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Aim and Scope

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RESEARCH PAPERS

CLINICAL CORNER

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Strategic Self-Talk and Readiness Potential in Pistol Shooting: A Pilot Study on the Attentional Self-Talk Mechanism

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Abstract

Considerable evidence through self-reports and behavioral data suggests that the facilitating effects of strategic, instructional self-talk can be attributed to attentional mechanisms. Nonetheless, the psychophysiological underpinnings of such mechanisms have been scantly explored. The aim of this pilot study was to provide preliminary evidence regarding the attentional mechanism of instructional self-talk by analyzing the readiness potential during the motor planning phase of a pistol shooting task. A within-subject, noncontrolled design was used involving nine novice participants who completed five sessions. These included familiarization with the task and preintervention assessment, three training sessions, and postintervention assessment. The SCATT shooting system was used to record and assess shooting performance and aim stability. A 32-channel EEG cap was used for the acquisition and analysis of the readiness potential. The analysis showed a positive trend for performance improvement from pre- to postintervention assessment. In parallel, considerable in effect size amplitude changes in the readiness potential before movement initiation were observed. These preliminary findings provide indications that the effectiveness of strategic, instructional self-talk in pistol shooting may be partly attributed to the amplitude changes in the readiness potential, highlighting an attention-based mechanism that reflects a potential effortless neurocognitive preparation of action effect.

Keywords: instructional self-talk; attention; preparatory motor planning; psychophysiology; EEG; sport

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Introduction

There is substantial evidence supported through meta-analytic and systematic reviews indicating that self-talk strategies in sport are effective for enhancing performance and facilitating learning (Hatzigeorgiadis et al., 2011; Tod et al., 2011). However, the varying effects observed in different sport settings and populations have forwarded the need to investigate the mechanisms underlying its effectiveness. Researchers exploring the effectiveness of self-talk have predominantly delved into two broad clusters of mechanisms, an attentional and a motivational (Galanis & Hatzigeorgiadis, 2020). Regarding the attentional mechanism, recent literature has provided evidence that self-talk can improve the focus of attention (Bell & Hardy, 2009), reduce reaction times in cognitive attention tasks (Galanis, Hatzigeorgiadis, Comoutos et al., 2022), and enhance sport task performance under attention-hindering conditions such as external distractions (Galanis et al., 2018), ego depletion (Galanis, Nurkse et al., 2022), and physical exertion (Galanis, Hatzigeorgiadis, Charachousi et al., 2022). While these studies provide valuable evidence for the attentional interpretation of self-talk effectiveness, they have primarily relied on self-reports, behavioral measures, and indirect effects through performance measures.

The integration of psychophysiological indices into the self-talk mechanism literature will deepen our understanding of the actual processes underlying the attentional mechanism. In this context, Sarig et al. (2023) utilized an eye-tracker apparatus to demonstrate that instructional self-talk prolonged the quiet eye duration and enhanced performance in golf putting. Another recent study (Bellomo et al., 2020) employed electroencephalography (EEG) to provide initial evidence into the brain underpinnings of instructional self-talk. The researchers observed increased parietal alpha power and weaker connectivity between frontal and parietal electrodes compared to other scalp sites, which may suggest that instructional self-talk facilitates a top-down control of action. Furthermore, self-talk has been shown to improve performance in an elbow joint position sense test, while depicting efficient electromyography (EMG) activity (Naderirad et al., 2023). Researchers suggested that lowered muscle activity and a reduced muscle cocontraction ratio seems to be linked to improved attentional focus. Considering these psychophysiological research perspectives, our study attempted to investigate the brain activation during strategic, instructional self-talk through EEG in a pistol shooting task.

According to the hypothesis proposed by Hatfield and Kerick (2007), performance in self-paced fine motor tasks, such as shooting, requires attentional skills characterized by increased neural efficiency. This efficiency is manifested through reduced energy expenditure or mental effort in the motor planning phase of a movement. Further support for the neural efficiency hypothesis comes from event-related potential studies on shooting and self-paced trigger pull movements (Di Russo et al., 2005), indicating that experts exert less effort and require less time to plan the execution of a motor action. This allows them to allocate the appropriate amount of task-related attentional resources while eliminating irrelevant stimuli. Additionally, minimizing the impact of distractions has also been linked to improved shooting performance, as shown in Bahrami et al. (2020). Considering these findings, along with the evidence regarding the attentional impact of self-talk, there is ground to postulate that strategic, instructional self-talk might serve as an effective cognitive strategy to enhance neural efficiency.

The purpose of our study was to investigate how event-related potentials change in response to strategic, instructional self-talk, thereby advancing an attentional interpretation of self-talk effectiveness. Event-related potentials are defined as manifestation indicators of cortical activation that occur in preparation for or in response to specific events (Woodman, 2010). One example of an event-related potential is the movement-related cortical potential, which features a slow-rising negativity starting before movement execution, peaks during motor initiation, and is followed by a positive reafferent potential. In self-paced movements, the movement-related cortical potential includes the readiness potential, which reflects the activation of premotor brain regions prior to the movement onset (Shibasaki & Hallett, 2006). This readiness potential has been interpreted as a sign of planning and preparation (Schurger et al., 2021). It is derived by averaging multiple responses (e.g., trigger pulls) to enhance the signal-to-noise ratio. According to Wright et al. (2011), a reduced negative amplitude of the readiness potential, coupled with later onset latency, has been associated with lessened time and attentional resources required in motor programming.

In the present study, we examined the effects of strategic, instructional self-talk on shooting performance, aim stability, and brain activity that occur during the preparatory phase preceding the trigger pull in novice participants. Drawing on a previous study that involved a similar shooting task and self-talk training (Tzormpatzakis et al., 2022), we expected instructional self-talk would enhance both shooting performance and aim stability. Furthermore, we explored the impact of strategic, instructional self-talk on brain activity during the motor planning phase, although we did not establish a specific hypothesis due to the infancy stage in the area of self-talk research and the lack of relevant findings.

Methods

Participants and Procedures

Considering the lack of prior studies on the relationship between strategic self-talk and readiness potential, and the pilot character of this innovative study, ten participants were recruited based on sample sizes from previous studies exploring EEG with pistol shooting (Bertollo et al., 2012; Di Russo et al., 2005). Ultimately, nine (six male) sport science students (*M* age = 24.7, *SD* = 0.72) completed the study's requirements; one individual dropped out after the baseline measure due to illness. All participants were right-handed and had no prior experience with pistol shooting. The study was designed in accordance with the Declaration of Helsinki and was approved from the bioethics committee of the institution where the research took place (re: 23002). A within-group, noncontrolled design was implemented for this pilot study. Participants attended five laboratory sessions including familiarization with the protocol and preintervention assessment, three shooting training sessions incorporating self-talk, and a postintervention assessment. During the first session, participants were informed about the study's requirements and procedures and provided informed consent. Then, they were introduced to the pistol shooting task, received relevant instructions, and observed a demonstration of the shooting technique. Each participant practiced ten familiarization shots, during which they received technical feedback. Following this, the EEG cap was set up, and the preintervention assessment took place, where participants completed 40 air-pistol shots in two blocks of 20 shots, with a 5-min break in between each block. The same 40-shot protocol was repeated in the following three training sessions (without the EEG cap). In these sessions, participants were also introduced and practiced using instructional self-talk. During the first training session, the experimenter introduced the concept of self-talk, and participants performed the shots using an instructional self-talk cue for each set of shots ("front sight" and "grip"). In the second session, participants performed the shots by using two different self-talk cues ("soft pull" and "stability"). In the third training session, participants were asked to choose among the previously used self-talk cues the one they found most beneficial for their performance, which would be eventually used for the postintervention assessment. Finally, during the postintervention assessment, participants performed the set of 40 shots using the self-talk cue of their choice, while EEG and performance metrics were recorded.

Apparatus and Measures

***Air Pistol and Shooting Simulator*.** A Pardini K10 Air Pistol along with the SCATT system, a shooting training system (Precision Sport Electronics SRL, Bucuresti, Romania), were utilized in this experiment. SCATT includes an optical device attached to the air pistol, which continuously tracks the aiming point by emitting light towards the target, and a computer software that analyzes shooting performance. Each shot is recorded when the trigger is pulled while the aiming point is on the target, enabling the capture of successive shots. The software logs the trajectory of each shot throughout the aiming period, which can later be analyzed offline. The target diameter was set at 6 cm and the distance between the participant and the target was 10 m, in accordance to the international shooting competition rules (https://www.issf-sports.org /theissf/rules/english_rulebook.ashx).

Two performance variables were assessed: (a) shooting score which was calculated as the total of the 40 shots, with scores for each shot ranging from 0 to 10.9, and (b) stability of aim, measured in millimeters, with smaller distances between the average points of the tracing representing greater stability in a given time-interval preceding each shot.

***Electroencephalography (EEG)*.** The 32-channel waveguard original cap (Advanced Neuro Technology, Enschede, Netherlands) with shielded wires to minimize the impact of external interference was used. The placement of the 32 electrodes followed the 10–20 electrode system (Oostenveld & Praamstra, 2001). The EEG data were recorded on the ASAlab software (Advanced Neuro Technology, Enschede, Netherlands) and then analyzed using BrainVision Analyzer 2.2 (Brain Products, Germany). To accurately classify the moment of shot release in the raw EEG data recordings, an electronic microphone with a sampling frequency of 1024 Hz was used. The microphone operated with the Power lab 16/30 acquisition system (AD Instruments, Australia) and was synchronized with the ASAlab EEG software to record the trigger for each shot.

Data Analysis

The EEG signal was sampled at 1024 Hz, and each participant underwent a multistep preprocessing pipeline. Initially, the common average reference technique was applied to re-reference the signals. Next, filtering was conducted using a 50 Hz notch filter, with low-pass and high-pass cutoff frequencies set at 0.5 Hz and 35 Hz, respectively. To mitigate noisy channels, topographical interpolation was carried out, followed by independent component analysis (ICA) to eliminate ocular and movement artifacts. In the following step, the raw data were inspected to identify segments containing artifacts. Subsequently, the data were segmented into epochs lasting 2000 ms, starting from 1500 ms before the shot and ending at 500 ms after it. On average, 7% of shots were rejected due to artifacts criteria violations, resulting an average 93% of the shots being selected and used for signal averaging. The baseline for each epoch was calculated from −2000 to −1500 ms before movement onset. Finally, grand averaging was applied to assess the readiness potential across all participants for both the pre- and postassessments.

In the present study, a data-driven approach was endorsed to select specific electrode sites to be considered for the analysis, as there was no prior evidence to guide specific research hypotheses. Among the electrode sites around the premotor and the primary motor cortices depicting the readiness potential during the motor planning phase. FC1 and Cz were selected for analysis because notable activation differences were observed. The averaged amplitude for three 500 ms temporal windows related to the preshooting phase (−1500/−1000 ms, −1000/−500 ms, −500/0 ms) was selected for statistical analysis. Given the pilot nature of the study and the limited power to test for statistical significance, effect sizes (Cohen's *d*) were calculated to examine the within-subject trends from pre- to postintervention assessments for performance, shooting stability, and EEG across the three temporal windows.

Results

Shooting Performance and Stability

Descriptive statistics and effect sizes for changes in shooting performance and shooting stability are presented in Table 1. The results when comparing pre- to postintervention scores revealed a considerable positive effect for shooting performance (d = .43) and aim stability (d = .53). Differences between post- and preintervention scores were calculated and correlation analysis showed that changes in shooting scores were related to changes in aim stability (r = −.39).

Table 1

Descriptive Statistics and Effect Sizes for the Pre- and Postassessments

	Pre		Post		
	M	*SD*	*M*	*SD*	*d*
Shooting					
Shooting Score	141.34	107.19	192.06	67.40	.43
Aim Stability (mm)	89.74	47.49	80.37	21.03	.18
EEG (μV)*					
CZ 1500–1000	0.48	0.22	0.41	0.38	.21
FC1 1500–1000	0.09	0.37	0.07	0.23	.04
CZ 1000–500	0.01	0.58	−0.04	0.23	.07
FC1 1000–500	−0.18	0.32	−0.16	0.30	.06
CZ 500–000	−1.49	0.54	−1.18	0.49	.54
FC1 500–000	−0.79	0.62	−0.39	0.44	.49

* = EEG activity averaged for every 500 ms.

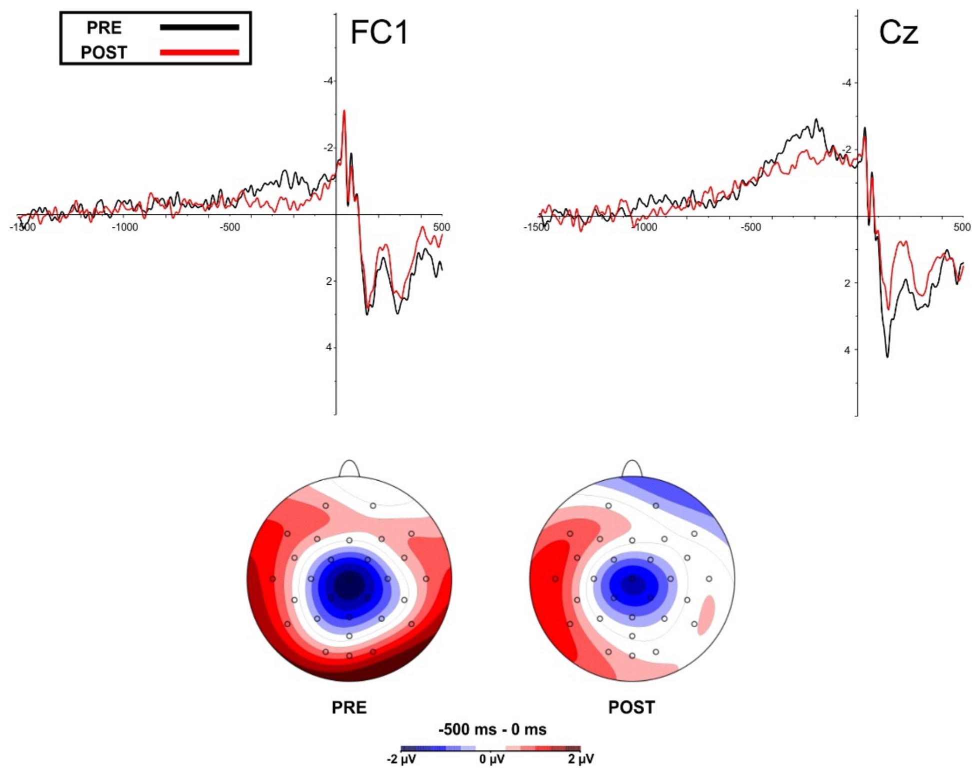
EEG

As depicted in Figure 1 (upper panel), the waveforms of both CZ and FC1 sites showed a similar decrease in negative amplitude during the first two time-windows (from −1500 ms to −1000 ms and from −1000 ms to −500 ms) when comparing the pre- and postintervention assessments. However, a different pattern emerged during the last temporal window preceding the pull of the trigger (from −500 ms to 0 ms). Indeed, during the last 500 ms prior to movement onset, both sites displayed a reduced negative amplitude in the post- compared to preintervention assessment. Furthermore, the topographic maps (Figure 1, lower panel) revealed a similar distribution of readiness potential in the assessments. Nonetheless, the motor-related negativity displayed in the postintervention map assessment was less negative than that of the preintervention map assessment.

Descriptive statistics and effect size of the changes observed from pre- to postintervention assessments are presented in Table 1. When comparing the average scores across the three selected temporal windows over Cz and FC1 sites, the effect sizes between pre- and postintervention assessments showed smaller effects for the −1500 ms to −1000 ms and from −1000 ms to −500 ms temporal windows (ranging from .04 to .21), compared to the effect sizes for the −500 to 0 ms temporal window, for both CZ and FC1 (d = .54 and .49 respectively).

Differences between post- and preintervention measures were calculated for the EEG variables. When examining the relationship between changes in shooting variables and changes in the readiness potential during the final time interval (−500 ms to 0), it was found that changes in CZ and FC1 were positively related to changes in aim stability (r = −.50 and r = −.53 respectively), but not with shooting performance (r = −.13, and r = .03 respectively).

Figure 1. *Topographic Maps.*



Note. Upper panel: Waveforms related to pretraining assessment in black and posttraining assessment in red over FC1 and Cz sites. Lower panel: Top-down view of the scalp topography over the −500/0 ms window for pre- and posttraining sessions.

Discussion

The investigation into self-talk mechanisms has primarily relied on behavioral and self-report measures. To advance our understanding of the mechanisms underpinning self-talk functioning, this pilot study adopted a psychophysiological perspective to explore potential associations between instructional self-talk and the motor planning phase in a pistol-shooting task. The results indicated a reduced negative amplitude in motor-related regions during the last 500 ms before shooting in the post- compared to the preintervention assessment. This finding suggests a reduction in resource allocation just prior to the movement onset, which may align with the neural efficiency hypothesis (Hatfield & Kerick, 2007).

