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Research paper

The effects of alpha/theta neurofeedback on mood, anxiety, emotion regulation and trait impulsivity

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ABSTRACT

Previous research showed that neurofeedback improved mood, anxiety and addiction symptoms and enhanced optimum performance among musicians and artists. Although the alpha/theta protocol was used in some of these studies, the results have been inconsistent, this is in part due to limited or no use of mock-feedback control groups and the focus being on mostly clinical samples. The current study aimed to comprehensively assess the effects of alpha/theta neurofeedback on state and trait emotions. Twenty-five participants who met the criteria for at least moderate anxiety on GAD-7 were assigned to either real or mock-feedback and completed nine sessions over five weeks. Pre and post emotion dysregulation (DERS-SF), trait impulsivity (SUPPS-P), anxiety (GAD-7) was measured at S1 and S9, and state mood (PANAS) was assessed pre and post each session. The results revealed significant reduction in anxiety among real feedback group at post-S9, while the state negative mood improved for both groups at post sessions. There was no significant change in emotion dysregulation or trait impulsivity from pre to post neurofeedback. Real feedback group showed significant within session increase in their theta/alpha ratio while there was no significant difference between sessions. Overall, the findings suggest that alpha/theta neurofeedback is an effective intervention for anxiety and improves state mood but does not lead to change in traits such as emotion-based impulsivity and emotion dysregulation. This is the first study to comprehensively assess alpha/theta neurofeedback training on different dimensions of emotions in a simulation-controlled design, limitations and implications are discussed.

1. Introduction

1.1. Background

Neurofeedback, also known as EEG-biofeedback, is a brain-computer interface (BCI) technique based on operant conditioning, where the learner receives real time audio or visual feedback of their brainwave activity, allowing them to learn to regulate it. The method has been applied to various mental health problems such as schizophrenia and bipolar disorders (Mohammadi et al., 2022), attention deficit hyperactivity disorder (ADHD) (Saif and Sushkova, 2023), personality disorders (Babaskina et al., 2023) and substance addiction (Martz et al., 2020), it has also been used for peak performance in healthy individuals including among those engaged in sports and music (Cheng et al., 2024; Gruzelier, 2013).

The EEG consists of different frequency bands, delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), sensorimotor (SMR) frequency (12–15 Hz), beta (13–30 Hz) and gamma (30–100 Hz) (Omejc et al., 2019), where each represents a particular physiological function. For example, while slow waves such as alpha frequencies are associated with peacefulness, meditation, deeply relaxed state, sensory motor rhythm (SMR) (13–15 Hz) is associated with mental alertness and physical relaxation (Marzbani et al., 2016). Markers have been identified that guide clinical applications. For example, Michelini et al. (2022) reported that event-related alpha, beta, and theta power are potential biomarkers of ADHD. Theta over beta ratio has been used as a measure to distinguish those with ADHD (Saif and Sushkova, 2023; Arns et al., 2014).

Alpha/theta neurofeedback aims to increase the learner's control over slow wave frequencies associated with deep relaxation through increasing the theta/alpha ratio in a training session (Gruzelier et al., 2014). It has been shown to have benefits in substance misuse (Dehghani-Arani et al., 2013) and improve performance of artists and

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musicians (Gruzelier et al., 2014). The alpha/theta protocol which aims to reward these frequencies to achieve the cross-over of the theta/alpha ratio, where theta amplitudes are higher than alpha was initially developed in 1990s, and used with auditory feedback, combined guided imagery and constructed visualizations. The protocol was trialed in treatment of male Vietnam combat veterans with dual diagnosis of posttraumatic stress and alcohol abuse. The study found that only three out of 20 experimental subjects had alcohol relapse at 26 months follow-up (Peniston and Kulkosky, 1991). It was also found that when subjects reported abreactive imagery, statistically reliable interaction revealed a cross-over where theta waves gradually increased and alpha waves decreased. More recently, these findings were supported by Rodriguez-Larios et al. (2020) that found during meditation (compared to rest and arithmetic task) alpha and theta frequencies tended to converge in the upper theta/lower alpha band (i.e. 7–9 Hz), thus increasing the incidence of cross-frequency ratios between 1.0 Hz and 1.5 Hz, whilst during arithmetic task (compared to rest and meditation) alpha and theta separated from each other, where higher alpha and lower theta frequencies were observed. This is in line with previous research showing that during effortful cognition there is an increase of alpha peak frequency (Haegens et al., 2014) and reduction in theta peak frequency (Rodriguez-Larios et al., 2020), while meditative states are accompanied by power increase in the lower alpha/upper theta band depicting cross-frequencies (Saggar et al., 2012).

