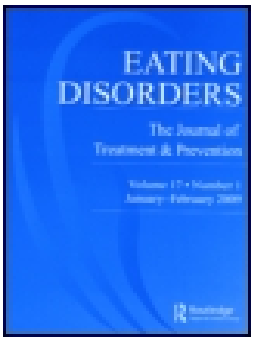

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ABSTRACT

A pre-post design including 22 females was used to evaluate the effectiveness of neurofeedback in the treatment of adolescent anorexia nervosa. Resting EEG measures and a psychological test-battery assessing eating behavior traits, clinical symptoms, emotionality, and mood were obtained. While both the experimental (n = 10) and control group (n = 12) received their usual maintenance treatment, the experimental group received 10 sessions of individual alpha frequency training over a period of 5 weeks as additional treatment. Significant training effects were shown in eating behavior traits, emotion regulation, and in relative theta power in the eyes closed condition. Although the results are limited due to the small sample size, these are the first empirical data demonstrating the benefits of neurofeedback as a treatment adjunct in individuals with anorexia nervosa.

Introduction

As a modern computer-related operant conditioning technique, neurofeedback (NF) is used as a therapy option in numerous psychological disorders (Masterpasqua & Healey, 2003). Participants learn to increase voluntary control over aspects of brain activity by reproducing internal sensations. By testing and adapting strategies, participants learn to modulate their electroencephalography (EEG) activity, and feedback is provided for a target amplitude range (Gunkelman & Johnstone, 2005). The published literature suggests that NF enhances attention and working memory (Wang & Hsieh, 2013), as well as cognitive (Zoefel, Huster, & Herrmann, 2011), and artistic performance (Gruzelier, 2009). In clinical settings, NF appears to improve

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therapy outcomes by changing long-standing EEG frequency patterns, and by regulating deficient brain patterns. If cortical functioning can be changed with NF, the need for medication might be diminished. Moreover, NF methodology provides positive reinforcement, which can promote feelings of self-efficacy and an improved internal locus of control (Gruzelier & Egner, 2004; Thompson & Thompson, 2003). Neurofeedback has been successfully used in the treatment of substance use disorder (Sokhadze, Cannon, & Trudeau, 2008), attention deficit hyperactivity disorder (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009), personality disorders (Surmeli & Ertem, 2009), affective disorders (Dias & van Deusen, 2011; Hammond, 2005), as well as anxiety disorders and post- traumatic stress disorders (Moore, 2000; Othmer & Othmer, 2009; Reiter, Andersen, & Carlsson, 2016). To date, no studies have been performed to evaluate NF in eating disorders.

Anorexia nervosa (AN) usually manifests during adolescence, predominantly afflicts young women, and is characterized by disturbed eating behavior resulting in severe psychological symptoms and maintenance of significantly low weight (American Psychiatric Association [APA], 2013). Interest has been recently focused on neurobiological changes including abnormal EEG patterns in individuals with AN. Jáuregui-Lobera (2012) reviewed EEG abnormalities in eating disordered individuals, and pointed to evidence of a central nervous system (CNS) dysfunction. Alterations within the theta (4–7 Hz), alpha (8–12 Hz), and beta band (13–22 Hz) are among those reported consistently (Grunwald et al., 2001; Rodriguez et al., 2007; Tóth et al., 2004). A predominance of alpha waves has been related to different human brain states ranging from a period of drowsiness prior to sleep to relaxed wakefulness and internal focus (Angelakis, Lubar, Stathopoulou, & Kounios, 2004; Klimesch, 1999), whereas theta power has been related to a range of cognitive processes (Klimesch, 1999) including cognitive interference (Nigbur, Ivanova, & Stürmer, 2011), and working memory (Nyhus & Curran, 2010). A state of alertness and attentional arousal is characteristic of a predominance of beta waves (Kaminski, Brzezicka, Gola, & Wróbel, 2011). Elevated EEG beta power has been associated with relapse in alcohol-dependent patients (Rangaswamy et al., 2002).

Hatch et al. (2011) reported that underweight individuals with AN exhibit reduced relative alpha power in frontal, central, and temporal brain regions, increased relative beta power in frontal areas, and elevated theta power in parietal-occipital regions compared with healthy controls. This reduced alpha/increased beta EEG pattern was interpreted as “hyperarousal” of the CNS, which normalized after weight gain. However, the elevated theta power persisted after re-feeding. Thus, atypical theta has been discussed as a trait marker for AN, or alternatively as a “scar effect” of a period of starvation on the brain (Hatch et al., 2011). In previous studies, the decreased alpha/increased beta complex as well as elevated theta power has been linked to anxiety (Knott, Bakish, Lusk, Barkely, & Perugini, 1996; Knyazev, Savostyanov, & Levin, 2004) and depressive symptoms (Grin-Yatsenko, Baas, Ponomarev, & Kropotov, 2009).