Previous studies have examined amplitude changes of readiness potential in relation to learning progress and expertise levels. In particular, research focused on skill learning has shown that learning progress is linked to a reduced negative amplitude of the readiness potential on the frontal cortex (Fz electrode site) and the primary motor cortex (Cz electrode site). This reduction suggests that less cortical resources are required to plan actions (Lang et al., 1992, Niemann et al., 1991). Accordingly, in relation to the level of expertise, a study comparing expert and novice marksmen (Di Russo et al., 2005) showed that experts exhibited a reduced negative amplitude of the readiness potential along with a later onset of the activity over the primary motor cortex. Our findings seem to coincide with this body of evidence, suggesting that the learning progress, facilitated by self-talk, led to readiness potential amplitude changes, possibly suggesting greater neural efficiency.

Self-talk in sport literature has supported the attentional effects of strategic self-talk on facilitating learning and improving performance. In our study, participants showed a considerable improvement in shooting performance, a moderate effect in aim stability, and a reduced negative amplitude of the readiness potential (i.e., the later component from −500 ms to 0) located in the primary and premotor cortex areas. Taken together, the findings provide indications that participants' training, which included instructional self-talk, increased performance in a newly acquired skill through improved allocation of attention during the motor preparation phase and enhanced stability.

Considering that our study was a pilot, noncontrolled attempt to provide preliminary evidence regarding the links between instructional self-talk and changes in the readiness potential, the interpretation of the results should be cautious. Our participants were novices with no prior shooting experience; thus, performance effects may be attributed to the learning process. However, there is compelling evidence supporting the effectiveness of strategic self-talk in novel tasks (Hatzigeorgiadis et al., 2011). Moreover, the results of a study applying a similar self-talk protocol in a controlled trial involving pistol shooting with novices (Tzompratzakis et al., 2022), showed a large effect when comparing the improvement of the strategic self-talk group with that of the control group. The above evidence provides a window for postulating that in our study the performance improvement and, respectively, the changes in the readiness potential were at least partly due to the strategic self-talk intervention; still, as already acknowledged, the lack of a control group is a limitation.

Future research should employ more comprehensive controlled trials with novices to reinforce our proposed readiness potential interpretation of self-talk effectiveness. Moreover, research involving more experienced or expert participants will enable us to further validate our interpretation but also explore further hypotheses, such as processing efficiency in motor programming, based on psychophysiological data. Yet, we consider this preliminary evidence valuable, as the study is among the first attempting to map event-related potential correlates of strategic instructional self-talk; thus, opening new pathways, beyond indirect evidence and behavioral data, for the investigation of self-talk mechanisms, which will enhance our understanding of the links between self-verbalizations and the functioning of the brain.

Author Disclosure

The authors report there are no grant support, financial interest, or conflicts of interest to disclose.

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Auditory Processing and Neuroregulation in Misophonia: A Comparative Study of Behavioral Measures

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Abstract

Misophonia is a condition of intolerance to certain sounds which act as triggers. This study investigates auditory processing abilities using behavioral measures in normal-hearing individuals with and without misophonia. Thirty participants aged between 18 and 30 years were included. They were divided into two primary groups: 15 individuals diagnosed with misophonia and 15 controls. All of the participants underwent auditory processing tests such as masking level difference (MLD), dichotic consonant-vowel (DCV), and pitch pattern tests (PPT). From the analyzed data, individuals with misophonia showed significantly reduced scores in DCV and PPT. Also, there was no significant difference in the thresholds of MLD at 500 Hz. This study highlights that the reduced scores of DCV and PPT in individuals with misophonia could be attributed to poor auditory cortical processing compared to the control group.

Keywords: misophonia; masking level difference; auditory processing abilities; binaural integration

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Introduction

The term *misophonia* is derived from the Greek words *misos* (meaning hate) and *phónè* (meaning sound). It is defined as a disorder wherein individuals experience reduced tolerance to specific auditory stimuli independent of the stimuli's loudness (Jastreboff & Jastreboff, 2002; Swedo et al., 2022). These stimuli, termed *triggers*, evoke an unpleasant or distressing experience associated with strong negative physiological (e.g., increased muscle tension, increased heart beat rate, sweating), emotional (e.g., anger, disgust, irritation, and anxiety) and behavioral (e.g., avoidance, escaping, and even aggression through verbal or physical outburst in extreme cases) responses, which are unexpected for such acoustic stimuli from a typically normal-hearing individual without misophonia (Swedo et al., 2022). These triggers can be specific auditory, visual, or audiovisual inputs (Aazh et al., 2019; Danesh & Aazh, 2020; Daniels et al., 2020; Jastreboff & Jastreboff, 2003, 2014). Sounds produced by humans, such as breathing, chewing, lip-smacking, and swallowing can be aversive auditory triggers (Hansen et al., 2021). Other human sounds not directly related to the human body include clicking, rustling, and typing, which can also be auditory trigger sounds (Hansen et al., 2021; Jastreboff & Jastreboff, 2003). Studies on the prevalence of misophonia have been reported among college students and the general population across various countries. Western countries vary from 4.6% to 54% (Brennan et al., 2023; Dixon et al., 2024). In India, the prevalence ranges from 15% to 34% (Aryal & Prabhu 2022; Gowda & Prabhu, 2024; Patel et al., 2022; Sujeeth et al., 2023; Yadav et al., 2024). Several neuroimaging studies have reported misophonia to have an etiology related to abnormal neural anatomy and physiological interactions between neural structures (Eijsker et al., 2021; Kumar et al., 2017, 2021; Neacsiu et al., 2022; Schröder et al., 2015, 2019). Also, the development of neurophysiological and neuroaudiological models to explain the pathophysiological process of misophonia shows a neurological basis and associates misophonia features with the cortical areas (Aryal & Prabhu, 2023c; Jastreboff & Jastreboff, 2023).

Central auditory processing is the ability of an individual to process auditory information in the central auditory nervous system (CANS). Understanding the neuroanatomy and physiology of the CANS will help us interpret its underlying processes and deficits (Bellis, 2011; Chermak & Musiek, 1997; Task Force on Central Auditory Processing Consensus Development, 1996). Auditory processing encompasses temporal processing, binaural interaction, integration, fusion, separation, and closure (Bellis, 2011; Chermak & Musiek, 1997; Task Force on Central Auditory Processing Consensus Development, 1996). Binaural integration involves the ability to simultaneously process and repeat auditory stimuli presented to both ears (Bellis, 2011). Whereas, binaural interaction refers to the brain's ability to interpret and process sounds presented simultaneously to both ears. This process occurs at the CANS level, particularly within the brainstem, where auditory information from both ears is integrated and interpreted (Bellis, 2011). Auditory temporal processing refers to the brain's ability to perceive and interpret the temporal characteristics of sound (Bellis, 2011; Chermak & Musiek, 1997). Traditionally, binaural interaction skills are evaluated using the masking level difference (MLD) test. Binaural integration abilities are measured through the dichotic consonant-vowel (DCV) test, which requires the individual to simultaneously process different consonant-vowel pairs presented to each ear and respond accordingly. Temporal processing skill is traditionally evaluated using the pitch pattern test (PPT) and duration pattern test (DPT). Alterations at the brainstem and cortical auditory processing could contribute to the heightened emotional responses to specific trigger sounds observed in misophonia.

Literature on auditory processing abilities reported no significant differences between individuals with misophonia and the control group (Ila et al., 2023; Madappally et al., 2024). However, the study by da Silva and Sanchez (2019) explored the selective attention of individuals with misophonia using dichotic listening tasks. Also, a recent study by Kim et al. (2023) reported that individuals with misophonia exhibited poor speech perception in the noise (SPIN) test at +20 and +5 signal-to-noise ratio (S/N). These results demonstrate possible poor auditory closure and binaural integration abilities in individuals with misophonia. Typically, individuals with normal hearing should be able to quickly tune out or ignore typical trigger sounds, such as chewing or sniffling, to keep their attention on more pertinent auditory information while in an environment. Nonetheless, most individuals with misophonia exhibit fixation and hyperfocus on these trigger sounds, such as chewing or sniffling, and encounter difficulty filtering out these sounds rather than background noise (Pellicori, 2020), while individuals with central auditory processing disorder (CAPD) do not appear to have autonomic nervous system arousal, which is a significant distinction between the two conditions (Pellicori, 2020). It is also reported that impaired auditory processing may have diminished N1 amplitude in individuals with misophonia (Schröder et al., 2014). However, studies by Ila et al. (2023) and Madappally et al. (2024) focused solely on individuals with mild to moderate misophonia, leaving the potential impact of more severe forms of the disorder on brainstem and cortical auditory processing unexplored. Similarly, Kim et al. (2023) did not specify the severity of misophonia in their sample. As a result, there is a possibility that variations in auditory processing may be associated with the severity of misophonia, with individuals exhibiting more severe symptoms potentially showing abnormal auditory processing at the brainstem and cortical level. Thus, it can be hypothesized that neural processing at these levels may be altered in individuals with misophonia with higher severity. Hence, the present study assesses auditory processing in individuals with moderate to severe misophonia.

Also, assessing auditory processing abilities in individuals with misophonia could provide valuable insight into atypical auditory processing patterns at the brainstem and cortical level, which may be associated with the disorder (Brout et al., 2018; Schröder et al., 2014). Hence, it would be intriguing to see the auditory processing abilities in individuals with misophonia utilizing behavioral auditory processing tests. Therefore, the current research aims to assess auditory processing abilities using behavioral measures in normal-hearing individuals with and without misophonia. The objective is to compare the scores of the DCV, PPT, and MLD thresholds between individuals with and without misophonia.

Materials and Methods

Participants

This research employed a standard group comparison design with purposive sampling. Thirty participants were recruited between 18 and 30 years (Mean age = 24.23, *SD* = 2.91 years). These participants were divided into two primary groups: one consisting of 15 individuals diagnosed with misophonia and the other of 15 controls (23 females and seven males). Among those in the misophonia group, 10 individuals were classified as having a moderate degree of misophonia, while five had severe misophonia. The Duke-Vanderbilt misophonia screening questionnaire was utilized to screen the participants (Williams et al., 2022). The selection of individuals with misophonia was based on the diagnostic criteria devised by Schröder et al. (2013a) and MisoQuest, as described by Siepsiak et al. (2020). The severity of misophonia was assessed using the Revised Amsterdam Misophonia Scale (RAMISO-S; Jager et al., 2020). The RAMISO-S scores were categorized as follows: 0–10 indicating no misophonia (subclinical), 11–20 indicating mild misophonia, 21–30 indicating moderate misophonia, and 31–40 indicating severe misophonia. Participants with scores of 10 or below were considered to have no misophonia, while those with scores of 21 or higher were included in the study.

The inclusion criteria for participants were as follows: no significant history of otological disorders, chronic or repeated exposure to loud noise, alcohol use, smoking, ototoxic medications, a family history of hearing loss, or any other medical conditions that could potentially influence the study outcomes. Individuals with tinnitus were excluded based on the scores of the Tinnitus Handicap Inventory (THI; Newman et al., 1996), and those with hyperacusis were excluded using the Modified Khalfa Hyperacusis Questionnaire (MKHQ; Khalfa et al., 2002). Also, those with phonophobia were excluded using the Decreased Sound Tolerance Scale-Screening (DSTS-S; Allusoglu & Aksoy, 2021).

Ethical Approval and Consent to Participate

In the current study, all of the testing procedures were accomplished using a noninvasive technique and adhered to the conditions of the institutional ethical approval committee. The institutional ethical approval committee approved the current study, AIISH Institute Review Board (IRB) Ref: SH/IRB/M.1/21/2024-25. The test procedures were clearly explained to the participants before testing. Written informed consent was taken prior to commencing the data collection.

Procedure

A comprehensive case history was obtained from each participant to screen for potential otological issues, hearing impairments, or noise exposure. Initially, participants underwent otoscopy to identify outer ear or ear canal anomalies. This was followed by a standard audiological test battery: pure tone audiometry, middle ear measures, and distortion product otoacoustic emissions (DPOAEs), all employed to assess hearing sensitivity, middle ear function, and outer hair cell function, respectively. These tests were performed in a randomized order for both ears.

Instrumentation. Tests were conducted in the acoustically treated room by the noise level standards specified by the American National Standards Institute (ANSI S3.1 1999, R2008) standards. The following calibrated equipment was utilized for this research: Inventis Piano (Inventis Padova, Italy), Grason-Stadler Tympstar Pro (Grason Stadler, Inc., MN, USA), and Otodynamics DP Echoport otoacoustic emission instrument (ILO292-USB-II, V6).

Pure-Tone Audiometry. Pure-tone audiometry was conducted to determine the hearing thresholds for air and bone conduction. Air conduction thresholds were measured at 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 kHz; while bone conduction thresholds were obtained at 0.25, 0.5, 1.0, 2.0, and 4.0 kHz, respectively. The modified Hughson-Westlake procedure, by Carhart and Jerger (1959), was utilized to ensure accurate threshold determination. Following the modified Hughson-Westlake procedure, normal hearing sensitivity was defined as a threshold of ≤15 dB HL across octave frequencies from 250 Hz to 8000 Hz for air and from 250 Hz to 4000 Hz for bone (Carhart & Jerger, 1959). The four-frequency pure-tone average (PTA) was calculated to quantify the hearing level by averaging the thresholds at 0.5, 1.0, 2.0, and 4.0 kHz (Carhart & Jerger, 1959).

Middle Ear Measures. Tympanometry was obtained with a probe tone of 226 Hz at 85 dB SPL, and acoustic reflexes were measured at 500, 1000, 2000, and 4000 Hz (Roeser et al., 2007). All participants exhibited 'A' type tympanograms and had present ipsi- and contralateral acoustic reflexes at 500 and 1000 Hz (Roeser et al., 2007).

Distortion Product Otoacoustic Emissions (DPOAE). DPOAEs were measured at octave and mid-octave frequencies between 1 and 6 kHz using 65/55-dB SPL stimulus levels. A S/N of +6 dB at three consecutive frequencies was used as the criterion for the presence of otoacoustic emissions (Kemp, 2007). All participants met the inclusion criteria and proceeded with auditory processing testing.

Auditory Processing Tests. Auditory processing tests were carried out for the following processes using a personal laptop coupled to the calibrated dual-channel audiometer. Testing was done at 50 dB SL (reference: speech recognition threshold). DCV was used to evaluate binaural integration, PPT to assess for temporal ordering (Bellis, 2011), and MLD to evaluate binaural interaction. The results of the auditory processing tests were tabulated for statistical analysis.

DCV Test

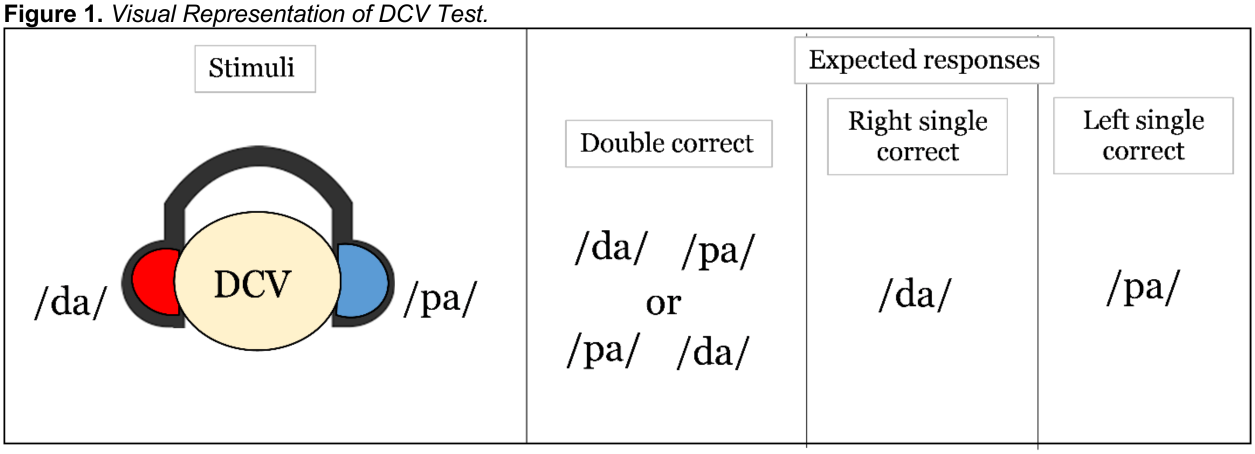
The DCV test assesses the binaural integration at the cortical level (Bellis, 2011). This test was administered using a personal laptop developed by Yathiraj (1999). Stimuli were routed through calibrated TDH 39 supra-aural headphones. The stimuli consist of six syllables (/pa/, /ba/, /ta/, /da/, ka/, /ga/), and it was randomly presented five times for 30 presentations to both ears at 50 dB SL (reference: speech recognition threshold) with a 0 ms lag between them. Before the actual testing, the participants were provided with practice items to ensure they understood the instructions.