Despite the advancement in research showing the mechanisms of alpha/theta training since its development in 1990, there is very limited number of research examining the efficacy of this protocol in anxiety disorders. Dadashi et al. (2015) in a quasi-experimental study recruited 28 patients with General Anxiety Disorders (GAD) and allocated half of them to receive neurofeedback while the other half was placed on the waiting list. The treatment group received 15 30-minute alpha and then 15 30-minute theta brain training sessions in the occipital area. The results showed that increase of alpha and theta brain waves amplitude in the occipital area in people with GAD reduced the symptoms of GAD in the treatment group, but no such change was observed in the waiting list group. However, the study did not use the alpha/theta protocol so a theta/alpha ratio (cross-over) could not be measured. Furthermore, the comparison group was a waiting list rather than a sham-control group (mock feedback), so it is hard to conclude that the improvements in anxiety were due to the sessions. Another issue is the length of the session, one hour session in total for both frequencies could lead to fatigue in participants. Hou et al. (2021) trained alpha frequencies on left and right parietal lobes (P3, P4) of 26 females with GAD diagnosis and allocated half to receive alpha training over P3 and the half over P4 in 10 sessions, each lasting 40 min over two weeks. Patients were also asked to practice at home without biofeedback. The study reported improvement in symptoms of anxiety and depression in both groups, suggesting alpha activity over the parietal lobe is effective in GAD patients. This study did not use a sham-control group and was all female, also it did not assess the efficacy of the alpha/theta protocol on anxiety to determine whether the frequency cross-over would have led to a better outcome. Furthermore, it is unclear how the practice of participants outside the sessions have contributed to their symptom improvements. Moradi et al. (2011) in a case study, tested the effects of beta-increase and alpha- increase EEG feedback training along with alpha-theta biofeedback training in two patients diagnosed with anxiety disorder. The Symptom Checklist-90-Revised (SCL-90-R) and patients' self-reports were used as measures of treatment efficacy. Following 30 sessions of EEG biofeedback within a three-month period, patients reported a significant reduction in anxiety-related symptoms, and at one-year follow up patients reported that they were symptom free. However, this is a case study with only two diagnosed patients and no control group.

Despite the support aforementioned studies provide for the efficacy of alpha training on trait anxiety, most studies did not use control group, and in some cases the sample sizes were very small to infer the effect reported (e.g., Moradi et al., 2011). Furthermore, studies are mostly conducted in clinics with clinical samples who knew the purpose of the sessions and had expectations, or wanted to be helpful to the clinician which may have resulted in demand characteristics or investigator bias that challenges the validity of the findings.

Moreover, the studies that have employed alpha/theta protocol have often tested its efficacy in addiction. A critical review of eight studies evaluating the efficacy of neurofeedback in alcohol use disorders reported that studies used alpha/theta protocol. The review acknowledged the scarcity of studies and the need for randomised studies to test the efficacy of this protocol which is thought to enhance relaxation, decrease anxiety and stress, prevent alcohol relapse, maintain abstinence and increase the feeling of well-being (Lima et al., 2022).

1.2. *The current study*

In this study, we sought to firstly investigate the effects of alpha/theta neurofeedback on trait anxiety in a simulation (mock-feedback) controlled design. Secondly, we tested whether the effects on trait anxiety and state positive and negative affect only lasts during the sessions or continues between sessions. Thirdly, we assessed whether alpha/theta neurofeedback would lead to reduction on any dimension of difficulties in emotion regulation and emotion-based trait impulsivity as a personality trait. We hypothesised that participants who receive real neurofeedback will report greater improvement in anxiety symptoms, mood, emotion regulation abilities and on emotion-based facets (positive and negative urgency) of trait impulsivity. The current study is the first to comprehensively examine the effects of a simulation-controlled alpha/theta neurofeedback on various dimensions of affect, including state, trait anxiety, emotion regulation and emotion-based trait impulsivity.

The more specific hypotheses were:

H_1: There will be a significant increase in positive affect and reduction in negative affect following real feedback as compared to simulation feedback.

H_2: There will be a significant difference between the real and simulation group in their anxiety level at post-neurofeedback sessions, with the real feedback group showing significantly lower anxiety symptoms.

H_3: Real feedback group will show significant improvement in their emotion regulation from pre to post neurofeedback sessions as compared to the simulation group.

H_4: Emotion-based impulsivity facets (negative and positive urgency) will significantly differ from pre S1 to post S9 between the real feedback and simulation groups, with the real feedback group showing lower urgency following neurofeedback sessions.

2. Methods

2.1. *Participants*

A priori power analysis was conducted to determine the sample size for the planned analyses, using G*Power software with 0.80 statistical power, medium effect size (f = 0.25) and 0.05 probability level, the projected sample size was N = 22. Thus, the total sample of N = 25 is considered adequate for the analyses performed, following exclusion of six participants due to incomplete sessions. The 88 % of the sample were female (N = 22), with only 3 male participants taking part in the study. The mean age of participants was M = 35.66 (SD=11.51) for the real feedback group, and it was M = 27.69 (SD=10.08) for the simulation group.

