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Neurofeedback Beta Down Training in Women With High State-Trait Anxiety and Elevated Beta Patterns in Temporal Lobes: A Pilot Study

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Abstract

This study intends to evaluate the effect of neurofeedback beta downtraining in the treatment of anxiety as a personality trait, measured in the State-Trait Anxiety Inventory (STAI), and to estimate the changes in the beta and high-beta rhythms in the left (T3) and right (T4) temporal lobes. An intrasubject analysis was carried out with six right-handed female university students who were submitted to a control and experimental condition (five neurofeedback seasons). In the results, it was observed that no significant changes were presented in the control stage. In turn, a significant reduction in the scores of the inventory was found in the experimental stage. On the other hand, even though in the experimental stage there was a decrease in the relative power of the beta and high-beta frequency bands, this was statistically significant in the beta band in T3 and T4 and in the high-beta band in T3. In conclusion, according to the results, neurofeedback had a significant effect on both reducing anxiety as a state and a personality trait, as well as reducing beta and high-beta patterns in the temporal lobes. The need for more studies with greater methodological rigor that can reassert or refute these results is noted.

Keywords: neurofeedback; state-trait anxiety; temporal lobes; electroencephalogram

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Introduction

According to the World Health Organization (World Health Organization [WHO], 2017), anxiety and depression are the two diagnostic categories of mental disorders with the highest prevalence in the world population and with the greatest impact on people's lives. In 2015, the WHO estimated that 3.6% of the world population had some type of anxiety disorder. This percentage corresponds to an approximate total of 264 million people who lived with the disease during that year (WHO, 2017).

State-Trait Anxiety Inventory

According to the dimensional model of anxiety proposed by Spielberger (1966), it is important to distinguish between anxiety as a person's transient state and anxiety as a relatively stable personality trait. Anxiety as a state (State-A) can fluctuate in intensity depending on daily events and is characterized by concern, muscle tension, and agitation associated with the momentary increase in the autonomic nervous system activity, such as increased heart rate, blood pressure, sweating, and sphincter control loss, among others (Forte et al., 2021). On the other hand, anxiety as a personality

trait (Trait-A) is characterized as a person responding constantly to a wide range of objectively nonhazardous situations as if they were threatening throughout various everyday situations. Such responses are disproportionate in intensity and frequency when compared to the objective magnitude of the threat (Spielberger, 1966).

The State-Trait Anxiety Inventory (STAI) is a self-report psychometric test that aims to assess the two previously mentioned anxiety components as a state and as a personality trait (Spielberger et al., 1983). It is one of the most used questionnaires in the study and detection of anxiety and has been widely leveraged in clinical and academic contexts from different cultures (Fioravanti-Bastos et al., 2011). It was translated into Portuguese and validated to be used with the Brazilian population by Biaggio et al. (1977).

State-A by itself does not represent a problem for people, as it works like an alert-sign warning about environmental threats and provides the necessary resources to face them. In this sense, State-A can be considered as a set of normal responses to the various situations of everyday life that generate stress. On the contrary, Trait-A is characterized by State-A intensity levels and response frequencies that outdo a person's capacity, causing clinically significant discomfort (Garcia et al., 2007). In such a way, Trait-A can be associated with difficulties in quality of life such as constant concern, low self-esteem, sleep disorders, emotional instability, hypervigilance, thoughts of vulnerability, exaggerated emotional reactions to real or imaginary threats, and excessive and constant levels of sympathetic autonomic activation of the nervous system (Rodríguez Landa et al., 2012).

Currently, there are various pharmacological and nonpharmacological approaches to treating anxiety, according to the intensity and characteristics of the symptoms. Psychotherapy and medications, such as antidepressants or anxiolytics, are among the main treatment modalities (Podea & Ratoi, 2011).

To early detect and implement the necessary measures for its timely treatment, a major focus of research and clinical practice has been on the study and detection of psychophysiological markers that reflect the neural and physiological characteristics of anxiety as a personality trait (Lee & Park, 2011). Based on the need for evidence-based intervention treatments, technological tools for neuromodulation have been developed since the 1960s to treat different clinically relevant symptoms such as anxiety (Nowlis & Kamiya, 1970). Neuromodulation tools can be understood as technological devices for direct intervention in the nervous system, developed to modify neuronal structure and/or function (Coben & Evans, 2011; Othmer, 2009).