Instructions. Instructions for DCV are as follows: *"You will be hearing two syllables – one in each ear. You need to repeat/write down both syllables regardless of the sequence."*

Scoring. For scoring, right single correct scores (RCS), left single correct scores (LCS), and double correct scores (DCS) were noted.

A visual representation of the DCV test is shown in Figure 1.

Figure 1. *Visual Representation of DCV Test.*



DCV - dichotic consonant-vowel.

Pitch Pattern Test (PPT)

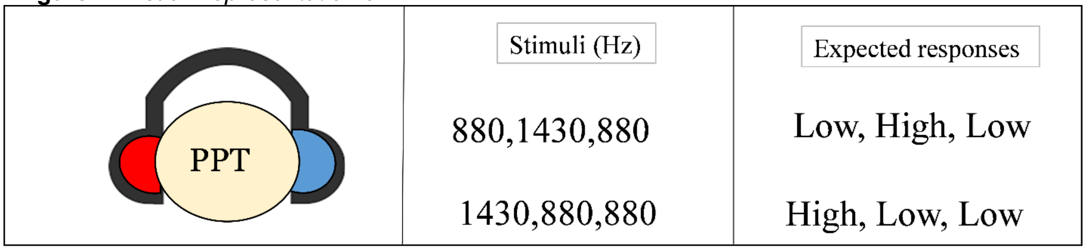
The PPT, employed to measure temporal ordering and developed by Tiwari (2003), was used to assess the cortical level (Bellis, 2011). It has six practice items in addition to 30 test items. Each item consists of three pure tones, each of 500 ms duration, separated by an interstimulus interval of 300 ms. The tone frequencies were 880 Hz (low) and 1430 Hz (high). Within each item set, two tones were similar and one was different due to the tone frequencies. The presentation level of the stimuli was at 50 dB SL. Before the actual testing, through practice items, participants were trained to distinguish between high and low tones by demonstrating the verbal tasks.

Instructions. Instructions for PPT are as follows: *"You will hear a sequence of three tones. Each tone will be either high-pitched or low-pitched. You need to repeat verbally/write down the sequences of tone, e.g., High-High-Low (HHL), Low-Low-High (LLH)."*

Scoring. Scoring was done based on the number of sequences correctly identified by the participants. If the participants responded correctly, a score of *1* for each correct response was given and *0* for every incorrect response.

A visual representation of the PPT is shown in Figure 2.

Figure 2. *Visual Representation of PPT.*



PPT - pitch pattern test.

Masking Level Difference (MLD)

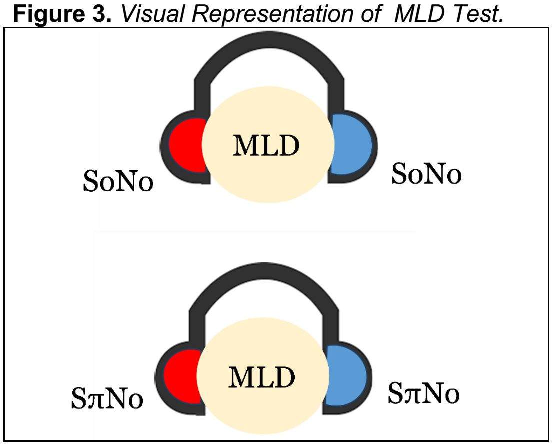
The MLD test assesses the binaural interaction at the brainstem level (Bellis, 2011). MLD was administered using a calibrated two-channel audiometer, where the signal (S) and the noise (N) were presented in homophobic (SoNo) and antiphrastic (SπNo) conditions bilaterally, and the masked thresholds were determined (Olsen et al., 1976). MLD was performed at 500 Hz with a pulse mode of 2.5 Hz, at 50 dB SL (reference: 500 Hz threshold) with 1 dB step size.

Instructions. Instructions for MLD are as follows: *"You will be hearing two stimuli (tone and noise) simultaneously in both ears; you need to pay attention and indicate when you hear the tone by raising a finger/pressing the response button given to you."*

Scoring. MLD was calculated as the difference in threshold between homophasic (SoNo) and antiphasic (SπNo) conditions (Olsen et al., 1976).

A visual representation of the MLD test is shown in Figure 3.

Figure 3. *Visual Representation of MLD Test.*



MLD - masking level difference.

Statistical Analyses

The statistical analysis was conducted using IBM SPSS Statistics (version 26, IBM Corp., Armonk, NY). The results of the Shapiro-Wilk's normality tests showed that the data were normally distributed. An independent *t*-test was done to check for any significant difference between the groups in the auditory processing abilities test scores.

Results

Comparison of DCV Scores in Individuals With and Without Misophonia

The results of the DCV test were subjected to a descriptive statistical analysis. Results show that right single correct, left single correct, and double correct scores were reduced in individuals with misophonia compared to control groups.

An independent *t*-test was conducted to determine the differences between the two groups. Independent *t*-test results showed a statistically significant difference, $t(28) = 3.64$, $p < .05$ for the right single correct score; $t(28) = 2.83$, $p < .05$ for the left single correct score; and $t(28) = 3.35$, $p < .05$ for double correct scores between the two groups.

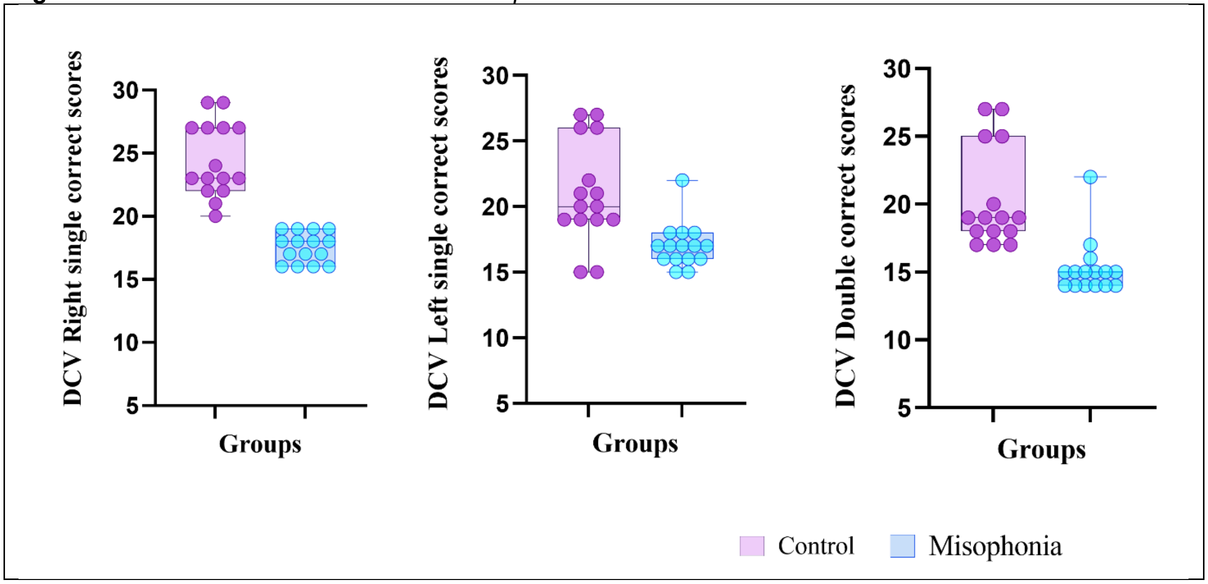
A comparison of DCV scores between the groups is provided in Figure 4.

Comparison of PPT Scores in Individuals With and Without Misophonia

The results of the PPT were subjected to a descriptive statistical analysis. Results show that PPT scores were reduced in individuals with misophonia compared to control groups.

Furthermore, an independent *t*-test was conducted to determine the differences between the two groups. Independent *t*-test results showed a statistically significant difference, $t(28) = 2.87$, $p < .05$, for PPT scores between the two groups.

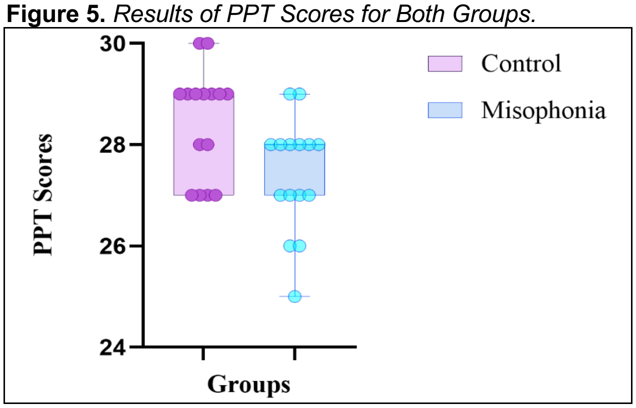
Figure 4. *Results of DCV Scores for Both Groups.*



DCV - dichotic consonant-vowel.

A comparison of PPT scores between the groups is provided in Figure 5.

Figure 5. *Results of PPT Scores for Both Groups.*



PPT - pitch pattern test.

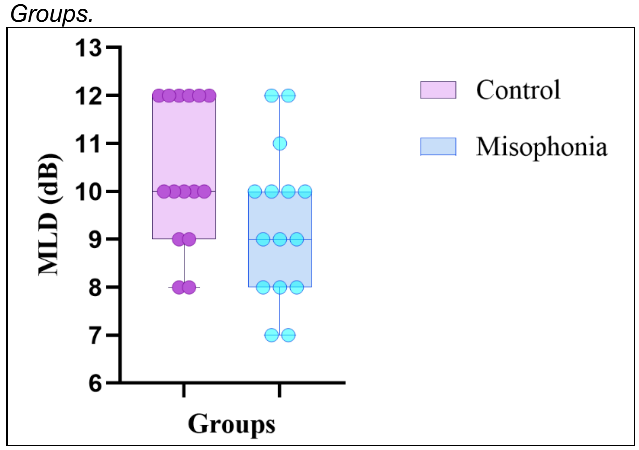
Comparison of MLD Thresholds in Individuals With and Without Misophonia

MLD results were subjected to a descriptive statistical analysis. Results show that the MLD thresholds at 500 Hz were similar between the two groups.

Furthermore, an independent *t*-test was conducted to see the differences between the two groups. Independent *t*-test results showed no statistically significant difference, $t(28) = 1.27$, $p > .05$, in MLD thresholds between the two groups.

A comparison of MLD thresholds (dB) between the groups is provided in Figure 6.

Figure 6. *Results of MLD Thresholds (dB) for Both Groups.*



MLD - masking level difference.

Discussion

The study results exhibited a significant difference between the groups in DCV and PPT, suggesting that binaural integration and temporal processing are altered. Hence, these findings indicate that individuals with higher severity of misophonia may experience disruptions in auditory processing at the cortical level. Our results are consistent with the study conducted by da Silva and Sanchez (2019), who also observed poorer scores in individuals with misophonia compared to control groups using a dichotic listening task. They proposed that individuals with misophonia might suffer from selective attention impairment (da Silva & Sanchez, 2019). This suggests that individuals with misophonia may not only exhibit heightened emotional responses to certain trigger sounds but also experience interference with their ability to process auditory stimuli effectively. The alignment between our findings and those of da Silva and Sanchez (2019) underscores the notion that individuals with misophonia may have broader deficits in selective auditory attention tasks.

These findings are further supported by Brout et al. (2018), who suggested that individuals with misophonia may have difficulty concentrating on neutral or complex sounds because their attention is drawn to trigger sounds, leading to impaired auditory processing. On the other hand, a study by Madappally et al. (2024) reported no deviations at the brainstem level utilizing a dichotic listening task. Similarly, Ila et al. (2023) found no significant difference in temporal processing tasks among individuals with misophonia. However, they stated that these results could be due to the inclusion of individuals with lesser severity (Ila et al., 2023; Madappally et al., 2024).

Neuroimaging studies, specifically those using functional magnetic resonance imaging (fMRI), have provided valuable insights into the neural mechanisms underlying misophonia. Individuals with misophonia exhibit heightened activation in brain regions associated with emotional processing, such as the anterior insula and amygdala, in response to aversive sounds (Eijsker et al., 2021; Kumar et al., 2017, 2021; Neacsiu et al., 2022; Schröder et al., 2015, 2019). This heightened emotional response may disrupt normal auditory processing pathways, leading to reduced performance on tasks like the DCV and PPT, which require focused attention on auditory stimuli without emotional interference (Schröder et al., 2013b). Furthermore, fMRI studies have suggested that individuals with misophonia may exhibit altered connectivity between the auditory cortex and regions involved in emotional regulation, which could contribute to deficits in sound discrimination (Eijsker et al., 2021; Kumar et al., 2017; Kumar et al., 2021; Neacsiu et al., 2022; Schröder et al., 2015, 2019). Rouw and Erfanian (2018) also proposed that misophonia is characterized by abnormal connectivity between these regions, potentially leading to an attentional bottleneck that could impair the ability to process auditory stimuli efficiently.

Electrophysiological evidence also indicates reduced amplitude in auditory-evoked cortical potentials in individuals with misophonia, reflecting early attentional auditory processing deficits (Aryal & Prabhu, 2023b; Schröder et al., 2013b, 2015). These findings suggest that heightened activation in the generators of auditory cortical potentials may contribute to reduced performance on auditory processing tasks. Another possible explanation is that the frontoparietal attentional networks, critical for selective attention, may be dysregulated in individuals with misophonia. Increased attention to emotionally salient sounds, such as trigger sounds, may divert cognitive resources from processing other auditory information, thereby leading to poorer scores on tasks that require binaural integration and temporal processing abilities (Cavanna & Seri, 2015; Jastreboff & Jastreboff, 2001). These findings are consistent with previous research suggesting attentional deficits in individuals with misophonia, where emotional responses overwhelm normal selective auditory processing mechanisms (Cavanna & Seri, 2015). Such results align with neurophysiological and neuroaudiological models that emphasize the role of attention in auditory perception and the processing of aversive sounds, as well as alterations in the cortical pathways in individuals with misophonia (Aryal & Prabhu, 2023c; Jastreboff & Jastreboff, 2023). Kumar et al. (2021) also observed that individuals with misophonia may have difficulty ignoring trigger sounds, which contributes to divided attention during tasks that require the simultaneous processing of multiple auditory stimuli in dichotic listening and temporal processing tests.

To the best of our knowledge, this is the first study to report deviances in auditory processing abilities within the misophonia population. Interestingly, in the present study, no significant difference was observed in the thresholds of MLD at 500 Hz, suggesting that auditory processing remains unaltered at the brainstem level in individuals with misophonia. Similarly, a study by Aryal and Prabhu (2023a) and Madappally et al. (2024) also found no abnormalities at the brainstem level. In contrast, Kim et al. (2023) observed deviances at the brainstem level by employing electrophysiological measures such as auditory brainstem response (ABR). However, in the study by Kim et al. (2023), the information on the inclusion of the severity of misophonia participants is not stated, which makes it difficult to directly compare their results with ours.

These methodological differences could be attributed to variations in outcomes regarding the relationship between misophonia and auditory processing abilities. Therefore, the findings of our study provide behavioral evidence for altered cortical auditory processing in individuals with higher severity of misophonia, resulting in poorer scores in the dichotic listening task and temporal processing tasks.

Conclusion

The current study aimed to investigate the auditory processing abilities of individuals with misophonia. Behavioral measures employed in this research indicate that individuals with a higher degree of misophonia may exhibit alterations in binaural integration and temporal ordering processes. These behavioral findings, while insightful, primarily reflect sensitivity to potential alterations in both the brainstem and cortical regions. However, to gain a more comprehensive understanding of auditory processing in misophonia, it is crucial to incorporate electrophysiological measures which would provide deeper insights into the neural mechanisms underlying these processes. Furthermore, future research examining the varying degrees of misophonia will be essential for elucidating how auditory processing abilities differ across individuals with this condition.

Implications of the Study

The findings from the present study have important implications for both the clinical understanding and management of misophonia. Firstly, the observed deviations in binaural integration and temporal processing in individuals with higher severity of misophonia suggest that auditory processing abnormalities may be more pronounced at the cortical level rather than the brainstem level. This highlights the need for future research to investigate how cortical auditory processing mechanisms contribute to the heightened emotional and attentional responses seen in individuals with misophonia.

From a clinical perspective, the identification of specific auditory processing deficits can help refine diagnostic criteria and therapeutic interventions for individuals with misophonia. For example, clinicians may consider incorporating auditory processing assessments into the diagnostic process to better understand the underlying neural mechanisms and tailor treatment strategies accordingly. Moreover, the results of this study stress the importance of considering the severity of misophonia in future research. As demonstrated by previous studies, auditory processing abilities may vary significantly depending on the degree of misophonia. This variability suggests that interventions aimed at improving auditory processing may need to be individualized, with varying approaches based on the severity and specific characteristics of each case.