Recent literature identifies the potential for the expedient use of NF as an adjunct to treatment in the clinical management of eating disorders (Bartholdy, Musiat, Campbell, & Schmidt, 2013; Reel, 2013). With NF, the patient is supposed to have a more active role in therapy, and engages the body into the healing process (Pop-Jordanova, 2009). The results obtained by Pop-Jordanova (2000) indicate that aspects of eating disorders could be related to emotional stress and different types of coping mechanisms, and could be mediated by biofeedback techniques. Therefore, NF might be especially effective for AN as a stress-related disorder, and could improve the perception of body-control in children suffering from AN (Pop-Jordanova, 2009). NF research on addiction provides further evidence for the potential of NF in the treatment of AN. Although there is controversy about implementing the addiction model for AN (Vandereycken, 1990), there is a high co-occurrence between addictive and eating disorders (Baker, Mitchell, Neale, & Kendler, 2010; Gadalla & Piran, 2007). Increased cortical arousal (low alpha/high beta activity), also found in substance abusers, worsens prognosis and facilitates relapse (Saletu-Zyhlarz et al., 2004). In the course of our research, we were recently able to show the benefits of increasing control over brain activity through slow-wave NF in a well-characterized sample of alcohol-dependent male patients (Lackner et al., 2015). In addition, it has also been demonstrated that NF can be effective for dealing with feelings of anhedonia and alienation (Unterrainer, Chen, & Gruzelier, 2014). Functional magnetic resonance imaging studies demonstrate emotion-processing deficits and alexithymia in AN (Bydlowski et al., 2005; Haynos & Fruzzetti, 2011; Russell, Schmidt, Doherty, Young, & Tchanturia, 2009; Zhu et al., 2012). Since alpha oscillating networks activity and frontal midline theta were continually associated with states of internalized attention and emotional experience (Aftanas & Golocheikine, 2001; Cavanagh & Shackman, 2015), slow-wave NF could probably have effects on emotion regulation in AN.

To summarize, few studies have assessed brain function in AN. Findings are somewhat inconsistent and empirical data have not yet contributed to clinical management. The debate on whether any EEG abnormalities are a result of structural brain changes secondary to starvation or are predisposing disease markers of AN has not been concluded. However, as a stress-reducing technique, alpha NF is assumed to regulate neural circuits related to the stress system (Thompson & Thompson, 2007). In addition, slow-wave NF is supposed to change deficient brain patterns and to reduce psychological symptoms including emotional stress and anxiety frequently associated with AN (Hammond, 2005; Moore, 2000). As proposed by Pop-Jordanova

(2000, 2009), it is very likely that young patients suffering from psychosomatic symptoms could benefit greatly from EEG biofeedback techniques by experiencing gaining control over physiological processes that are usually felt as uncontrollable. To test those hypotheses, 22 adolescents, who met the criteria for AN, participated in a study of whether, and in what manner, NF intervention may be helpful in symptom management. Besides the examination of EEG effects, there was a special focus on changes in eating behavior traits, clinical symptoms related to AN (e.g., emotional distress, depressive symptoms, psychological well-being), and emotion regulation.

Method

Participants and study design

Twenty-two adolescent females diagnosed with AN (aged 12 to 18 years), and treated at the Psychosomatic Division of the Pediatric Department of the University Children's Hospital Graz, were selected from sequential intakes and randomly allocated to one of two groups with the constraint that the groups be matched regarding age. Randomisation was carried out at the time of recruitment of participants. While the control group (CG, n = 12) received the treatment as usual (medical attendance, behavior-oriented weight gain programme, psychosocial therapy, individual and family psychotherapy for in- and outpatients, the individuals of the experimental group (EG, n = 10) additionally participated in NF as a treatment adjunct two times per week for 5 weeks. Two patients in the CG dropped out between pre- and post-test, so that this group eventually consisted of 10 patients for the pre-post analyses. All participants met the *DSM-5* criteria for AN (APA, 2013) as evaluated via a structured diagnostic evaluation by a clinical psychologist. Psychiatric comorbidity was assessed through medical history and indicated that one patient in the EG and three from the CG met the criteria for diagnosis of depression. In the EG, 40% of patients showed past or habitual binge behavior, in the CG 16.7%. The patients were treated either as in- or outpatients (depending on their actual body mass index [BMI]), but all patients received comparable treatment during the course of the study (e.g., conjoint AN group therapy once a week, medical attendance and psychological treatment) (Scheer & Zoubek, 2007). Exclusion criteria for NF participation were epilepsy or acute psychotic symptoms; no participants were excluded by these criteria. In addition, clinical characteristics including BMI, dieting, and psychiatric comorbidity did not differ between the groups at pre-test. Table 1 shows the sample characteristics. Members of the treatment team were not involved in providing NF therapy or in assigning groups. The study was approved by the local ethical committee of the Medical University of Graz, in accordance to the Declaration of Helsinki (EK-Nr: 2215ex10/11).

Table 1. Clinical characteristics of females with a history of anorexia nervosa in the EG (n = 10) and in the CG (n = 12).

Characteristics	*EG*	CG	Statistics	*p*
BMI pre-test	14.82 (1.64)	16.00 (1.68)	−1.65	.114
Previous diets	5.22 (9.44)	2.25 (1.91)	−.325	.745
Illness duration (months)	9.55 (4.79)	12.17 (7.71)	−.972	.343
Treatment duration (months)	7.63	11.73	−1.66	.097
Psychiatric comorbidity (yes/no)	1/9	3/9	.883	.388
Psychopharmacological treatment (yes/no)	1/9	0/12	1.26	.262
Binge eating (yes/no)	4/6	2/10	1.50	.221
Subjective rating for treatment motivation (1 = low-10 = high)	5.80 (3.01)	7.25 (2.42)	−1.25	.224

Note. Data shown are mean and standard deviations for continuous variables or frequencies for discrete variables. Statistics testing differences between EG and CG at pre-test are χ2 for discrete variables, and *t*-tests (independent *t*-test, and Mann Whitney-U-test) for continuous variables; CG = control group, EG = experimental group, BMI = body mass index.

