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A Case Study Utilizing Virtual Reality to Reduce Behavioral Symptoms and Brainwave Activity Related to Anxiety

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Abstract

Of the mental health disorders, anxiety conditions maintain the highest base rate. The goal of this case study was to demonstrate the effectiveness of TRIPP VR, a virtual reality meditation application, utilizing a qEEG analysis program to recognize significant changes in brain wave patterns governing neuroelectrical impulses when compared to pretest results. Additional outcome measures included behavioral rating scales. A 13-year-old female demonstrating clinical signs of anxiety completed the required trials. Twenty-five sessions of meditation using TRIPP VR were administered to the participant over 8 weeks. Metrics used to demonstrate effectiveness included qEEG analysis and behavioral rating scales via a pre–post test design. Behavioral rating scales and qEEG analysis (which both use a normative population database) revealed marked decreases in the patient's negative affect and anxiety as well as a significant decrease in hiBeta (20–30 Hz) amplitudes. Significant physiological changes were also noted in regions of interest (ROI) proposed to correlate with anxiety, impulsivity, depression, and emotional inhibition. Of note, the patient remained "at risk" for anxiety. The current findings provide preliminary evidence which demonstrates the immersive potential of VR therapy to reduce symptoms of anxiety and possibly other psychological conditions. Limitations and the implications of these findings are discussed.

Keywords: qEEG; brain maps; virtual reality; VR therapy; TRIPP; anxiety; behavioral rating scales

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Introduction

Although standard treatment regimens have been established to treat anxiety, a variety of modalities continue to surface, particularly as technology advances. Methodologies for assessing gains in treatment are also numerous and include subjective report as well as quantifiable objective measures. Expansion of intervention modalities poses benefit for providers, their clients, and public health efforts. Cavallo et al. (2023) conducted a review of the scientific literature and found that over the past several years the application of virtual reality (VR) for mental health treatment has increased and is also supported by the American Psychiatric Association (APA, 2021). VR therapy is being promoted nationally and internationally for mental health conditions by companies such as Amelia Virtual Care (Gurr & Laitz, 2023) based upon clinical case studies that rely upon subjective outcome variables. In fact, EaseVRx recently received FDA approval for their VR treatment for patients 18 years or older diagnosed with chronic lower back pain (Food and Drug Administration [FDA], 2021).

Anxiety conditions are the most prevalent mental health disorders in the world, occurring cross-culturally and impacting 4% of the global population in 2019 (World Health Organization [WHO], 2023). Alongside gold standard interventions such as cognitive behavioral therapy and psychopharmacology, meditation is a recognized tool utilized in the treatment of generalized anxiety disorder, social anxiety disorder, and other

anxiety-related diagnoses (Goldin et al., 2015; Hoge et al., 2013). As technology-based approaches grow in accessibility and relevance, VR interventions for anxiety continue to garner research attention. Studies have demonstrated that VR meditation interventions can significantly improve anxiety levels, worry, negative mood, and quality of life (Berberyan et al., 2023; Lepilkina et al., 2023; Riches et al., 2023). Beyond meditation, other applications include biofeedback-related treatments, breathwork and exposure and response therapy (Donnelly et al., 2021). Though novel utilities and drawbacks remain under investigation, VR interventions for the treatment of anxiety exhibit numerous benefits for the anxious client.

Meditation interventions for anxiety are beneficial with or without VR components, illustrating the power of the practice (Navarro-Haro et al., 2019; Poetar et al., 2023). However, VR modalities have been shown to uniquely strengthen mental health treatment. The immersive nature of VR is often heralded as a major benefit of the tool, increasing a user's sense of presence and therefore engagement (Cavallo & Brubaker, 2024; Curran & Hollett, 2024; Goral et al., 2024; Navarro-Haro et al., 2017; Seabrook et al., 2020). This has implications for mental health treatment, as difficulty with "buy-in" and continued engagement can act as barriers to continuing treatment. One study examining a mindfulness-based intervention with and without an adjunctive VR module for those with generalized anxiety disorder demonstrated improved adherence to treatment for the VR condition (Navarro-Haro et al., 2019). Other studies have shown similar outcomes, citing reduced dropout rates for those receiving VR imagery versus standard imagery during relaxation (Malbos et al., 2022). Further, some findings support advantages of VR-based meditation interventions that surpass participant engagement and perceived presence. It has been shown that VR treatments can aid in producing physiological changes in healthy and anxious groups (Mazgelyté et al., 2021; Tarrant et al., 2018). Lastly, a growing number of studies highlight the superiority of VR based interventions as compared to conventional meditation and mindfulness (Kaplan-Rakowski et al., 2021; Ma et al., 2023).

Though a promising treatment modality, barriers to utilizing VR meditation interventions have also been explored. As compared to traditional anxiety interventions, the use of a VR console or device necessitates an additional element of consideration for treatment. Difficulty with portability has been identified as a challenge (Nicksic Sigmon et al., 2023). Additionally, though the immersive nature of VR tools has proven additive, it can also have adverse effects. In assessing motion sickness, some investigators have reported minimal impact on participants (Seabrook et al., 2020). However, simulator sickness has been shown to prevent engagement for others (Gao et al., 2024; Mimnaugh et al., 2023). Other barriers include weight of the VR device and perceived video quality (Seabrook et al., 2020). Further, optimal dosage for VR sessions remains unknown, affecting clinical implementation (Gao et al., 2024; Ma et al., 2023).

Alongside advancements in treatment fueled by technology, novel outcome methodologies have surfaced and continue to garner interest. Quantitative electroencephalography (qEEG) has demonstrated considerable potential for a variety of clinical applications, including epileptic screening and diagnosis, arrhythmia and stroke monitoring, and mood/anxiety disorders (Popa et al., 2020). Though exploration of the utility of qEEG has been plentiful, few studies have examined its suitability for VR interventions. To date, only one study has called the validity of qEEG data acquisition for VR users into question (Cavallo et al., 2023). Researchers tasked participants with staring at a neutral stimulus for a brief period both with and without a VR console; minimal differences in brainwave patterns were found between the two conditions, providing preliminary evidence of qEEG data obtained in conjunction with a VR platform. Barring this investigation, there is a dearth of knowledge surrounding the use of qEEG as an outcome variable for VR interventions. In one investigation that employed qEEG analysis for a VR mindfulness intervention in a sample of anxious participants, both VR and non-VR conditions experienced reduced anxiety; however, qEEG data aided in differentiating the groups, demonstrating a shift from higher to lower beta frequencies for those receiving the VR module (Tarrant et al., 2018). Additionally, traditional EEG analyses have been effectively employed for VR meditation interventions, evidencing comparable potential (Fu et al., 2021; Zhang et al., 2021).

The present study aims to examine the effectiveness of a VR meditation application (TRIPP VR) using several objective outcome measures including brainwave analysis. As efficacious anxiety treatment is pertinent to public health, it is vital to continue exploring methodologies for intervention and treatment progression. While VR meditation has shown promise in improving mood symptoms, level of engagement and quality of treatment, its utility for anxiety conditions and relevant physiological

impacts continue to warrant exploration. Existing research suggests that VR may produce physiological changes, but qEEG has rarely been used to assess VR interventions. This case study will be the first to explore the effectiveness of the TRIPP VR application for a participant with clinically significant anxiety, utilizing rating scales and qEEG analysis in an effort to underscore objectivity and further bolster the utility of specific qEEG analysis tools which pinpoint regions of interest (ROI). In light of available empirical evidence, it is hypothesized that the participant will experience decreases in anxiety, coupled with aligning shifts in electrical activity following the intervention, particularly in the amplitude reduction of beta frequencies.