Neurofeedback in the Treatment of Anxiety

Neurofeedback is a noninvasive neuromodulation tool focused on assessing and training brain electrical activity patterns (Bielas & Michalczyk, 2021; Hampson et al., 2020; Price & Budzynski, 2009). Between 1960 and 1970, it was discovered that it was possible to condition and train the brain wave patterns. Some of these papers started with alpha-wave training for concentration and relaxation (Kamiya, 2011; Nowlis & Kamiya, 1970). Others were focused on handling sensorimotor rhythm waves to control epilepsy (Sterman & Friar, 1972).

During a neurofeedback session, the person receives constant audiovisual feedback about the spectral parameters corresponding to specific EEG frequency ranges (Dessy et al., 2020). This tool works as a noninvasive modality of conditioning brain activation itself (Larsen & Sherlin, 2013), as feedback works as a contingent reinforcement to the neural adjustments that are presented during the session, thus generating the conditioning of new patterns (Yucha & Montgomery, 2008).

According to Larsen and Sherlin (2013), on an efficacy rating scale of 1 to 5, neurofeedback is rated at level 4 of moderate efficiency in treating diagnoses such as anxiety, as multiple studies with this technique showed positive results in improving clinically relevant symptoms for various forms of anxiety disorders (Choi et al., 2023; Hammond, 2005; Kerson et al., 2009; Micoulaud-Franchi et al., 2021). Likewise, according to the systematic review by Santana and Bião (2018) and Choi et al. (2023), neurofeedback is effective in the treatment of anxiety, although the need for more studies that may reassert or refute these results is noted.

Neurofeedback, also known by the name of EEG biofeedback, has proved to be potentially effective in reducing mood disorders among post-COVID-19 patients. The technique was demonstrated to be capable of improving cognitive and executive functions and reducing the anxiety, panic, and fear symptoms (Kopańska et al., 2022).

Neurofeedback treatment can be divided into two stages: (a) an evaluation stage, in which a quantitative electroencephalogram (qEEG) is performed and the brain activation patterns are

identified; and (b) an intervention stage, in which the corresponding protocols are applied according to the needs demonstrated in the brain activation patterns recorded by the qEEG (Patil et al., 2023).

The results of a qEEG reflect consciousness statuses and different levels of physiological and cognitive excitation. That is, activity in the delta (2–4 Hz) and theta (4–8 Hz) frequencies is known as slow waves that are associated with sleep, drowsiness, or relaxation states, whereas activity within the alpha (8–12 Hz), beta (12–23 Hz), high-beta (23–38 Hz), and gamma (38–42 Hz) frequency ranges refers to fast waves, which are associated with alertness and cognitive activation (Faller et al., 2019; White & Richards, 2009).

As a personality trait, anxiety is closely related to constant stress statuses and high levels of cognitive and physiological excitation. Thus, Trait-A is highly associated with higher cortical activity levels in the beta and high-beta waves in a qEEG (Micoulaud-Franchi et al., 2021; Thompson & Thompson, 2007).

The amygdala and hippocampus are subcortical structures that have been widely associated with the classical response of struggling or escaping as a fast way of responding to environmental threats (Verbitskii, 2019). In the various anxiety disorders, an increase has been found both in the amygdala functional activity and in its volume (Barrós-Loscertales et al., 2006). Therefore, a hyperactive amygdala can be an indicator of constant emotional responses of fear, aversion, and stress (Wheelock et al., 2021). However, the amygdala is not the only structure in charge of producing the entire emotional response. For this, all the cortical regions interact with several subcortical structures in the process to perceive and elaborate the different components of the emotional response (Barreto & Silva, 2010). Of all the brain cortex areas, the most extensively connected to the limbic system are the temporal and frontal lobes (Kamali et al., 2023). In anxiety disorders (e.g., phobia, panic, and generalized anxiety, etc.), high-beta activity levels have been observed in the lateral prefrontal and anterior temporal cortical areas (Davidson, 1992). Therefore, beta and high-beta activity levels in the temporal lobes in a qEEG are highly correlated with negative emotional states, associated with amygdala hyperactivation levels (Gordeev, 2007), mainly when these irregular activity levels are found in the right anterior frontotemporal portion (Davidson et al., 2000).