Participation involved informed consent by parents and subjects. All participants agreed to be randomized and received no remuneration. Figure 1 demonstrates the time sequence of the experiment.

Psychological measurement

Before and after treatment, participants completed a standardized psychological test-battery including self-report measurements of psychological well-being, eating behavior traits, and psychopathology. The following seven psychometric instruments were administered in the German language, along with a subjective motivation scale and an NF evaluation form (assessing acceptance and satisfaction with the training at post-test).

Three Factor Eating Questionnaire (FEV)

The German version of the Three Factor Eating Questionnaire (FEV) by Pudel and Westenhöfer (1989) assesses eating habits on three subscales: “dietary restraint,” “disinhibition,” and “hunger.” This scale has demonstrated discriminant, convergent, and predictive validity.

Eating Disorder Cognition Questionnaire (FEDK)

The Eating Disorder Cognition Questionnaire (FEDK) measures dysfunctional cognitions associated with eating disorders on three subscales: “body and self-esteem,” “restriction and dieting,” and “eating and loss of control.” Reliability and content validity with eating disorder pathology were found to be good (Legenbauer, Vocks, & Schütt-Strömel, 2007a).

Body Image Avoidance Questionnaire (BIAQ)

The Body Image Avoidance Questionnaire (BIAQ) measures behavioral tendencies that frequently accompany body-image disturbance, including

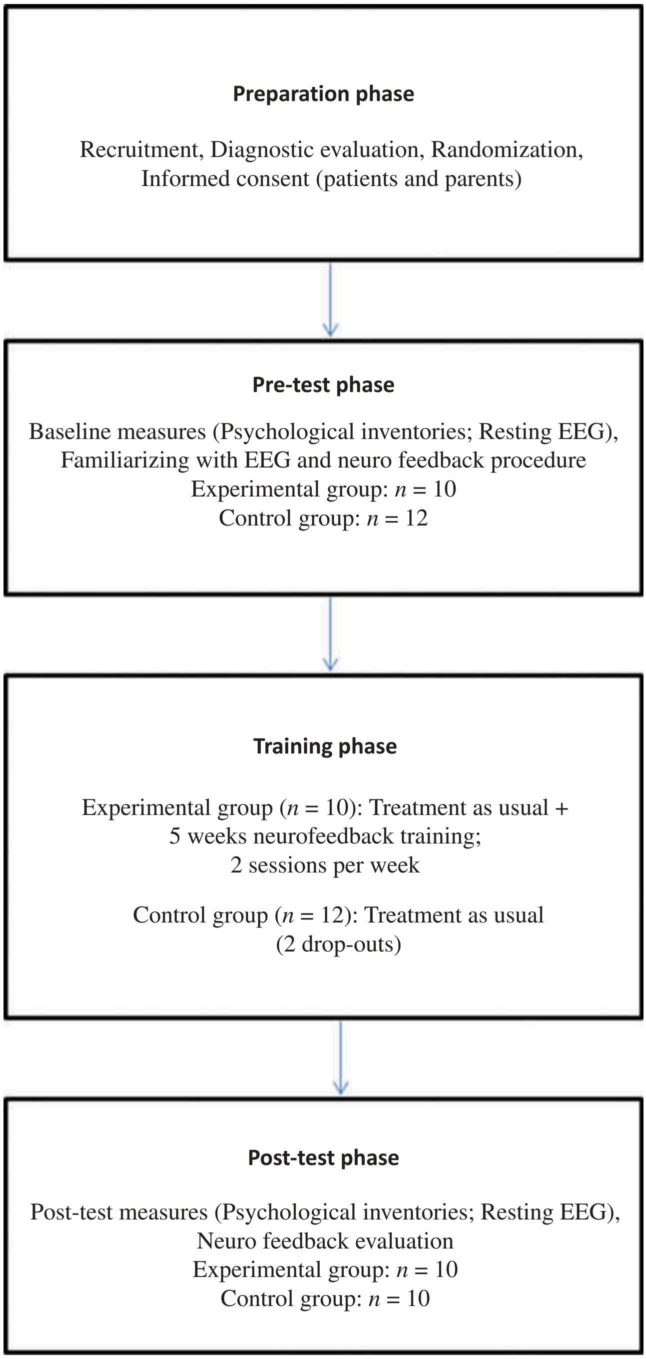

Figure 1. Time sequence.

avoidance of tight-fitting clothes ("clothing"), social outings ("social activities"), and "eating restraint." A German language validated version demonstrating good reliability and convergent validity for eating disorder symptoms was used (Legenbauer, Vocks, & Schütt-Strömel, 2007b).

Zerssen BfS Self-Rating Mood Scale (Bf-S)

The Zerssen BfS Self-Rating Mood Scale (Bf-S) is a German mood scale using complementary adjective pairs to evaluate the present state of mind (Van Zerssen & Koeller, 1976).

Emotional Competence Questionnaire (EKF)

The Emotional Competence Questionnaire (EKF) by Rindermann (2009) evaluates the ability to recognize and control one's own emotions ("recognising and understanding own emotions" and "regulating and controlling own emotions") and to recognize emotions in others ("recognising and understanding other's emotions") as well as "emotional expressivity." The EKF has demonstrated good factorial and criterion validity.