Materials and Methods

Participants

The intervention was performed as a case study on a 13-year-old female showing clinically significant levels of anxiety. Since the participant was a minor, signed parental consent was received to provide the VR treatment and pre–post assessments from the participant's parents.

Equipment

The tools used to complete this case study were the TRIPP app, an Electro-Cap, and a VR headset. TRIPP is a VR app, available on the Meta Quest and other VR platforms, that was created to assist individuals in developing meditation skills and improving focus and a sense of calm through 8- to 12-min guided sessions, 3–5 times a week.

Electro-Cap. QEEG data was acquired utilizing a standard Electro-Cap 19-channel EEG with ear lead attachments (Bio-Medical Instruments, Clinton Township, MI). They are made of an elastic spandex-type fabric with recessed, pure tin electrodes attached to the fabric. The electrodes on the standard caps are positioned to the International 10–20 method of electrode placement. The size utilized for the current experiment ranged from 52–56 cm (medium).

VR Headset. The VR headset used to complete the TRIPP app sessions was the Meta Quest 2 headset (formerly the Oculus). The headset includes two handheld controllers. The Meta Quest 2 is usually used for gaming and watching 360-degree VR videos with 20 pixels per degree visuals and a fast-switch LCD display spanning 1832 x 1920 pixels per eye with a 120 Hz refresh rate. The headset weighs 503 g and measures 224 x 450 mm.

Measures

The case study included baseline testing and postintervention testing. The pre–post testing involved measurements of qEEG brain mapping analysis and behavioral rating scales.

Behavioral Rating Scales

The rating scales utilized for the current case study included the Behavior Assessment System for Children (BASC-3) and the Millon Adolescent Clinical Inventory (MACI-II). The BASC-3 is a self-report rating scale which identifies areas where adolescents are in the at-risk and/or clinically significant range for behavior and emotional problems. This process is done through a clinical and adaptive *t*-score profile composed based on the patient's self-report. The report can also be completed by the patient's parent or teacher. The MACI-II is an additional social and behavior rating scale that interprets if there are mental health concerns utilizing age-based comparisons. The MACI-II displays the following primary analyses: (a) profile summary for personality patterns, (b) expressed areas of concern, and (c) clinical syndrome scores. These MACI-II scores are based on normative data presented according to percentile ranks with cut-off scores for interpretable or clinically significant levels of elevation. For the purposes of the current case study, only the clinical syndrome scales were analyzed since the other two types of primary scores produced by the MACI-II lend themselves toward clinical and subjective interpretation.

QEEG Brain Mapping Analysis

QEEG is a procedure that processes the recorded EEG electrical activity of the brain with multiple sensors through an amplifier connected to a computer. The obtained EEG is processed with various algorithms, such as the fast Fourier transform (FFT). Using statistical analysis, the metrics are compared to a normative database of reference values. Colorized brain maps are produced as a result of the analysis. QEEG information is used as a tool to interpret areas of brain dysregulation and function by various experts. Pre–post qEEGs allow for tracking of changes in brain function as a result of various interventions such as neurofeedback, exercise or medication. This case study design also employed BrainMaster's *Z*-Builder EEG analysis program to identify significant changes in an individual's qEEG based upon the hypothesis that traditional qEEG analysis approaches using normative comparisons appear to be less sensitive to changes in atypical population samples. BrainMaster's *Z*-Builder EEG analysis

program compares the individual to their own baseline qEEG analysis (Collura & Tarrant, 2020).

Procedure

The participant completed 25 sessions using the TRIPP VR app as a treatment protocol over an 8-week period with initial guidance provided by a technician. Prior to the first session, the participant completed two behavioral rating scales that were delivered and completed electronically on a secure server. During the first session, the participant received an initial qEEG assessment before using the VR TRIPP. Subsequently, during the initial session, the subject wore a VR headset for approximately 10–12 min while watching and participating in VR guided meditation videos. The VR videos are designed to regulate breathing with an immersive and interactive experience. The participant then took the VR equipment home for 8 weeks. Throughout those 8 weeks, they received weekly check-in emails. These emails included questions such as “how often do you remember to do your VR exercises?” and “do you have a specific time that you begin your sessions?” At the end of 8 weeks, the participant came back to the office to return the VR equipment and complete the post qEEG and the behavioral rating scales (BASC-3 and MACI-II). A subsequent parental rating form for the BASC-3 was completed by the same parent that completed the BASC-3 prior to the intervention phase.

Data Analysis

QEEG is produced through statistical analysis of the EEG; that is, conversion of the time domain EEG record (voltage plotted against time) to the frequency domain (amplitude or power plotted against frequency) using the FFT. The qEEG bands considered were delta (1–3 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (15–20 Hz), and high beta (20–30 Hz). In this study, raw EEG data were collected noninvasively from the participant’s scalp before their first session and after the 8 weeks using a BrainMaster Discovery 20-channel EEG (BrainMaster Technologies, Bedford, OH). Electrode caps were used to place recording electrodes over the 19 standard regions defined by the International 10/20 system referenced to linked ears: Fp1, Fp2, F3, F4, F7, F8, T3, T4, C3, C4, P3, P4, T5, T6, O1, O2, Fz, Cz, and Pz. All channels of EEG were acquired with 24-bit resolution at the sampling rate of 256 Hz. Automated artifacting using SARA was uniformly applied without exception in order to remove human error or bias in the analysis and selection of which data should be rejected. The NeuroGuide EEG and qEEG analysis system software (Applied Neuroscience, Inc., Largo, FL) was used for the signal processing of the qEEG. Quantitative data were presented using absolute power group means comparison between the pre–post intervention brain waves. Statistical analyses were also performed utilizing NeuroStat’s paired *t*-test for comparing the absolute power differences between the pre–post test results conditions across the 19 scalp locations acquired for each of the five previously mentioned frequency bandwidths. Finally, critical *p*-values for determining level of significance were reported for both the paired *t*-test and BrainMaster’s *Z*-Builder EEG analysis tool.

