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LORETA Neurofeedback at Precuneus: A Standard Approach for Use in Incarcerated Populations With Substance Use Problems

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Abstract

Introduction. The objective for this case grouping study was to evaluate the feasibility and application of a standard protocol of LORETA neurofeedback (LNFB) at the precuneus to aid inmates in reducing symptomatic issues and recidivism in a local correctional facility. LNFB is a noninvasive, operant conditioning technique for improving neural signatures of self-regulation to reduce stress and the experiences of psychopathology as measured by objective tests. **Methods.** This case grouping includes 63 individuals (19 female) with a mean age of 37.11 (*SD* = 9.69). All participants signed informed consent and completed objective measures and EEG/LORETA baseline data. All participants completed 20 sessions of LNFB at precuneus targeting α current source density (CSD) on 20 consecutive business days. **Results.** Significant reductions on most scales of the PAI were present post-LNFB training. The sLORETA data shows significant differences in all ranges of current source density in medial and inferior frontal regions, anterior cingulate, and parietal regions posttraining. Among the 63 participants, 74.6% had not been rearrested for any reason postrelease. Additionally, 82.5% had not been rearrested due to substance use postrelease. **Discussion.** This case grouping offers support to the potential use of standard procedures for LNFB protocol targeting the left precuneus in aiding inmates with substance use disorders (SUD) in achieving better self-regulation and reducing relapse and rearrest rates.

Keywords: substance use disorders; neurofeedback therapy; Peniston protocol; Scott-Kaiser modification; qEEG; relapse prevention

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Introduction

Substance use disorders (SUD) are highly prevalent among incarcerated populations, posing significant challenges to the criminal justice system and public health. In the United States, it is estimated that approximately 65% of inmates meet the criteria for SUD (Bronson, 2017). This statistic underscores the critical need for effective intervention strategies within correctional facilities. Current treatment models for SUD in jail and prison settings have demonstrated modest to low efficacy. Meta-analyses have indicated that traditional treatment approaches, such as cognitive-behavioral therapy (CBT) and medication-assisted treatment (MAT), often yield effect sizes that may not be sufficient to produce substantial reductions in recidivism. For instance, a meta-analysis by Landenberger and Lipsey (2005) reported that CBT programs for offenders resulted in an average reduction in recidivism rates of approximately 25% compared to control groups, translating to a modest effect size. Similarly, a systematic review by Moore et al. (2019) found that while MAT is effective in reducing opioid use postrelease, its impact on recidivism remains less conclusive, indicating the need for further research to determine its effectiveness in reducing reoffending or rearrest rates. These findings suggest that while CBT and MAT offer benefits, their effects on recidivism are limited, highlighting the need for integrative treatment models that address the multifaceted nature of criminal behavior and SUD.

Various treatment models, including behavioral therapies (such as CBT), pharmacotherapy (e.g., methadone and buprenorphine for opioid addiction), 12-step programs (e.g., Alcoholics Anonymous), and residential rehabilitation have shown variable degrees of efficacy. For example, meta-analyses have shown that CBT yields moderate effect sizes, typically ranging from d = 0.45 to d = 0.70, depending on the population and implementation (Magill & Ray, 2009). Pharmacotherapies such as methadone and buprenorphine demonstrate strong efficacy in reducing opioid use, with effect sizes for retention in treatment ranging from d = 0.82 to d = 1.26 but less consistent effects on reducing relapse or recidivism (Mattick et al., 2014). Meanwhile, 12-step programs and residential rehabilitation report more variable success rates, with effect sizes often influenced by participant engagement, ranging from d = 0.30 to d = 0.55 (Kelly et al., 2020). Research consistently emphasizes that a "one-size-fits-all" standardized approach is insufficient; however, developing novel standardized frameworks that incorporate individualized components, including neurofeedback, could significantly improve understanding and treatment of SUD populations. Comprehensive treatment programs addressing multiple facets of addiction—including mental health, social support, and co-occurring disorders—tend to yield better and more sustainable outcomes.

Despite the reported successes in some treatment models, the efficacy of SUD treatment in the United States is frequently marred by inconsistent results, which often stem from variability in treatment protocols, differences in study populations, and the lack of standardized methodologies. Poor replication of findings is further compounded by limited longitudinal studies and inadequate controls for confounding variables, while challenges in generalizing research data are exacerbated by underrepresentation of diverse populations and the heterogeneity of SUD presentations (Magill et al., 2014; McLellan et al., 2000; Thibault & Raz, 2016). These inconsistencies highlight the need for more rigorous and standardized approaches to studying and delivering SUD treatment. The National Institute on Drug Abuse (NIDA) has long emphasized that effective treatment for SUD often requires prolonged engagement and multiple episodes of intervention. This perspective was articulated in NIDA's publication, "Principles of Drug Addiction Treatment: A Research-Based Guide," first released in 1999 and updated in subsequent editions, including the third edition published in 2012. The guide states, "Recovery from drug addiction is a long-term process and frequently requires multiple episodes of treatment." Relapse rates for SUD vary depending on the substance and population. Generally, relapse rates for SUD are estimated to be between 40% and 60%, underscoring the chronic nature of addiction and the need for ongoing management and support (NIDA, 2020b). In incarcerated populations, the risk of relapse is even higher. NIDA reports that 85% of the prison population has an active SUD or was incarcerated for a crime involving drugs or drug use, and individuals with opioid use disorder face a significantly increased risk of overdose following release from incarceration (NIDA, 2020a). These statistics highlight the critical importance of providing comprehensive and continuous treatment for individuals with SUD, both during incarceration and after release, to effectively reduce relapse rates and support long-term recovery. Treatment success, therefore, is often seen as a process rather than a single event. A major issue in substance abuse research is the difficulty in replicating treatment outcomes across different studies and populations. Some landmark studies have shown promising results in controlled environments but have failed to reproduce similar effects when applied in real-world settings, leading to concerns about generalizability. For example, in clinical trials, pharmacotherapies like naltrexone and methadone have been effective in reducing opioid use, but their impact is less robust when implemented in community treatment settings where variables such as access, compliance, and follow-up support differ significantly (Kleber, 2007).

Additionally, meta-analyses and systematic reviews often suffer from methodological heterogeneity, making it difficult to draw firm conclusions. Many studies lack control groups, suffer from selection bias, or are based primarily on self-reported outcomes, which can distort the reliability of the data. While self-reported data can offer valuable insights, reliance solely on subjective measures may introduce biases and limit the reliability and generalizability of findings. In the context of neurofeedback and its more sophisticated varieties, incorporating objective outcome measures—such as quantitative electroencephalography (qEEG), low-resolution electromagnetic tomography (LORETA) contrasts, performance, and psychological metrics—is essential to accurately assess treatment efficacy and ensure robust, reproducible results (Hammond, 2011). However, research supports the validity of self-report data in measuring treatment efficacy, particularly when combined with objective measures. This dual approach enhances the accuracy of outcome assessments and provides a more comprehensive understanding of treatment effects (Del Boca & Noll, 2000; Miller, 2000).

The lack of standardization in treatment programs across facilities also makes it challenging to generalize results. As Humphreys and Tucker (2002) note, generalization is further complicated by demographic and socioeconomic factors that influence treatment access and success rates, with underserved populations often experiencing worse outcomes. While there are proposed effective treatments available for substance abuse, the field is hampered by issues of replication and generalizability. Broader, more rigorously controlled studies are needed to enhance the evidence base for neurofeedback modalities in substance abuse treatment. By "broader," we refer to research that includes diverse populations, such as individuals from various socioeconomic, racial, and gender groups, as well as studies conducted in multiple settings, including correctional facilities, outpatient and inpatient clinics, and community-based programs. This diversity, combined with rigorous methodology and real-world applications, can improve the generalizability and practical integration of neurofeedback into substance abuse treatment programs in the United States. (Sokhadze et al., 2008).