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Author Disclosure

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Sleep Impairment Compromises Young Collegiate's Resting-State Brain Wave Activity and Prefrontal Cognition

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Abstract

Introduction. Sleep problems are common among university students and have been linked to weakened brain abilities and cognitive functioning. Electroencephalography (EEG) and event-related potentials (ERP) are important and tests routinely done to assess brain abilities and cognitive functions. Therefore, present study aims to examines the relationship between sleep functions and various domains of brain and cognitive abilities in sleep-disturbed collegiates. **Method.** Thirty-two collegiates participated in this study. Sleep functions such as sleep quality and daytime sleepiness were subjectively assessed using Pittsburgh Sleep Quality Index (PSQI) and Epworth Sleepiness Scale (ESS), respectively. EEG brainwaves (alpha-Hz, beta-Hz, delta-Hz, and theta-Hz) and ERP P300 (amplitude-μV [AMP], latency-ms [LAT]) were recorded using RMS analysis and auditory-oddball paradigm, respectively. **Results.** Pearson's correlation analysis revealed statistically significant linear correlation between PSQI and AMP ($r = -0.485$, $p = .005$), PSQI and LAT ($r = 0.354$, $p = .047$), ESS and AMP ($r = -0.478$, $p = .006$), and ESS and LAT ($r = 0.436$, $p = .013$). Considering EEG brainwaves, both PSQI ($r = -0.364$, $p = .040$) and ESS ($r = -0.409$, $p = .020$) demonstrate statistically significant linear correlation with alpha. Further, regression analysis revealed that sleep functions (PSQI and ESS) were found to significantly predict AMP, LAT, and alpha. **Conclusions.** In collegiates with sleep disturbances, measures of prefrontal cognition and EEG brainwaves are substantially correlated with sleep-related characteristics.

Keywords: sleep disturbance; cognitive impairment; electroencephalography; event-related potential; young collegiates

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Introduction

In today's world, sleeplessness is a relatively common problem. Sleep problems are common among university students, with a reported prevalence ranging from 19.2 to 57.5 percent, and it can have serious long-term consequences (Manzar, Zannat, et al., 2015). Sleep disturbances have a negative impact on an individual's general physiology, including reduced cognitive performance (Sweileh et al., 2011). Babkof and colleagues (2005) discuss the relevance of the "sleep-based neuropsychological viewpoint," which argues that sleep disorders affect cognitive function by interfering with the functioning of certain cortical areas (Babkof et al., 2005). The most popular theory in this area is Horne's theory of prefrontal vulnerability (Horne, 1993). Since the hippocampus and prefrontal cortex are in charge of regulating cognition, this shows a complicated presentation of cognitive disorders. A variety of cognitive areas, including memory, executive function, concentration and attention, speed of information processing, perception, and inhibitory function are all affected by sleep disturbances (Haimov & Shatil, 2013). Importantly, cognitive and brain abilities can be assessed using a variety of techniques. The two most widely used noninvasive methods are event-related potentials (ERP) P300 and electroencephalography (EEG; Woodford & George, 2007).

According to thorough and rigorous review, ERP P300 can be utilized as a neurophysiological marker to measure cortical arousal since it is sensitive enough to detect changes in arousal level. In human participants that are sleep deprived, the majority of research analyzing ERP have reported considerably lower amplitudes and longer latencies in comparison to controls (Morris et al., 1992). It is crucial to keep in mind, though, that because all the trials were conducted in a lab and participants were compelled to skip sleep, there was potential for a number of psychological confounds. Few research studies have also attempted to address the same question by using patients with clinically documented sleep disturbances; however, their findings have been inconsistent (Turcotte et al., 2011). While some studies comparing ERP responses showed no significant effect of the previous night's sleep quality on long latency responses in sleep-disturbed participants and their healthy counterparts (Devoto et al., 2003), other researchers found significant changes in the morphology of P300 in response to the previous night's poor sleep quality (Shishkin et al., 2009). Another main noninvasive technique for gathering data from the human brain is EEG (Coburn et al., 2006). Sleep problems have been found to disrupt people's performance on resting-state EEG (Verweij et al., 2014). According to recent research, certain oscillatory patterns in spontaneous EEG are linked to neuropsychopathologies like sleep disorders, depression, and some learning disabilities. These oscillatory patterns also serve as trustworthy indicators of brain dysfunction (Coburn et al., 2006).

Therefore, corpus of research suggests that a study should look into the relationship between sleep, cognitive factors, and resting-state brain waves in order to address the impaired brain functioning in adolescents and young adults who have sleep disruptions. Therefore, in this study we primarily aim to explore the relationship of sleep function measures (such as sleep quality using the Pittsburgh Sleep Quality Index [PSQI] and daytime sleepiness using the Epworth Sleep Scale [ESS]) with cognitive abilities (such as ERP P300 latency [LAT] and ERP P300 amplitude [AMP]) and resting-state EEG measures in young collegiates with sleep impairment; and secondarily we aim to find out if the sleep impairment is a potential predictor for cognitive function deficits and brain wave disturbances. To the best of our knowledge, this is the first study to evaluate the association of sleep functions with cognitive variables and brain wave profile.

Materials and Methods

Sample Size

Number of subjects was determined with Software G. Power 3.1.9.2 using data from a previous study (Aseem et al., 2021), which investigated the association between sleep profile and cognitive functions using PSQI and LAT, respectively, in sleep-disturbed collegiates with mild cognitive impairment. A total of 32 subjects were shown to be necessary with the effect size of 0.52 (high), alpha level of 0.05, and power (1-beta) of 0.88.

Procedures

With reference number 19/2/213/JMI/IEC/2019, the Institutional Ethics Committee (IEC) of Jamia Millia Islamia (Central University), New Delhi, India, approved the study. The study was carried out at Jamia Millia Islamia's Neurophysiology Lab, which is part of the Centre for Physiotherapy and Rehabilitation Sciences. The 1964 Helsinki Declaration and its updates were adhered to when doing the research for this study. After a preliminary diagnostic interview and evaluation of the entrance requirements, participants were told about the study at the first contact and their written informed consent was collected, following which screening for the impaired sleep symptoms was done using PSQI (Buysse, 1989) in young collegiates.

Participants

A total of 50 students from Jamia Millia Islamia, 26 female and 24 male, ages 18 to 28, had their eligibility for PSQI (Buysse, 1989), with subjects experiencing sleep difficulties (poor sleepers) at the time of their recruitment with PSQI scores > 5 (Manzar, Moiz, et al., 2015) examined. Subsequently, the ESS (Johns, 1991) was employed to assess symptoms of daytime sleepiness in individuals diagnosed with insomnia. The assessment of brain waves (EEG) and cognitive function features (ERP) was then completed. Physiotherapists who performed the assessment received training on conducting the assessments as per standard operating procedure. Every test was delivered in a standardized manner, and the sequence in which they were given to each subject was followed. Out of the 50 participants, 38 met the requirements. Out of those 38, six people declined to take part in the research. The study was comprised of 32 individuals, 15 of whom were male and 17 of whom were female. Every person who was included reported having regular or modified normal vision, normal hearing, and basic English language comprehension. In order to reduce the possibility of bias in the study's results, participants were excluded if they had a history of neurological, psychological, or mental problems; alcohol consumption, substance abuse, use of centrally active drugs (that may affect ERP and EEG), or if they had taken sleeping pills for the previous 6 months. The study participants were 32 young collegiates with impaired sleep. Details of their sleep functions, cognitive functions and brain waves characteristics are shown in Table 1.

Outcome Measures

Sleep Functions.

- **Sleep Quality.** The PSQI, a self-rated questionnaire consisting of 19 items, was utilized to evaluate the subjective quality of sleep throughout the preceding month. The 19 questions are aggregated into seven clinically derived component scores, each equally weighted from 0 to 3. Using the seven component scores, a total score ranging from 0 to 21 is computed; higher values correspond to lower quality sleep (Buysse, 1989).
- **Daytime Sleepiness.** Subjective daytime sleepiness is measured by ESS. The ESS uses a 4-point Likert response system (rated from 0 to 3) to assess a person's likelihood of falling asleep in different scenarios. Higher numbers indicate more extreme tiredness. The answers to each item are added up to get a total score between 0 and 24; a score of more than 10 denotes severe daytime sleepiness (Johns, 1991).

Cognitive Functions.

ERP P300 latency and ERP P300 Amplitude.

ERP P300 elements (LAT and AMP) pertaining to information processing and attention are present throughout awake. P300 is the most well-known of these elements and is thought to be the electrophysiological correlate of cognition (Hull & Harsh, 2001). The ERP P300 wave's amplitude and latency were also measured. The individual was seated in a comfortable position. The scalp was carefully cleaned with N-Prep skin preparation gel (Weaver and Company, USA) before EEG paste (Ten20 conductive) was applied to different parts of the scalp to become ready for electrode insertion. Ag-AgCl disc electrodes were employed as recording electrodes. Reference electrodes were affixed to the mastoid (A1), the active electrode on the vertex (Cz), and the ground electrode on the forehead (FPz). The techniques employed in previous studies to quantify the auditory ERP (AERP) were followed during the implantation of this electrode (S. Lee et al., 2004). While employing the typical auditory oddball paradigm, participants completed a task, and the AERP were recorded. While listening to two distinct sound types through headphones, the respondents were instructed to count the number of (rare, goal stimulus) presentations of a high-pitch tone (S1) as opposed to the number of (common, nontarget stimuli) presentations of a low-pitch tone (S2). In line with earlier research, the target: nontarget ratio for the S1 and S2 sounds was selected at random (Aseem et al., 2018; H.-J. Lee et al., 2003). Every stimulation was separated by 1 s. Every tone had a 50-ms duration. During the recording of the AERP, subjects were asked to avoid head, neck, and eye movement (Chatterjee et al., 2012).

Resting-State EEG Brain Waves. All participants in the current study had their resting EEG recorded on an EEG machine, which was used to examine brain activity (Fisch, 1991). Prior to recording the EEG, a square wave calibration signal with known input was captured for at least 10 s and stored with the EEG in accordance American Clinical Neurophysiology Society 2008 guideline. A check of all electrode digital EEG recording systems was stored for at least 10 s of recording (Ebersole & Pedley, 2003), and electrophysiological signals were normalized (Qureshi & Jha, 2017). To minimize circadian variations, EEG recordings were conducted at the same time of day for 20 min in a relaxed supine position with eyes closed. During each recording, environmental factors that affect EEG, such as temperature, noise, or bright light were controlled. Additionally, participants were instructed not to consume any caffeine-containing products or engage in excessive physical activity for the preceding 24 hr because these factors can also affect changes in resting EEG waves. The subjects were told to refrain from making unnecessary motions as well as from wearing any metal or electronic devices during the experiment. Before the experiment, the scalp's oil and dead skin cells were removed from the area where the electrode was attached with an alcohol swab. NūPrep skin prepping gel (Weaver and Company, USA) was then used to gently clean the scalp. Before the experiment, the participants rested in a sedentary position for 5 min. For the purpose of placing electrodes, Ten20 conductive EEG paste was applied to various areas of the scalp. Electrodes made of Ag-AgCl discs were used for recording. The EEG electrodes were placed for 16 scalp channels at frontoparietal (FP1–FP2), midfrontal (F3–F4), lateral-frontal (F7–F8), temporal (T3–T4), dorsotemporal (T5–T6), central (C3–C4), parietal (P3–P4), and occipital (O1–O2) regions following the

International 10–20 System of Electrode Placement. The left and right earlobes (A1 and A2) were used as the locations for the reference and ground electrodes. These electrodes were connected to the EEG-32 SS Traveler, a 22-channel digital EEG machine, of which 16 channels were used. Alpha waves (≥50% of the recording) were confirmed before and after the study, with electrode impedance maintained below 5 kΩ. The RMS analysis software was used to process and analyze the EEG data. By visual inspection, the sweeps and blink artifacts were eliminated. During preprocessing, recordings were re-referenced using a common average reference. In order to determine the mean power frequency (MPF), frequency band analyses were carried out using the fast Fourier transformation (FFT). The EEG frequency was set to the delta wave (0.5–4.0 Hz), theta wave (4–7 Hz), alpha wave (8–13 Hz) and beta wave (14–30 Hz), and they were analyzed and calculated with MPF. Following the exclusion of all artifacts at all channels that exceeded ±100 V, each participant's artifact-free epochs were calculated.

Statistical Analysis

SPSS version 28.0 was utilized for conducting statistical analysis. The distribution of all outcome measures was shown to be normal using the Shapiro-Wilk test, skewness, and histogram. The outcome variables that show nonnormal distribution were analyzed using a nonparametric test or log-transformed before proceeding to inferential analysis. The Pearson correlation coefficient was used to calculate the associations between cognitive functions and sleep. *R* values of 0.10 or less are frequently seen as having a small impact, 0.10 to 0.50 as having a moderate impact, and 0.50 or more as having a considerable impact (Alghwiri et al., 2018). Multiple linear regression was performed gradually to see if sleep functions significantly predicted cognitive functions and EEG brain waves after adjusting for confounders. Regression analysis was used to investigate the predictive power of age, gender, and body mass index (BMI) in relation to sleep measurements.

Results

A sample of 32 sleep disturbed collegiates with demographic characteristics mean (age = 20.93 ± 1.50 years, height = 161.84 ± 6.53, weight = 65.45 ± 3.98 kg, and BMI = 26.90 ± 1.09 kg/m²) was assessed for sleep functions (measured by PSQI and ESS), cognitive functions (measured by ERP P300), and brain waves characteristics (EEG; Table 1).

Table 1

Mean and Standard Deviation Scores for Sleep Measures, Encephalographic Brain Waves and Cognitive Functions in College Students With Sleep Disturbance

Test	Mean	*SD*
Sleep Measures		
PSQI (score)	9.75	0.98
ESS (score)	11.50	0.50
EEG Brain Waves		
Alpha (Hz)	0.02	0.002
Beta (Hz)	3.38	0.10
Delta (Hz)	0.65	0.09
Theta (Hz)	0.08	0.005
Cognitive Functions		
AMP (µV)	3.64	0.59
LAT (ms)	265.14	45.24

Abbreviation: PSQI: Pittsburgh Sleep Quality Index; ESS: Epworth Sleep Scale; EEG: electroencephalography; AMP: event-related potential P300 amplitude; LAT: event-related potential P300 latency; *SD*: standard deviation. Data are presented as mean and *SD*.

To evaluate the association between several areas of sleep function (PSQI and ESS), cognitive functions (AMP and LAT), and brain waves (alpha, beta, delta, and theta), we computed Pearson's correlation (Table 2).

Table 2
Correlation Analysis Between Sleep Measures (Sleep Quality and Daytime Sleepiness), EEG Brain Waves (Alpha, Beta, Delta, and Theta) and Cognitive Functions (Event-Related Potential P300 Amplitude and Event-Related Potential P300 Latency) in College Students With Sleep Disturbance (R and P Values Are Presented)

	Sleep Measures			
	PSQI		ESS	
	r	*p*	*r*	*p*
EEG Brain Waves				
Alpha	−0.36*	.04*	−0.40*	.02*
Beta	−0.11	.53	0.13	.45
Delta	0.30	.09	−0.03	.83
Theta	0.31	.07	0.07	.66
Cognitive Functions				
AMP	−0.48**	.005**	−0.47**	.006**
LAT	0.035*	.04*	0.43*	.01*

Abbreviation: PSQI: Pittsburgh Sleep Quality Index; ESS: Epworth Sleep Scale; EEG: electroencephalography; AMP: event-related potential P300 amplitude; LAT: event-related potential P300 latency. *$p < .05$; **$p < .01$

The relationship between PSQI and beta was computed, and it shows a nonstatistically significant weak negative correlation (r = −0.11, p = .53). Similar correlation analyses were performed between PSQI and delta (r = 0.30, p = .09) and between PSQI and theta (r = 0.31, p = .07), but no association was found in any of this analysis. Intriguingly, a negative linear correlation between PSQI and AMP (r = −0.48, p = .005**; Figure 1B), positive linear correlation between PSQI and LAT (r = 0.35, p = .04*; Figure 1C), and negative linear correlation between PSQI and alpha (r = −0.36, p = 0.04*; Figure 1A) was found, demonstrating that participants who showed increased amplitude value for P300 wave, decreased latency value for P300 wave and had less sleep problems when analyzed for PSQI score, respectively.