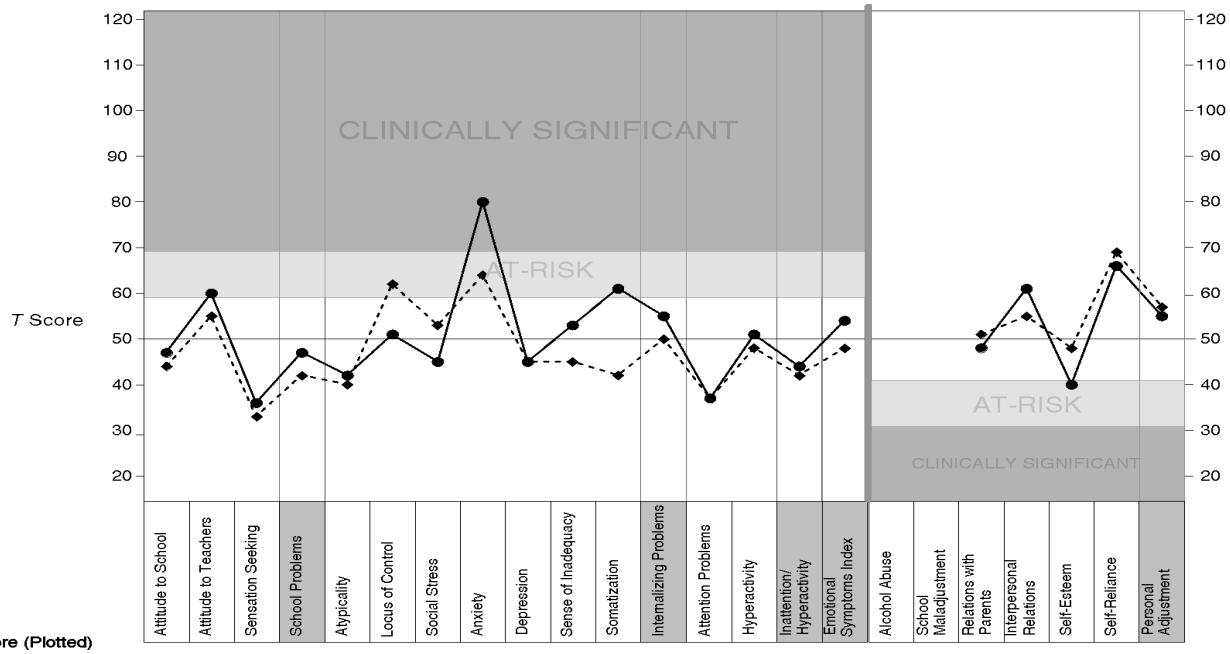
Results

The case study included one adolescent female participant who met criteria for a generalized anxiety disorder based upon prior psychological evaluation results. Overall, behavioral rating scales and qEEG analyses illustrated moderate decreases in the subject’s anxiety symptoms as measured by behavioral rating scales and electrical brain activity. An examination of each outcome measure is presented below.

Behavioral Rating Scales

BASC-3. The participant and their guardian completed the BASC-3 rating scale prior to and following the VR meditation intervention (Reynolds et al., 2015). The BASC-3 measures several areas related to the behavioral and emotional well-being of children and adolescents. Of note, one subscale directly measures anxiety, while others assess different areas of functioning such as depression, self-esteem, and tendencies to internalize. An assessment of adaptive functioning is also embedded in the measure. For clinical scales, *t*-scores below 60 are considered unremarkable; between 60–69 indicate *at-risk* or slightly elevated levels of concern and are associated with behaviors that should be monitored; and above 70 reflect *clinically significant* or markedly elevated concerns that require immediate attention. For adaptive scales, *t*-scores are interpreted inversely, where *t*-scores above 70 are considered *very high*, indicating complete mastery in a specific adaptive area; between 60-69 are *high*; between 41–59 are *average*; between 31–40 indicate *at-risk adaptive behaviors*; and those below 30 reflect *adaptive functioning that is clinically significant*. Figures 1 and 2 illustrate the pre–post *t*-score values for each of the domains and subdomains.

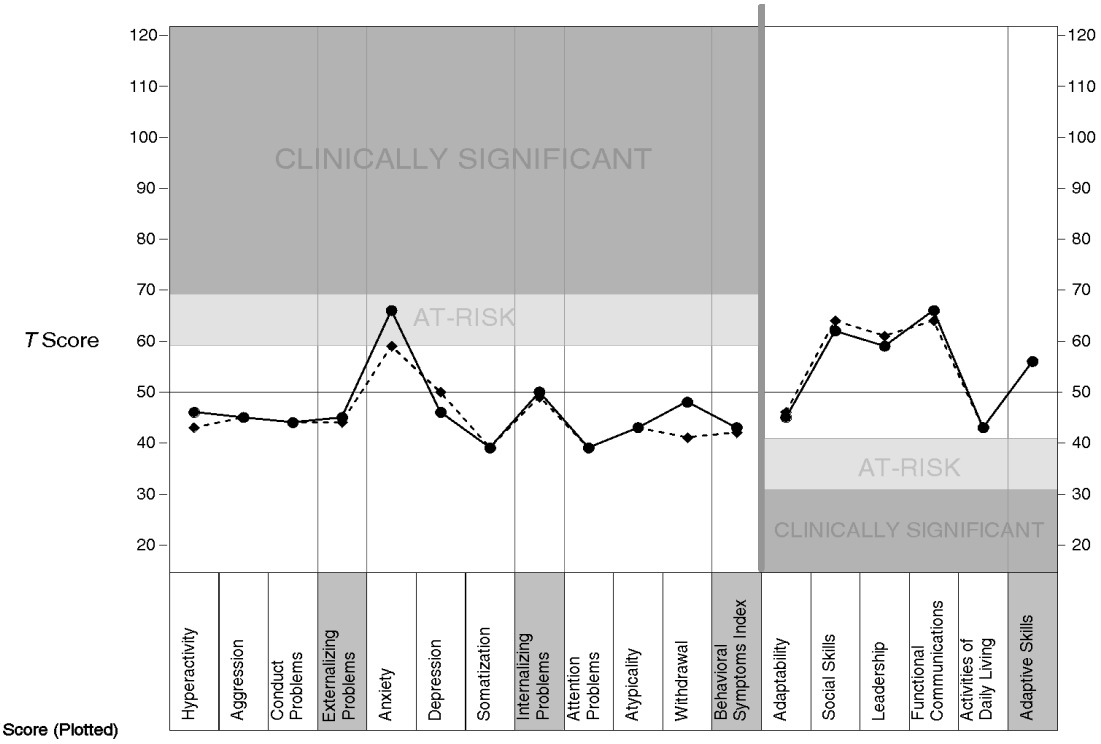
Figure 1. *Participant Self-Report for the BASC-3.*



T Score (Plotted)																							
Pre	47	60	36	47	42	51	45	80	45	53	61	55	37	51	44	54	--	--	48	61	40	66	55
Post	44	55	33	42	40	62	53	64	45	45	42	50	37	48	42	48	--	--	51	55	48	69	57

Note. -- indicates that the scale is not available for this form or the age at the time of the administration is not scorable for the norm group selected.

Figure 2. *Guardian Report for the BASC-3.*



T Score (Plotted)																		
Pre	48	45	44	45	66	46	39	50	39	43	48	43	45	62	59	66	43	56
Post	43	45	44	44	59	50	39	49	39	43	41	42	46	64	61	64	43	56

Perceptions of anxiety symptoms improved across raters. After the 8-week, 25-session intervention, the participant's self-rated anxiety decreased from a *t*-score of 80 (99th percentile) to 64 (90th percentile). Though anxiety remained a relevant behavioral area for monitoring, scores indicated notably decreased severity of symptoms such that the participant's *t*-score no longer fell in the clinically significant range according to a normative sample. Regarding guardian ratings, *t*-scores for anxiety decreased from 66 (92nd percentile rank) to 59 (84th percentile rank) such that the posttest *t*-value fell into the unremarkable or typical range. Additional changes were noted on the self-report form. The participant was no longer in the at-risk range for somatization, dropping from a *t*-score of 61 (86th percentile rank) to a *t*-score of 42 (15th percentile rank), representing typical levels of somatic complaints. Additionally, scores were in the at-risk range for self-esteem concerns prior to the module; self-ratings in this area improved similarly, with t-scores increasing from 40 (14th percentile rank) to 48 (32nd percentile rank). Of note, the participant's locus of control score evidenced an increase from a pretest *t*-score of 51 (64th percentile rank) to a posttest *t*-score of 62 (87th percentile rank), indicating mildly at-risk levels following the intervention.