Delivering SUD treatment within correctional facilities presents unique challenges due to environmental and psychological factors inherent to incarceration. Factors such as hypervigilance, threats to personal safety, the overall stressful milieu, and loss of agency can significantly impact therapeutic outcomes. While these confounds are widely recognized, controlling for them in the research analyses remains complex. Some studies have attempted to address these issues by implementing structured treatment programs and providing training for correctional staff to foster a more supportive environment. Comprehensive strategies to fully mitigate these confounds are still under development, and further research is needed to establish effective methods for controlling these variables in both treatment delivery and outcome assessment (Zaller et al., 2022). Incarcerated individuals often experience heightened states of hypervigilance due to the constant need to be alert to potential threats and changes in their environment. This state of chronic vigilance can impair the ability to relax and engage fully in therapeutic activities. Hypervigilance is associated with increased anxiety and stress, which can hinder the effectiveness of therapies that require a calm and receptive mindset, such as CBT and mindfulness-based interventions (MBD; Johnson et al., 2012). The correctional setting is inherently stressful due to the omnipresent threats to personal safety from other inmates or institutional policies, and this fear for personal safety can create an environment of distrust and defensiveness, making it difficult for inmates to take full advantage of therapy sessions. This constant state of fear and hypervigilance can undermine the establishment of a therapeutic alliance between the inmate and the therapist, which is crucial for effective treatment outcomes (Haney, 2006), especially if the individual has prior experiences of traumatic stress or other comorbid conditions. The prison environment is characterized by numerous stressors, including overcrowding, lack of privacy, and rigid routines. These factors contribute to high levels of baseline stress and anxiety among inmates. Such an environment can exacerbate symptoms of SUD and make it challenging for inmates to focus on and benefit from therapeutic interventions. Continuous stress can also lead to maladaptive coping mechanisms, such as substance use, which further complicates the treatment process (Wolff et al., 2011).

Access to quality mental health care in correctional facilities continues to be limited due to resource constraints, understaffing, and inadequate training of mental health professionals. This can result in insufficient individualized care and follow-up, reducing the overall effectiveness of traditional therapies for inmates with SUD (Binswanger et al., 2012). Additionally, the stigma associated with mental health issues and substance use within prison culture can deter inmates from seeking help or fully participating in available treatment programs. Frequent transfers between facilities and the lack of continuity in care can disrupt the therapeutic process. Consistent, long-term therapeutic relationships are often essential for effective SUD treatment, but the transient nature of inmate populations can prevent the establishment of such relationships. This lack of continuity can lead to fragmented care and diminish the therapeutic benefits of traditional interventions (Chandler et al., 2009). More recent reports indicate that these challenges persist, leading to insufficient individualized care and follow-up, which reduces the overall effectiveness of traditional therapies for inmates with SUD. For instance, prisons and jails remain some of the largest de facto mental health care providers, yet they often lack the necessary resources to meet the demand for services (Prison Policy Initiative, 2022). Additionally, the National Alliance on Mental Illness (NAMI) reported that approximately three in five individuals (63%) with a history of mental illness do not receive mental health treatment while incarcerated in state and federal prisons (NAMI, 2022). These findings highlight the ongoing need for systemic improvements to address mental health care deficiencies in correctional settings.

The objective for this case grouping study was to evaluate the feasibility and application of a standard protocol of LORETA neurofeedback at the precuneus to aid inmates in reducing symptomatic issues based on datapoints within the scales of the Personality Assessment Inventory (PAI) and reduce recidivism in the Newaygo County Correctional Facility. LORETA neurofeedback (LNFB) is a noninvasive, operant conditioning technique that aims to aid the individual in improving neural signatures of self-regulation to reduce stress and the endorsement of symptomatic experiences as measured by objective tests. Recent studies have shown that LNFB and the *z*-score version can be beneficial in improving self-regulation across various mental health disorders, including SUD, by promoting neuroplasticity and enhancing self-regulation (Cannon et al., 2014; Fahrion et al., 1992; Faridi et al., 2024; Faridi et al., 2022).

LNFB is a neuroimaging technique that allows for the noninvasive modulation of brain activity by providing real-time feedback based on electrical activity within the brain. The specific region of interest used in this implementation of LNFB is a three-voxel cluster of neurons in the left precuneus, a part of the parietal lobe that plays a critical role in a variety of high-level cognitive functions, including self-referential processing, episodic memory, awareness, and aspects of memory retrieval (Cannon et al., 2014; Castellanos et al., 2008; Cavanna & Trimble, 2006; Dadashi et al., 2015). The precuneus is particularly significant in the context of SUD for several reasons. The precuneus is involved in the default mode network (DMN), which is typically increased in amplitude during rest and involved in self-reflective thought. Although, there has been disagreement with this concept of "rest" given the actual phenomenology of baseline tasks described as attention and the maintenance of complex behaviors (e.g., following and complying with the instructions given for the procedure, such as monitoring artifact production, being still, focusing, and relaxing). This effect can be present in any neuroimaging technique since the requirements for participants are similar (Cannon & Baldwin, 2012). Dysregulation of DMN has been implicated in various psychiatric conditions, including addiction. The precuneus, in the context of Brodmann areas (BA) 19 is highly involved in episodic memory and self-referential processes. In individuals with SUD, the DMN often shows abnormal patterns of connectivity, which may contribute to the persistent, self-focused negative thinking and cravings characteristic of addiction (Cannon et al., 2014). This protocol has been applied in groups that include children with prenatal drug exposure, where neurofeedback at precuneus aimed to improve sustained attention and cognitive, social and emotional deficits and behavioral issues stemming from early neurodevelopmental disruptions (Cannon et al., 2018; Kelley, et al., 2019). In adults and adolescents with SUD, LNFB has been employed to enhance self-regulation and reduce relapse rates by normalizing aberrant neural activity patterns. Additionally, we have applied this technique to clients suffering from anxiety, depression, and traumatic stress, leveraging the precuneus's role in self-referential and episodic memory processing to improve emotional regulation and decrease symptom severity. Although data have been presented at numerous conferences, comprehensive data from these studies have yet to be fully published.

LNFB enables precise targeting of specific brain regions by modeling the source of electrical activity within the brain. Unlike traditional neurofeedback, which infers brain activity based on electrical signals measured at the scalp, LORETA provides a more accurate representation of neuronal activity. This precision is particularly beneficial for targeting the alpha frequency range within regions such as the precuneus, which is known to play a critical role in self-referential processing and DMN. Training currents (mA/cm^2) directly within the brain allows for more effective modulation of specific brain rhythms, such as alpha waves. Alpha waves are associated with a relaxed, yet alert state of mind and are crucial for cognitive functions such as attention, memory, and emotional regulation. By directly influencing the neuronal sources of these waves, LNFB can achieve more significant and sustained changes in brain activity compared to traditional scalp-based methods. LNFB's ability to target specific cortical and subcortical structures can enhance neuroplasticity—the brain's ability to reorganize itself by forming new neural connections. This is particularly important in the context of SUD, where maladaptive neural circuits contribute to the pathology of addiction. By promoting adaptive changes in neural activity, particularly in the alpha frequency range, LNFB can support recovery and aid clinicians in reducing the risk of relapse.

Methods

This group case study employed a quasi-experimental design with pre- and postintervention electroencephalogram (EEG), LORETA, and objective measures to evaluate the effects of precuneus-targeted neurofeedback on recovery and recidivism reduction in a local jail population. This case grouping was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. This group case of LNFB was an application of a learning technique that has been used for the past 15 years and as such no institutional review board was employed. However, strict adherence to prior studies and usage was adhered to with review and approval by Newaygo County Mental Health (NCMH) and Newaygo County Corrections (NCC). All participants provided informed consent, and the study design minimized risk while ensuring the confidentiality of participant data. The researchers followed appropriate and ethical protocols for protecting human subjects. NCC and NCMH vetted, approved, and referred all participants for the program. Participants were advised they could withdraw from the study at any time without attempts to reconcile or any potential negative consequences. All participants signed informed consent and then completed the Self-Perception and Experiential Schemata Assessment (SPESA) and the PAI prior to EEG baseline collection. All questions the clients may have had about procedures were answered by technicians during this session. The Newaygo County Jail allowed the use of a property room with proximity to command center to conduct the LNFB sessions. All participants completed demographic information on the SPESA as part of the intake process.

Measures

Personality Assessment Inventory (PAI). The PAI (Lutz, FL) is an objective inventory of adult personality that assesses psychopathological syndromes and provides information relevant for clinical diagnosis, treatment planning, and screening for psychopathology. This assessment contains 344 items that constitute 22 nonoverlapping scales covering the constructs most relevant to a broad-based assessment of mental disorders: four validity scales, 11 clinical scales, five treatment scales, and two interpersonal scales. To facilitate interpretation and to cover the full range of complex clinical constructs, 10 scales contain conceptually derived subscales. The scales listed in the table are somatic (conversion, somatization, health concerns); anxiety (cognitive, affective, physiological); anxiety-related disorders (obsessive-compulsive, phobias, traumatic stress); depression (cognitive, affective, physiological); mania (activity level, grandiosity, irritability); paranoia (resentment, hypervigilance, persecution); schizophrenia (psychotic experiences, social detachment, thought disorder); borderline features (affective instability, identity problems, negative relations, self-harm); antisocial features (antisocial behaviors, egocentricity, stimulus-seeking); aggression (aggressive attitude, verbal aggression, physical aggression).