Figure 1A. *Pearson Correlation Analysis Showing the Statistically Significant Association of PSQI (Pittsburgh Sleep Quality Index) With Alpha (Resting EEG Alpha Wave).*

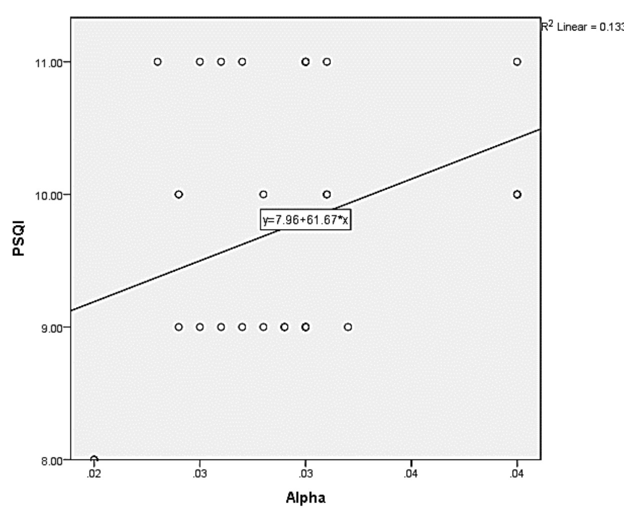


Figure 1B. *Pearson Correlation Analysis Showing the Statistically Significant Association of PSQI (Pittsburgh Sleep Quality Index) With AMP (Event-Related Potential P300 Amplitude).*

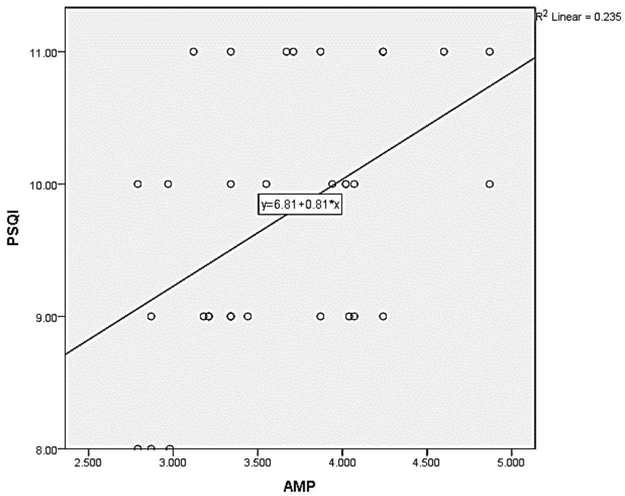
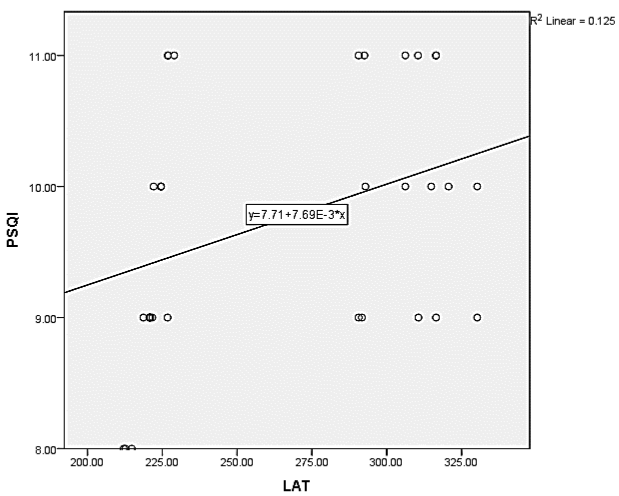


Figure 1C. *Pearson Correlation Analysis Showing the Statistically Significant Association of PSQI (Pittsburgh Sleep Quality Index) With LAT (Event-Related Potential P300 Latency).*



Further, participants with increased alpha power have less sleep disruption. We next conducted a Pearson's correlation for sleep function (ESS), cognitive functions (AMP and LAT), and brain waves (alpha, beta, delta, and theta; Table 2). The relationship between ESS and beta was computed, but it did not show any association (r = 0.13, p = .45). Similarly, a correlation analysis was also done between ESS and delta (r = −0.03, p = .83) and between ESS and theta (r = 0.07, p = .66), but no relation was found in this analysis. Importantly, a negative linear correlation between ESS and AMP (r = −0.47, p = .006**; Figure 2B), positive linear correlation between ESS and LAT (r = 0.43, p = .01*; Figure 2C), and negative linear correlation between ESS and alpha (r = −0.40, p = .02*; Figure 2A) were found, demonstrating that participants who showed increased P300 wave amplitude decreased P300 wave latency and are less likely to feel drowsy during daytime. Further, participants having increased alpha power have less chances of daytime sleepiness.

Figure 2A. *Pearson Correlation Analysis Showing the Statistically Significant Association of ESS (Epworth Sleep Scale) With Alpha (Resting EEG Alpha Wave).*

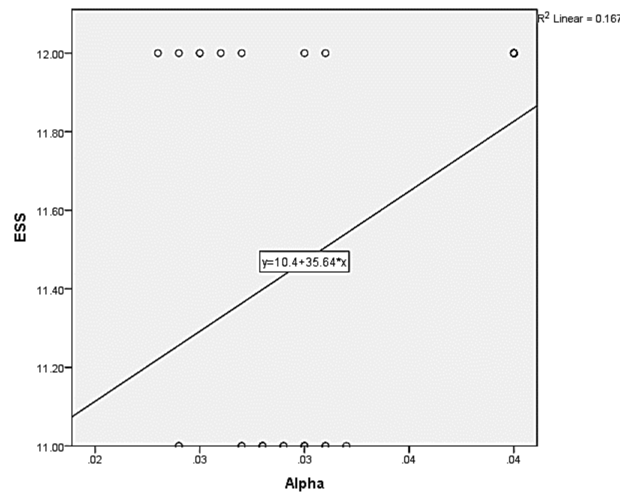


Figure 2B. *Pearson Correlation Analysis Showing the Statistically Significant Association of ESS (Epworth Sleep Scale) With AMP (Event-Related Potential P300 Amplitude).*

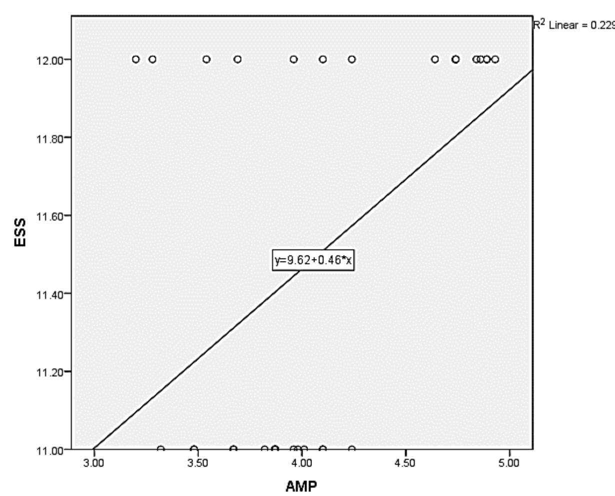
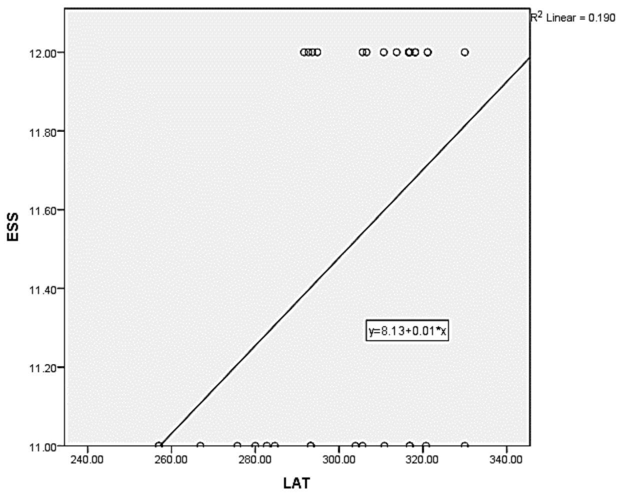


Figure 2C. *Pearson Correlation Analysis Showing the Statistically Significant Association of ESS (Epworth Sleep Scale) With LAT (Event-Related Potential P300 Latency).*



Multiple stepwise linear regression analyses (R^2) were carried out for PSQI with AMP, LAT, and alpha (Table 3). The regression analysis (R^2) revealed that PSQI was found to significantly predict the AMP, $F(1, 30) = 9.23$, $P = .005$*, with an R^2 of 0.23 and beta coefficient of −0.29; LAT, $F(1, 30) = 4.29$, $P = .04$*, with an R^2 of 0.12 and beta coefficient of 16.27; and alpha, $F(1, 30) = 4.58$, $P = .04$*, with an R^2 of 0.13 and beta coefficient of −0.002. Similarly, regression analysis (R^2) was carried out for ESS with AMP, LAT, and alpha (Table 3). The value of R^2 revealed that ESS was found to significantly predict the AMP, $F(1, 30) = 8.90$, $P = .006$**, with an R^2 of 0.22 and beta coefficient of −0.49; LAT, $F(1, 30) = 7.06$, $P = .01$*, with an R^2 of 0.19 and beta coefficient of 17.04; and alpha, $F(1, 30) = 6.01$, $P = .02$*, with an R^2 of 0.16 and beta coefficient of −0.005.

Table 3
Findings of Multiple Stepwise Linear Regression Analysis (R^2 and Beta Coefficients Values are Presented)

Regression Weights	Beta Coefficients	R^2	F	p-value
PSQI → Alpha	−0.002	0.13	4.58	.04 *
PSQI → AMP	−0.290	0.23	9.23	.005**
PSQI → LAT	16.270	0.12	4.29	.04 *
ESS → Alpha	−0.005	0.16	6.01	.02*
ESS → AMP	−0.490	0.22	8.90	.006**
ESS → LAT	17.04	0.19	7.06	.01*

Abbreviation: PSQI: Pittsburgh Sleep Quality Index; ESS: Epworth Sleep Scale: EEG: electroencephalography; AMP: event-related potential P300 amplitude; LAT: event-related potential P300 latency. *$p < .05$; **$p < .01$

Discussion

It has been demonstrated that university students' sleep habits have a variety of effects on their brain and cognitive abilities. Lee and colleagues showed that sleep deprivation lengthens the LAT and shortens the AMP (H.-J. Lee et al., 2003). Furthermore, on a range of cognitive tasks, the group experiencing sleep problems did worse on a variety of cognitive tests (Haimov & Shatil, 2013). The neuropsychological batteries test (NBT; Robbins et al., 1994), electrophysiological and EEG techniques like ERP (Duncan-Johnson & Donchin 1982), and imaging techniques like functional magnetic resonance imaging (fMRI; Lee et al., 2004) are some of the methods used to test cognition. Even while fMRI is more accurate, its expensive cost prevents it from being used frequently in clinical settings. According to Hanagasi & colleagues, (2002), the ERP P300 is the most widely used and unique biomarker for assessing cognition, and it can be used often in clinics (Hanagasi et al., 2002). These assessments have reached a degree of consistency that establishes them as the gold standard for assessing higher order cognitive processes. In this work, we assessed how sleep functions (PSQI and ESS), cognitive functions (ERP P300), and brain waves (resting EEG) relate to one another in sleep-disturbed college students. Additionally, we evaluated the target sample's cognitive abilities and brain waves in relation to sleep quality parameters.

This study's main findings are as follows: (a) measures of prefrontal cognitive functions and alpha brain wave are significantly correlated with subjective sleep quality and daytime sleepiness; and (b) the PSQI global score and ESS score, which indicate overall sleep quality and daytime sleepiness respectively, were found to significantly predict cognitive alterations and EEG brain alpha rhythm in sleep-deprived college students, even after correcting for a variety of clinical covariates that may influence human brain wave profile. In the current study, sleep quality (PSQI) and daytime sleepiness in sleep-disturbed college students showed a strong link with the tests evaluating prefrontal cognitive functions like AMP and LAT evaluated on ERP P300. The current study's results are in line with those of an earlier investigation, which found a statistically significant positive association between PSQI global score and LAT and a statistically significant negative correlation between the PSQI global score and AMP (Aseem et al., 2021). These findings are in line with earlier research on smaller samples (Aseem et al., 2018), as these studies show that sleep deprivation impairs cognitive performance, mood profile, and motor function. Sleep deprivation leads to a destabilization of the waking state and overall neurocognitive function (Goel et al., 2009) by weakening the peak circadian drive for wakefulness over time (Xu et al., 2011) and affecting brain processing (Wright et al., 2012). The prefrontal cortex, the portion of the brain linked to attention and working memory, is where the detrimental effects of these neurocognitive effects are most noticeable (Alhola & Polo-Kantola, 2007) and direct correlation between sleep-related memory issues and anatomical alterations in the prefrontal cortex was found (Acosta-peña et al., 2015). Our research also showed that total sleep quality is a significant predictor of prefrontal cognitive abilities. Prefrontal cortex and anterior cingulate cortex play a major role in working memory, attention, and executive function (Kondo et al., 2004). Furthermore, neuronal activity originating from the prefrontal cortex and probably the temporoparietal junction makes up the P300 triggered in the auditory oddball (Friedman, 2003). It has been demonstrated that activating this network lessens postacute sleep deprivation (Wu et al., 1999). Very few preliminary research (Kronholm et al., 2009) demonstrate similar ability of subjective sleep measuring scales to predict cognitive deterioration, however not supported by adequate literature.

We also looked for correlations between various EEG brain waves from resting states and sleep functions (PSQI and ESS). The Pearson's correlational analysis revealed a negative statistically significant relationship between the PSQI global score and the alpha band, and it also revealed a substantial impact of the PSQI global score on the power of the alpha band. Our results support one study that discovered a statistically significant relationship between alpha band and sleep quality (PSQI; Xiong et al., 2023). This suggests that there is a correlation between the alpha EEG brain wave and the subjects' sleep quality, and that when other factors are taken into account, the subjects' sleep quality can independently influence the alpha band power. The PQSI scores, on the other hand, did not significantly affect the EEG brain waves in the beta, theta, or delta bands in this model, which may suggest that the association between the PQSI scores and other frequency bands was not significant in this dataset. Additionally, the present study's finding of a negative correlation between ESS and alpha band is consistent with earlier research (El Mekkawy et al., 2022), which shows that an increase in the patient's degree of sleepiness was accompanied by an increase in the ESS score and decrease in alpha relative power. Our results, however, showed a negative connection, in contrast to the prior study's positive correlation (Grenèche et al., 2008). This could be explained by the fact that, in contrast to what we did in our work, they employed absolute alpha power rather than relative or mean frequency alpha power in their quantitative EEG analysis.

Conclusion

Overall, the study's findings suggest that assessing the brain function state of sleep deprived college students may be accomplished by a combination of quantitative EEG and ERP P300 analysis. In any clinical research situation, these approaches would provide sufficient recording and subsequent comparison with other neurophysiological and cognitive characteristics. Finally, our study offers early data about the relationship between sleep function measurements (PSQI and ESS) and cognitive functions associated to the prefrontal brain in a sample of college students. Moreover, there were noteworthy associations found between the alpha band EEG data and sleep functions (PSQI and ESS). Nevertheless, our study has number of possible disadvantages, one of being the small convenience sample size, which may limit the generalizability of the findings to broader college populations. Further, without a control group of students without sleep disturbances, it is challenging to establish causality or compare cognitive functioning between the groups. It should be noted that complete brain montages were not employed for resting EEG recordings in the current investigation because we measured the brain waves using

(16 + 2 = 18) electrodes. For ERP P300 recording in our work, we only used two sites (Cz and Fpz), despite the fact that high-density arrays are already available therefore, future studies might employ various numbers of channels and sensory inputs.

Authors' Declarations

The authors declare no conflict of interest. There was no grant support for this study. There is no financial interest.

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Teleneuropsychometry Solution in Resource-Constrained Setting – An Initial Experience in Adults With Brain Tumors

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Abstract

Background. Teleneuropsychometry constitutes a sophisticated technological innovation that enhances access to specialized neuropsychological services for patients situated in geographically remote or resource-limited contexts. When optimally utilized, teleneuropsychometry emerges as an advanced modality for bridging the gap between patient and neuropsychologists, facilitating timely preoperative cognitive evaluations. **Methods.** The study delineates two case reports of brain tumor patients who underwent teleneuropsychometric assessment prior to surgical interventions while also critically analyzing the complexities inherent in establishing such a service. **Results.** Both patients successfully completed the assessments with minimal assistance, providing valuable insights into their cognitive abilities. These insights enabled the medical team to customize surgical planning and anticipate potential risks. **Conclusion.** The findings reinforce the growing body of evidence supporting the feasibility of teleneuropsychometric assessments in a resource-constrained environment and highlights their broader applicability within the domains of neuro-oncology.

Keywords: teleneuropsychometry; brain tumor; PEBL software; neuropsychological battery

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Background

The Inter Organizational Practice Committee (IOPC) definition of teleneuropsychiatry focuses on enabling clinical interactions and neuropsychological evaluations through teleconferencing technologies. Specifically, they characterize it as "the application of audiovisual technologies to allow for the conduct of clinical interactions with patients via teleconferencing to perform neuropsychological evaluations" (Bilder et al., 2020). In parallel, the Indian Psychiatric Society partnered with the Telemedicine Society of India and National Institute of Mental Health and Neurosciences to publish operational guidelines for telepsychiatry in May 2020 (Dinakaran et al., 2020). These guidelines aim to help standardize and regulate the growing practice of telepsychiatry in India. Teleneuropsychiatry and teleneuropsychometry have the potential to transcend geographical barriers between patients and healthcare professionals. The increasing accessibility of user-friendly smartphones and advances in communication technologies have facilitated greater digital inclusions across India, enabling broader access to remote healthcare services (Nadkarni et al., 2023). In light of this, the present study aimed to evaluate the feasibility of conducting teleneuropsychometric assessments for adult patients with brain tumors in eastern India, prior to surgical interventions. The patients were admitted to a tertiary care center in the region, where neuropsychological services were unavailable. The assessments were conducted remotely by a neuropsychologist based at an institute in southern India.