German Children's Depression Inventory (CDI)

The German Children's Depression Inventory (CDI) by Kovacs (1984; German translated version DIKJ) was used to assess depressive symptoms. In paediatric samples, the DIKJ demonstrated good re-test reliability and criterion validity (Stiensmeier-Pelster, Schürmann, & Duda, 1989).

Brief Symptom Inventory (BSI)

The Brief Symptom Inventory (BSI) by Franke (2000), a short-version of the Symptom Checklist-90-Revised (Franke & Derogatis, 2002, was used to measure mental health and emotional distress by evaluating symptoms on nine scales including somatisation, obsessive-compulsive behavior, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation and psychoticism. The BSI also includes three scales that capture global psychological distress: the Global Severity Index, the Positive Symptoms Total, and the Positive Symptoms Distress Index. In German samples, comparisons with SCL-90-R showed comparable psychometric qualities and high inter-correlations with established clinical rating scales (Geisheim et al., 2002).

Subjective treatment motivation

Subjective treatment motivation was assessed on a self-made scale ranging from 1 (*low*) to 10 (*high*).

EEG recordings

Participants were fitted with an electrode cap with an Ag/AgCl electrode system and impedances at all channels were reduced to below 5 kΩ. Spectral resting EEG was assessed before and after training in two conditions: 3 minutes of eyes closed and 3 minutes of eyes open. Electrodes were placed at the positions Fz, Cz, P3, P4, Pz, Oz (according to Jasper, 1959) with the Cz electrode at the intersection between the distance of the two ears and of the nasion and inion).

Electrodes were referenced to linked earlobes and the ground electrode was placed 1.5 cm anterior to Fz. In order to detect eye-blinks, an electro-oculogram was assembled above and beside the left eye. Data were digitized at a sampling rate of 256 Hz and passed through a 4–30 Hz band-pass filter. NF training and resting EEG data were recorded using a g.tec EEG system (USB biosignal amplifier). The EEG was recorded in an upright position in a therapy room of the University Children's Hospital, Graz. All EEG recordings (feedback and resting EEG) took place in the afternoon and were conducted at approximately the same time of day (±1 h).

Neurofeedback training procedure

Online visual NF was implemented via SIMULINK software (The MathWorks, Natick, Massachusetts, USA). During NF, EEG signals were obtained from six electrodes in the same locations as the resting EEG. Raw signals were band-pass filtered in the respective target bands (for precise frequencies see below; 6th order Butterworth IIR) and squared to obtain power estimates. The NF protocol expected to enhance individual alpha frequency (IAF) was conducted over a period of 5 weeks, with each participant receiving two training sessions per week. The elected training electrode was the one with the highest manifestation of alpha peak (Pz). The alpha peak was assessed before each session at Pz and the individual alpha band was adjusted at 2 Hz on either side of the peak. Each training session lasted for approximately 20 minutes, with EEG data gathered in seven runs. Before each session and between the runs, a fixation cross was presented after a random delay of up to 2 seconds.

The group training protocol consisted of a visual feedback loop in the form of a ball, representing IAF (Figure 2). The participants' goal was to enhance their alpha activity by raising the ball over a marked line. By holding the ball over the threshold, participants could change the colour of the ball from blue to yellow. The individual threshold was initially determined on the median IAF of the baseline run and progressively adapted using the median power of each previous feedback run. Additionally, two sorts of faces (smiling vs. frowning) were presented to the subjects after each run (see Figure 2).

Figure 2. Training screens.

In addition, participants were rewarded by getting points (displayed on the screen) after each training run. At the end of each session, an overall score was presented. Participants were instructed to find the most successful mental strategy to change the colour and to gain points.

Data analysis and statistics

Raw EEG data were band-pass filtered 4–30 Hz due to the amplifier configuration, and were manually corrected for eye movements and artefacts (via MATLAB). All epochs with artefacts were excluded from the EEG analysis. Spectral analyses were conducted for the 3-minute baseline condition for the frequency bands theta (4–7 HZ), alpha (8–12 Hz), and beta (13–22 Hz) at the electrode sites Fz, Cz, P3, P4, Pz, Oz. For statistical analyses, absolute (μV^2) and relative EEG (%) power was averaged for each electrode (relative power quantifies EEG power in each band relative to the whole spectrum).

Differences between the groups at pre-test were examined by the Student's *t*-test for independent samples, the Mann-Whitney U test or the chi-square test. For EEG data analyses, we calculated analyses of covariance (ANCOVAs) using group (EG vs. CG) as the independent variable and absolute/relative EEG power at post-test as dependent variables (for each frequency, band data were averaged across electrodes). In addition, multivariate analyses of covariance (MANCOVAs) were computed with electrodes (Fz, Cz, P3, P4, Pz, Oz) used as the within-subject factor. In all analyses, EEG power at pre-test was treated as a covariate. Additionally, individual descriptive analyses for each subject were conducted and are displayed graphically (see Figure 3).

For questionnaire data, (M)ANCOVAs were performed with group (EG vs. CG) as a between-subject factor, value at post-test as a within-subject factor, and range of pre-test score as a covariate. Additionally, paired sample *t*-tests were conducted to examine pre-to-post changes within the groups. Repeated measures ANCOVAs were used for evaluating time x group effects in BMI. To investigate associations between EEG and psychometric data, correlational analysis was performed.