Self-Perception and Experiential Schemata Assessment (SPESA-45). The SPESA (Knoxville, TN) was designed to detect negative, average, or positive perceptions of self, and perception of self-in-experience (ES) across three life domains: childhood, adolescence, and adulthood (Cannon et al., 2008). This instrument taps into endogenous and exogenous experiences of an individual with respect to emotional abuse, self-efficacy, self-image, and self in relation to others. There are a total of 45 items, and each domain consists of 15 items. The items are scored (2, 1, −1, −2) and summed for each life domain.

Exclusion criteria included a prior or recent diagnosis of epilepsy, any neurological disease, or a history of severe traumatic brain injury (TBI) involving blood or diffuse axonal injury, psychiatric diagnoses with active psychosis, and violence-related charges. These criteria were established to ensure participant and technician safety and the validity of the data collected. Upon completion of these criteria, clients completed 5-min eyes-closed and eyes-opened EEG baselines as premeasures. Participants then completed a 3-min process in which they watched the 19-channel EEG on the monitor and were instructed to produce artifacts, such as eye blinks, eye movement, tongue movement, jaw tension, neck tension, and general head movements. They were advised as to the inhibitory nature of these events and that awareness and control of these events would aid in progress.

Participants

This case grouping includes 63 individuals (19 female) with a mean age of 37.11 (*SD* = 9.69), 58 of whom were right-handed. The initial participant count was 110, with 64.5% completing the protocol and 35.5% dropping out. Only those who completed all sessions, as well as post-LNFB baseline and PAI measures, were included in the final analysis. The SPESA is an intake assessment and not used as a postmeasure. Eight participants were either transferred to prison or released before protocol completion, resulting in a final analyzed sample of 63. In this study of 63 participants, the racial composition included two Black, two Native American, one Hispanic, and three mixed-race individuals, closely reflecting the demographic makeup of Newaygo County, Michigan.

LNFB is an operant conditioning technique that provides the user real-time information about the EEG sources current source density (CSD) levels in a specific intracortical region of training (ROT). Through feedback the user can then change the CSD at the ROT to influence improvements in cognitive, attentional, and affective processes. These works and an examination of functional connectivity of EEG CSD in the default network during self-perceptive and self-relevant contexts the impetus for the current LNFB paradigm in the precuneus, as well as work demonstrating the parieto-occipital region to be important in the treatment of posttraumatic stress disorder (PTSD), SUD, and attention-deficit/hyperactivity disorder (ADHD; Cannon, 2014; Peniston & Kulkosky, 1989; Saxby & Peniston, 1995).

Participants were prepared for EEG recording using a measure of the distance between the nasion and inion to determine the appropriate cap size for recording (Blom & Anneveldt, 1982). The head was measured and marked prior to each session to maintain consistency and for placement of frontal electrodes. After fitting the caps, each electrode site was injected with electrogel and prepared so that impedances between individual electrodes and each ear were less than ~10 kΩ. The LNFB training was conducted using the 19 leads of the standard international 10–20 system with linked ear reference. The center voxel for a three cluster of voxels for the ROT was located at Talairach coordinates ($x = -31$, $y = -81$, $z = 22$). The data were collected and stored utilizing the Deymed Diagnostics (Payette, ID) TruScan Acquisition system with a band-pass set at 0.5–64.0 Hz at a rate of 256 samples per second. FFT settings for EEG were delta (1–4 Hz), theta (4–8 Hz), alpha-1 (8–10 Hz), alpha-2 (10–13 Hz), beta (13–21 Hz), and high beta (21–40 Hz). We use standard 9-mm tin cups ear electrodes. All recordings and sessions were carried out by one of three trained technicians in the property room provided by the Newaygo County Sheriff's Department (NCSD).

LNFB training sessions were composed of six 5-min rounds and were conducted five times per week for 20 consecutive weekdays. For each session, we collected ~3-min presession eyes-opened baselines. Each session required ~50 min to complete. In the preliminary session, the participants were instructed to control tongue and eye movements, blinks, and muscle activity in forehead, neck, and jaws. This enabled the subjects to minimize the production of extracranial artifacts in electromyography (EMG), electro-oculogram (EOG), etc., during the sessions. During the preliminary session, shaping was induced to set thresholds such that each participant could meet the reward criteria (e.g., generate the desired response at a minimal rate), and participants were informed of the inhibitory and reward aspects of the training. Standardized thresholds were then set and maintained for each participant. Participants were able to choose from a selection of 25 games for the sessions. The participants were provided visual and auditory feedback and points were achieved when they were able to simultaneously increase alpha CSD (8–13 Hz) at the ROT, while minimizing EMG (35–55 Hz) and EOG (1–3 Hz) in linear combinations of channels (EMG: T3, T4, T5, T6, O1, and O2; EOG: FP1, FP2, F3, F4, F7, and F8). These criteria had to be maintained for 0.75 s to achieve 1 point. The auditory stimuli provided positive reinforcement with a pleasant tone when the criteria were met. Similarly, the visual stimuli were activated when the criteria were met (e.g., a car or a spaceship driving faster and straighter). Alternatively, slower speed of the car, driving in the wrong lane, or the spaceship flying slowly and crooked were seen when the criteria were not met (Deymed Diagnostics). The score for meeting the criteria was also seen by the participants in a small window of the game screen. Additionally, the visual stimuli contained a signal for reward and inhibits relative to a threshold level, and a bar graph illustrating reward, EOG, and EMG. After completing at least 10 sessions without missing, inmates were permitted to use DVD movies for the A/V feedback mechanism. The DVD covaries with the inhibit and reward features by the sound diminishing or the screen being blurred or noise added when the criteria are not met.

In contrast with studies utilizing traditional neurofeedback, the whole-head EEG data with 19 electrodes were continuously stored during the sessions. In addition, the participants in this study were encouraged to keep a written journal of sleep patterns, mood, and overall cognitive and attention processes, and to note specifically any odd occurrences. EEG data for all participants were analyzed at premeasures and across each session with NeuroGuide (Applied Neuroscience, Tampa, FL) and contrasted to normative samples in the Lifespan database. NeuroGuide employs automatic artifact identification procedures that were utilized for gross artifact contamination, then EEG data were converted to Lexicor format and edited with Eureka3 software by Nova Tech EEG (Mesa, Arizona). All EEG data were processed with particular attention given to the frontal and temporal leads. All episodic blinks, eye movements, teeth clenching, jaw tension, body movements, and possible electrocardiogram (EKG) were removed from the EEG stream by visual inspection. Fourier cross-spectral matrices were computed and averaged over 75% overlapping 4-s artifact-free epochs, which resulted in one cross-spectral matrix for each subject and each discrete frequency. These cross-spectral matrices constitute the input for LORETA estimation in the frequency domain. The common average reference was computed by the Eureka3 software prior to the standardized LORETA (sLORETA) computations.

We utilized IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY) to analyze the obtained data. First, we utilized a repeated measures analysis of variance (ANOVA) to contrast the obtained scores for the PAI pre- and post-LNFB training. Secondly, we utilized paired *t*-tests to contrast each scale of the PAI using within-subjects comparisons. Independent *t*-tests were conducted to evaluate potential differences on the SPESA and PAI between males and females in this study. This analysis was prompted by a substantial body of research indicating that females with SUD often present with higher levels of psychological distress, including anxiety, depression, and trauma-related symptoms, compared to their male counterparts (Greenfield et al., 2007; Najavits et al., 2010). We utilized chi-square tests for goodness-of-fit to determine whether observed group differences significantly deviated from expected proportions for SPESA demographic data. These data were coded in binary form, with expected proportions based on an equal probability model (i.e., 50/50 distribution), given the absence of prior empirical benchmarks for these variables.