Participants who met the GAD-7 cut off point for at least moderate anxiety (mild anxiety = 5; moderate = 10; severe = 15; Spitzer et al., 2006) were selected from a pre-survey they have completed online on Qualtrics through the university community page. The pre-survey included a number of questionnaires described in the methods section and it was completed by 250 participants between October 2023 and

November 2024. Participants who met the criteria were invited through an email to take part in a neurofeedback study without providing a detailed explanation for how they met the requirements. They were then randomly assigned at a 1:1 ratio into two groups to receive either real or simulation feedback prior to arriving at the lab to prevent researcher bias, and were told that they would receive full debrief after the final session. The neurofeedback setting was changed by the first author to either simulation or real feedback prior to meeting the participant. All procedures were exactly the same for participants in both groups including the alpha and theta feedback sounds, only that the simulation group's brain activity was not connected to the feedback. The recruitment was done by the co-authors who did not know about the settings. Due to different availability of the researchers, some of the data collection was done by the first author. So, the study was not fully double blind. However, since the protocol used was eyes-closed and did not require any communication between researchers and participant, we believe the potential researcher bias should be minimal if any. The pre and post sessions state affect questionnaire (PANAS) was completed online through Qualtrics, participants did not need to communicate with the researcher.

The sessions were carried out twice a week over 5 weeks. Participants were excluded if they had any other mental health diagnosis that could affect the outcome.

The ethical approval for this study was obtained from the ethics panel of the School of Human and Social Sciences at the university and followed the British Ethics Code of Conduct for human research.

2.2. Measures

2.2.1. General anxiety disorder (GAD-7) (Spitzer et al., 2006)

GAD-7 is a valid and reliable self-report tool for screening for anxiety disorders and its severity, and consists of seven items. The items ask questions about the anxiety level experienced over the last two weeks and are rated on a continuum form 0-Not at all to 3-Nearly every day. The scores range from 0 to 21. Scores of 5, 10 and 15 are considered as cut-off points for mild, moderate and severe anxiety respectively. All participants in the current study had at least a score of 7 (N = 2), with the majority scoring above 10 (N = 19). Participants completed the GAD-7 at pre Session 1 (S1) and post Session 9 (S9).

2.2.2. Difficulties in emotion regulation scale-Short form (DERS-SF) (Kaufman et al., 2016)

The DERS-SF is a short version of the 36 items Difficulties in Emotion Regulation Scale which is a measure used to identify difficulties in regulating emotions in adults. Same as the long version, DERS-SF (18-item) has six subscales and high internal reliability (Cronbach's alpha ranging from.78 to 0.91 for total scores and six subscales). The subscales include Strategies (limited access to emotion regulation strategies), Nonacceptance (tendency toward negative secondary responses to negative emotions or denial of distress), Impulse (difficulties in controlling behavior when upset), Goals (difficulties in concentrating and accomplishing tasks while experiencing negative emotions), Awareness (lack of emotional awareness or inattention to emotional responses) and Clarity (the extent to which individuals are unclear about which emotions they are experiencing). Higher scores indicate higher difficulties in emotion regulation. DERS-SF was administered pre S1 and post S9 in this study.

2.2.3. Trait impulsivity (SUPPS-P) (Cyders et al., 2014)

The short Urgency (negative), Perseverance, Premeditation, Sensation Seeking, Positive Urgency was used to measure trait impulsivity at pre S1 and post S9. This is a short 20 item version of the long UPPS-P which consisted of 59 items. The Short UPPS (SUPPS-P) shares the same internal reliability as the long version (α = 0.74–0.88 across subscales) and includes the same subscales. Positive and negative urgency measures the tendency to act rashly while in positive or negative affective state respectively; sensation seeking measures tendency to engage in risk behaviors, while (lack of) perseverance assesses the inability to complete a task to the end, and (lack of) premeditation is the inability to plan behaviors.

2.2.4. State affect (PANAS; Watson et al., 1988)

The Positive Affect Negative Affect Scale was used before and after each neurofeedback session to measure the state mood of real and simulation groups. This brief scale is comprised of 20 items, with 10 items measuring positive affect (e.g., excited, inspired) and 10 items measuring negative affect (e.g., upset, afraid). Each item is rated on a five-point Likert Scale, ranging from 1 = *Very Slightly or Not at all* to 5 = *Extremely*, to measure the extent to which the affect has been experienced in a specified time frame. The scale has excellent internal reliability, for the Positive Affect Scale, the Cronbach alpha coefficient ranged between 0.86 to 0.90; and for the Negative Affect Scale it was between 0.84 to 0.87.

2.3. Procedures

Neurofeedback sessions were performed using the Brain Master Discovery 24E (Ohio, USA) with the active electrode placed at Pz and reference and ground electrodes at mastoids (Billinger et al., 2013; Raymond et al., 2005). We have replicated the procedures of Raymond et al. (2005) for the neurofeedback sessions. Participants completed nine sessions of either real or simulation neurofeedback over five weeks.