Results

There was no significant difference between the groups at pre-test for BMI and treatment motivation (see Table 1) or in the psychological test variables, with the exception of the scales "eating and loss of control" from the FEDK, $t(20) = 2.27$, $p = .035$; see Table 2 for means and standard deviations.

Repeated measures ANCOVAs showed no time x group effect for BMI, $F(1/18) = .098$, $p = .758$; EG: $M_{pre} = 14.82$ ($SD = 1.64$), $M_{post} = 15.51$ ($SD = 1.39$); CG: $M_{pre} = 16.00$ ($SD = 1.68$), $M_{post} = 17.04$ ($SD = 1.29$).

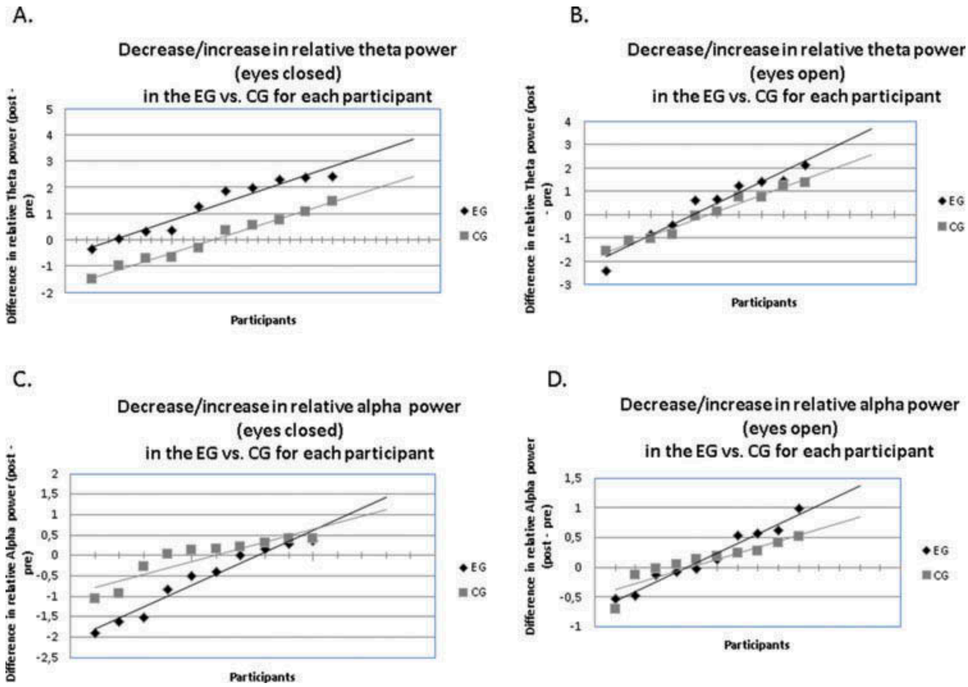

Figure 3. Pre-post change in theta and alpha power displayed for each participant.

Table 2. Pre-post results for eating behavior traits (FEV, FEDK, BIAQ).

		EG *Means* (+/- *SD*)		CG *Means* (+/- *SD*)					
		Pre	Post	Pre	Post	*F* value (*p*) ANCOVA	Eta squared	EG *t* score	CG *t* score
FEV									
	Dietary restraint	13.60 (6.40)	13.90 (6.30)	14.60 (5.56)	13.60 (5.91)	1.08 (.314)	.060	1.94	1.09
	Disinhibition	6.10 (3.67)	7.50 (4.22)	4.00 (1.94)	4.00 (1.70)	17.38 (.001) †	.506	−2.81†*	.00
	Hunger	3.80 (4.34)	4.60 (3.50)	3.00 (2.83)	3.00 (2.87)	5.33 (.034) †	.239	−.77	.00
FEDK									
	Body and self esteem	19.20 (11.74)	20.60 (12.42)	15.60 (6.31)	16.30 (7.86)	3.74 (.70) †	.180	−.43	−.57
	Restriction and dieting	17.40 (8.24)	16.20 (9.85)	11.20 (6.51)	11.50 (7.82)	8.03 (.011) †	.321	.58	−.22
	Eating and loss of control	12.00 (6.96)	10.00 (6.39)	6.40 (4.86)	9.50 (6.10)	.985 (.335)	.055	1.72	−2.77*
BIAQ									
	Clothing	9.10 (4.63)	8.20 (5.29)	8.60 (3.34)	7.80 (3.65)	.793 (.387)	.050	.53	.95
	Social activities	4.00 (3.20)	4.10 (3.04)	4.60 (3.17)	5.10 (4.23)	.007 (.934)	.000	−.10	−.53
	Eating restraint	6.20 (3.33)	6.00 (3.74)	6.20 (2.35)	5.40 (2.84)	1.91 (.187)	.113	.30	1.31

Note. †indicates significant results and statistical trends ($p < .10$) are presented in bold letters. Results for analyses of co-variance (ANCOVA) and paired-sample *t*-tests. $*p < .05$. EG = experimental group, CG = control group, FEV = German version of the Three Factor Eating Questionnaire, FEDK = Eating Disorder Cognition Questionnaire, BIAQ = Body Image Avoidance Questionnaire.

Between-group comparisons

Psychometric measures

(M)ANCOVAs (controlling for test score at pre-test) indicated significant differences in eating behavior trait scales at post-test between EG and CG. The EG increased in "disinhibition" and decreased in "restriction and dieting" and by trend in "eating and loss of control" (see Table 2).