Finally, records were analyzed for repeat arrests after LNFB for the total number of completed participants and rearrest for any cause (e.g., probation, fine payments, etc.) and the number of drug or alcohol-related rearrest using binomial chi-square analyses. The inmate rearrests are monitored by the NCC administration and reported to NCMH directors. These data are monitored and consist of all participants who completed the protocol and have been released over the course of the last ~6 years. If the inmate is rearrested, the data are codified for further statistical procedures; for example, 0 = *probation violation*, *difficulty paying fines* and 1 = *drug use (relapse) and associated legal violations*. The sLORETA analyses were conducted with the statistical parametric mapping (SPM) software within the sLORETA software. These statistical contrasts are used to assess neural activity differences between post- and prebaseline EEG recordings under eyes-open conditions. In the sLORETA, control of the familywise error (FWE) rate is achieved by performing 5,000 data randomizations. This approach, a nonparametric permutation test, with a subject wise control helps manage the risk of Type I errors (false positives) by establishing an empirical distribution against which actual data is compared. By using 5,000 randomizations, sLORETA provides a robust means to test the significance of observed results, increasing confidence that findings are not due to chance while balancing the control of FWE across multiple comparisons.

Results

SPESA demographic and assessment data indicate that 27% of participants (17 individuals) had no prior treatment for SUD, while the remaining 73% reported undergoing at least one prior treatment for a substance abuse disorder. The mean number of prior treatments was 2.18 (*SD* = 2.64). A chi-square test for goodness-of-fit revealed a significant difference in the treatment history for this population of 63, $X^2(1, N = 63) = 38.00$, $p < .000$. There was not a significant difference on the SPESA total score between genders, although females scored more negatively, than males with female mean (−4.52), *SD* = 23.25 and males mean (−0.77), *SD* = 29.04; the contrast result showed $t(61) = -0.498$, $p = .620$. Interestingly, males scored higher than females on the PAI scales of somatic experiences with $t(61) = 2.33$, $p = .023$, health concerns $t(61) = 2.56$, *p* = .013, persecution with *t*(61) = 2.56, *p* = .037 and social detachment, *t*(61) = 2.10, *p* = .039.

Educational backgrounds varied, with most individuals graduating high school; some reported leaving in the 10th or 11th grade, while others attended a university or community college. Nearly half of the participants (49%) reported experiencing abuse during childhood, adolescence, or both. A chi-square test for goodness-of-fit indicated that the observed proportion did not significantly differ from an expected proportion of 50%, $X^2(1, N = 63) = 0.016$. $p = .700$. Seventy-three percent of participants indicated that drug or alcohol use was present in the home throughout their developmental years. A chi-square test for goodness-of-fit revealed a significant difference from the expected proportion of 50%, $X^2(1, N = 63) = 13.34$, $p < .001$. Thirty-six percent of participants reported a prior psychiatric diagnosis in childhood or adolescence with associated medication use. A chi-square test for goodness-of-fit indicated a significant difference from the expected proportion of 50%, $X^2(1, N = 63) = 5.58$, $p = .032$. Fifty-five percent of participants noted the presence of violence in their home environments during development. A chi-square test for goodness-of-fit showed no significant difference from the expected proportion of 50%, $X^2(1, N = 63) = 0.778$, $p = .378$. Regarding substance preferences, 25% of participants identified alcohol as their primary substance, 19% cited opiates, and 55% reported methamphetamine. A chi-square test for goodness-of-fit revealed a significant difference in the distribution of primary substances, $X^2(2, N = 63) = 14.38$, $p < .001$. Notably, approximately 85% of the participants reported experiencing traumatic head injury that was not addressed medically with potential postconcussive effects; these incidents included motor vehicle accidents, high school sports injuries, domestic violence, general fighting, and falls. These differential aspects of traumatic head injuries and application of neurofeedback have been discussed in research data (Gupta, et al., 2020).

Figure 1 shows the plots for visualization of pre- and posttraining contrasts for PAI scales, in the figure the *x*-axis shows the scales for the PAI and the *y*-axis shows the *t*-values for the scales, with significant decreases across nearly all scales except for grandiosity and verbal aggression. Using a repeated measures ANOVA with Greenhouse-Geiser correction, significant effects were observed, $F(1, 30) = 176.20$, $p < .000$, partial $\eta^2 = .85$, with observed power at 1.00, indicating sufficient sample power to detect effects. Table 1 shows the corresponding values for the paired comparisons for the graph in Figure 1. The scales not showing significant decrease at posttraining were grandiosity and verbal aggression.

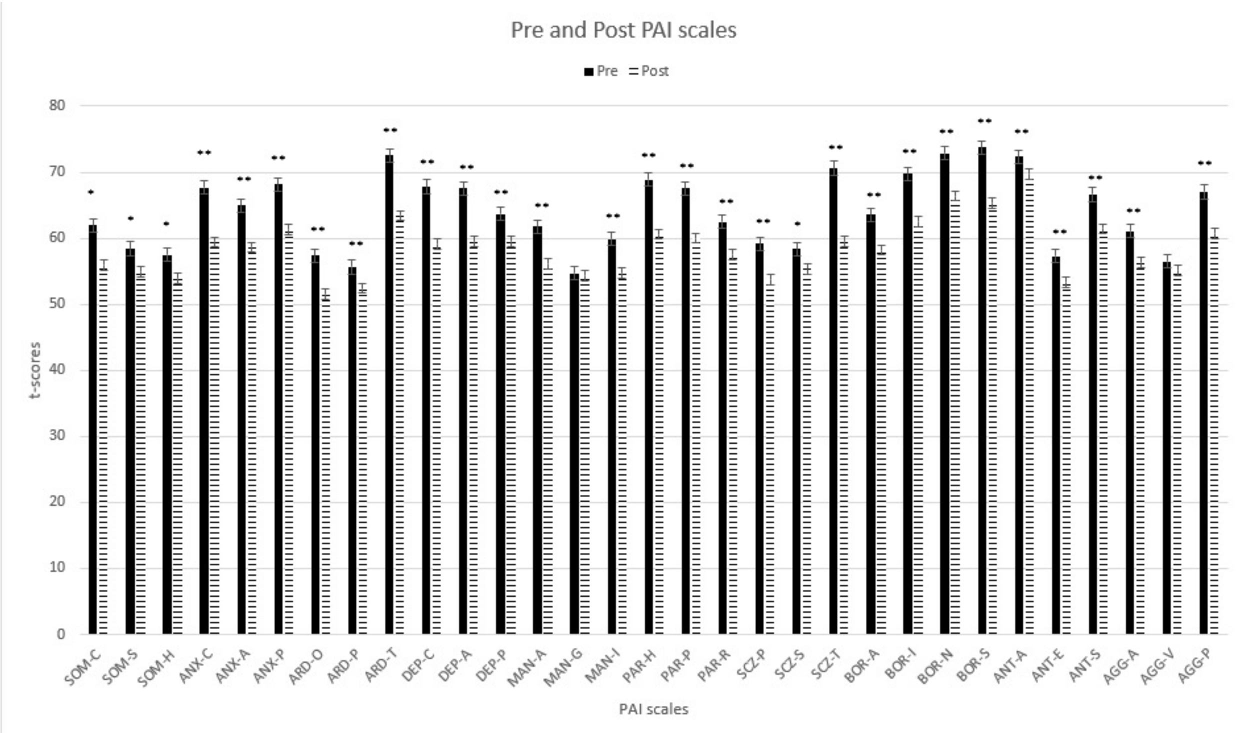
Table 2 shows the results for the sLORETA post > pre-EOB contrast results. In the table from left to right are the frequency in terms of CSD, BA and hemisphere (right, left, or middle), neuroanatomical label, *t*-value for the result and the probability of the *t*-value. The data illustrate notable changes in activity within the medial frontal gyrus (delta), inferior frontal gyrus (theta), anterior cingulate gyrus (alpha-1), paracentral lobule (alpha-2), postcentral gyrus (beta-1), and lingual gyrus (high-beta). Among these, the strongest effects were observed in beta-1 and high-beta frequencies, with *p*-values indicating statistical significance at $p < .01$. Below each set of images for each frequency, the scales for the results of exceedance proportions based on sLORETA parameters are shown. A nonparametric analysis was performed on binomial data to assess rearrest rates for any reason and specifically for substance-related rearrest postrelease. Among the 63 participants, 47 (74.6%) had not been rearrested for any reason, yielding a chi-square of 15.25 ($p < .000$). Additionally, 52 (82.5%) had not been rearrested due to substance use, with a chi-square of 26.68 ($p < .000$). These chi-square results indicate that such rates are unlikely due to chance.