Upon arrival, participants sat comfortably in a chair and were asked to complete Pre-PANAS questionnaire on Qualtrics. They were then prepared for the session, a 10–20 system adjustable EEG cap (Free-Cap, Feiner) which uses saline as conductive was used and electrodes were attached, impedance were checked through the Discovery hardware and visual inspection of the raw signal. In their first session, participants were explained the principles of neurofeedback and were asked to close their eyes and relax as deeply as possible without falling asleep. Prior to the first session, the individual's dominant alpha frequency (IAF) was assessed in an eyes-closed, 2-minutes feedback-free session as recommended by Doppelmayr et al. (1998) (also Raymond et al., 2005; Hou et al., 2021). Accordingly, the mean modal alpha frequency was extracted from this assessment, alpha band was calculated as 1.5 Hz above and below of this value. Theta was defined at 3 Hz frequency and the median frequency of theta lay 4 Hz below the IAF. For example, for a participant with an IAF of 10 Hz, alpha would be defined as 8.5–11.5 Hz and theta as 4.5–7.5 Hz (Raymond et al., 2005). The artefact threshold that was pre-set in this protocol was used (240 μV).

The training protocols were set following the assessment session to reflect each participants baseline alpha and theta frequencies. Additionally, the threshold for reinforcement of alpha and theta was set at 60 % and updated, such that alpha and theta amplitudes exceeded the threshold approximately 60 % of the time. The training sessions were all eyes closed and incorporated feedback in the form of sounds. When participants' alpha exceeded their theta, they heard 'crashing waves' sound through the computer speakers and when theta exceeded alpha, they heard soft 'music' sound. Each frequency band had an amplitude threshold, and supra-threshold bursts of alpha or theta were rewarded by high or low pitch gong sound respectively. Participants were explained that the aim was to be in a state where theta exceeds alpha when they can hear more of the music and less of the crashing waves. They were asked to relax and visualize themselves in their best possible version. This type of guided imagery was used as it is thought to enhance the change. Participants were reminded that although the aim is to achieve the cross-over where theta is higher than alpha, they should not make efforts as this could be distracting from the alpha/theta neurofeedback experience. They were told that they may hear more of the theta sound over time. Each session lasted for 20 min. During the session, the researcher monitored the sessions for excessive delta activity indicating that participants may be falling asleep, in such cases, tapped their shoulder gently to ensure that they were awake. The EEG data was gathered in 20 '1-minute' runs.

The only difference between real and simulation group was that the simulation group listened to prerecorded sounds within the software during the sessions; they heard the same alpha and theta sounds, resembling the feedback to real feedback group, however, there was no relationship between the brainwave activity and the sounds they heard. Before and after each session, participants in both groups were asked to complete PANAS pre and post questionnaire. Prior to being selected for the experiment and at the end of the final session, participants additionally completed a longer survey that included trait anxiety, trait impulsivity and emotion regulation questionnaires. After the final session, all participants were asked the extent to which they felt that they were in control of their brainwave activity (i.e., if they thought that they were able to control what sounds being played) on a rating scale ranging from 1-'not at all' to 5- 'very much in control'.

3. Results

All descriptive and inferential statistics were performed using statistical analysis package for social sciences (SPSS) V26.

3.1. Between groups comparisons

The group difference at pre-testing was nonsignificant for age, anxiety (GAD-7), emotion dysregulation facets (DERS) and emotion-based trait impulsivity facets (Positive Urgency, Negative Urgency). Table 1 demonstrates the descriptive statistics at pre-neurofeedback training for both groups.

3.2. Perceived control of EEG

A Mann-Whitney *U* test showed no difference between perceived control of Real Feedback and Simulation group ($U = 75.00$, $z = -0.172$, $p = 0.894$) suggesting that both groups felt equally in control of their brainwave activity. The mean rank of perceived control for real feedback group was 13.23, and for Simulation it was 12.75. The mean perceived control reported for the real feedback group was $M = 2.83$ ($SD = 0.80$) and for the simulation group, $M = 2.85$ ($SD = 1.19$).

Table 1
Pre-neurofeedback differences between real feedback and simulation groups in age, anxiety (gad-7), difficulties in emotion regulation and urgency sores.