Table 3 shows the results for the other test parameters: There was a positive training effect for emotional competence, more precisely in the

Table 3. Pre-post results for clinical scales (Bf-S, DIKJ, BSI) and emotional competence (EKF).

		EG *Means* (+/- *SD*)		CG *Means* (+/- *SD*)					
		Pre	Post	Pre	Post	*F* value (*p*) ANCOVA	Eta squared	EG *t* score	CG *t* score
Bf-S		29.20 (16.33)	27.20 (10.95)	23.70 (9.31)	22.90 (6.32)	1.82 (1.95)	.097	.645	.198
DIKJ		18.10 (10.89)	16.10 (12.23)	18.40 (7.55)	15.90 (9.34)	1.44 (2.47)	.078	1.47	1.99
BSI									
	Somatization	8.20 (6.88)	7.00 (5.87)	8.20 (6.93)	7.20 (7.22)	2.45 (.152)	.214	.822	1.40
	Obsessive-compulsive	7.80 (5.01)	7.50 (7.43)	7.10 (5.92)	7.00 (4.50)	.285 (.606)	.031	.205	.100
	Interpersonal sensitivity	6.90 (5.04)	5.00 (4.45)	6.30 (3.34)	5.20 (2.62)	.035 (.856)	.004	2.58†*	1.41
	Depression	9.80 (8.09)	7.50 (5.99)	8.00 (5.56)	7.20 (4.16)	1.58 (.204)	.150	1.65	1.02
	Anxiety	6.20 (6.23)	5.50 (6.22)	4.50 (6.04)	5.10 (5.53)	.019 (.894)	.002	.938	−.452
	Hostility	5.60 (6.17)	4.10 (4.56)	5.30 (4.52)	4.30 (2.87)	.005 (.946)	.000	1.65	1.19
	Phobic anxiety	4.30 (4.14)	4.10 (5.51)	2.80 (3.08)	2.30 (2.06)	2.07 (.184)	.187	.142	.958
	Paranoid ideation	7.20 (5.31)	5.00 (3.92)	5.50 (3.10)	6.20 (4.78)	.002 (.964)	.000	1.72	−.685
	Psychoticism	7.40 (5.68)	6.50 (5.75)	5.40 (3.20)	5.90 (4.91)	.906 (.366)	.091	.585	−.412
EKF									
	General emotionality	51.88 (7.31)	52.15 (9.23)	47.28 (6.90)	47.95 (6.15)	3.69 (.077) †	.221	−.144	−.336
	Recognizing and understanding own emotions	44.60 (11.52)	48.40 (12.00)	41.70 (8.81)	41.70 (8.78)	4.82 (.047) †	.271	−.165	.000
	Recognizing and understanding other´s emotions	70.20 (12.82)	65.80 (14.77)	63.30 (10.57)	61.70 (9.13)	3.27 (.094) †	.201	2.60†*	.550
	Regulating and controlling own emotions	44.00 (7.89)	43.60 (11.06)	37.20 (9.07)	39.60 (7.24)	5.76 (.032) †	.307	.198	−1.30
	Emotional expressivity	48.70 (16.01)	50.80 (15.59)	46.90 (13.21)	48.80 (9.67)	.055 (.818)	.004	−.637	−.493

Note. †indicates significant results ($p < .05$) and statistical trends ($p < .10$). Results for analyses of co-variance (ANCOVA) and paired-sample *t*-tests. *$p < .05$. EG = experimental group, CG = control group, Bf-S = Zerssen BfS self-rating mood scale, DIKJ = German Version of the Children's Depression Inventory, BSI = Brief Symptom Inventory, EKF = Emotional Competence Questionnaire.

subscale "recognising and understanding own emotions." In the subscale "regulating and controlling own emotions," the CG improved in comparison to the EG. No significant training effects were found for the clinical symptom scales (Bf-S, BSI, DIKJ).

Relative EEG spectra

ANCOVAs for overall EEG band power indicated a significant group effect in resting EEG at post-test in eyes closed for theta power, $F(1/17) = 4.476$, $p = .049$, $\mu^2 = .208$. Paired sample t-tests revealed that there was a significant increase in the EG in relative theta power in the eyes closed condition from pre-test to post-test; no significant change was found in the CG. Results from t-tests, means and standard deviations are shown in Table 4. No NF effects were found for theta power in eyes open, $F(1/17) = .034$, $\mu^2 = .002$, alpha power (eyes closed: $F(1/17) = 4.415$, $\mu^2 = .206$; eyes open: $F(1/17) = .05$, $\mu^2 = .003$) or beta power (eyes closed: $F(1/17) = .238$, $\mu^2 = .014$; eyes open: $F(1/17) = .263$, $\mu^2 = .015$; all $p > .051$). Data further show that in relative theta power in eyes closed, 90% of participants were above the trend line. That is, they increased theta from pre- to post-test. In the CG, half the participants increased, half decreased (see Figure 3A).

For electrode-specific analyses, MANCOVAs indicated no significant multivariate effects, however, trends were observed in theta eyes closed, Cz: $F(1/17) = 3.302$, $p = .087$, and Pz: $F(1/17) = 3.358$, $p = .089$, indicating higher scores in the EG than in the CG at post-test.