According to the results obtained in the study by Ribas et al. (2018) based on the learning curve model proposed by Peter Van Dausen (Ribas, Ribas, & Martins, 2016), there is a statistically significant correlation between the symptoms associated with anxiety, insecurity, fear, panic, and phobia with high levels of beta and high-beta waves in the temporal lobes when compared to the respective control. Thus, the anxiety response can be observed when the relative power of the beta waves (12–23 Hz) is greater than 17% and that of the high-beta ones (23–38 Hz) is greater than 10% in the temporal lobes. According to the learning curve model, this pattern is known as “hot temporals” and is associated with the idea that the temporal lobes present excessive levels of fast activity.

EEG data analysis employs two primary methodologies: population-based and pattern-based approaches. In the former, client measures undergo comparison with a database spanning 3 decades, yielding *z*-scores that highlight deviations in specific brain regions from the population norm. However, the interpretation of these deviations as positive or negative, adaptive or maladaptive, remains ambiguous. Conversely, the pattern-based approach identifies consistent activation patterns associated with problematic aspects of individuals' lives through quantitative EEG research. These patterns are discerned by contrasting individuals with specific concerns, such as anxiety or ADHD, against the broader population to ascertain recurring disparities. The learning curve model aims to discern particular brain patterns, such as the hot temporals pattern and establish tailored training objectives to address each individual's unique requirements.

Several research studies have confirmed the efficacy of neurofeedback in the treatment of anxiety (Chen & Lin, 2020; Choi et al., 2023; Hammond, 2003, 2005; Jones & Hitsman, 2018; Micoulaud-Franchi et al., 2021; Mennella et al., 2017; Moore, 2005); however, there are no studies evaluating neurofeedback interventions specifically in the beta and high-beta wave patterns in the temporal lobes, which, as mentioned, have important links with the limbic system in charge of processing emotional information and with an acknowledged connection with the development of anxiety disorders (Forte et al., 2021; Lee & Park, 2011; Ribas et al., 2018).

Based on the aforementioned, the objective of the current research was to assess the effect of the neurofeedback neuromodulation tool in the

treatment of anxiety as a personality trait. More specifically, the study aims at evaluating the possible changes generated after the neurofeedback interventions, focusing attention on two aspects: (a) the subjective perception of anxiety, as measured by STAI; and (b) brain activation patterns in the temporal lobes, as measured by a qEEG.

Method

The study procedures were approved by the Tropical Medicine Center (*Núcleo de Medicina Tropical*, NMT) at the Federal University of Pará (CAAE No.: 25068619.8.0000.5172/Opinion No.: 3,784,218) and the participants signed the Free and Informed Consent Form (FICF).

Participants

The STAI questionnaire was answered by 100 university women aged between 18 and 35 years old. Fifteen of them were preselected, as they met the inclusion criteria and obtained scores above 50 points in the Trait-A form from the STAI by Biaggio et al. (1977). A qEEG was administered to assess all 15 students, and six participants were selected for the intervention process as they presented the hot temporals brain pattern, the object of the current study. All the participants selected were right-handed to avoid asymmetries in the interhemispheric brain activity influenced by hand dominance (Davidson, 1988). Table 1 summarizes the criteria to include and exclude research participants.

Table 1

Inclusion and Exclusion Criteria

Inclusion	Exclusion
• Women • Age between 18 and 35 years old • Trait-A STAI score > 50 points • Hot temporals brain pattern • University students • Right-handed	• Psychotherapeutic or psychiatric treatment • Comorbidity with other diseases: other mental disorders; hypertension; diabetes; obesity. • Using a medication known to exert an influence on the EEG measurements (antidepressants and anxiolytics, etc.)

Procedures

State-Trait Anxiety Inventory (STAI). STAI has 40 items formulated in a Likert self-report format, with scores for each individual item varying from 1 (*absolutely not*) to 4 (*very much*). The questionnaire consists of two subscales: State A and Trait A, and each one is comprised by 20 items that should be answered according to the person's perception. The State A form seeks answers based on how the person feels at that moment or on that day (e.g., I feel calm, I feel safe, I'm tense). On the other hand, the Trait A form seeks answers based on how the person generally feels (e.g., I feel good, I get tired easily, I want to cry).

The questionnaire was adapted through a digitalized version in Google Forms, although the original structure of the questions and answers was maintained. Subsequently, it was sent to the participants in the online modality. The answers were forwarded directly to the researcher.