MACI-II. The participant also completed the MACI-II (Millon et al., 2020). This rating scale is tailored to measure adolescent mental and behavioral health concerns. It contains several dozen scales in five clinically relevant domains. Among the areas measured are personality patterns, expressed concerns and clinical syndromes. Only the clinical syndrome scales were analyzed for the current study. Scores are presented as base rates (BR), which are set to reflect the prevalence rates of clinical syndrome criteria or classification. BR scores below 75 are *unremarkable*. Those between 75 and 85 are considered to be *present*, and scores above 85 are deemed *prominent and clinically significant*. Table 1 illustrates that prior to the intervention, the participant had a BR of 95 for anxious feelings,

Table 1

Pre vs. Post Self-Report for the MACI-II

Clinical Syndromes	Score PR	BR	Profile of BR Scores 0 60 75 85 115
Pretest			Present Prominent
Binge-Eating Patterns	58	60	
Substance-Abuse Proneness	30	0	
Delinquent Predisposition	9	0	
Anxious Feelings	76	95	
Depressive Affect	23	20	
Suicidal Tendency	21	0	
Disruptive Mood Dysregulation	22	20	
Post-Traumatic Stress	60	63	
Reality Distortions	23	9	

Clinical Syndromes	Score PR	BR	Profile of BR Scores 0 60 75 85 115
Posttest			Present Prominent
Binge-Eating Patterns	23	0	
Substance-Abuse Proneness	30	0	
Delinquent Predisposition	9	0	
Anxious Feelings	65	85	
Depressive Affect	6	0	
Suicidal Tendency	21	0	
Disruptive Mood Dysregulation	17	10	
Post-Traumatic Stress	45	45	
Reality Distortions	23	9	

which is considered prominent. Postintervention, the BR score for this subdomain was 75, eliminating the clinical relevance of this symptom. All other scales within the clinical syndrome profile were at nonclinical levels both before and after the intervention. Although nonclinical, a trend was evidenced posttreatment for decreased patterns of binge eating (a BR decline of 60 points), depressive affect and disruptive mood dysregulation (BR declines of 20 points), and posttraumatic stress (BR decline of 18 points).

QEEG Analysis

The 19 channels EEG recording had a duration of 6:03 min for eyes open and a duration of 6:02 min for eyes closed condition for raw EEG signals (see Figure 3). After applying SARA to automatically remove artifact, EEG recordings of 4:38 min for eyes open and 3:44 min for the eyes closed condition were produced and used for data analysis. Figure 4 presents qEEG analyses from the qEEG Pro report, which provides EEG Biomarkers based upon surface amplitude results and the agreement between the EEG results and the patients' symptoms. The red bars in Figure 4 reflect that the participant's symptom severity for anxiety remained unchanged. However, the relationship between the participant's brain activity deviations from a normative population and the participant's symptoms, as depicted by the green pie chart in Figure 4, revealed a 20% decrease in the deviant brain activity specific to anxiety and insomnia. The "high" color intensity depicted for anxiety and insomnia indicates a robust level of scientific support for the association between these biomarkers and the disorder (Keiser, 2018).

Figure 3. *Raw EEG Segment for Eyes Closed Condition.*

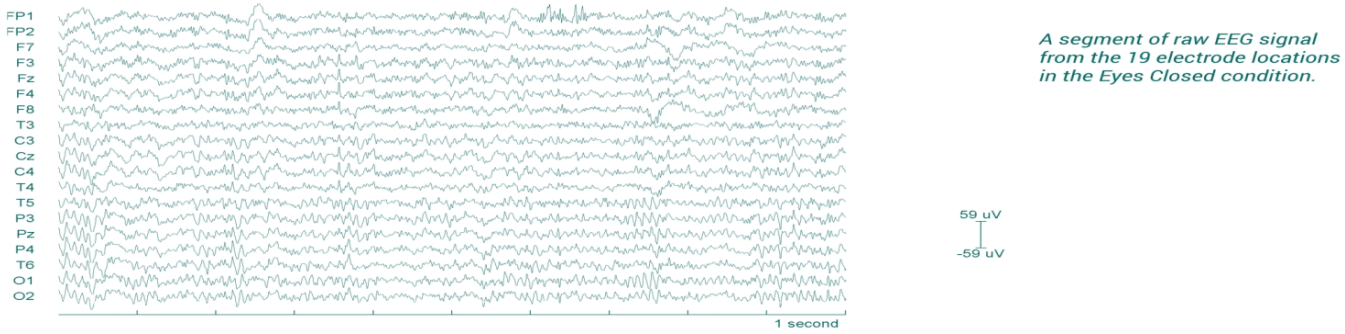
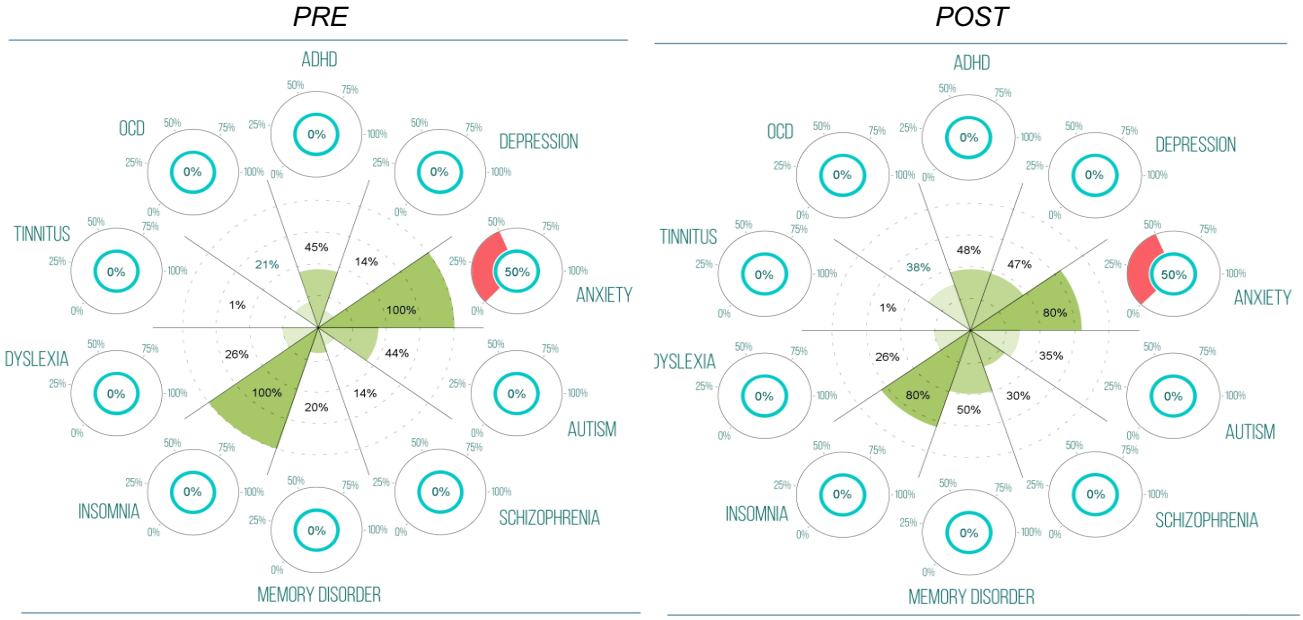
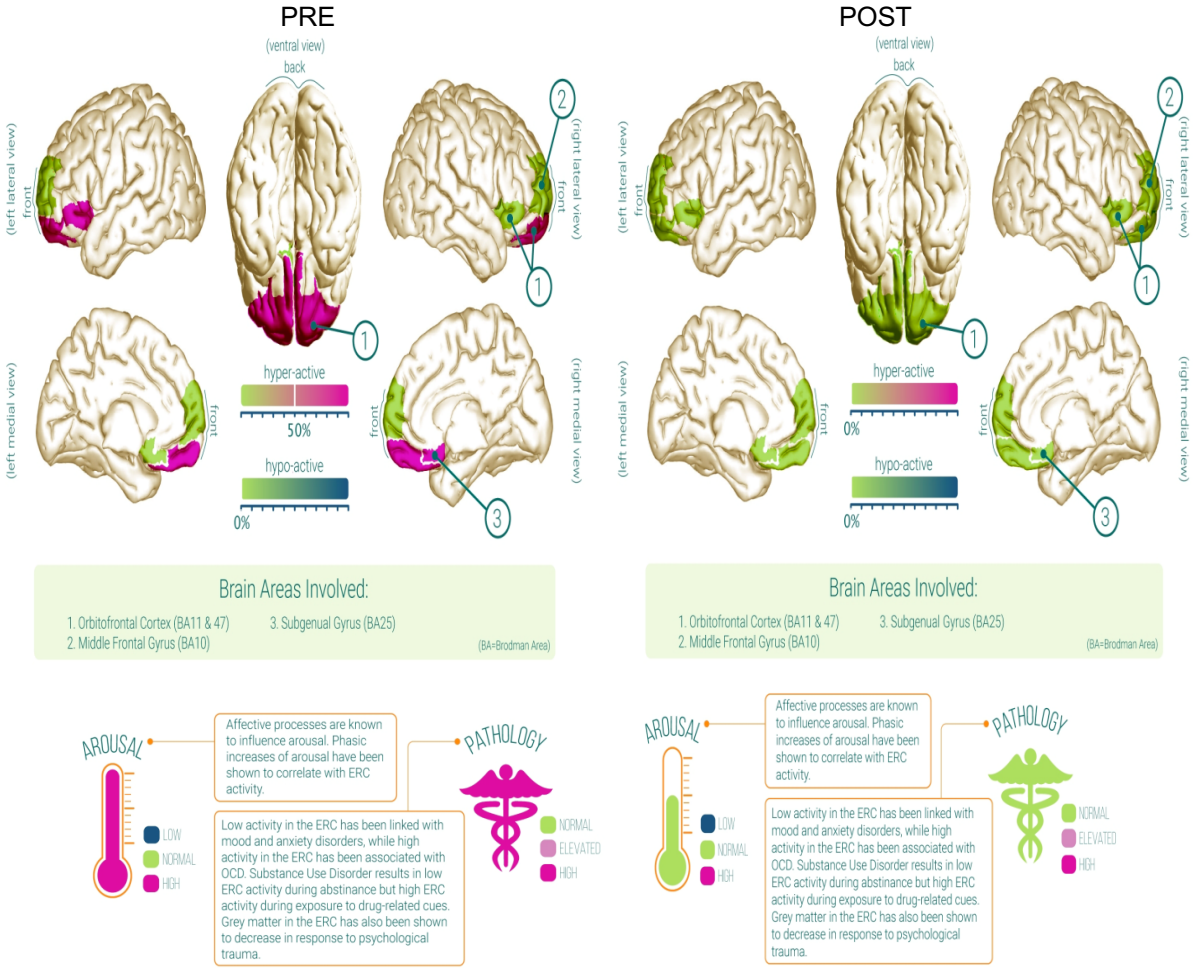