Case Presentation

Case 1. A young adult, high school graduate presented with a 3-year history of intermittent headaches accompanied by multiple episodes of convulsion. On examination, the patient's Mini-Mental State Examination (MMSE) score was 25/30 without any focal neurological deficit. The patient underwent a teleneuropsychometric assessment preoperatively. The battery of tests that were administered included tests of executive function: animal names test (verbal fluency), verbal *n*-back test (verbal working memory), Corsi Block Span Test (visuospatial working memory); tests of learning and memory: Rey Auditory Verbal Learning Test (verbal learning and memory), Rey-Osterrieth Complex Figure (ROCF) test (visual memory); and visuospatial ability: Osterrieth complex figure test (CFT; visuospatial construction). Corsi Block Span Test was administered using Psychology Experiment Building Language (PEBL) while the other tests were tests from the National Institute of Mental Health and Neurosciences (NIMHANS) neuropsychology battery. The patient had deficits in verbal working memory, verbal encoding, and visuospatial construction, indicating involvement of left frontal, left anterior temporal, and right parietal lobes. The patient reported no challenges in navigating the PEBL software, despite lacking prior experience with the platform. The result of the teleneuropsychometric assessment was validated through an in-person evaluation at the hospital, suggestive of a low-grade glioma. The additional confirmation of an irregularly shaped mass in the anterior left frontal lobe was provided by an additional sequence in the form of a contrast enhanced magnetic resonance imaging (CEMRI) scan. This mass was hyperintense on T2 weighted sequences and hypointense on T1 weighted images. With the patient's consent, an awake left frontal craniotomy was planned for lesion removal. The intricate surgery was performed with the utmost care and precision under local anesthesia to allow for meticulous intraoperative neurological monitoring. By the day's end, the entire space-occupying lesion (SOL) had been removed without complication. Postoperatively, the patient recuperated promptly with no new deficits and was fit for discharge on the second day after the procedure.

Case 2. A young adult with a middle school grade level of education presented with a history of right focal seizures with secondary generalization, without any history of focal neurological deficit. On examination, the patient's MMSE score was 29/30. The patient had right-sided conductive hearing loss secondary to chronic otitis media. The teleneuropsychometric assessment included the tests described in Case 1. The patient had deficits in verbal working memory, verbal encoding, and verbal and visual memory. Their teleneuropsychometric assessment was suggestive of left frontal and bilateral temporal involvement which was corroborated by an in-person neuropsychometric assessment. During teleneuropsychometry, the patient did not require any significant assistance and was able to use the PEBL software on their own. The patient's CEMRI brain showed the presence of T1 hypointense, T2 hyperintense, and noncontrast enhancing SOL in the left inferior frontal gyrus (Figure 1D, 1E, and 1F). The person underwent left frontal awake craniotomy and gross total excision of the tumor. The patient developed dysphasia and right hemiparesis which improved at the 3-month follow-up.

Methodology

This study employed a case-based observational design to explore the feasibility of teleneuropsychometric testing in preoperative neurosurgical patients. Two patients with different levels of education were enrolled according to their neurosurgical diagnosis, experience with digital technology, and access to a stable internet connection. Testing was conducted with PEBL software on Google Meet with minimal on-site supervision. The cognitive domains assessed were verbal fluency, working memory, visuospatial, verbal list learning, and visual memory consolidation. Feasibility measures of patient navigation, need for assistance, and technical problems were assessed.

Ethical Consideration

The study was conducted in keeping with ethical guidelines for online psychological testing and in line with institutional policies. Ethical compliance was reviewed in consultation with All India Institute of Medical Sciences (AIIMS) Bhubaneshwar. Written informed consent was taken from all the participants before the tests. Confidentiality was maintained by using secure data storage and transmission. The patients were informed about the voluntary nature of the tests and could withdraw at any point of time.

Measures

Verbal Fluency (Animal Naming Test). The animal naming task was used to assess verbal fluency and has been recognized as a valuable tool for evaluating cognitive function in patients with reduced phonemic fluency and other neurological disorders (Thwaites, 2018). In cases where patients exhibit nonspecific symptoms such as headaches, the test may serve as an early indicator of potential brain tumors. A low score—fewer than 17 animals named per minute—should prompt neuroimaging as the next step (Zienius et al., 2022).

Visuospatial Working Memory (Corsi Block Test). Visuospatial working memory was assessed using the Corsi Block-Tapping Test. This is especially useful for identifying cognitive deficits linked to neurological disorders. Block tap sequences must be replicated, and the Corsi span is the longest sequence that is accurately replicated. According to Kessels et al. (2000), this test has demonstrated usefulness in identifying cognitive impairment in a variety of neurological conditions including brain tumors. It can also be used in multilingual populations like India because of its nonverbal format. Impaired visuospatial working memory, which is frequently seen in patients with parietal or frontal lobe dysfunction, may be indicated by lower spans (usually less than five; Avons & Trew, 2006).

Verbal Learning and Memory (Auditory Verbal Learning Test [AVLT]). Verbal learning, recognition, and both immediate and delayed recall were evaluated using the AVLT. Over the course of five trials, participants were asked to recall a list of 15 words (Geffen et al., 1997). Following the introduction of a second list to evaluate interference, the first list was recalled both immediately and later. Total words remembered over five trials, delayed recall, and recognition were all factored in the scoring (Kessels et al., 2000). Healthy people typically remember 50–65 words during trials and more than 10 words after a delay (Poreh et al., 2016). Lower scores could indicate memory loss, which is frequently associated with dysfunction of the temporal lobe (Fernaeus et al., 2013). The AVLT's straightforward, language-adaptable format makes it appropriate for use in Indian contexts (Vakil & Blachstein, 2007).

Visuospatial Construction. Using the Rey-Osterrieth Complex Figure (ROCF) test, visual-spatial planning, memory, and construction were evaluated. To test visuospatial memory, participants were given a complex geometric figure to copy followed by immediate and delayed recall tasks. The accuracy and positioning of figure elements in the copy, immediate recall, and delayed recall conditions determined the score (Shin et al., 2006). According to Dassanayake et al. (2025), normative participants usually score between 32 and 36 on the copy phase. Lower recall scores suggest potential deficit in executive function or visuospatial memory (Fastenau et al., 1999). The ROCF's minimal reliance on language and nonverbal format make it appropriate for the Indian population (Langer et al., 2022).

Test Validation

The PEBL test battery was rigorously validated before being used to guarantee its validity and reliability in the study setting. Accurate assessments in India's multilingual environment depend on an understanding of linguistic background. According to research on verbal fluency tests, multilingual people who view English as their first language frequently outperform people for whom English is a second language. This underscores the necessity of integrating language skills into neuropsychological assessments to improve their precision across a range of backgrounds (Ferreira-Correia et al., 2024).

A systematic adaptation procedure was used to guarantee the linguistic and cultural appropriateness of the neuropsychological tests given through PEBL in this bilingual study. Important measures were taken to preserve the psychometric integrity of the test battery in participants who spoke Odia, even though the study concentrated on the viability of two neurosurgical cases.

Linguistic and Cultural Adaptation. Bilingual neuropsychologists and language specialists used a forward-backward translation protocol to translate the test instructions from English to Odia. To guarantee semantic and conceptual equivalency, disagreements were settled by consensus (Beaton et al., 2000). To ensure clarity and cultural relevance, the translated version was pilot tested with Odia speakers.

Viability in Participants. Two neurosurgical patients with varying educational backgrounds received the modified battery through teleneuropsychology. Language and face validity were confirmed by the fact that both participants finished tasks with little help and successfully understood instructions. Contextual sensitivity was further supported by the observation that working memory and verbal fluency performance patterns matched anticipated educational influences.

Reliability and Validity Evidence. Previous research has shown strong test–retest reliability for important PEBL tasks (e.g., attentional vigilance $r = .79$; pursuit rotor $r = .86$; Mueller & Piper, 2014; Piper et al., 2012) despite the fact that statistical reliability could not be tested in this two-case design. Due to their nonverbal culturally neutral design, PEBL tasks are ideal for use in multilingual contexts and have also demonstrated construct and criterion validity with recognized neuropsychological tests (Piper et al., 2012).

Even in a constrained case-based framework, these procedures made sure the modified PEBL battery was feasible, linguistically appropriate, and culturally relevant for preoperative patients who spoke Odia.

Setup

The setup used for teleneuropsychometric assessment included a standard personal computer (PC) running Windows 10 operating system, equipped with a HD webcam, speakers, and microphone. Face-to-face communication was facilitated via Google Meet, while the neuropsychometric assessment utilized the NIMHANS neuropsychology battery and PEBL software was used. PEBL is an open source psychology software that contains a battery of cognitive tests which can be customized for patient specific needs (Mueller & Piper, 2014) and is compatible with Windows, Linux, and MacOS operating systems (Mueller & Piper, 2014).

To ensure seamless test administration, TeamViewer software was used to remotely share the screen with the patient, allowing real-time interaction with the PEBL interface. The assessment was conducted in a distraction free room equipped with the aforementioned hardware and a stable internet connection. A chaperone was available on site to provide technical support as needed. The neuropsychologist administered the neuropsychometric assessment session remotely via Google Meet, ensuring real-time supervision and guidance.

Results

Neuropsychological Findings and Correlation With Imaging

In the first case, the neuropsychological assessment revealed deficits in verbal working memory, visuospatial working memory (Corsi block), and significant deficit in verbal and visual memory (AVLT and CFT). Performance on the verbal *n*-back test indicated working memory deficits, while the CFT showed difficulties in the visuospatial construction and recall. These findings are indicative of left frontal, left anterior temporal, and right parietal involvement, aligning with the imaging results showing a T1 hypointense and T2 hyperintense SOL in the left anterior frontal lobe (Figures 1A and 1B). The noncontrast-enhancing nature of the lesion (Figure 1C) further supports the structural basis for the observed cognitive dysfunction.

In the second case, the neuropsychological assessment identified deficits in verbal fluency, verbal working memory, verbal encoding, and both verbal and visual memory. Notably, the patient's performance was particularly impaired on the AVLT, verbal *n*-back test, and CFT. These findings are further supported by imaging that revealed a SOL in the left inferior frontal gyrus, characterized as T1 hypointense and T2 hyperintense (Figures 1D and 1E). The lack of contrast enhancement (Figure 1F) indicates a nonenhancing lesion that correlates with the observed cognitive deficits.

Discussion

One of the key global health challenges is overcoming the logistical barriers that confront adults with brain tumors in accessing preoperative neuropsychological testing. Technology provides a solution to the barriers, enabling more effective and accessible testing for those who require it.

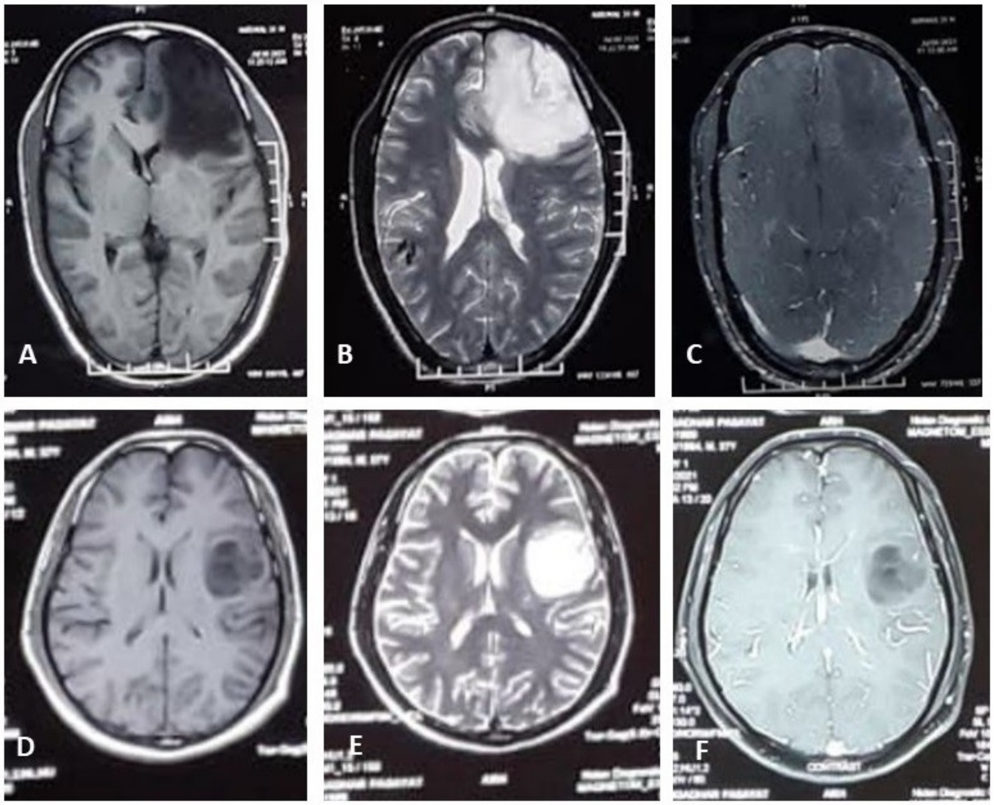
Feasibility of Teleneuropsychometric Assessement

This study involving two patients indicates that teleneuropsychometric assessment of preoperative neurosurgical patients is feasible. Despite the fact that one of the patients had a low educational background (middle grade), the patient had no difficulty in using and navigating the PEBL software. Both patients needed minimal assistance from the on-site supervisor during the conduction of the test.

Technological Penetration and Patient Adaptability

India has witnessed a surge in smartphone ownership over the last decade which has acclimated patients to utilizing technologically-enabled solutions routinely. This familiarity with technology portends well for incorporating digital platforms into clinical care. The battery of neuropsychological evaluations examined various cognitive domains through measures of verbal fluency, verbal working memory capacity, visuospatial sketchpad function, verbal list learning and subsequent recall, visual memory consolidation and retrieval abilities, and visuospatial construction skills. Following administration of the tests via the PEBL software and a Google Meet teleconference, the neuropsychologist furnished a structured interpretation of the assessment results.

Figure 1. *MRI Images Showing SOLs in Case 1 and Case 2.*



Note. SOL = space-occupying lesion. All images were acquired at 66 × 53 mm (300 × 300 DPI).
1A. Case 1. T1 weighted image showing a hypointense SOL in left frontal lobe.
1B. Case 1. T2 weighted image showing hyperintense appearance of SOL in the left frontal lobe.
1C. Case 1. Postcontrast image does not show any contrast enhancement.
1D. Case 2. T1 weighted image showing a hypointense SOL in left inferior frontal gyrus.
1E. Case 2. T2 weighted image showing hyperintense SOL in left inferior frontal gyrus.
1F. Case 2. Postcontrast image does not show any contrast enhancement.

Comparative Studies in Teleneuropsychometry

Similar teleneuropsychological assessments have been done in patients with Parkinsonism to assess their candidacy for deep brain stimulation (Sarno et al., 2022). A similar assessment of neurocognitive function was done using teleneuropsychometry in neuro-oncological patients by Gardner et al. (2021). They assessed teleneuropsychology as a direct-to-home service. They found that in 98% of the cases the neuropsychologists were able to fulfil the predetermined target of their assessment. Common problems were patient dysregulation and slow and unreliable internet. They identified the advantages of teleneuropsychometry as saving travel time, reduction in anxiety, and improved concentration due to the absence of examiner in the same room.

Reliability and Validity of Remote Assessment

Brearly et al. (2017) conducted a systematic review and meta-analysis to assess the effect of video conference administration of adult neurocognitive tests. They found that studies that utilized high-speed internet connections showed consistent performance in both teleneuropsychological and on-site assessment. On subgroup analysis, they found that verbally mediated tasks including digit span, verbal fluency, and list learning were unaffected by teleneuropsychometry. However, the Boston Naming Test score was one-tenth of a standard deviation less than the on-site score.

Implementation in the Indian Context

In the Indian setting, teleneuropsychiatry facilities have been provided to the inmates of central prisons by NIMHANS (Agarwal et al., 2019). The standard operating procedure of setting up a teleneuropsychometric service for neurosurgical patients should include staff training in the use of software being employed for testing and communication (Smolders et al., 2024). The patients should be selected carefully and guided through the whole process. No high-level or specialized hardware is required, a regular PC with a good internet connection is sufficient for teleneuropsychometric assessment. Some limitations include the lack of Indian norms for PEBL-based tests.

Limitations

Although the PEBL test battery was thoroughly checked for linguistic and cultural appropriateness using a forward-backward translation protocol, a significant drawback that impacts the findings' wider applicability is the absence of comprehensive Indian normative data. The test was effectively modified for participants who spoke Odia, yet extensive study is required to create uniform standards for India's heterogeneous multilingual groups. The results' generalizability is limited by the case-study design, which only examined two neurosurgical patients; further research is needed to validate these findings in a variety of contexts.