Quantitative Electroencephalogram (qEEG). Silver electrodes (Nicolet Scientific Instruments Ltd), conductive paste (Ac Cream by Spes Medica), and abrasive gel for cleaning the scalp (NuPrep by Spes Medica) were used, in addition to the Q-Wiz electroencephalograph (Pocket Neurobics) with four simultaneous channels for individual electrodes and a 21-channel cap interface. The sampling rate was 512 Hz. Each channel has a 0.2-Hz high pass filter. Real-time acquisition, processing, and reproduction of biological signs were performed in the BioExplorer software (CyverEvolution Inc.). For data processing, the TRAINER'S QEEG (TQ-7) software (BrainTrainer, version TQ-7.5.9.2), based on the learning curve model was used, which offers high-resolution brain information such as frequency distribution maps, absolute and relative amplitude distributions, histogram graphs, asymmetry graphs and coherence tables, among other forms of EEG analysis (Ribas, Ribas, de Oliveira, et al., 2016).

Conventional EEG research commonly involves simultaneous recordings from 19 channels, necessitating at least 2 min of artifact-free EEG data for analysis. However, advancements in neurofeedback systems have aimed to enhance accessibility within clinical settings. As a result, these systems often utilize a smaller number of active channels for both assessment and training purposes. The current study sought to reproduce standard neurofeedback assessment conditions.

Considering the purpose of neurofeedback assessment is to make it easily accessible, shorter recording times are used while ensuring data quality through artifact removal. Consequently, the qEEG was recorded at rest in two conditions: (a) 1 min with the eyes closed; and (b) 1 min with the eyes open. Twelve points were measured with monopolar assembly (FZ, PZ, CZ, OZ, F3, F4, P3, P4, T3, T4, C3, and C4, with linked references on the mastoid bones behind the ears), according to the 10–20 International System (Klem et al., 1999). Following data collection, the gathered data underwent processing using the TQ-7 processing software for artifact removal and posterior analyses.

The filtering of artifacts, including electromyography (EMG) artifacts, and its differentiation from actual beta power in EEG recordings were also addressed using TQ-7 data processing software. This software utilizes an algorithm that distinguishes EMG artifacts from genuine beta activity by analyzing their amplitude and frequency characteristics. EMG artifacts generally present higher amplitudes and broader frequency ranges than neuronal signals (Yu, 2021). To confirm the reliability of these measures, the TQ-7 software sets low-frequency thresholds to filter out artifacts associated with eye blinks, eye movements, and cable movements, and high-frequency thresholds for muscle tension, movement, and electromagnetic artifacts. During the assessment, the system ensures that at least 50% of the recording is free of artifacts, requiring a minimum of 30 s of artifact-free data for each electrode placement to guarantee the data's validity. The software detects these potential artifacts and highlights epochs containing significant artifacts to discard them for further analysis. Subsequently, it conducts a detailed frequency analysis on the remaining epochs. To analyze the qEEG results, the beta (12–23 Hz) and high-beta (23–38 Hz) ranges in the left and right temporal lobes were considered.

In the context described, data analysis was conducted without relying on database comparisons, utilizing the pattern-based approach. Rather than comparing individual measures to a database, this methodology concentrates on identifying consistent activation patterns associated with specific concerns, such as the hot temporal pattern linked to anxiety, within the individual's EEG data. This approach offers a more focused and personalized analysis of the individual's brain activity, yielding insights into underlying neural changes that could serve as effective targets for neurofeedback interventions.

Neurofeedback Intervention Protocol. The protocol design was developed by the BrainTrainer company (Ribas, Ribas, de Oliveira, et al., 2016). For its execution, two separate EEG channels with monopolar assembly are used. The active electrodes were positioned on the left (T3) and right (T4) temporal lobes, with linked references on the right and left mastoid bones and ground electrode on CZ. For this protocol, it is possible to make adjustments that allow decreasing the amplitude of specific frequency bands such as beta and high beta.

For all intervention sessions, the participants wore high-definition earbuds and remained seated in a reclining chair with a headrest in front of a TV screen. During the session, the participants watched landscaping videos on the TV screen while receiving auditory feedback through the earbuds and visual feedback through the TV screen. For the research object, the training was selected to inhibit the amplitude corresponding to the 19–38 Hz frequency range. During the first 30 s of the intervention protocol, the BioExplorer software establishes a baseline to place a threshold that acts as the training range. Thus, for example, if during the first 30 s, the system establishes a threshold of 20 microvolts (μV) for the 19–38 Hz frequency range, then, throughout the protocol, each time the group of pyramidal neurons near the electrode fire below 20 μV, the patient hears a high-pitched piano note. The sounds or screen brightness acted as feedback linked to the active channels being trained. The patient only listened to the piano sound after recording the values stipulated in the baseline for the specific frequency range being trained. The more piano sounds heard by the participant, the more adequate were the trained brain waves. The same happened with screen brightness: the brighter, the better the response of the trained waves.