Variable	Real M (SD)	Simulation M (SD)	*t*	*p*	*Cohen's d*
Age	35.66 (11.51)	27.69(10.08)	−1.846	0.08	−0.73
GAD-7	13.67 (3.11)	11.92(4.27)	−1.158	0.26	−0.46
DERS-SF					
Strategies	7.58(3.34)	7.38 (2.39)	−0.172	0.86	−0.06
Nonacceptance	7.33(3.47)	7.08 (2.53)	−0.212	0.83	−0.08
Impulse	7.50 (3.70)	6.23(3.11)	−0.930	0.36	−0.37
Goals	12.17 (3.09)	10.54 (2.43)	−1.46	0.16	−0.58
Awareness	6.33(2.01)	6.85(2.94)	0.504	0.62	0.20
Clarity	6.42(2.50)	6.31(2.13)	−0.117	0.91	−0.05
DERS total	47.33 (14.79)	44.38(9.90)	−0.590	0.56	−0.23
SUPPS-P					
Negative urgency	11.08 (2.53)	9.92(2.99)	−1.02	0.31	−0.42
Positive urgency	7.08(2.53)	8.00(3.58)	0.732	0.47	0.29

Note. DERS-SF = Difficulties in Emotional Regulation Scale Short Form; SUPPS-P = Short UPPS-P Impulsive Behaviour Scale values for each of the analyses are shown for Real feedback (n = 12) and Simulation (n = 13). $^{*}p < 0.05$, $^{**}p < 0.01$.

3.3. Mood

The Positive Affect Negative Affect Scale (PANAS) was used before and after each neurofeedback session to measure the state mood of real and simulation groups.

A 2x2 (time x group) ANOVA was conducted to explore whether state negative affect changed after sessions 1, 5 and 9. Levene's test was nonsignificant in all sessions suggesting equal variances for the real and simulation groups can be assumed for all the sessions ($p > 0.05$). As the sphericity assumption was violated, the Greenhouse-Geisser correction was applied (Field, 2013). The post-session means for negative affect were lower than the pre-session scores for both real and simulation groups after all sessions, with greatest pre-post session difference observed after the first session.

Table 2 depicts the mean and standard deviations before and after sessions 1, 5 and 9. The ANOVA results showed a significant main effect of time ($F\ (1,23) = 7.116$, $p < 0.001$) indicating that both real and simulation sessions improved the negative affect at post sessions. Although it was close, the interaction effect of time by group was nonsignificant ($F\ (1,23) = 2.468$, $p = 0.06$), suggesting that improvements in negative affect did not differ between real and simulation feedback groups.

Fig. 1 shows the mean scores for negative affect before and after sessions 1,5 and 9.

For the Positive Affect, there was no significant main effect of time or an interaction of time by group, indicating that the positive affect did not change from pre to post neurofeedback sessions for either real feedback or simulation group.

3.4. Anxiety

Trait anxiety was measured using General Anxiety Disorder Scale (GAD-7). The GAD-7 was administered prior to Session 1 and at the end of Session 9. There was no significant difference between real and simulation groups in their anxiety level at pre session (See Table 1). The anxiety pre-score for the simulation group ranged from 7 to 21, and for the real group the range was between 10 and 21.

There was a reduction in anxiety symptoms by 5.67 points from pre to post session in the real feedback group (pre M = 13.67, SD = 3.11; post M = 8.00, SD = 4.34), while the reduction from pre to post sessions was only minimal in the simulation group (pre M = 11.92, SD = 4.27; post M = 11.62, SD = 4.94). Prior to conducting a 2x2 (time x group) ANOVA the normality assumption was checked performing a Shapiro Wilk test for the pre-GAD scores and it was satisfied ($W\ (25) = 0.947$, $p = 0.212$). The main effect of time ($F(1, 23) = 20.374$, $p < 0.001$) and the interaction effect of time by group ($F(1,23) = 16.393$, $p < 0.001$) were significant indicating that there was a significant reduction in the anxiety levels of both real feedback and simulation groups from preS1 to post S9 and that the reduction was significantly more for those in the real feedback group Fig. 2.

Table 2
Pre and Post Neurofeedback mean scores of Negative Affect for Real Feedback and Simulation groups.

Measure	Real M (SD)	Simulation M (SD)
Negative affect pre S1	26.18(8.84)	24.77(7.75)
Negative affect post S1	21.00 (7.39)	17.77(6.48)
Negative affect pre S5	18.91(7.24)	22.00(6.65)
Negative affect post S5	16.18(5.67)	20.15(5.64)
Negative affect pre S9	18.00(5.68)	22.23(8.14)
Negative affect post S9	17.55(6.89)	20.00 (8.17)

Note. Mean and standard deviation of real and simulation groups for Negative affects before and after sessions 1, 5 and 9.

Fig. 1. Mean negative affect scores for Real feedback and Simulation groups pre and post sessions 1, 5 and 9.

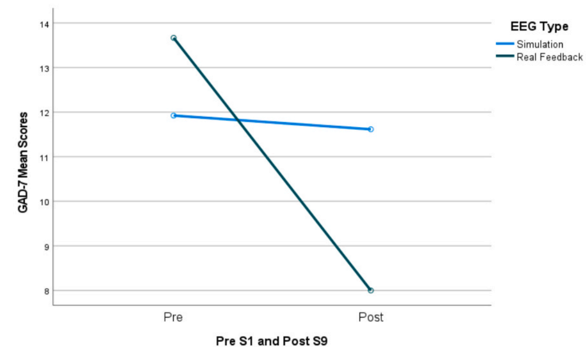

Fig. 2. Mean GAD scores for Real feedback and Simulation groups pre session 1 and post sessions 9.