Figure 4. *EEG Biomarker Match Pre vs. Post.*



The qEEG Pro report also uses source localization techniques to determine the activity and connectivity of well-known "resting-state networks" based upon scientific literature (Keiser, 2018) that indicates the following networks represent functional units: the default mode network, the dorsal attention network, the emotion regulation cortex, the sensory motor cortex, the memory network, and the visual cortex. For the purposes of the current case study, only those networks which revealed abnormal arousal and pathology during the pre-test qEEG assessment are presented. Analysis of the results revealed only the emotion regulation cortex (ERC) to be implicated as all other networks failed to reveal abnormal brain activity levels both before and after the intervention. The ERC plays a role in emotion regulation, empathy, risk assessment, decision-making, and fear processing. The ERC also consists of the middle frontal gyrus, which is involved in emotional decision-making and the orbitofrontal gyrus, which is known for its role in the evaluation of emotional stimuli and the representation of the somewhat intangible concepts of personality or "cognitive style." The subgenual gyrus is also part of the ERC and plays a role in regulating emotion, endocrine function, and autonomic states associated with the neural processing of fear, reward, and stress. Figure 5 depicts a clinically significant improvement in the hyperactive connectivity levels in the orbitofrontal cortex and subgenual gyrus before (50%) and after (0%) hyperactive connectivity levels, resulting in brain activity specific to the ERC being restored from high arousal and pathology levels to normal levels. *Z*-score analysis (Table 2) revealed excessive hyperactivity in the prefrontal and frontal lobe due to significantly higher amplitude in the High Beta waves.

Figure 5. *Pre vs. Post Brain Activity in Resting-State Network: The Emotion Regulation Cortex.*



Z-Scores Analysis

The results of the generated brain maps from the normative database did show statistically significant changes. The *z*-score analysis of the absolute power metric was utilized for analysis where the colors depicted in the maps below (see Figure 6) indicate the amount of standard deviation represented as *z*-scores. Based upon clinical practice, clinically significant deviations are indicated with an absolute *z*-score value of two or greater. The brain maps presented in Figure 6 suggest that, prior to the intervention, this individual presented with excessive High Beta activity present in the frontal, parietal and occipital cortices due to excessive power in those regions. Postassessment of brain activity evidenced decreased High Beta activity in the frontal lobe by at least one standard deviation (*z*-score difference of 1 or greater). A *z*-score comparison (see Table 2) revealed significantly elevated power levels greater than two standard deviations from the normative database at the following locations in the High Beta frequency: Fp1 (*SD* = 2.2), Fp2 (*SD* = 2.2), F3 (*SD* = 2.3), Cz (*SD* = 2.2), C4 (*SD* = 2.3), T5 (*SD* = 2.3), P3 (*SD* = 2.6), Pz (*SD* = 2.8), P4 (*SD* = 2.8), and T6 (*SD* = 2.6). A postintervention *z*-score analysis (Table 2) revealed a decrease in power which represented typical power levels according to a normative database at the following locations in the High Beta frequency: Fp1 (*SD* = 1.2), Fp2 (*SD* = 1.2), F3 (*SD* = 1.4), and C4 (*SD* = 1.9).