A single-factor intersubject pretest and posttest experimental design was used, with each participant as their own control (Kazdin, 2017). Data analysis was performed in blocks according to their mean values and standard deviations. Thus, all the participants were grouped and subjected to two conditions: control and experimental, with manipulation of the independent variable in the latter. As can be seen in Table 2, the research was developed in four phases: (a) Pretest 1; (b) Pretest 2; (c) intervention; and (d) posttest.

Table 2
Study Phases

Control			
Pretest 1	Pretest 2	Intervention	Posttest
STAI/qEEG	STAI/qEEG	Neurofeedback (five sessions)	STAI/qEEG
Experimental			

In the control stage, STAI and the qEEG were applied in order to compare their results between Pretest 1 and Pretest 2. This first research stage corresponded to the control stage, where the mean values of the tests before the intervention were compared. The experimental stage was initiated the 1st week after Pretest 2. Five sessions of the same neurofeedback protocol were applied in the temporal lobes during 2 weeks. The posttest was performed 1 week after finishing the intervention. The objective of the experimental phase was to compare the Pretest 1 and Pretest 2 results to the posttest separately.

Results

To evaluate the effect of neurofeedback in the treatment of anxiety, the STAI and qEEG variables were measured before and after the intervention. The Pretest 1 results were compared to those of Pretest 2 (control stage) and the Pretest 1 and Pretest 2 results were compared to those of the posttest (experimental stage).

Initially, basic descriptive statistics were performed to characterize the study variables; subsequently, normality tests were carried out using the Shapiro-Wilk test. Finally, to quantify and evaluate the changes between the pre and postintervention study variables, comparative statistics were applied using the calculation of comparison of related means, Student's *t* test for paired samples. The statistical decisions were calculated considering $p < .05$ as the significance level.

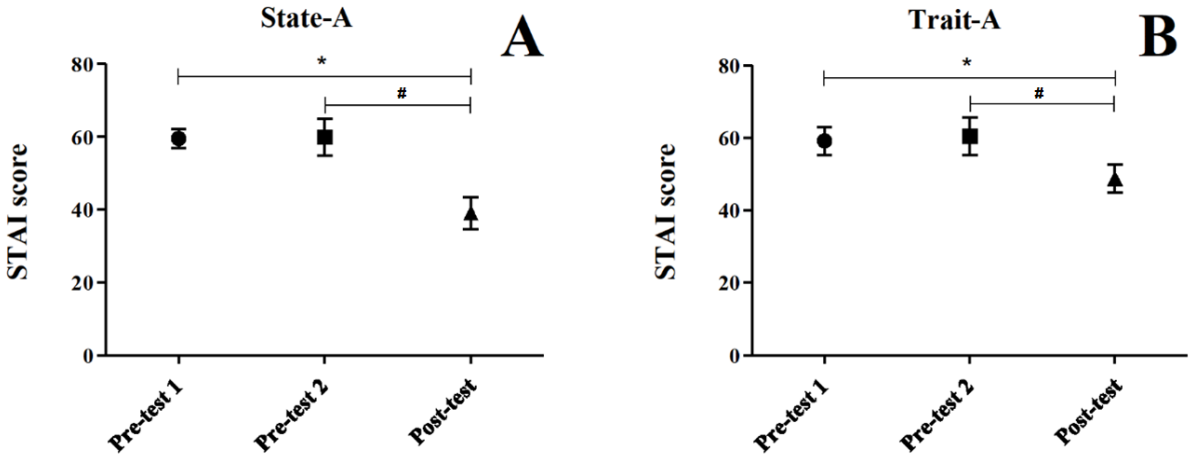
STAI Results. Table 3 shows the descriptive and comparative statistics corresponding to the STAI Pretest 1, Pretest 2, and posttest phases. Figure 1 shows the mean STAI scores in its two forms: (A) State-A and (B) Trait-A.