Table 1
Paired Samples Test Results Corresponding to Figure 1, Pre- and Post-PAI Results

Pair		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
1	SOMC1–SOCM2	6.01613	19.99466	2.53932	0.93843	11.09382	2.369	61	.021
2	SOMS1–SOMS2	3.53226	8.87013	1.12651	1.27967	5.78485	3.136	61	.003
3	SOMH1–SOMH2	3.51613	7.70085	0.97801	1.56048	5.47178	3.595	61	.001
4	ANXC1–ANXC2	8.24194	11.54987	1.46684	5.30882	11.17505	5.619	61	.000
5	ANXA1–ANXA2	6.33871	10.18025	1.29289	3.75341	8.92401	4.903	61	.000
6	ANXP1–ANXP2	6.88710	11.01133	1.39844	4.09074	9.68345	4.925	61	.000
7	ARDO1–ARDO2	5.77419	9.03984	1.14806	3.47850	8.06988	5.030	61	.000
8	ARDP1–ARDP2	3.22581	8.51887	1.08190	1.06242	5.38919	2.982	61	.004
9	ARDT1–ARDT2	9.11290	9.87148	1.25368	6.60602	11.61979	7.269	61	.000
10	DEPC1–DEPC2	8.62903	10.63744	1.35096	5.92763	11.33044	6.387	61	.000
11	DEPA1–DEPA2	7.98387	11.91843	1.51364	4.95716	11.01058	5.275	61	.000
12	DEPP1–DEPP2	4.17742	9.44271	1.19923	1.77942	6.57542	3.483	61	.001
13	MAN1A–MANA2	5.61290	11.19185	1.42137	2.77071	8.45510	3.949	61	.000
14	MANG1–MANG2	0.35484	8.68973	1.10360	−1.85194	2.56162	0.322	61	.749
15	MANI1–MANI2	5.16129	10.55383	1.34034	2.48112	7.84146	3.851	61	.000
16	PARH1–PARH2	8.22581	12.14586	1.54253	5.14134	11.31028	5.333	61	.000
17	PARP1–PARP2	7.50000	10.34765	1.31415	4.87219	10.12781	5.707	61	.000
18	PARR1–PARR2	4.95161	9.97279	1.26655	2.41900	7.48423	3.910	61	.000
19	SCZP1–SCZP2	5.43548	9.52240	1.20935	3.01725	7.85372	4.495	61	.000
20	SCZS1–SCZS2	2.93548	8.91650	1.13240	0.67112	5.19985	2.592	61	.012
21	SCZT1–SCZT2	11.12903	11.61187	1.47471	8.18017	14.07790	7.547	61	.000
22	BORA1–BORA2	5.35484	10.55524	1.34052	2.67431	8.03537	3.995	61	.000
23	BORI1–BORI2	7.27419	10.88715	1.38267	4.50937	10.03901	5.261	61	.000
24	BORN1–BORN2	6.45161	10.38548	1.31896	3.81419	9.08903	4.891	61	.000
25	BORS1–BORS2	8.38710	14.02498	1.78117	4.82542	11.94878	4.709	61	.000
26	ANTA1–ANTA2	2.67742	8.08312	1.02656	0.62469	4.73015	2.608	61	.011
27	ANTE1–ANTE2	3.95161	11.13174	1.41373	1.12468	6.77855	2.795	61	.007
28	ANTS1–ANTS2	5.20968	12.67259	1.60942	1.99144	8.42791	3.237	61	.002
29	AGGA1–AGGA2	4.67742	9.61177	1.22070	2.23649	7.11835	3.832	61	.000
30	AGGV1–AGGV2	1.37097	9.19414	1.16766	−0.96391	3.70584	1.174	61	.245
31	AGGP1–AGGP2	6.35484	11.63248	1.47733	3.40074	9.30894	4.302	61	.000

Note. In the figure from left to right are the scales from the PAI being contrasted, the mean, standard deviation, standard error for the mean, 95% confidence intervals, t-value, degrees of freedom and probability for obtained t-value. The scales showing no significant changes were grandiosity and verbal aggression.

Figure 1. *Pre- and Post-PAI Results.*



* Represents significant differences between pre and post with α < .05 and ** represents significant differences with α < .01. The scales showing no difference are grandiosity (MAN-G) and verbal aggression (AGG-V).

Table 2
The Corresponding sLORETA Images for Paired Contrasts, Displaying Standard MRI-Based Horizontal, Sagittal, and Coronal Sections

Frequency	Brodmann Area	Neuroanatomical label	*t*	*p*
Delta	9M	Medial frontal gyrus	0.329	.001
Theta	47R	Inferior frontal gyrus	−0.608	.000
Alpha-1	32L	Anterior cingulate gyrus	2.72	.008
Alpha-2	31M	Paracentral lobule	2.60	.011
Beta-1	2L	Post central gyrus	−3.70	.000
High-beta	19L	Lingual gyrus	2.81	.006

Note. Images highlight the regions of maximum difference as identified in Figure 2. Each image includes the *x*, *y*, and *z* coordinates alongside the *t*-value for the respective paired contrast.