Paired *T*-Test Analysis

Neuroguide's NeuroStat statistical software was utilized to provide an analysis of any significant intraindividual differences. This allows the analysis to measure improvement based upon the individual's unique EEG activity as opposed to a comparison against a normative database targeting significant differences represented by populations means only. Figure 7 presents the paired *t*-test data for the within-subject, single case design. *P*-values are presented both pictorially in the brain maps as well as numerically. The color legend located below the brain maps indicates that statistically significant brain activity differences ($p < .05$) existed post intervention in the following EEG frequency bands and brain regions: Delta (left frontal, $p = .006$; right frontal, $p = .009$; left central, $p = .001$; frontocentral, $p = .005$; parietal, $p < .04$), Theta (left frontoparietal = .002; right frontal parietal, $p = .000$; left frontal, $p = .000 - .01$; right frontal, $p = .000 - .001$; left central, $p = 0.000$; right central, $p < .04$; left temporal, $p < .02$; frontocentral, $p = .001$; central, $p = .002$), Alpha (left frontoparietal, $p = .001$; right frontoparietal, $p = .001$; left frontal, $p = .000 - .01$; right frontal, $p = .000 - .002$; left central, $p = .000$; left parietal, $p = .005$; right parietal, $p < .05$; left occipital, $p < .02$; right occipital, $p = .006$; left temporal, $p = .000 - .001$; frontocentral, $p = .001$; central, $p = .002$), Beta (left frontoparietal, $p = .000$; right frontoparietal, $p = .000$; left frontal, $p = .000$; right central, $p < .03$; right occipital, $p = .000$; left temporal, $p = .001$; right temporal, $p = -.001$), and High Beta (left frontoparietal, $p = .000$; right frontoparietal, $p = .000$; left frontal, $p = .000 - .001$; right frontal, $p = .001$; left temporal, $p = .000$; right temporal, $p = -.009$).

Figure 6. *Pre vs. Post qEEG Absolute Power (uV Sq) Z-Score Values.*

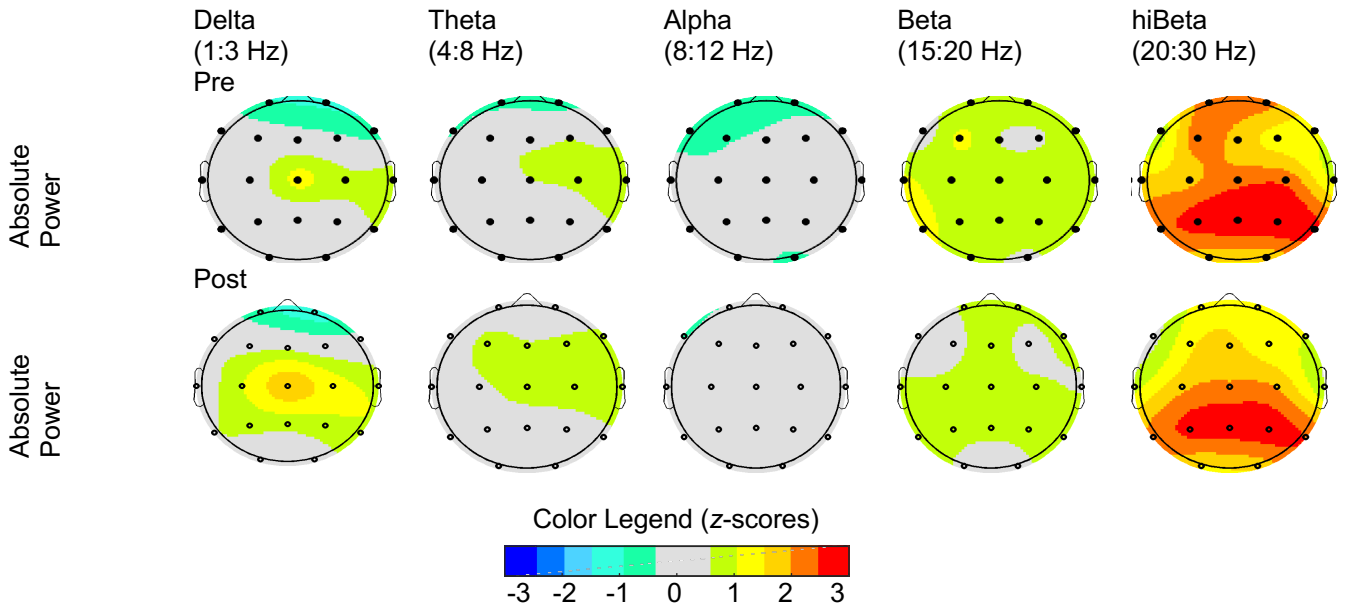
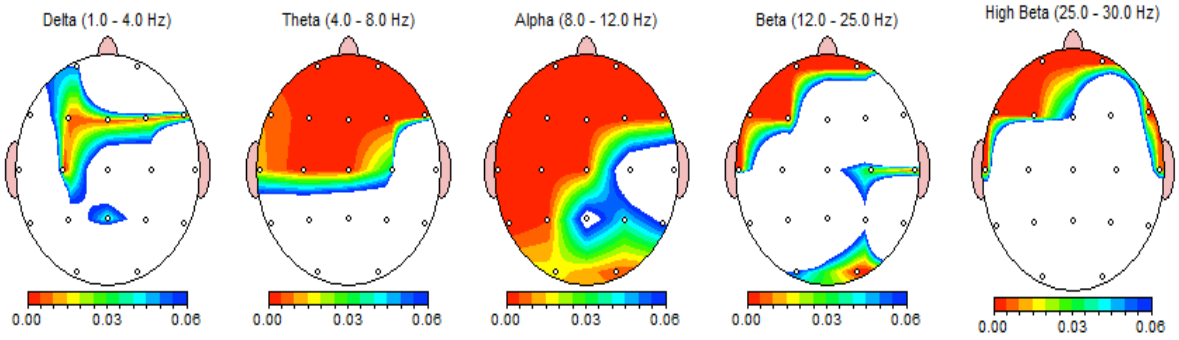


Table 2
Pre vs. Post Amplitude Z-Scores According to Location and EEG Frequencies