Table 3
Descriptive and Comparative Statistics Corresponding to the STAI Pre and Posttests

Control						
	Pretest 1		Pretest 2			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
State-A	59.50	6.53	59.83	12.37	−0.077	.471
Trait-A	59.17	9.41	60.5	12.63	−0.628	.279
Experimental						
	Pretest 1		Posttest			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
State-A	59.50	6.53	39.00	10.71	3.154	.013*
Trait-A	59.17	9.41	48.83	9.52	2.488	.028*
	Pretest 2		Posttest			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
State-A	59.83	12.37	39.00	10.71	2.486	.028*
Trait-A	60.5	12.63	48.83	9.52	2.110	.044*

* = Descriptive and comparative statistics of the Trait-A STAI scores in the Pretest 1, Pretest 2, and posttest phases.

Figure 1. *Mean Scores Corresponding to the STAI Pretest and Posttest Phases*.



Note. Mean STAI scores in its (A) State-A and (B) Trait-A form. * = Significance between Pretest 1 and posttest; # = Significance between Pretest 2 and posttest.

Analysis of qEEG Results. The analysis of the qEEG results was based on the mean values corresponding to the relative power of the wave amplitude of the frequency bands, also known as the relative power of the frequency bands, which are expressed in microvolts (μV). Data were collected from 12 evaluated EEG points but for research purposes, only data obtained about the beta (12–23 Hz) and high-beta (23–38 Hz) frequency bands at T3 and T4 were used. Table 4 shows the descriptive and comparative statistics corresponding to the Pretest 1, Pretest 2, and posttest phases of the mean values corresponding to the beta wave relative power at T3 and T4. Figure 2 shows the mean scores corresponding to the beta wave relative power at (A) T3 and (B) T4.

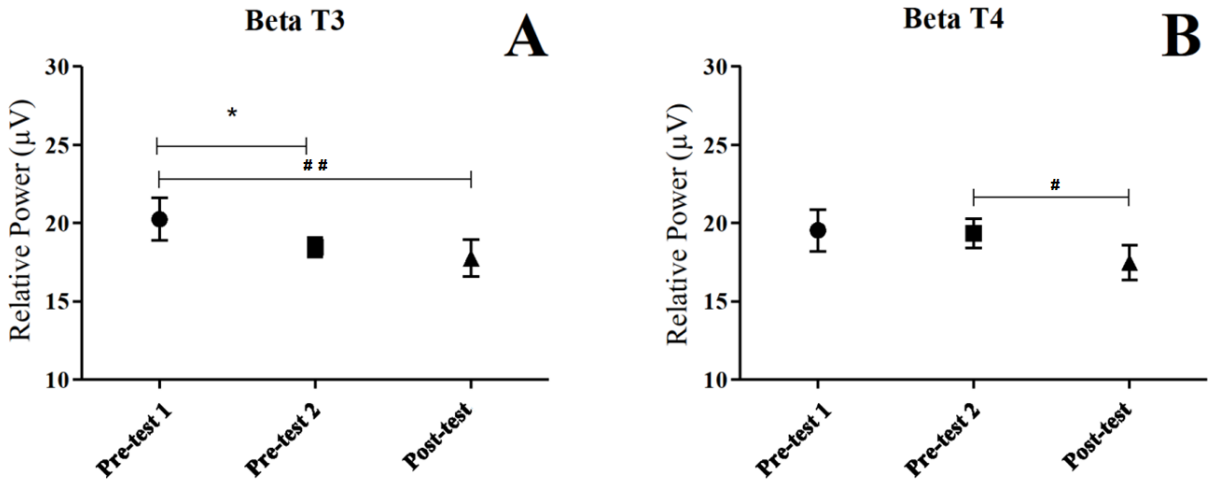
Table 4

Descriptive and Comparative Statistics Between the Pre and Posttests – Beta at T3 and T4

Control						
	Pretest 1		Pretest 2			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
T3	20.27	3.33	18.47	1.51	2.1000	.045*
T4	19.55	3.26	19.35	2.31	0.1622	.439
Experimental						
	Pretest 1		Posttest			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
T3	19.93	3.68	17.77	2.87	4.070	.005**
T4	19.55	3.26	17.47	2.70	1.916	.057
	Pretest 2		Posttest			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
T3	18.47	1.51	17.77	2.87	0.806	.229
T4	19.35	2.31	17.47	2.70	2.393	.031*

* = Descriptive and comparative statistics corresponding to the mean beta relative power at the T3 and T4 points for the Pretest 1, Pretest 2, and posttest phases.