Figure 2. *Shows the sLORETA Images Corresponding to Table 2.*

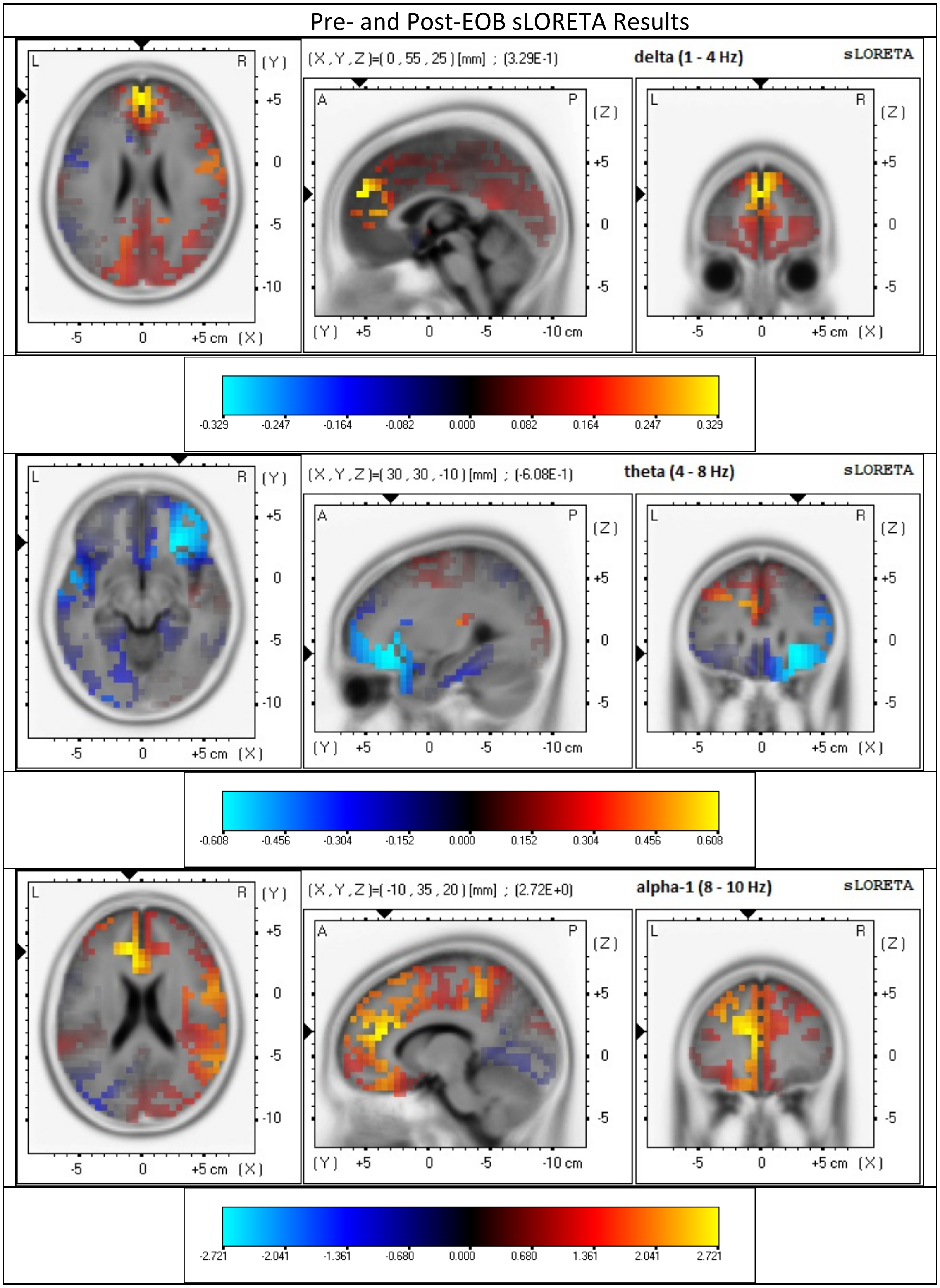
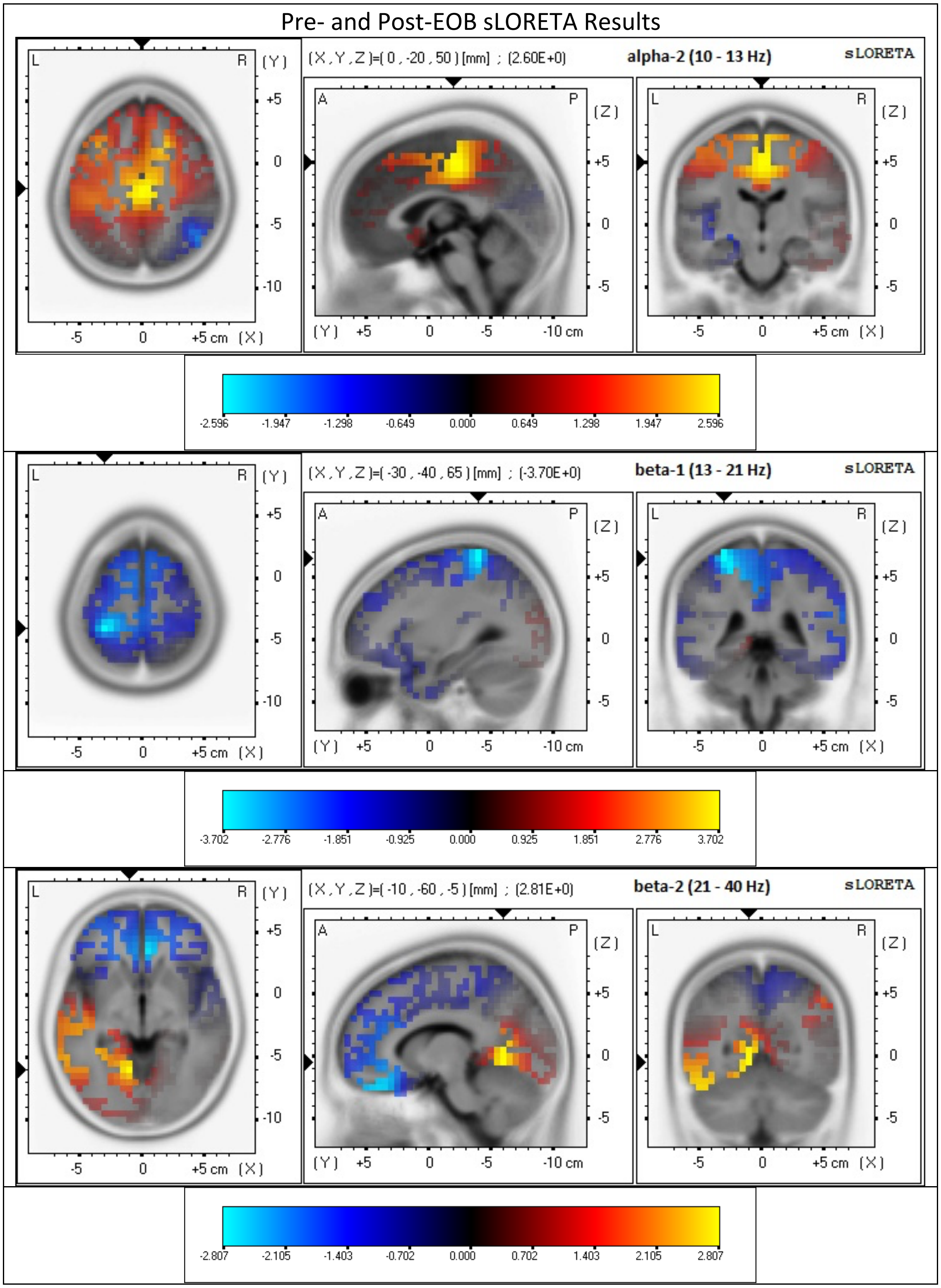


Figure 2. *Shows the sLORETA Images Corresponding to Table 2.*



Note. In the images there is a horizontal, sagittal and coronal view of the brain with CSD amplitude results shown in the images. In the top of each image are the *x*, *y*, and *z* coordinate for the max difference, result of *t*-tests and frequency bin.

Discussion

This case grouping offers support for the potential of a standardized LNFB protocol targeting the left parietal precuneus in aiding inmates with SUD in achieving better self-regulation and potentially reducing rearrest rates. The LNFB showed significant reductions in various PAI scales, suggesting improvements in self-regulation skills and reductions in internal strife and distress. Neurofeedback protocols targeting the precuneus—implicated in self-regulation and awareness—align with studies showing neural adjustments that correspond to behavioral improvements (Cannon, 2014; Cannon et al., 2014).

Among the 63 participants, 74.6% had not been rearrested for any reason. Additionally, 82.5% had not been rearrested due to substance use. The follow-up period for these data spans from the study onset in 2020 to present (approximately 5 years), with rearrest risk accumulating over time unless a participant is rearrested for any reason. A further distinction was made between relapse-related and nonrelapse-related arrests, with some participants being rearrested for probation violations such as difficulty paying fines rather than substance use relapse. Prior research indicates that recidivism rates among individuals with SUD are typically high. For example, national data show that within 3 years of release, approximately 68% of drug-involved offenders are rearrested (Chandler et al., 2009). Other studies report that over 50% of individuals with a history of substance dependence are rearrested within 6 months postrelease. In comparison, the significantly lower rearrest rates observed in this study suggest a potential positive impact of neurofeedback (NFB) on postrelease outcomes, though further research is needed to determine the extent to which these differences persist over longer periods and across larger samples.

The observed increase in delta CSD within medial frontal, right temporal, and posterior medial regions emphasizes these areas' involvement in key processes associated with self-regulation and stress management. Medial frontal regions, part of the DMN, are linked to self-reflective thought, internal language processing, and attentional control (Gusnard et al., 2001; Raichle, 2015; Raichle et al., 2001; Sheline et al., 2009). Right temporal involvement aligns with sensory processing of environmental cues and emotional regulation (Schilbach, Eickhoff, Mojzisch, et al., 2008; Schilbach, Eickhoff, Rotarska-Jagiela, et al., 2008). The posterior medial regions, meanwhile, participate in stress modulation and metabolic control, supporting adaptive responses to internal and external stimuli (Shannon & Buckner, 2004; Vincent et al., 2010).

The observed decrease in theta CSD within the right inferior BA 47, alongside lesser reductions in the orbitofrontal, left temporal, and posterior regions, suggests a shift in regions responsible for emotional regulation and inhibition control. Right BA 47, within the orbitofrontal cortex, plays a role in decision-making and impulse control, which can be essential in modulating emotional responses and evaluating consequences (Rolls, 2021; Rolls et al., 1994). Decreases in theta activity here may also reflect altered connectivity with networks supporting attention and goal-directed behavior (Knyazev & Slobodskoy-Plusnin, 2009; Knyazev et al., 2009). These changes may impact emotional regulation and inhibitory control, which are often targets in substance use treatment.

Alpha-1 (8–10 Hz) showed significant increase at left and medial BA 24 and 32 with lesser increases in right temporal regions at insular cortex and parietal regions associated with sensory and interoceptive processes. This increase in alpha-1 CSD (8–10 Hz) at anterior cingulate, as well as in the insular and parietal regions, aligns with enhanced self-regulation, emotional awareness, and interoceptive processes. These regions are thought to be highly involved in attentional control, error monitoring, and emotion regulation (Devinsky et al., 1995). The insular cortex supports interoceptive awareness, influencing emotional and sensory experiences, while parietal areas contribute to spatial and sensory processing, integrating body and environmental awareness (Craig, 2009a, 2009b, 2011a, 2011b).