Pre	Absolute Power (uV^2)									
Ch	Delta	*Z*-Delta	Theta	*Z*-Theta	Alpha	*Z*-Alpha	Beta	*Z*-Beta	hiBeta	*Z*-hiBeta
FP1	26.7	−0.9	11.0	−0.6	7.9	−0.6	4.8	0.9	9.4	2.2
FP2	25.5	−1.1	10.9	−0.6	8.8	−0.5	5.1	0.9	9.6	2.2
F7	25.7	0.0	8.8	−0.4	5.9	−0.8	3.3	0.2	4.9	0.8
F3	27.7	0.0	20.4	0.4	12.6	−0.4	8.5	1.1	11.1	2.3
Fz	29.2	0.0	24.0	0.4	14.8	−0.3	6.5	0.5	7.9	1.7
F4	26.1	−0.2	21.9	0.5	14.8	−0.2	6.6	0.5	8.3	1.3
F8	19.0	−0.6	11.0	0.2	8.3	−0.3	4.6	0.9	6.2	1.2
T3	13.8	0.2	8.9	0.2	9.1	0.1	5.2	1.1	8.1	1.6
C3	24.5	0.2	18.0	0.1	18.0	−0.2	6.5	0.8	7.7	1.8
Cz	42.1	1.2	29.8	0.6	20.2	−0.3	7.9	1.0	9.4	2.2
C4	30.4	0.7	23.5	0.7	19.7	−0.1	7.8	1.0	9.7	2.3
T4	18.7	0.9	12.1	0.9	11.1	0.3	5.0	0.9	5.9	1.0
T5	20.4	0.3	14.7	0.3	24.4	0.0	8.0	1.2	9.5	2.3
P3	27.6	0.2	19.5	0.2	34.5	0.0	8.1	0.8	10.7	2.6
Pz	28.3	0.0	20.7	0.0	31.2	−0.3	8.7	0.9	11.1	2.8
P4	27.9	0.1	20.0	0.2	32.7	−0.1	8.4	0.8	12.1	2.8
T6	26.5	0.5	18.0	0.5	29.8	0.0	7.8	1.0	12.0	2.6
O1	26.4	0.0	17.9	0.1	54.3	−0.1	10.3	0.8	14.6	1.7
O2	26.5	0.0	18.6	0.1	41.2	−0.4	9.3	0.5	14.0	1.6
Post	Absolute Power (uV^2)									
Ch	Delta	Z-Delta	Theta	Z-Theta	Alpha	Z-Alpha	Beta	Z-Beta	hiBeta	Z-hiBeta
FP1	28.1	−0.8	14.4	0.1	9.5	−0.3	4.3	0.6	5.9	1.2
FP2	23.2	−1.3	13.2	−0.1	10.3	−0.2	4.5	0.7	6.3	1.2
F7	28.8	0.3	10.7	0.1	7.5	−0.4	3.0	0.0	4.1	0.4
F3	30.8	0.4	23.6	0.7	15.8	0.0	5.8	0.4	7.6	1.4
Fz	33.2	0.4	26.5	0.6	17.7	0.0	7.3	0.8	7.5	1.6
F4	29.0	0.1	23.9	0.7	17.5	0.1	6.3	0.4	7.8	1.2
F8	23.2	−0.2	13.5	0.7	11.6	0.3	4.3	0.7	5.8	1.0
T3	13.6	0.2	10.1	0.5	10.3	0.3	4.1	0.7	5.2	0.8
C3	32.3	1.0	20.9	0.4	24.5	0.3	6.2	0.7	7.7	1.8
Cz	51.8	1.8	34.4	0.9	26.1	0.1	6.9	0.7	8.7	2.1
C4	36.8	1.3	24.8	0.8	24.3	0.2	6.5	0.6	8.4	1.9
T4	18.6	0.9	11.0	0.7	12.7	0.5	4.1	0.5	4.8	0.6
T5	23.0	0.5	15.6	0.4	32.7	0.3	6.5	0.8	8.8	2.1
P3	33.6	0.6	20.1	0.2	43.4	0.3	7.5	0.7	10.5	2.6
Pz	37.3	0.7	22.2	0.2	40.4	0.1	7.5	0.6	10.4	2.7
P4	37.2	0.8	21.8	0.3	45.5	0.2	7.9	0.7	11.3	2.7
T6	31.8	0.9	18.3	0.5	39.2	0.3	7.6	0.9	11.2	2.4
O1	31.8	0.4	18.9	0.2	67.9	0.1	9.0	0.5	13.4	1.5
O2	32.4	0.4	20.4	0.3	64.4	0.0	9.0	0.4	14.5	1.7

Figure 7. *FFT Absolute Power Paired T-Test: Post Minus Pre Brain Maps.*



While Figure 7 simply indicates whether a significant change existed between pre vs. post-qEEG absolute power, Table 3 and Figure 8 below provide directional change indicators. Significant *p*-values presented in red font indicate a significant increase in amplitude/power in the indicated qEEG frequency bandwidths following the intervention. Conversely, significant *p*-values presented in blue font indicate a significant decrease in amplitude/power in the indicated qEEG frequency bandwidths following the intervention. The significant changes in amplitude from the post minus pre differences depicted in Figure 8 below indicate the magnitude of change in microvolts across the five qEEG frequency bandwidths. Based upon the brain maps displayed in Figure 8, the participant demonstrated increased power in frontal-central Delta up to 7.0 uV. Sq., frontal-central Theta up to 5.7 uV. Sq., central-parietal Alpha and occipital Alpha up to 10.8 uV. Sq., and right-central occipital Beta up to 12.0 uV. Sq. Conversely, the participant demonstrated decreased power in frontal High Beta and in left-temporal High Beta up to −2.3 uV.Sq. This indicates that the participant's overall brainwave power mean higher frequency shifted from the Beta/High Beta to higher Alpha mean frequency levels.

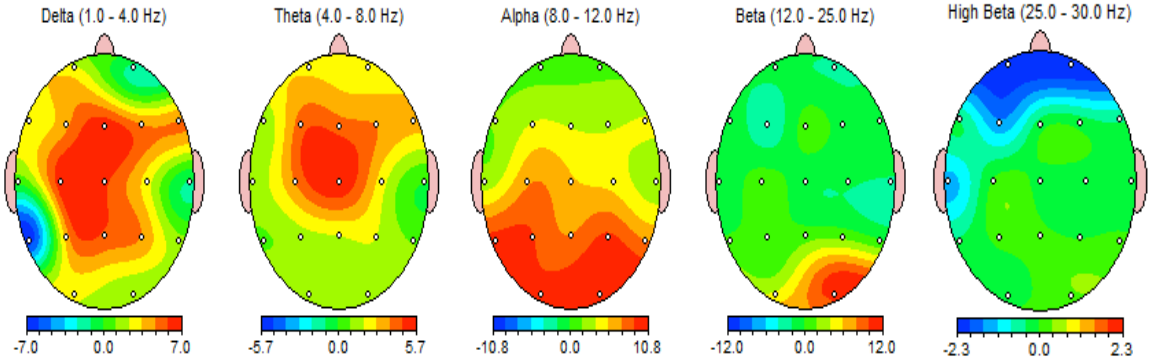
Table 3
FFT Absolute Power Paired T-Test: Post Minus Pre (P-Value)

	Delta	Theta	Alpha	Beta	High Beta
Intrahemispheric: Left					
FP1	0.050	0.002	0.001	0.000	0.000
F3	0.006	0.000	0.000	0.000	0.000
C3	0.001	0.000	0.000	0.221	0.643
P3	0.081	0.122	0.005	0.559	0.187
01	0.128	0.155	0.018	0.055	0.875
F7	0.113	0.010	0.000	0.004	0.000
T3	0.436	0.011	0.001	0.001	0.000
T5	0.869	0.121	0.000	0.928	0.292
Intrahemispheric: Right					
FP2	0.500	0.000	0.001	0.000	0.000
F4	0.009	0.001	0.002	0.224	0.300
C4	0.115	0.036	0.090	0.025	0.345
P4	0.081	0.119	0.041	0.071	0.613
02	0.298	0.178	0.006	0.000	0.208
F8	0.003	0.000	0.000	0.946	0.001
T4	0.643	0.830	0.116	0.000	0.009
T6	0.517	0.784	0.061	0.469	0.355

Table 3
FFT Absolute Power Paired T-Test: Post Minus Pre (P-Value)

	Delta	Theta	Alpha	Beta	High Beta
Intrahemispheric: Center					
Fz	0.005	0.001	0.000	0.259	0.067
Cz	0.116	0.000	0.002	0.073	0.339
Pz	0.036	0.130	0.071	0.178	0.269