Generally, we observed substantially more increasing trend lines in both theta and alpha power in the EG compared with the CG (see Figure 3).

No significant results were found for absolute EEG power.

Correlation analyses

When correlating EEG data with clinical data, we found that high relative theta power at post-test was associated with a decreased Positive Distress

Table 4. Mean EEG band power (Theta, Alpha, Beta) in eyes open and eyes closed at pre- and post-test for the eg and the cg (statistical results from paired sample t-tests).

	EG *Means (+/- SD)*		CG *Means(+/- SD)*			
	Pre	Post	Pre	Post	EG t score	CG t score
Eyes open						
Theta	4.49 (1.06)	4.75 (1.15)	5.15 (.96)	5.10 (.83)	−.57	.14
Alpha	3.21 (1.05)	3.37 (1.14)	3.28 (.66)	3.37 (.79)	−1.02	−.88
Beta	2.09 (.47)	2.00 (.57)	1.80 (.35)	1.75 (.33)	1.23	.64
Eyes closed						
Theta	3.38 (.081)	4.63 (.97)	3.97 (.96)	3.97 (1.03)	−3.69†**	.01
Alpha	3.86 (.93)	3.98 (.94)	4.80 (1.32)	4.75 (1.23)	2.23	.34
Beta	1.92 (.65)	1.91 (.52)	1.34 (.41)	1.41 (.37)	.21	−2.37*

Note. †indicates significant results.*p > .05, **p < .01. EG = experimental group, CG = control group, EEG = electroencephalography; theta band power 4–7 Hz, alpha band power 8–12 Hz, beta band power 13–22 Hz.

Index from the BSI in the EG (eyes closed: $r = -.68$, $p = .031$). Beta power at post-test was positively correlated with obsessive-compulsive behavior (eyes open: $r = .65$, $p = .044$; eyes closed: $r = -.64$, $p = .045$), interpersonal sensitivity (eyes closed: $r = .65$, $p = .044$), and anxiety (eyes open: $r = .79$, $p = .006$; eyes closed: $r = .72$, $p = .019$). Alpha power at post-test was negatively associated with anxiety (eyes open: $r = -.64$, $p = .046$). No relationship was found in the EG between eating behavior traits and EEG data, or in the CG between EEG and all psychometric data.

Discussion

This article presents a novel treatment approach for AN. While several clinical groups suggest integrating NF into AN treatment (Bartholdy et al., 2013; Reel, 2013), this is the first experimental study evaluating the effectiveness of NF intervention as a treatment adjunct in a sample of female adolescents with AN. Our findings show that patients with AN treated with a 5-week alpha NF protocol significantly improved in eating behavior traits and recognising one's own emotions. Eating behavior trait effects were observed particularly on the "disinhibition" and "hunger" scale of the FEV, and on the scale "restriction and dieting" from the FEDK. Statistical trends were observed on "body and self-esteem" (FEDK). Against our hypotheses, we did not find any NF effects on the clinical scales or BMI. The results concerning EEG indicated an increase in the theta band in an eyes closed condition in the EG from pre- to post-test. In contrast, no expected changes in alpha activity through NF were demonstrated. These observations will be discussed later in more detail.

The specific psychopathology of AN is complex. Disturbed eating behavior includes excessive dieting and dysfunctional cognition concerning eating and food consumption (APA, 2013). The construct of "disinhibition" of the FEV is characterized by losing control over food consumption and is related to suggestibility via situational factors or emotional states (Laessle, Tuschl, Kotthaus, & Prike, 1989). "Disinhibition" is proposed as an opposite pole to restrained eating. Pudel and Westenhöfer (1989) suggest that a high value on the scale "disinhibition" is associated with higher food intake. In the present study, we observed increased "disinhibition" through NF which suggests a counter-acting response to rigid AN pathology. Apparently, the elevation of disinhibition processes and the related decrease of cognitive control in the brains of individuals with AN after NF intervention seem to support the hypothesis of greater perceived voluntary control through NF. Moreover, the disturbed perception of hunger normalized in the NF group over the course of NF training. Reduced perception of body signals is often a core psychopathological element in AN, and plays an important role in the maintenance of eating disorders (Pollatos et al., 2008).

Data further show that NF improves the ability to recognize one's own emotions. These results support the assumption that NF facilitates the adoption of an internal focus (Angelakis et al., 2004; Thompson & Thompson, 2003). Knowing one's own emotions is one domain of emotional intelligence and could help to develop new strategies and protection skills against the eating disorder, and could counteract emotional stress and the maintenance of AN. No effects were found in emotion regulation or in the EKF subscale "recognising and understanding other's emotions," which is commonly known as one aspect of "theory of mind" (Russel et al., 2009). On the contrary, the CG improved on the scale "regulating and controlling own emotions" in comparison to the EG. Haynos and Fruzzetti (2011) pointed out that the role of emotion dysregulation in AN has been neglected in the past and should be incorporated into treatment strategies. We recommend further investigation of the impact of NF as a potentially social-cognitive based treatment in AN. Future studies should investigate the effects of NF training with more advanced "theory of mind" tasks.