3.5. Emotion regulation

Difficulties in emotion regulation were measured using the short-DERS at pre session 1 and post session 9. The real feedback group showed greater reductions in emotion regulation difficulties at post sessions as compared to simulation group. The total pre-DERS for real feedback group was 6.5 points higher (M = 47.33, SD = 14.79) than the total post-DERS (M = 40.83, SD = 10.02) as compared to simulation pre-DERS (M = 44.38, SD = 9.90) and post-DERS (M = 44.15, SD = 14.72) total scores which showed only minimal reduction.

However, a 2x2 (time x group) ANOVA revealed no main effect of time ($F(1,23) = 1.113$, $p = 0.30$) or time by group interaction ($F(1,23) = 0.965$, $p = 0.336$), indicating no significant difference from pre to post session for either real feedback or simulation group for overall difficulties in emotion regulation scores. In separate analyses, we have examined the subscales. As the assumption of normality was violated for some of the subscales, we conducted the non-parametric Mann-Whitney test to explore the pre to post session difference. The results were also nonsignificant.

3.6. Trait impulsivity

Trait impulsivity was measured using the SUPPS-P scale at pre S1 and post S9. Following assumptions testing, a 2 × 2 (time × group) repeated measures ANOVA was conducted to test the difference between real feedback and simulation groups for the pre and post sessions total SUPPS-P scores. Both the main effect ($F(1,22) = 0.049$, $p = 0.82$), and the interaction effect of the total SUPPS-P ($F(1,22) = 0.921$, $p = 0.34$) were nonsignificant. To test whether emotion-based impulsivity facets (negative and positive urgency) differed from pre S1 to post S9 between real feedback and simulation groups, two separate 2 × 2 (time × group) ANOVA were performed for each type of urgency. The results revealed that the main effect of negative urgency ($F(1,22) = 0.019$, $p = 0.89$) and the interaction effect ($F(1,22) = 1.560$, $p = 0.22$) were nonsignificant. Similarly, positive urgency did not significantly differ between real feedback and simulation groups from pre to post sessions. The main effect ($F(1,23) = 0.00$, $p = 0.98$), and the interaction effect of positive urgency were nonsignificant ($F(1,23) = 1.054$, $p = 0.31$).

3.7. Neurofeedback training

Participants completed nine sessions of real or simulation feedback. For the real feedback group, theta/alpha ratio (t/a) was calculated for each 1-minute time period of the 20 min session in all the sessions. The data was then pooled for all sessions and all participants in the real feedback group. The mean theta/alpha ratio was calculated for each minute across all sessions. Spearman's rank correlations revealed that theta/alpha ratio significantly increased within each 20-minute session (Spearman's rho = 0.955, $p < 0.001$, 95 % CI [.74, 0.78]). Fig. 3 depicts the mean theta/alpha ratio within sessions.

However, the mean theta/alpha ratio did not show a significant increase across sessions (Spearman's $rho = -0.150$, $p = 0.700$).

4. Discussion

The current study investigated the effects of nine sessions alpha/theta neurofeedback training over medial parietal site (Pz) on state mood, trait anxiety, emotion dysregulation and emotion-based trait impulsivity facets. This is the first study to comprehensively assess alpha/theta neurofeedback training on different dimensions of emotions in a simulation (mock feedback) controlled study. Overall, findings partially supported the effects of alpha/theta neurofeedback on state and trait anxiety (H_1 and H_2), while hypotheses predicting the effects of alpha/theta neurofeedback on emotion regulation and emotion-based trait impulsivity (H_3 and H_4) were rejected. The more specific findings and their implications are discussed below.

4.1. State and trait mood

The results revealed that neurofeedback sessions significantly improved negative affect at post sessions for both real and simulation feedback groups, with the greatest improvement (pre-post NF mean difference) after the first session, partially supporting H_1. However, there was no difference between groups or between sessions. This finding is partially in line with Hou et al. (2021) where there was a main effect of time suggesting both groups (26 females with anxiety

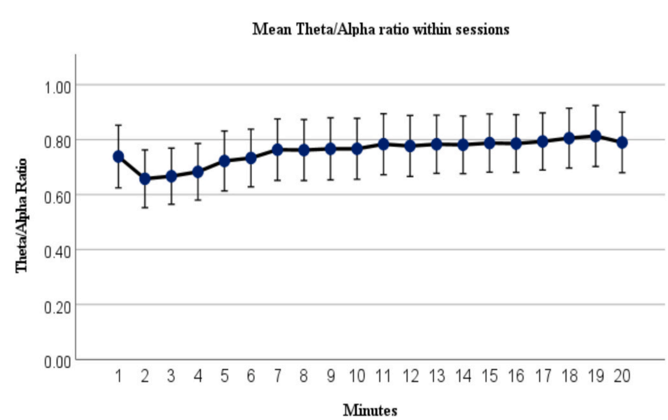

Fig. 3. Mean (Standard error of the mean) theta/alpha ratios of the Real group for 1-min periods averaged across sessions. The theta/alpha ratio rose progressively within sessions (Spearman's rho = 0.955, p < 0.001, 95 % CI [.74, 0.78].