Even though PEBL's nonverbal tasks are culturally fair and ideal for multilingual settings, some tasks may still need further modification to improve their applicability in remote contexts. Test performance may be impacted by variations in internet connectivity, especially in remote or underprivileged areas, which could further complicate the teleneuropsychological evaluation procedure.

The reliability, validity, and generalizability of the results can be enhanced by future research involving a larger sample size and conducted across different linguistic groups in India. Addressing task adaptation and internet infrastructure challenges will further aid in improving the teleassessment methodology.

Implications and Future Direction

This particular investigation revealed that providing teleneuropsychometric services to individuals undergoing neurosurgery can successfully be achieved remotely. Regular administration of such remote evaluations will help expand access to care in regions with inadequate penetration of healthcare. As experience increases, future neuropsychometric assessments have the potential to be applied to additional pathologies like traumatic brain injury and postoperative cognitive rehabilitation. Establishing teleneuropsychometric services demands staff training, judicious patient selection, and structured testing procedures. Standard equipment suffices, though Indian norms for PEBL-based tests are still lacking. In conclusion, teleneuropsychometric assessments for neurosurgical patients prove to be feasible and reliable. Remote neuropsychometric care can enhance access to healthcare in underprivileged areas. Further validation may allow teleneuropsychometry to be extended to other conditions, such as head trauma and cognitive rehabilitation. The application of such services warrants additional research.

Conclusion

The neuropsychological test results validate the structural brain abnormalities detected in imaging, indicating specific impairments associated with identified lesions. These findings emphasize the essential findings of neuropsychological assessment in identification and localization of cognitive deficits within neurological conditions. The results confirm that teleneuropsychological assessments are both valid and feasible for evaluating neurosurgical patients. Remote neuropsychometric services can potentially improve access to healthcare in rural and underdeveloped regions. Teleneuropsychometry may be extended to other disorders such as traumatic brain injury and cognitive rehabilitation after further validation. The use of such services needs to be planned, trained, and developed in infrastructure terms to make it accessible and useful for the masses.

Author Declarations

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Electrophysiological and Behavioral Markers of Empathy-Mindfulness Associations in Novices: Evidence for "Empathic Affectfulness"

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Abstract

Objectives. This study explored how trait and state mindfulness relate to empathic traits in Indian novice meditators, using behavioral and electroencephalography (EEG) measures. **Methods.** Two independent samples were utilized. Sample 1 (*n* = 580) provided self-report data assessing empathy, mindfulness, and personality traits. Sample 2 (*n* = 97) underwent Ānāpānasati-based meditation, wherein EEG-based neural oscillations and self-reported feedback were assessed. **Results.** Trait mindfulness was positively associated with perspective taking (PT) and negatively with personal distress (PD), independent of personality traits. State mindfulness showed feeble associations: discontinuity of mind (DOM) correlated positively with PD and prefrontal cortex (PFC) beta power, while theory of mind (TOM) positively related with PT. PT was also linked to a lower PFC gamma; thereby, both PT and PD possibly reflected impedance towards novice meditative states. Post hoc, empathic affectfulness (EA)—conceptualized as "PT minus PD"—emerged as a potential marker of affect-conscious empathy, showing modest state-wise association with lower DOM and PFC beta-gamma activity, and strong positive interrelationship with trait mindfulness. **Conclusions.** PD consistently demonstrated negative correlations with mindfulness. In contrast, PT, although positively associated with EA and trait mindfulness, seemed to hinder novice meditation by promoting unnecessary mentalizing in state contexts. Overall, the empirical findings supported EA plausibly as a novel mechanism.

Keywords: trait empathy; trait mindfulness; state mindfulness; ānāpānasati-meditation; electroencephalography (EEG)

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Introduction

Empathy and mindfulness are among the most prominent constructs in psychological research, influencing well-being, interpersonal relationships, and prosocial behavior (K. W. Brown et al., 2007; K. W. Brown & Ryan, 2003; Telle & Pfister, 2016). Empathy encompasses the ability to understand and share the feelings of others, facilitating social connections and emotional communication (He et al., 2022). Mindfulness, on the other hand, refers to the practice of maintaining a moment-to-moment awareness of experiences, thoughts, and emotions in a nonjudgmental manner.

Defining Trait Empathy, State Mindfulness, and Trait Mindfulness

Empathy is the ability of individuals to perceive and respond to the thoughts and emotions of others. Trait or dispositional empathy refers to a consistent personality characteristic that reflects this ability (Himichi et al., 2021). Trait empathy is typically categorized into two main components: emotional empathy, which involves the often automatic experience of sharing others' emotions, and cognitive empathy, which is the conscious ability to recognize and understand others' thoughts and feelings (Goldman, 2011). These components were further divided by Davis (1983) in a four-dimensional structure: perspective taking (PT), empathic concern (EC), personal distress (PD), and fantasy (FS). PT reflects the cognitive ability to adopt another's viewpoint, facilitating understanding and communication. EC pertains to the emotional capacity to feel compassion and concern for others, motivating prosocial behavior. PD involves self-oriented emotional responses, such as anxiety or discomfort, in reaction to others' distress. FS measures the tendency to identify with characters in fictional scenarios, indicating imaginative empathy.

Mindfulness is the ability to be aware of and attentive to the body, thoughts, environment, sensations, and feelings (K. W. Brown & Cordon, 2009). It may be a personality trait (i.e., trait mindfulness) but also temporarily achieved via an activity as meditation (i.e., state mindfulness; Goilean et al., 2023). Trait mindfulness (TMIND) encompasses five primary subdimensions, as evaluated through the self-report Five-Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006). These subdimensions include observing (OBS), which involves noticing internal and external experiences; describing (DES), which pertains to labeling experiences with words; acting with awareness (AA), which refers to engaging in tasks with full attention; nonjudging of inner experience (NJ), which entails refraining from evaluating thoughts and feelings; and nonreactivity to inner experience (NR), which involves allowing thoughts and emotions to pass without impulsive reactions. Baer et al. (2006) proposed that these facets collectively shape an individual's mindfulness and influence emotional regulation and well-being.

Similarly, state mindfulness (SMIND) can be tested along different dimensions of resting-state cognition (Brahmi et al., 2025a; Diaz et al., 2013). One widely used measure, the Amsterdam Resting State Questionnaire (ARSQ), evaluates seven key dimensions: discontinuity of mind (DOM), which reflects mind wandering and distractions; planning (PLN), which captures future-oriented thinking; comfort (CMF), assessing physical and emotional ease; sleepiness (SLP), indicating drowsiness or the urge to sleep; somatic awareness (SOA), which measures awareness of bodily sensations; self (SLF), reflecting self-focused attention; and theory of mind (TOM), which gauges thoughts about others' perspectives. These factors collectively provide insight into the dynamic and fluctuating nature of SMIND during nonmeditative, restful periods (Diaz et al., 2014).

The Interrelationship Between Empathy and Mindfulness

Although these constructs have been established to be distinct, research indicates a complex relationship between them (Wallmark et al., 2013). Mindfulness practices, particularly those involving meditation, have been shown to enhance empathy by fostering greater emotional awareness and regulation (Fulton & Cashwell, 2015; Jones et al., 2019). For instance, mindfulness-based interventions have demonstrated moderate effects in improving empathy among healthy populations, with longer and more intensive interventions yielding stronger outcomes (Cheang et al., 2019; Hu et al., 2022; Liberman et al., 2024; Silveira et al., 2023). Additionally, studies suggest that certain facets of mindfulness, such as OBS and AA, are positively correlated with cognitive empathy, while facets like NR may be inversely related to emotional empathy (Cooper et al., 2020; Fuente-Anuncibay et al., 2020; Himichi et al., 2021).

While mindfulness-based practices have been widely studied for their effects on empathy and related psychological outcomes, the underlying nuanced mechanisms, particularly in novice meditators within specific cultural contexts like India, remain underexplored (Hu et al., 2022; Lim et al., 2015). In the Indian context, mindfulness practices like yoga and meditation are integral to cultural and spiritual traditions (Anālayo, 2021; Kirmayer, 2015). Therefore, research has begun to explore how these practices influence psychological traits; for example, a study found that yoga and meditation practitioners exhibited higher levels of empathy and self-transcendence compared to nonpractitioners (Sarathe, 2022). However, more comprehensive studies on broad Indian populations remain scarce (Fuente-Anuncibay et al., 2019). Therefore, the present study aims to bridge the gap by investigating the associations between novice mindfulness and empathy within the Indian cultural settings.

The Present Research

This research aimed to examine how trait and state mindfulness are associated with trait empathy in a large Indian novice meditator sample. First, the association between trait empathy and trait mindfulness was explored, while accounting for the influence of individual personality traits; and later, gender and academic inclination. Second, the study examined the relationship between trait empathy and state mindfulness using self-reported behavioral data collected from participants during a tri-stage Ānāpānasati-based meditation intervention (Brahmi et al., 2024a; Brahmi et al., 2025b). Lastly, this study explored EEG-based spectral powers recorded during the same tri-stage meditation intervention to look at the neural correlates of novice SMIND and its association with trait empathy.

Methodology

Participants

This study included two separate samples: Sample 1 (*n* = 580) took a series of asynchronous self-report questionnaires, and Sample 2 (*n* = 97) was involved in an in-person evaluation. The research adhered to the ethical guidelines of the Indian Council of Medical Research (ICMR) and received approval from the Institute Ethics Committee of the Indian Institute of Technology, Delhi (IEC-IITD; Proposal No. P021/P0101). All participants provided informed consent prior to their participation in the study.

Sample 1. A total of 580 respondents (50.17% female; mean age = 22.52 years; *SD* = 4.45 years) affiliated with Indian universities at various levels and proficient in English were recruited using purposive and snowball sampling techniques. They completed three self-report questionnaires online, namely: the Interpersonal Reactivity Index (IRI), FFMQ, and International Personality Item Pool Big-Five Factor Markers (IPIP-BFM). They also provided basic demographic information, including gender and academic streams (STEM and non-STEM), to act as additional controls.

Sample 2. A total of 97 predominantly male novice meditator students (90 males) were recruited through convenience sampling with the same eligibility requirements as Sample 1 to ensure comparability (mean age = 24.59 years, *SD* = 5.18 years). Of this, 87 consented to concurrent EEG examination (82 males). This in-person sample began with a stress-inducing arithmetic task for 30 min, simulating the daily life stressors, followed by a tri-stage meditation intervention inspired by an ancient mindfulness technique called Ānāpānasati (Brahmi et al., 2025a; Sivaramappa et al., 2018, 2019). Subsequently, it involved a resting state (RS: 5 min), followed by a period of breath counting (BC: 5 min), and lastly a silent breath focus (BF: 8–10 min) stage. SMIND was then measured via the ARSQ.

Instruments

Behavioral Self-Report Questionnaires. Participants in Sample 1 completed three behavioral measures. The IRI was used to measure trait empathy and its four subscales (Davis, 1980). It was chosen for its established application and satisfactory psychometric properties in the collectivistic context (Brahmi et al., 2024b; Siu & Shek, 2005). The reliability coefficients Cronbach's α and McDonald's ω for the subscales in Sample 1 were found to be PT (α = .619, ω = .656), FS (α = .719, ω = .737), EC (α = .676, ω = .68), and PD (α = .646, ω = .663). Further, TMIND was assessed using the five dimensions of the FFMQ (Baer et al., 2013). Use of the FFMQ in literature supports examining the impact of mindfulness-based interventions and the structural differences influenced by individual meditation experience (Baer et al., 2006; Bohlmeijer et al., 2010; Lilja et al., 2012). Cronbach's α and McDonald's ω for the subscales in Sample 1 were OBS (α = .732, ω = .740), DES (α = .805, ω = .808), AA (α = .859, ω = .859), NJ (α = .831, ω = .832), and NR (α = .726, ω = .729). The total TMIND score (α = .814, ω = .823) also exhibited strong reliability.

To control for personality traits, the IPIP-BFM was employed, which assesses extraversion (EX), agreeableness (AG), conscientiousness (CT), neuroticism-inverted (or emotional stability, N'), and openness to experience (OC; Goldberg, 1992). The IPIP-BFM is a well-validated instrument with prior studies in Indian personality research (Arora & Rangnekar, 2016; Brahmi et al., 2024b). Cronbach's α and McDonald's ω for the personality subscales in Sample 1 were as follows: EX (α = .786, ω = .788), AG (α = .689, ω = .72), CT (α = .699, ω = .702), N' (α = .815, ω = .823), and OC (α = .726, ω = .742).

Lastly, the ARSQ was employed on Sample 2, posteriori the completion of the tri-stage intervention to assess SMIND (Diaz et al., 2013). The questionnaire integrates insights from cognitive psychology, neuroimaging, and research on the default mode network (Buckner et al., 2008; Smallwood & Schooler, 2006). Additionally, it has been utilized in apriori studies involving Indian novice meditators (Brahmi et al., 2024a; Brahmi et al., 2025a). Cronbach's α and McDonald's ω for its seven dimensions in Sample 2 were as follows: DOM (α = .64; ω = .66), TOM (α = .661; ω = .675), SLF (α = .654; ω = .709), PLN (α = .773; ω = .783), SLP (α = .796; ω = .811), CMF (α = .813; ω = .824), and SOA (α = .596; ω = .608).

Overall, all the subdimensions of all the employed self-reports had demonstrated satisfactory interitem reliability and construct validity within the two samples through Jamovi's Factor module, making the data fit to proceed (T. A. Brown, 2015; Cronbach, 1951; Pruzek, 2005; Revelle, 2024).

Electroencephalography (EEG). EEG data were recorded using Brain Products' Recorder Software (v1.25.001) and EasyCap system, employing a 64-Ag/AgCl electrodes configuration aligned with the extended International 10–20 system, at a sampling rate of 500 Hz (Homan et al., 1987). The impedance levels of the electrodes were consistently maintained between 5 and 15 kΩ across the three experimental stages in Sample 2. FCz served as the reference electrode and AFz as the ground. Signals were amplified using a LiveAmp (Brain Products) and filtered with a third-order sinc low-pass filter (.01–131 Hz).

Preprocessing and spectral analyses were conducted using MATLAB R2021a and EEGLAB v2023, employing the Artefact Subspace Reconstruction-Independent Component Analysis (ASR-ICA) methods (Delorme & Makeig, 2004; Plechawska-Wójcik et al., 2023). Notably, only the middle two-thirds of meditation segments were selected (Rodriguez-Larios et al., 2020), and data were downsampled to 250 Hz. An IIR-Butterworth bandpass filter (1–60 Hz) and a line noise removal Zapline notch filter (50 Hz) were then applied (de Cheveigné, 2020). Further, artefact correction was achieved employing the ASR-cleandata method (Chang et al., 2020). Therein, channels with spectral power deviating more than ± 3 standard deviations were omitted. Subsequently, ICA decomposition, IC labeling, and IC rejection were conducted to eliminate noise with labels exceeding 0.5 (Chang et al., 2020; Pion-Tonachini et al., 2019). Lastly, interpolation was conducted on bad channels and the online reference channel (FCz), reprocessing the EEG data, whereafter mean-mastoid rereferencing was applied to all channels.

Spectral power indices were extracted from the preprocessed-rereferenced data using EEGLAB's eegstats plugin (Version 1.2), which applied a Fourier transformation to convert signals from the time to the frequency domain. Average power (dB/Hz) was computed per participant and across all channels for each of the three stages of the tri-stage paradigm. These analyses focused on five frequency bands, delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–60 Hz); over three brain regions, the midline default mode network (DMN), the prefrontal cortex (PFC), and the occipital region (OCC), as follows:

- OCC Electrodes: O1–2, Oz, PO3–4, POz (Elvsåshagen et al., 2014)
- PFC Electrodes: FP1–2, AF3–4, AFz, F1–F4, Fz (Michels et al., 2010)
- DMN Electrodes (excluding PFC): CP1–CP4, CPz, P1–P4, Pz, PO3, PO4, POz, Oz (Fomina et al., 2015)

Statistical Analysis

The associations between trait empathy and trait mindfulness in Sample 1 were examined using correlation and linear regression. Additionally, to assess whether these associations were confounded by personality traits (Brahmi et al., 2023; Persson & Kajonius, 2016), it was controlled by using hierarchical regression (Toto et al., 2014). The significance level was adjusted to .0125 for the multiple comparisons, given the four IRI subscales, through Bonferroni correction in the analyses conducted.

The interrelationships between empathic traits and state mindfulness in Sample 2 were investigated similarly. Herein, Bonferroni corrections again adjusted the significance threshold to .0125 for the four concurrent tests. Lastly, in Sample 2, the EEG spectral correlates associated with state mindfulness were examined for interrelationships with empathic traits. Notably, EEG spectral correlates were considered during the BF-stage only, towards assessing state mindfulness, as the RS and BC stages were conceptually priming stages towards the final Ānāpānasati-based BF stage (Brahmi et al., 2025a). Further, these spectral correlates were considered a unified factor when applying Bonferroni corrections to avoid overly conservative significance levels owing to the large number of comparisons. Significance thresholds were accordingly adjusted, with alpha set at .0125 given the four empathy subscales' comparisons. Due to the male-dominated nature of the Sample 2, despite prior research indicating an absence of statistically significant gender differences in trait and state mindfulness, these analyses were considered exploratory (Brahmi et al., 2025a).