The increase in alpha-2 (10–13 Hz) activity in BA 31, particularly in the medial posterior and paracentral lobule, suggests a heightened level of brain activity in areas associated with sensory integration, attention, and some aspects of self-regulation. BA 31, part of the posterior cingulate cortex (PCC), plays a role in the DMN, which is involved in introspection, memory, and the integration of sensory information. The lesser increase observed across the cingulate cortex, as well as in bilateral temporal and frontal regions, may indicate a more subtle modulation of higher cognitive functions, including emotional regulation, decision-making, and attention, which are associated with these areas (Craig, 2002, 2009b; Devinsky et al., 1995). This kind of shift in alpha-2 power could suggest an enhancement in the ability to manage cognitive and emotional processes, potentially leading to improvements in focus, self-regulation, and even mood stabilization, especially when considered in the context of neurofeedback training or therapeutic interventions for substance abuse and inmates with SUD. Recent neurofeedback studies have shown significant alterations in brainwave activity in specific regions, with beta-1 (13–21 Hz) activity being particularly notable in methamphetamine use (Nooripour, et al., 2021) in the context of inmate recovery programs (Fielenbach, et al., 2018). For example, the Neurofeedback Recidivism Reduction Project, a collaboration between Community Solutions, Inc. (CSI) and the Wuttke Institute for Neurotherapy, assesses whether neurofeedback can significantly reduce recidivism among formerly incarcerated individuals (Wuttke Institute, 2021). Similarly, the Santa Barbara County Probation Department implemented a Neurofeedback Recidivism Reduction Project targeting inmates assessed as high-risk to reoffend, combining neurofeedback interventions with standard treatment programs to evaluate their efficacy in reducing recidivism (Santa Barbara County Probation Department, 2021). These initiatives highlight the potential of neurofeedback, particularly in modulating beta-1 activity, as a promising tool in inmate recovery and recidivism reduction efforts.

This study specifically observed a significant decrease in beta-1 activity at BA 2 and surrounding sensory regions, with lesser decreases noted in the frontal, temporal, and right parietal regions. These findings provide important insights into how modulating beta-1 activity could influence sensory processing, cognitive functions, and emotional regulation during recovery from addiction. BA 2, located in the primary somatosensory cortex, plays a critical role in processing tactile information from the body. The observed decrease in beta-1 activity in this region may indicate a reduction in the processing of sensory input or a calming effect on hyperactive sensory systems. Such modulation could lead to enhanced sensory integration or a reduction in heightened sensory sensitivity, which is often observed in individuals with anxiety, stress, or overactive responses to stimuli (Lubar, 1997). In the context of recovery, this could promote greater emotional regulation and a less reactive state, which is beneficial for individuals in early recovery phases. While beta-1 activity in frontal regions (involved in executive functions like decision-making and cognitive control) and temporal regions (which are associated with memory and emotional processing) showed lesser reductions, the observed changes still suggest a modulation of cognitive and emotional processes associated with numerous functions and the DMN (Buckner, 2012; Buckner et al., 2008; Burton et al., 2004; Gusnard et al., 2001; Raichle, 2015; Raichle & Snyder, 2007). A subtle decrease in beta-1 activity in these areas might indicate an enhancement of focus and cognitive flexibility—key elements for individuals in recovery who need to regulate emotions and make better decisions. Moreover, these reductions could point to improved attention and memory functions, critical for successful reintegration into society (Sterman, 2000). Similarly, the right parietal regions, involved in spatial processing and attention, showed a lesser decrease in beta-1, suggesting that the neurofeedback protocol had a selective impact on cognitive control and attention systems. This may indicate a more modulated focus in spatial awareness and sensory processing, allowing for a reduction in cognitive overload or distractions, which can be particularly helpful for individuals who are recovering from the effects of addiction (Gadea et al., 2020). The overall decrease in beta-1 activity across these brain regions suggests a calming effect on overactive brain networks and a shift towards more integrated and efficient brain function. These changes could be particularly beneficial for inmates in recovery, as they may facilitate improved emotional regulation by reducing sensory overload and enhancing the brain's ability to filter out irrelevant stimuli. Better decision-making by enhancing the ability to control impulsive behavior, a crucial factor in reducing recidivism and promoting sustained recovery. Enhanced attention and cognitive flexibility, which could lead to improved engagement in therapeutic activities, social interactions, and reintegration into society (Scott et al., 2005). The neurofeedback-induced decrease in beta-1 activity in sensory and cognitive regions offers promising evidence that neurofeedback can help regulate brain activity related to addiction and recovery. The findings suggest that modulating beta-1 rhythms can enhance sensory processing, emotional regulation, and cognitive control, all of which are critical for successful recovery and reducing recidivism in inmate populations. In addition to the lingual gyrus, beta-2 increases were also noted in temporal, parietal, and parahippocampal regions. These areas are involved in memory, spatial navigation, and emotional processing.

The modulation of beta-2 in these regions may suggest an enhanced ability to process and store emotional or environmental memories, which could facilitate more adaptive responses to stressors or triggers in recovery. Temporal regions are important for auditory processing and long-term memory, and the increases could be associated with enhanced recall of emotional or autobiographical events, possibly aiding in self-reflection and learning from past experiences. Parietal regions are important to spatial attention and sensory integration, and noted increases could enhance the integration of sensory information with cognitive processes, potentially improving attention span and focus (Gevensleben et al., 2014). The parahippocampal region plays a key role in memory encoding and retrieval, particularly in the context of emotional memories and spatial navigation and increases in higher ranges of beta activity here may improve the ability to manage and interpret stressful situations, by enhancing the processing of memories that are contextually linked to emotional regulation and coping strategies (Buckner et al., 2008).

The results for the analyses of postrelease rearrest rates showed a postrelease nonrearrest rate of 74.6% and a nonsubstance-related rearrest rate of 82.5%measured from the time of initial arrest and after release from the jail. The program has been in progress since summer of 2020 indicating significant effects for LNFB program, surpassing those seen with traditional therapies such as CBT in correctional settings. This aligns with research demonstrating that neurofeedback can reduce SUD-associated impulsivity and relapse in various populations (Scott et al., 2005). Meta-analyses often show mixed results due to protocol inconsistencies and small sample sizes, highlighting the need for standardized protocols (Thibault & Raz, 2017). Further replication of these methods, especially within diverse and larger samples, could reinforce neurofeedback's role in reducing recidivism and enhancing rehabilitation outcomes. The findings demonstrate significant differences in activity across multiple brain regions and frequency domains, highlighting the importance of targeted neurofeedback interventions. Changes in the anterior cingulate gyrus, paracentral lobule, and lingual gyrus emphasize the potential for neurofeedback to modulate activity in areas associated with emotional regulation, sensory integration, and cognitive and emotional processing.

The left precuneus, located in BA 7 and ventral portions of BA 19, plays a critical role in self-referential processing, episodic memory retrieval, and the DMN. Research has demonstrated its involvement in psychological distress, including depression and anxiety, where hyperconnectivity or dysregulation of the DMN has been observed (Cavanna & Trimble, 2006). Additionally, the precuneus is vital for integrating memory and emotional experiences, which are frequently disrupted in populations with SUD and histories of trauma, as seen in inmate populations (Castellanos et al., 2008; Cavanna, 2007; Cavanna & Trimble, 2006; Cunningham et al., 2017; Dadario & Sughrue, 2023; Feldstein Ewing & Chung, 2019; Flanagin et al., 2023; Fomina et al., 2016).

Anecdotal reports from the jail administration suggest that younger individuals with a history of SUD exhibit a higher likelihood of relapse and rearrest compared to inmates aged 30 or older in this study. This pattern aligns with existing research indicating that younger populations with SUD face unique challenges, including heightened impulsivity, incomplete neural development in areas associated with decision-making and self-regulation (e.g., the prefrontal cortex), and limited exposure to sustained recovery environments. These factors contribute to higher rates of recidivism and treatment dropout among younger individuals. Studies have also shown that younger adults often encounter barriers to effective intervention, such as a lack of age-appropriate treatment programs and the influence of peer networks that reinforce substance use behaviors (Belenko et al., 2013; Fox et al., 2008; Sinha, 2008). Furthermore, the neurodevelopmental vulnerability of younger individuals may exacerbate difficulties in managing cravings and adopting long-term coping strategies, underscoring the need for tailored interventions that address age-specific risk factors. These findings highlight the importance of integrating neurofeedback and other evidence-based treatments aimed at improving self-regulation and resilience in younger inmates, with an emphasis on early and targeted interventions to mitigate the cycle of relapse and rearrest.