diagnosis) showed improvements after the neurofeedback sessions reflected in reduced State-Trait Anxiety (STAI) and Beck Depression Inventory (BDI) scores and there were improvements after four weeks as compared to the baseline however, no difference between groups were found following 10 sessions of alpha training on either right or left parietal lobe. Although this study is partially comparable, while both groups in Hou et al. received real feedback on either hemisphere, the current study demonstrated improvements in negative affect for both real and simulation feedback groups at post sessions but not between sessions. There was no difference in state positive affect at post sessions between groups or any overall effect to show significant improvement in positive affect, suggesting that neurofeedback may have a greater effect in alleviating negative affective states. These finding are also in agreement with Raymond et al. (2005) where real alpha/theta neurofeedback group showed a notable difference on the 'energetic-tired' facet of the state mood (POMS), reporting higher energy as compared to mock feedback group, (total N = 12).

As hypothesized (H_2), anxiety symptoms were significantly reduced from pre-S1 to post S9 for only real feedback group but no difference was observed in the simulation group. Cheng et al. (2024) using a total of 34 subjects, 17 with anxiety disorder and 17 healthy, recorded electroencephalography (EEG) resting state signal and mindfulness-based EEG signal (8 mins recording), and found that mindfulness-based EEG led to improvements in anxiety through the increase in gamma power. The enhancement in this wave power represented an improvement in the subjects' mindfulness ability. The study supports that neurofeedback improves anxiety through increase in mindfulness. However, Cheng et al. did not use mock feedback control group or alpha/theta protocol, thus cannot be compared to the current study. Orendáčová et al. (2022) using a different type of neurofeedback (Othmer method) also found significant reduction of severity of post-COVID anxiety and depression persisting for at least one month, however, that study did not use alpha/theta protocol or a mock feedback control group. Future mock (simulation) controlled studies using alpha/theta neurofeedback needed to confirm the current study finding where state mood is enhanced for both group, trait mood (i.e., long term anxiety) improved distinctly in real feedback group as compared to simulation group after nine sessions of neurofeedback.

4.2. Emotion regulation

The total scores and the six facets of emotion regulation difficulties (DERS) were assessed pre-S1 and post S9 for both groups; although there was a greater reduction in difficulties at post S9 for real feedback group as compared to simulation group, the difference was not significant. There was no main effect of time indicating that difficulties in emotion regulation for both groups did not change significantly from pre S1 to post S9, and no interaction of time by group suggesting difficulties in emotion regulation did not differ between groups after the sessions, therefore, H_3 was rejected. Bressler et al. (2023) using a sample of police officers (N = 13) and different method of neurofeedback (6 sessions) found that participants learned to downregulate the activity in individualized areas of emotion regulation network by using their own preferred strategies, however, there were no pre to post difference on DERS. Furthermore, although the study used control group (N = 13), the paricipants in that group did not receive any (mock) neurofeedback.

4.3. Personality

The results for the trait impulsivity measure (SUPPS-P) revealed that when affect related facets were analysed separately (i.e., positive and negative urgency at pre S1 and post S9) there was no main effect of time indicating that the trait impulsivity scores from pre-to post session were nonsignificant for both affect related trait impulsivity. The interaction effect was also nonsignificant, suggesting that there was no difference in pre to post trait impulsivity facets between real feedback and simulation groups, therefore H_4 was rejected. These findings are similar to other trait measures used in other studies. For example, Raymond et al. (2005) did not find a significant pre-post neurofeedback difference in personality change using Personality Syndrome Questionnaire (PSQ) in a healthy sample ($n = 12$). Dalkner et al. (2017) evaluated the effects of alpha/theta neurofeedback on Clinical Personality Accentuations and the NEO-Five-Factor Inventory in individuals with alcohol use disorder. Twenty-five males were investigated using a pre-test/post-test design with a waiting-list control group. Participants were randomly assigned either to an experimental group ($n = 13$) receiving 12 sessions of neurofeedback twice a week as a treatment adjunct over a period of 6 weeks, or to a control group ($n = 12$) receiving treatment as usual. The study showed improvements in Avoidant Personality Accentuation within the experimental group suggesting that neurofeedback appears to alleviate symptoms in personality disorders such as avoidance and stress rather than leading to changes in personality. In support of this, no significant changes were reported in NEO-Five Factor Inventory scores from pre to post sessions. Dalkner et al. did not use mock neurofeedback control group so the findings should be interpreted with caution.

The findings on the assessment of personality traits so far indicate that although neurofeedback may not have a direct effect on personality traits which are more stable constructs, it appears to have some effect on the symptoms such as stress and avoidance in personality disorders.