Figure 2. *Mean Values Corresponding to the Beta Wave Relative Power at T3 and T4*.



Note. Mean beta wave relative power at the (A) T3 and (B) T4 point. * = Significance between Pretest 1 and posttest; # = significance between Pretest 2 and posttest.

Table 5 shows the descriptive and comparative statistics corresponding to the Pretest 1, Pretest 2, and posttest phases of the mean values corresponding to the high-beta wave relative power in the temporal lobes. Figure 3 shows the mean scores corresponding to the high-beta wave relative power at (A) T3 and (B) T4.

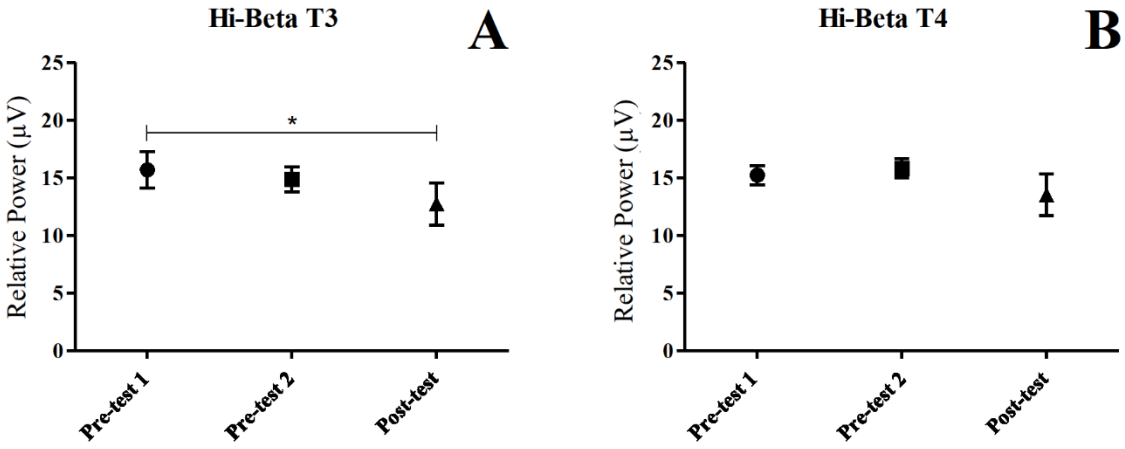
Table 5

Descriptive and Comparative Statistics Between the Pre and Posttests – High-Beta at T3 and T4

Control						
	Pretest 1		Pretest 2			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
T3	15.70	3.86	14.87	2.71	0.9245	.199
T4	15.23	2.08	15.83	2.07	0.5061	.317
Experimental						
	Pretest 1		Posttest			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
T3	15.70	3.86	12.73	4.46	2.215	.038*
T4	15.23	2.08	13.53	4.42	0.896	.206
	Pretest 2		Posttest			
	$\bar{x}$	σ	$\bar{x}$	σ	*t*	*p*
T3	14.87	2.71	12.73	4.46	1.396	.110
T4	15.83	2.07	13.53	4.42	1.098	.161

* = Descriptive and comparative statistics corresponding to the mean high-beta relative power at the T3 and T4 points for the Pretest 1, Pretest 2, and posttest phases.

Figure 3. *Mean Values Corresponding to the High-Beta Wave Relative Power at T3 and T4*.



Note. Mean high-beta wave relative power at the (A) T3 and (B) T4 point. * = Significance between Pretest 1 and posttest.

Discussion

The objective of this study was to evaluate the effect of neurofeedback interventions in the treatment of anxiety as a personality trait and to estimate the changes in brain patterns of the beta and high-beta rhythms in the left (T3) and right (T4) temporal lobes.

When analyzing the STAI results, it can be observed that in the control stage, no statistically significant differences were found between the mean scores corresponding to the Pretest 1 and Pretest 2 phases of the State-A or Trait-A forms. On the other hand, in the experimental stage, there was a statistically significant decrease in the scores between the STAI pretests 1 and 2 and posttest, both in its State-A and Trait-A forms. These results show a statistically significant difference in the STAI scores before the neurofeedback intervention process. These results coincide with research studies that acknowledge the efficacy of neurofeedback in the treatment of anxiety (Chen & Lin, 2020; Choi et al., 2023; Hammond, 2003, 2005; Jones & Hitsman, 2018; Larsen & Sherlin, 2013; Mennella et al., 2017; Micoulaud-Franchi et al., 2021) and support the hypothesis that intervention protocols focused on decreasing the relative power of the beta and high-beta frequency bands in the temporal lobes has the potential to treat and reduce the anxiety symptoms.