The left precuneus as a standard approach to target specific neurofeedback is particularly relevant in these contexts due to its dual role in cognitive and emotional regulation. Interventions targeting this region via neurofeedback could further validate and replicate the findings especially concerning SUD with inmates and facilitate improvements in emotional regulation, episodic memory, traumatic stress, self-awareness, and self-regulation by addressing DMN and system wide dysregulation; training in this area could reduce psychological distress, a significant barrier to recovery in SUD (B. Zhang et al., 2021; L. Zhang et al., 2019; R. Zhang et al., 2020; S. Zhang & Li, 2010). Given its central role in these processes, further research is warranted to explore the effectiveness of left precuneus training across SUD populations. Studies focusing on inmates could evaluate its impact on psychological well-being, recidivism rates, and rehabilitation, as well as treatment compliance. Similarly, SUD treatment settings may benefit from integrating precuneus-focused neurofeedback or traditional neurofeedback to address the neurophysiological, arousal, emotional, and cognitive characteristics of this population.

Individuals with SUD face a wide range of pervasive challenges that extend beyond physical dependence on substances, affecting nearly every aspect of their lives. These problems often include difficulties in maintaining stable employment, financial instability, disruption of familial structures, loss of social and intimate relationships, and impaired abilities to form social support networks and self-regulation skills. SUD is strongly associated with disrupted employment histories and financial insecurity. Substance use often leads to job loss, reduced workplace productivity, and barriers to reentry into the labor force due to stigma and criminal records (Volkow et al., 2016). Financial problems can be exacerbated by the high costs associated with substance use and treatment, as well as by difficulties in accessing resources needed for financial recovery, such as housing or education assistance (Brucker, 2007; Dunigan et al., 2014; Gomez et al., 2014; Sherba et al., 2018; Zuvekas & Hill, 2000). Family structures are frequently strained in SUD populations, with substance use contributing to neglect, conflict, and breakdowns in trust (McCrady, 2013; Owens et al., 2013). Parents struggling with SUD often face the added burden of child welfare interventions, while children in these families may experience long-term developmental and emotional consequences. Social and intimate relationships are similarly affected, as substance use impairs communication, erodes trust, and contributes to isolation and alienation from supportive networks. One of the hallmarks of SUD populations is difficulty establishing and maintaining effective social support systems. Social networks often become dominated by relationships centered around substance use, leaving individuals with fewer prosocial connections (Kaskutas, 1998b; Kaskutas et al., 2002). The loss of healthy relationships and the stigma surrounding SUD further complicate efforts to reintegrate into supportive social environments, making recovery more challenging. Deficits in self-regulation are central to SUD, with individuals experiencing difficulties in managing impulses, emotions, and stress. These impairments are linked to both neurobiological changes, particularly in the prefrontal cortex, and the behavioral patterns reinforced during substance use (Sinha, 2008, 2009). Poor self-regulation skills not only contribute to relapse but also hinder individuals' ability to engage in therapy, maintain healthy routines, and rebuild their lives posttreatment or postincarceration. Addressing these challenges requires comprehensive, multidimensional interventions that go beyond substance cessation to include vocational training, financial counseling, family therapy, and skills-based approaches to self-regulation and social reintegration. Programs that incorporate evidence-based practices such as CBT, neurofeedback, and peer support groups have shown promise in mitigating these challenges and supporting long-term recovery (Kaskutas, 1998a, 1998b; Kaskutas et al., 2002; McCrady, 2013). Although the current study did not find significant differences between genders on the SPESA and most scales of the PAI, this lack of difference may reflect the limited number of female participants or the influence of the correctional environment, which may impose similar stressors across genders. Future research should aim to further investigate these gender-based differences with larger, more balanced samples and explore how gender-specific interventions might better address the unique psychological needs of female inmates with SUD.

This study has several limitations that should be considered when interpreting the findings. First, the sample was heterogeneous in terms of drugs of choice and comorbid conditions, which may introduce variability in training outcomes. A more homogeneous sample could provide clearer insights into the effects of the neurofeedback protocol on specific subgroups within the population. The sample size, though sufficient to identify statistically significant effects, could benefit from being larger to enhance the generalizability of the results. Additionally, the sample included a limited number of female participants, which restricts the applicability of the findings to female inmates with SUD. Greater representation of diverse populations, including varying ethnicities and cultural backgrounds, would also improve the study's relevance to broader SUD populations. Another limitation was the inability to control variability in the types of psychiatric medications that inmates may have been taking during the study. These medications could have influenced neurofeedback outcomes, adding a confounding variable that complicates the interpretation of results. Future studies should aim to standardize or account for psychiatric medication use to isolate the effects of neurofeedback interventions more clearly. Addressing these limitations in subsequent research will strengthen the validity and applicability of findings, paving the way for more targeted and effective interventions. Recidivism in this study is defined as rearrest, recognizing that for many individuals with SUD, prior incarceration patterns resembled a revolving door. Before participating in NFB, many individuals cycled in and out of the system, with shorter periods of incarceration escalating into longer sentences or more serious offenses, such as possession, theft, or other felony convictions, underscoring the strong association between SUD and repeated criminal justice involvement.

The study's logic follows guidance from well-established research indicating that SUD prevalence is disproportionately high among incarcerated populations (NIDA, 2020a), and among those with SUD, criminal recidivism rates remain elevated due to a combination of substance-seeking behaviors, impaired decision-making, and socioenvironmental risk factors (Chandler et al., 2009). While LNFB is hypothesized to enhance self-regulation and reduce relapse risk, thereby mitigating one of the primary drivers of rearrest, we acknowledge that direct data linking ongoing substance use or relapse to criminal recidivism were not explicitly presented in the current analysis. To strengthen this link, future research should incorporate longitudinal tracking of substance use relapse postrelease and examine its relationship with rearrest rates. Additionally, integrating urine toxicology screenings or self-reported substance use data with criminal records could provide a clearer picture of the extent to which NFB-induced self-regulation improvements translate into sustained reductions in both substance use and criminal behavior.

While rearrest rates were tracked, detailed information regarding substance use relapse postrelease was not gathered. This represents a limitation of the study, as understanding the relationship between neurofeedback interventions and substance use behaviors postincarceration is crucial for evaluating the full impact of the training. Future research should aim to include comprehensive postrelease follow-up assessments that monitor substance use patterns alongside recidivism. Such data would provide valuable insights into the effectiveness of neurofeedback in supporting sustained recovery and reducing the likelihood of reoffending.

This study's population is unique in that all participants were abstinent from substances at the time of the study, having been incarcerated long enough to ensure that any immediate or short-term effects of detoxification procedures were no longer present. The jail employs rigorous drug screening and monitoring protocols to minimize the risk of substance use among inmates, creating a controlled environment ideal for evaluating neurofeedback's effects on self-regulation and rehabilitation outcomes. This strict oversight reduces confounding factors typically associated with substance use, providing a clearer assessment of the intervention's impact within a stable population. The length of time between the conclusion of NFB training and release from jail varied among participants. While some individuals were released within days to weeks following the completion of the protocol, others had months to several months remaining on their sentences. To account for this variability and provide continued support, inmates with longer sentences were offered an additional 10 sessions of NFB upon request. This variation in posttraining incarceration duration may have influenced the degree to which participants were able to integrate and maintain self-regulation skills learned during neurofeedback, potentially impacting long-term outcomes. Future studies should consider tracking postrelease outcomes over an extended period and examining whether continued access to neurofeedback or other interventions in the correctional setting leads to greater stability and reduced recidivism.

These findings emphasize the urgent need for more integrative treatment models that incorporate neurofeedback as a core component in addressing SUD, particularly in populations with high relapse risks, such as incarcerated individuals. Standardized protocols, such as LNFB targeting the left precuneus, offer a promising avenue to enhance emotional regulation, self-awareness, and cognitive processing. The observed improvements in self-regulation and reduced internal distress underscore the potential of neurofeedback to address the complex neurobiological and behavioral challenges associated with SUD. However, to establish neurofeedback as a reliable and scalable intervention, replication of these findings across diverse populations and settings is essential. Reporting comprehensive outcomes, including psychological, neurobiological, and behavioral measures, will further validate this approach and guide its integration into broader therapeutic frameworks for SUD and rehabilitation. By advancing research in this area, and its benefit to clinicians within the treatment setting, we can pave the way for innovative interventions that reduce relapse rates, enhance quality of life, and promote lasting recovery.

Author Disclosure

Dr. Cannon is CEO of Currents and has proprietary interest in the procedures used in this study. He is also Editor-in-Chief of *NeuroRegulation*.

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