The NF intervention under investigation was based on an alpha training protocol. Contrary to our hypothesis, the AN children who performed alpha NF, showed no significant resting EEG changes in alpha power when compared to the CG. However, the results provide evidence that theta, as a marker for elevated relaxation (Jacobs & Friedman, 2004) and mental processing (Klimesch, 1999) increased through NF. Orekhova, Stroganova, Posikera, and Elam (2006) showed that in children, theta oscillations are strongly related to behavioral states with substantial attentional and emotional load. In addition, elevated theta power, especially frontal midline theta, has been related to positive emotional experiences (Aftanas & Golocheikine, 2001). In our study, increased relative theta power was related to a decrease in global psychological distress in the NF sample. However, we tried to find some further possible explanations for the findings regarding EEG theta power changes.

This individualized alpha training is not effective in increasing alpha activity, but could have cognitive effects

The training, as provided in the present study, was adjusted to each patient (i.e., individualized NF). Therefore, it may be possible that, with low initial baseline rates, little effort was required from participants to achieve training success. The adolescents may have learned to reduce effort, but not to increase alpha activity. In that case, NF could be effective because of a placebo response, and more specifically within the meaning of cognitive training. Kober, Witte, Ninaus, Neuper, and Wood (2013) suggest that mental strategies used to gain control over one's own brain activity play an important role in successful NF performance. Accordingly, another study demonstrated the effectiveness of NF without a direct effect on brain activity, but via mental strategies and control beliefs (Witte, Kober, Ninaus, Neuper, & Wood, 2013). The authors propose that participants with a high internal locus of control might consume additional cognitive resources. This higher effort in turn may interfere with brain states of relaxation, as reflected by theta activity in the present study. Ninaus et al. (2013) observed that NF recruits the neuronal correlates of cognitive control even when only "sham" NF is presented.

It is assumed that individualized NF, as applied in practice with the aim of normalising deviant brain activity, is not as efficient in changing EEG activity as standardized NF training is, where the aim to self-control brain activity is more effective (Logemann, Lansbergen, Van Os, Böcker, & Kenemans, 2010). To address these potential problems, we recommend a baseline adaption after each run that constrains participants to exert themselves more. Even so, the existing considerations generated by our results provide a strong argument that a well-designed learning paradigm is useful in interpreting NF training effects. An evaluation of our NF protocol in other samples could shed light on the mental strategies used.

Theta reflects low alpha in adolescents

It is well documented that alpha frequency increases from childhood to adulthood. Previous studies have shown that in normally developing children, alpha power can be in a lower frequency range and therefore sometimes is mistaken as theta power (Clarke, Barry, McCarthy, & Selikowitz, 2001).

Alpha NF training has a non-specific effect (e.g., relaxation, internalized attention, mindfulness)

It has previously been demonstrated that slow-wave NF is used successfully as a stress-reducing technique (Batty, Bonnington, Tang, Hawken, & Gruzelier, 2006). Aftanas and Golocheikine (2001) report associations of both frontal midline theta and low alpha oscillation networks with states of internalized attention. Increased frontal midline theta power during meditation has also been observed (Cahn & Polich, 2006).

Limitations, clinical implications, and conclusion

Limitations

Small sample size was a major limitation of the present study. Due to this, these findings can serve only as pilot data suggesting further research. The limited spatial sampling due to the small number of electrodes possibly obscured lateralized effects, and the large age range of the sample (which correlates to ranges in neural development) were further inherent problems.

In addition, as we investigated patients in the hospital, there was no shielded room for EEG recordings available. Self-report measures for the eating behavior traits were used and the CG received no additional treatment, which further limits interpretation. A passive CG design has to face problems of unspecific effects and expectancy. The best option for NF evaluation would be to use a sham-feedback design for the CG. However, as we conducted a proof-of-principle study applying NF to adolescents with AN for the first time, we decided to use a waiting-list group which is potentially more ethically preferable. In addition, to show feasibility of neurofeedback in AN treatment for the first time, no primary outcome has been defined and a broad psychological test-battery was used. For a future large-scale study, more specific measures of change of eating disorder behavior and general psychopathology, such as the EDE-Q (Hilbert, Tuschen-Caffier, Karwautz, Niederhofer, & Munsch, 2007) should be used. Regrettably, long-lasting effects of NF are unknown and might be the subject of long-term studies.

Clinical implications

Neurofeedback is a neuroscientific treatment approach with the potential to directly influence deficient brain function and related behavioral and cognitive deficits. Individuals with AN could benefit by improving their control over physiological processes usually perceived to be beyond conscious control. In addition, slow-wave NF has previously been discussed as a relaxation technique effective in stress-related disorders. Patients with poor compliance or at risk of drug abuse could particularly benefit from non-pharmacological treatment approaches. From a clinical perspective, the success of NF was also demonstrated by the subjective evaluation forms (indicating high acceptance and satisfaction with the NF treatment) and reports from family and treating physicians. However, there was no significant weight increase through NF or improvements in clinical scales. Nevertheless, based on our findings and clinical observations, we recommend considering the potential of NF as a treatment adjunct in AN therapy programmes. More randomized control trials with larger samples and further information for practical use are needed.

Conclusion

The present study illustrated the process and the results of applying NF to adolescent females suffering from AN. Findings showed significant improvements in eating behavior traits related to cognitive processes associated with food consumption and rigid eating. In addition, NF may improve recognition of one's own emotions, but had no effect on clinical symptoms. Regarding brain activity, preliminary changes through NF were observed, and these may be further examined with respect to other behavioral indicators. Given the limitations of the small sample size, we believe it is premature to conclude that NF training as a treatment adjunct is applicable in patients with AN, and effectively reduces parameters related to eating disorder pathology.

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