The results of this study evidence the participants' favorable evolution after undergoing the intervention procedure, observing significant improvements in the anxiety as measured by STAI both in its State-A (Figure 2A) and Trait-A (Figure 2B) forms. It is important to note that, although the research focused on anxiety as a personality trait, it was also possible to observe in the results that anxiety as a state response was also reduced. This result is common and logical, as a decrease or increase in Trait-A generates a decrease or increase in State-A, although this effect is not necessarily observed in the other direction. In other words, an increase or reduction in State-A not necessarily increase or reduce Trait-A (Spielberger et al., 1983).

Among the results obtained in the qEEG, in the experimental stage, a statistically significant decrease in the relative power of the beta frequency bands (Figure 3A and Figure 3B.) is observed in both temporal lobes.

When analyzing the results about the relative power of the high-beta frequency band, it can be summarized that in the control stage there was no significant difference between the mean values corresponding to the relative power of the wave between pretests 1 and 2 for T3 or T4. On the contrary, in the experimental stage there was in fact a significant reduction in the mean value between pretest 1 and the posttest at the T3 point. In turn, at the T4 point a decreasing trend can be observed in the results, although this difference was not statistically confirmed.

Limitations and Future Research

The current study elucidates several limitations that prevent the generalization of its findings. Notably, the sample is characterized by specific features, comprising only six participants. Furthermore, it is essential to emphasize that the sample selection was nonrandom and based on convenience according to the accessibility of the participants. Future research could increase the number of participants to enhance statistical accuracy, as well as explore methodologies for the random selection of participants within a larger sample.

Most of the qEEG evaluation processes present difficulties inherent to their execution, such as variations in brain patterns resulting from daily habits and other artifacts related to the measuring process, such as muscle and eye movements and even the electrical grid. In the research, the same times and conditions were always maintained, both for the evaluations and for the intervention sessions, to reduce the aforementioned interferences to the minimum possible. However, for future research studies, it is recommended to control these and other external variables that can interfere with data from tools as sensitive as an EEG.

According to the scientific literature, the number of sessions can exert an influence on the results of the changes in the brain patterns. Therefore, the proposal for future research studies is to conduct more sessions to assess data stability and trends. Although there is no consensus in scientific research on the minimum number of sessions for the treatment, the results of this study suggest that, even with five sessions, neurofeedback can produce positive effects in reducing the symptoms, in line with the results obtained in other research studies that evidence the efficacy of neurofeedback in the treatment of anxiety (Santana & Bião, 2018; Gadea et al., 2020).

An additional limitation in our study arises from the limited literature available on the use of the TQ-7 software for EEG data processing in scientific research. Originally developed for neurofeedback interventions and widely used around the world, the TQ-7 software was not specifically designed for research purposes, which presents challenges for its application in scientific studies. While the software has been utilized in some research contexts, such as the study by Ribas et al. (2018) on the hot temporals brain pattern, and in other case studies (Habib et al., 2023; Ribas et al., 2017; Solano & Basile, 2020), comprehensive validation studies specific to this software are lacking. This gap underscores the importance of conducting validation studies to ensure the reliability and accuracy of the TQ-7 software when used for research purposes. Such studies would enhance confidence in the software's ability to accurately process EEG data and filter artifacts, thereby improving the robustness and replicability of findings in future research using this tool.

Neurofeedback is a technique that still needs to be studied more rigorously; however, it shows potential to be an efficacious and nonpharmacological complementary treatment option for the intervention of affective disorders such as anxiety. When addressing research on neurofeedback within a specific population, as in the current study, it is essential to carefully consider the impact of external validity. The application of interventions like neurofeedback can be highly influenced by the specific characteristics of the studied population, such as age, health conditions, and specific brain patterns. Consequently, the challenge of generalizing the results to other populations becomes a significant concern. Individual nuances and inherent variabilities in different groups can limit the extension of findings, impairing the ability to extrapolate the benefits of the intervention beyond the studied research group. Therefore, reflection on external validity is crucial to understanding the extent to which the findings can be applied to other contexts and groups, providing a more comprehensive insight into the effectiveness of neurofeedback in different conditions.

Author Disclosure

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