4.4. Neurofeedback training

The results showed significant and gradual within session rise in theta/alpha ratio which indicates deep relaxation state that resemble a meditative state. However, the between sessions change was nonsignificant suggesting that theta/alpha ratio did not significantly increase from S1 to S9. This is consistent with Raymond et al. (2005), and Egner and Gruzelier (2004).

The current study allows comparison to a previous study that used the same protocol, number and duration of the sessions. Raymond et al. showed greater increase within sessions as compared to the current study, the lower but steady increase in the current study could be due to larger number of participants (N = 25) as compared to their study (N = 12, although not provided, assuming N = 6 in real NF group).

Overall, the current study demonstrated that nine sessions of alpha/theta neurofeedback have improved state affect within sessions and reduced anxiety significantly in real neurofeedback group as compared to simulation group. However, the emotion-based trait impulsivity was not reduced as a result of neurofeedback. Similarly, although emotion regulation difficulties showed some decrease at post session for real group, this did not differ between real feedback and simulation groups. The results indicate that despite the promising results of alpha/theta NF sessions in some aspects of emotions and in anxiety disorders, the effect on traits which are more stable constructs is limited. Although previous studies demonstrate that NF sessions improve symptoms of personality disorders among patient samples, the change in healthy samples (e.g., reduction in trait impulsivity) does not appear to be substantially affected by neurofeedback sessions, supporting the theories of personality that traits are stable constructs.

Future studies are required to replicate the findings of the current study with different dimensions of emotions and longitudinally in a simulation-controlled trials to explore consistency. This is also important since alpha/theta is a widely used protocol in private clinics with high costs and often offered at varying sessions, with sometimes over 40 sessions, thus it is crucial to have more evidence base for standardization of the NF training, including establishing the optimum number and duration of sessions.

Most previous studies have been conducted with either no control group or control groups without mock-feedback trials (e.g., waiting list, only assessing through pre and post self-report scales). The mock-NF control in future studies an important issue that should be addressed in order to better understand the sensitivity and efficacy of NF sessions, as without these sessions, we cannot conclude the true efficacy of the NF sessions. Furthermore, not using appropriate control groups can significantly increase the risk of type 1 error and can also contribute to ceiling effects, making it difficult to accurately assess the true impact of the intervention being studied; essentially, without a comparison group, it is hard to determine if observed changes are due to the intervention itself or other external factors (Andrade, 2021).

4.5. Limitations

The current study should be considered with its limitations. Firstly, the sample consisted of predominantly female participants (88 %), so the results cannot be generalized to wider population. However, this appears to be an issue in many previous neurofeedback studies, for example, Hou et al. (2021) recruited 26 female patients with GAD, Bressler et al. (2023) 28 male police officers, Rodriguez-Larios studied 43 male meditators, Dalkner et al. (2017) recruited 30 male Alcohol Use Disorder patients, Raymond et al. (2005) only 12 medical students with no gender information provided. This could be due to the difficulty in first, finding participants that fit a specific criterion for participation, secondly due to the required commitment to the sessions. Future studies should aim to address this limitation, perhaps by allowing longer time for data collection to ensure balanced gender representation in studies.

Secondly, the GAD cut off point for two participants were slightly below the moderate anxiety criterion according to GAD-7 which classifies 10 and above as moderate, while these participants scored 7. They were included as excluding two participants did not make any difference to the results. Future studies should aim to ensure balanced number of participants for each cut-off point to explore whether the efficacy of the sessions differ by the severity of anxiety.

Finally, the study used single blind design where participants did not know whether they were in the real or simulation feedback condition. Although, the settings were prepared by the first author, and the recruitment and data collection were done by the co-authors who did not know about the settings, due to different availability of the researchers, sometimes the data collection was done by the first author. So, the study was not fully double blind. However, since the protocol used was eyes-closed and did not require any communication between researchers and participant, we believe the potential researcher bias should be minimal if any. The other difficulty using double blind design is that since neurofeedback requires trained researchers to use the equipment and setting up at each session prior to participant's arrival, it is almost impossible for any researcher involved not to know the difference between conditions. Future research could have two researchers involved at each session, while one prepares the setting the other can be there for any participant enquiries pre or post session.

In conclusion, while nine sessions of alpha/theta neurofeedback over the medial parietal lobe appears to be effective in improving negative affect and in reducing anxiety, the sessions did not alter emotion-based trait impulsivity (positive and negative urgency) or emotion regulation abilities as measured by DERS-SF. Also, interestingly, while state negative affect improved from pre to post sessions for both real and simulation feedback groups, trait anxiety was significantly reduced from pre-S1 to post-S9 for only real feedback group.

CRediT authorship contribution statement

Linda Dinc: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Daniel Rybski:** Visualization, Project administration, Formal analysis, Data curation. **Jessica Dineen:** Project administration, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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