Figure 8. *FFT Absolute Power Difference: Post Minus Pre (uV Sq).*



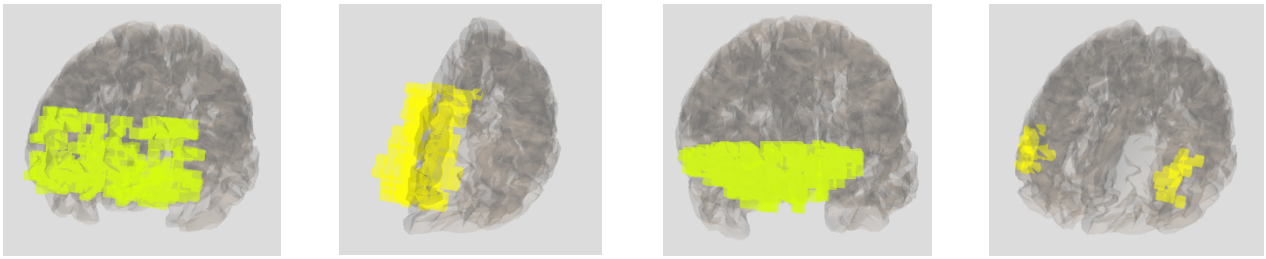
Z-Builder ROI

Finally, the *Z*-Builder tool compares specific Brodmann areas (BA) representing definitive regions of the cerebral cortex associated with specific sensory, motor, and higher cognitive functioning behaviors. The present *Z*-Builder analysis focused solely on the BA ROIs specific to biomarkers related to anxiety. The *Z*-builder analysis compares the individual to their own baseline qEEG. The BA ROI's selected for pre-post comparison were BAs 10, 11, 32, and 46. Because the *Z*-builder analysis program does not provide brain map comparisons of pre-post differences, Table 4 below provides *Z*-score values for ROIs for which a *Z*-score, or standard deviation, of ±0.7 or higher was obtained, as per the recommendations of the *Z*-Builder developer (Collura & Tarrant, 2020). Significant changes were evidenced in the Beta (12–25 Hz) and High Beta (25–30 Hz) wavebands. Many of the BA ROIs listed in Table 4 indicate a significant change postintervention with the greatest magnitude of change occurring in a reduction of High Beta in BA 10 (*SD* = −1.09), BA 11 (*SD* = −1.035), and BA 46 (*SD* = −1.005). Figure 9 provides a visual representation of the BA brain regions positively impacted along with the neuropsychological functions correlated with the specific BA.

Table 4
Z-Builder Specific BA ROI Analysis

ROI Name	Beta.LR	Hibeta.LR
Brodmann 10	−0.763	−1.09
Brodmann 11	−0.829	−1.035
Brodmann 32	−0.456	−0.831
Brodmann 46	−0.862	−1.005
Color Code for *Z*-value		
Z-score is >/= 0.70 − 0.99		
Z-score is >/= 1.00		

Figure 9. *Z-Builder.*



Brodmann 10 | Brodmann 11 | Brodmann 32 | Brodmann 46

Site	BA ROI	Function
Fpz	10, 11, 32	emotional inhibition, oversensitivity, impulsivity, motivation, and attention
Fp1	10, 11, 46	cognitive emotional valancing (lateral orbital frontal), irritability, intrusiveness, depression, social awareness (approach behaviors)
Fp2	10, 11, 46	emotional inhibition (lateral orbital frontal), impulsivity, tactlessness, mania, social awareness (avoidance behaviors)

Discussion

This case study set out to determine the efficacy of TRIPP VR, a VR meditation application, as measured by standardized behavioral rating scales and changes in physiological brainwave patterns. The findings from this investigation highlight several important considerations for the use of virtual and augmented reality technologies in anxiety treatment approaches and general mental health interventions.

As predicted, the case study demonstrated notable and significant decreases in the participant's anxiety levels, as evidenced by both behavioral rating scales and qEEG analysis. The reduction of the participant's anxiety symptoms supports the potential of TRIPP VR as a viable treatment approach for anxiety disorders. The immersive nature of VR meditation interventions may facilitate greater engagement and adherence to treatment, which can be a significant advantage over traditional modalities. In fact, the present case study yielded similar decreases in Beta activity while implementing VR-based training as evidenced in a prior study (Cavallo & Brubaker, 2024), which coined the term "beta shunting." Further research should continue to explore the theoretical implications that VR training minimizes and/or blocks out external distractions at a level that promotes lower beta frequencies, thus allowing the user to engage in a more immersive learning experience.

The fact that the participant remained in the at-risk range for anxiety suggests that while the intervention may be beneficial, TRIPP VR is not yet a standalone intervention and should be integrated with other therapeutic approaches for comprehensive treatment. Nonetheless, these findings, combined with the qEEG data revealing significant decreases in excessive frontal High Beta amplitude, indicate the potential for VR mindfulness training to result in brain state changes. When considering a recent randomized control study completed by Kral et al. (2022), which failed to replicate prior research findings suggesting structural brain changes (as assessed through fMRI) following traditional mindfulness interventions, the present case study findings suggests that mindfulness training delivered in a VR environment can result in a change in EEG brain activity. Furthermore, the paired combination of physiological and behavioral outcome measures employed in the current study provided a robust qualitative analysis, which yielded congruent and symbiotic levels of improvement in the participant's behavioral and physiological manifestations of anxiety. While the results of this case study are promising, they are also limited by the study's design. The single-case approach limits the generalizability of the findings. Additionally, the participant's age and development are not fully representative of the broader population with anxiety disorders. To establish the efficacy of TRIPP VR, larger-scale studies are necessary. Additionally, diversifying the participant sample and including a control condition are recommended to expand findings. Such studies should also explore longitudinal effects and the sustainability of the observed benefits.

The positive outcomes observed in this case study suggest that TRIPP VR, in combination with qEEG analysis, holds potential as an innovative tool for anxiety treatment. For clinicians, incorporating VR-based interventions could enhance the therapeutic treatment approaches and offer patients novel, engaging options. Additionally, the feasibility and convenience of VR technology make it an enticing option, particularly in settings with limited access to traditional therapies. The results also suggest that VR could be an effective and very practical tool for school counselors and psychologists to use in an educational setting to address test anxiety and general school-related anxiety. Exploring the integration of TRIPP VR with other therapeutic modalities, such as cognitive-behavioral therapy, could provide insights into optimal treatment combinations. Investigating the use of EEG analysis tools in conjunction with VR and augmented reality interventions could also further delineate the neurophysiological factors underlying anxiety reduction and expand the development of personalized treatment protocols. For example, in the current case study the participant successfully restored High Beta amplitude brainwave activity to typical levels in the frontal and prefrontal cortices following the VR intervention. However, according to a normative qEEG database, although the participant's High Beta amplitudes decreased slightly in the parietal and temporal lobes following the VR intervention, the amplitude levels continued to fall at or greater than two standard deviations above typical levels. From a clinical perspective, the combination of behavioral and physiological data suggests that the participant gained a better sense of cognitive and/or executive functioning control of their anxiety but might still struggle with autonomic sensory-motor manifestations of anxiety (i.e., twirling hair, picking at nails, verbal rumination, etc.). Therefore, while the VR training resulted in clinically significant improvements, a clinician might also build upon such success by introducing additional training modalities, such as biofeedback and/or neurofeedback, to target improvements in anxiety-related behaviors associated with High Beta amplitudes in the parietal and temporal lobes.

In conclusion, this case study provides preliminary evidence supporting the use of TRIPP VR as an effective tool for reducing anxiety. While further research is necessary, the integration of technological advancements in mental health treatment offers promising avenues for enhancing patient outcomes.

Author Disclosure

The authors declare that they have no conflicts of interest to disclose. Also, there are no financial interests related to this study that could be perceived as influencing the results or interpretation of the manuscript.

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