All of the correlations (Pearson's), linear regression, hierarchical regression analyses, and post statistical assumptions' validation were executed in R-Jamovi utilizing "car" package (Fox & Weisberg, 2018; Richardson & Machan, 2021); barring in Sample 2, which employed robust correlations, based on percentage bend algorithm, executed in WRS2 package in R (Mair & Wilcox, 2020), accounting for the ill-effects of skewed data distributions and outliers.

Results

Associations Between Trait Empathy and Trait Mindfulness (Sample 1)

Correlations and Linear Regression Analyses. Correlation and regression analyses examined the associations between trait empathy dimensions and trait mindfulness facets (Table 1). The TMIND was significantly positively correlated with PT and EC, and negatively correlated with PD. Among the subdimensions, OBS, DES, and AA were the most consistently and positively associated with empathy components, particularly PT and EC. Conversely, PD showed strong and widespread negative associations across most mindfulness dimensions, suggesting that greater dispositional mindfulness is linked to lower levels of distress in emotional empathizing contexts. Overall, these patterns suggest that higher trait mindfulness is broadly associated with enhanced cognitive empathy, particularly PT, and reduced affective overwhelm, as reflected in lower PD (Harari et al., 2010).

Linear regression analyses supported these findings. TMIND significantly predicted each empathy dimension, with the largest proportion of variance explained for PD. The individual trait mindfulness facets also emerged as significant predictors across multiple empathy outcomes. Notably, PT was positively predicted by OBS, DES, and AA, while PD was negatively predicted by all subscales of trait mindfulness besides OBS. Together, these findings indicate that cognitive empathy is generally positively associated with trait mindfulness, particularly in terms of PT. In contrast, affective empathy shows a more complex pattern: while EC is modestly enhanced by mindfulness, PD is substantially reduced, suggesting a buffering effect of novice TMIND on emotional empathic reactivity.

Table 1

Coefficients of Correlation and Linear Regression Conducted Between Trait Empathy Dimensions and Trait Mindfulness Dimensions

Dimensions of Trait Mindfulness			Dimensions of Trait Empathy			
			EC	PT	FS	PD
	TMIND	R^2	0.0858***	0.118***	0.0876***	0.241***
		r	0.133**	0.265***	−0.086*	−0.452***
		β	0.133***	0.265***	−0.0856*	−0.452***
	OBS	*r*	0.148***	0.244***	0.202***	−0.031
		β	0.157***	0.1635***	0.2136***	−0.0101
	DES	*r*	0.177***	0.228***	−0.001	−0.276***
		β	0.139***	0.1476***	0.0168	−0.1619***
	AA	*r*	0.136***	0.136***	−0.164***	−0.335***
		β	0.152***	0.1524***	−0.1133*	−0.1712***
	NJ	*r*	−0.052	−0.046	−0.195***	−0.372***
		β	−0.121**	−0.0831	−0.1142*	−0.2991***
	NR	*r*	-0.071	0.186***	−0.026	−0.155***
		β	−0.153***	0.1057*	−0.131**	−0.1791***

Note. * $p < .05$; ** $p < .0125$; *** $p < .001$ (After the Bonferroni corrections, only the *p*-values having ** and *** were taken as significant, as the significance threshold was set at .0125). TMIND implies OBS + DES + AA + NJ + NR. TMIND = trait mindfulness, OBS = observing, DES = describing, NJ = nonjudging of inner experience, NR = nonreactivity to inner experience, AA = acting with awareness, EC = empathic concern, PT = perspective taking, FS = fantasy, PD = personal distress.

Hierarchical Regression Analyses. To assess whether the mindfulness trait explains unique variance in trait empathy beyond broad personality traits, hierarchical regressions were conducted using the IPIP-BFM as control variables in Step 1, followed by the trait mindfulness subcomponents in Step 2 (Table 2). TMIND contributed small yet significant additional variance in the prediction of PT, FS, and PD. Looking at the individual facets, PT remained significantly and positively predicted by TMIND and specifically by NR. In the case of PD, the addition of trait mindfulness explained a meaningful reduction in distress, with NJ and TMIND emerging as significant negative predictors. Also, FS related positively with OBS, however, not with the TMIND. These findings suggest that the capacity to understand others' perspectives is linked to the novice's ability to remain nonreactive to internal states, while a less judgmental attitude is associated with a diminished experience of emotional empathetic distress.

Table 2

Hierarchical Regression Conducted Between Trait Empathy Dimensions and Trait Mindfulness Dimensions After Controlling for Personality Traits

		Dimensions of Trait Empathy			
		EC	PT	FS	PD
Step 1 R^2 (%)		39.8***	22.8***	14.7***	29.7***
Step 2 R^2 (%)		40.9***	26.9***	18.3***	33.4***
ΔR^2 (%)		1.18*	4.02***	3.61***	3.61***
β for Dimensions of Trait Mindfulness	OBS	0.0352	0.0732	0.15***	−0.00331
	DES	0.0567	0.0657	−0.0782	−0.0926*
	AA	0.0801	0.0908	−0.0627	−0.05664
	NJ	−0.0472	−0.0556	−0.0844	−0.17413***
	NR	−0.0718	0.1442***	−0.0785	−0.06741
	TMIND	0.0426	0.1656***	−0.0844	−0.2142***

Note. * $p < .05$; ** $p < .0125$; *** $p < .001$ (After the Bonferroni corrections, only the *p*-values having ** and *** were taken as significant, as the significance threshold was set at .0125). TMIND implies OBS + DES + AA + NJ + NR. The given beta values are exclusive betas calculated after controlling for personality traits. TMIND = trait mindfulness, OBS = observing, DES = describing, NJ = nonjudging of inner experience, NR = nonreactivity to inner experience, AA = acting with awareness, EC = empathic concern, PT = perspective taking, FS = fantasy, PD = personal distress.

Post Hoc Statistical Analysis. The statistical analysis conducted to investigate the interrelationships between trait empathy and trait mindfulness revealed significant correlations, specifically between trait mindfulness and the PT and PD dimensions of trait empathy. Moreover, the positive association of PT and the negative association of PD with trait mindfulness persisted even after accounting for personality traits, highlighting a distinct relationship between these factors (Figure 1). Subsequent post hoc statistical analyses were considered by combining these facets as PT minus PD, which was later named empathic affectfulness (EA). Bonferroni corrections were applied, herein, adjusting the significance levels to .008 for six independent tests.

Post hoc analyses found significant positive correlations between EA and all the dimensions of trait mindfulness, including the composite TMIND (Table 3). Linear regression analysis further supported these influences, with TMIND explaining substantial variance as a positive significant predictor. Additionally, hierarchical regression revealed that all mindfulness dimensions accounted for substantial variance, controlling for personality, gender, and academic choices; with ΔR^2 = 4.06% for OBS + DES + AA + NJ + NR and ΔR^2 = 3.66% for TMIND, the latter serving as a significant predictor of EA (β = .26204, Padj < .008). These results indicate the role of novice TMIND in promoting empathic understanding of others and alleviating emotional distress, consequently underlining the emergent phenomenon of EA (Birnie et al., 2010).

Table 3

Coefficients of Correlation and Linear Regression Conducted Between Empathic Affectfulness and Dimensions of Trait Mindfulness, Besides and Beyond the Influence of Personality Traits, Gender, and Academic Choices

Dimensions of Mindfulness (N = 580)	Correlation Coefficient (r) with EA	β Towards EA	Exclusive β Towards EA
OBS	0.18***	0.113**	0.04956
DES	0.347***	0.213***	0.10947**
AA	0.33***	0.222***	0.09961*
NJ	0.24***	0.163***	0.09046*
NR	0.232***	0.198***	0.14179***
TMIND	0.498***	0.4972***	0.26204***

Note. * $p < .05$; ** $p < .01$; *** $p < .008$ (After the Bonferroni corrections, only the p-values having *** were taken as significant, as the significance threshold was set at .008). TMIND implies OBS + DES + AA + NJ + NR. EA implies PT minus PD. The exclusive β is calculated after controlling for personality traits, gender, and academic choices. EA = empathic affectfulness, OBS = observing, DES = describing, NJ = nonjudging of inner experience, NR = nonreactivity to inner experience, AA = acting with awareness.

Interrelationships Between Trait Empathy and State Mindfulness (Sample 2)

Correlations and Linear Regression Analyses. Correlation and linear regression analyses explored the associations between trait empathy and novice state mindfulness facets. Although no correlation results survived Bonferroni correction, three moderate associations emerged at the uncorrected threshold (Table 4). Specifically, PT showed a positive correlation with TOM, and PD was positively associated with DOM. Additionally, SMIND composite scores (Brahmi et al., 2025b) were negatively correlated with PD, suggesting that greater present-centered awareness may buffer against affective reactivity and emotional overwhelm. Linear regression supported these findings, with TOM significantly predicting PT (R^2 = 6.75%, p = .01, β = .26) and DOM predicting PD (R^2 = 6.29%, p = .013, β = .251).

These patterns, although weak, indicate that empathic traits of PT and PD may have impacted novice SMIND, owing to overemphasized perspectivation and mental restlessness, respectively. Due to weak results in correlation and linear regression, further hierarchical regression was not pursued.

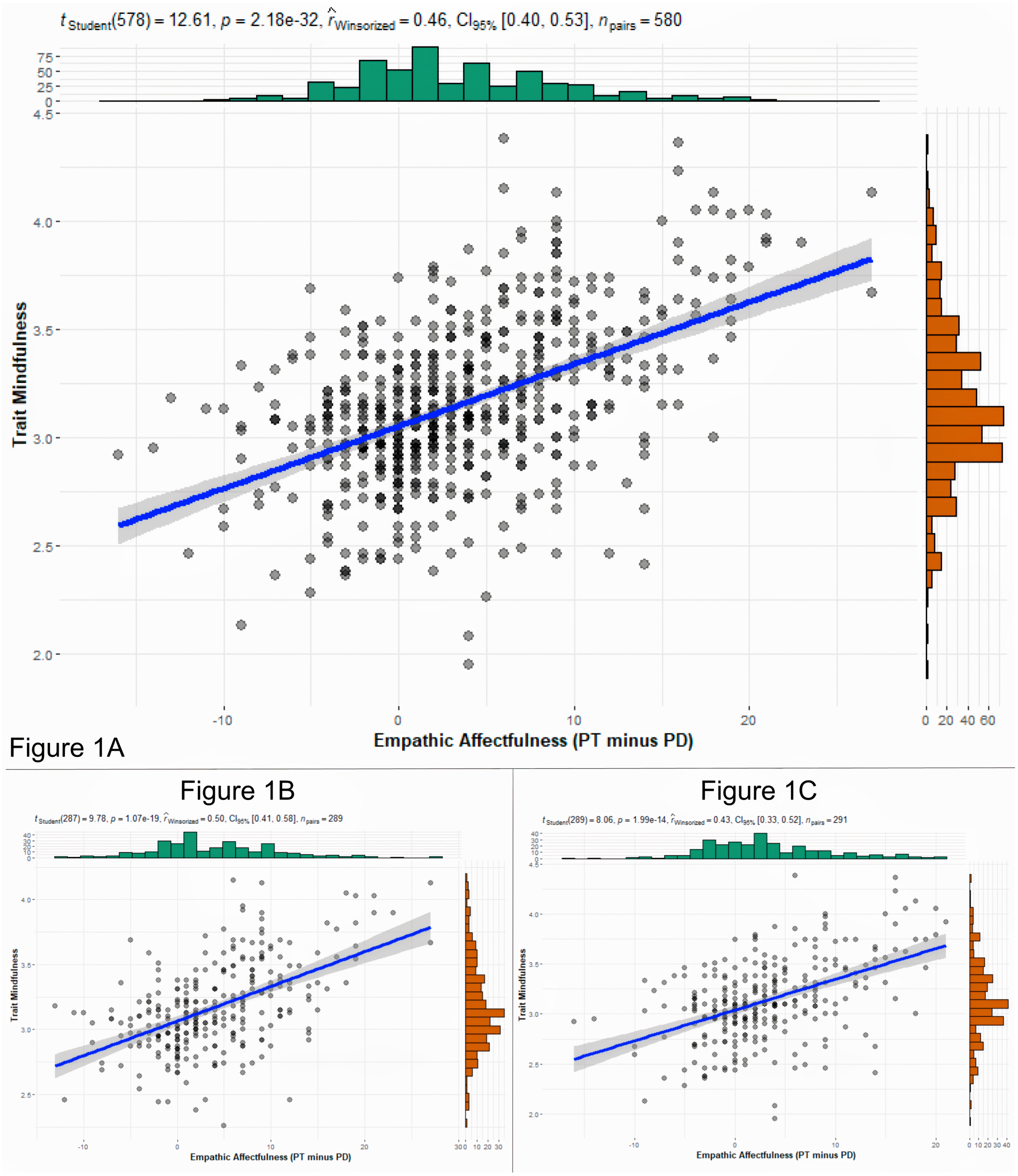
Post Hoc Statistical Analysis. Based on the observed associations of PT-TOM and PD-DOM, post hoc analysis was conducted, finding a negative association between EA (PT minus PD) and DOM (β = −.29, R^2 = 8.42%, p = .004). Furthermore, a partial correlation exploration revealed a significant negative association between EA and DOM ($r_{partial}$ = −.255, p < .001), post controlling for the residual empathy factors, and other state mindfulness subdimensions. The findings suggest that fragmented thoughts, as observed during meditation, are inversely associated with the novice's mindful capacity to empathize with others without being emotionally overwhelmed.

Associations Between State Mindfulness' EEG Spectral Correlates and Trait Empathy (Sample 2)

Exploratory analyses revealed no significant associations between trait empathy and EEG spectral correlates of state mindfulness at the corrected level (α = .0125). However, PT marginally correlated negatively with PFC gamma power (r = −.255, p = .0158), and this was considered in the context of the present analysis.

Post Hoc Statistical Analysis. Upon post hoc analysis, both the high frequency spectral powers in the PFC region associated negatively and significantly with EA (PFC-β: r = −.25, p = .0182; PFC-γ: r = −.266, p = .0118). Besides, given that self-reported DOM during the BF stage of the intervention was revealed to be negatively correlated with EA, an association of positive nature was further observed between PFC beta power and DOM (r = .293, p = .0053). No such association was observed between TOM and PFC gamma power, to mirror the observed self-reported association of PT-TOM.

Figure 1. *Scatter Plots With Marginal Histograms Illustrating the Correlation Between Trait Mindfulness and Empathic Affectfulness (EA).*



Note. Scatter plots with marginal histograms illustrating the correlation between trait mindfulness and EA (Computed as PT minus PD) in (A) Total sample (*N* = 580; Males = 289; Females = 291), (B) Males-only (*N* = 289), and (C) Females-only (*N* = 291).

Marginal histograms along the right and top axes visualize the distributions of trait mindfulness and EA, respectively, using parametric statistics. Plots were generated using '*ggstatsplot*' (Wickham et al., 2007) and '*ggplot2*' (Patil, 2024) via the '*ClinicoPath*' *Jamovi* Module (Balcı, 2020).

Table 4
Correlation Coefficients (r) Between State Mindfulness and Trait Empathy

		Dimension of Trait Empathy			
		EC	PT	FS	PD
Dimension of State Mindfulness	DOM	0.029	−0.166	0.012	0.251*
	TOM	0.084	0.26*	0.153	0.054
	SLF	0.072	0.081	0.112	0.092
	PLN	0.022	−0.009	−0.031	0.121
	SLP	−0.022	0.054	−0.019	0.137
	CMF	−0.127	0.087	0	−0.175
	SOA	0.023	0.029	0.05	0.027
	SMIND	−0.078	−0.049	−0.052	−0.229*

Note. * $p < .05$; ** $p < .0125$; *** $p < .001$ (After the Bonferroni corrections, only the p-values having ** and *** were taken as significant, as the significance threshold was set at .0125). SMIND implies CMF + SOA–TOM–DOM–SLF–PLN–SLP. EC = empathic concern, PT = perspective taking, FS = fantasy, PD = personal distress, DOM = discontinuity of mind, TOM = theory of mind, SLF = self, PLN = planning, SLP = sleepiness, CMF = comfort, SOA = somatic awareness.

The findings implied that a higher EA and PT was related to reduced high-frequency (beta-gamma) and gamma activity, respectively, in the PFC region during novice breath-focused meditative states. In continuation of the EA-DOM negative association, EA was linked inversely to both DOM and PFC beta power, while the latter two associated positively.

Discussion

This study examined the interrelationships of trait empathy with trait and state mindfulness in novice Indian meditators, employing a trait-only behavioral-only Sample 1 and a mixed trait-state Sample 2 with a combined neurobehavioral approach. The findings shed light on the role of novice mindfulness, both as a stable trait and as a transient state, in modulating empathetic traits.

Novice Mindfulness Traits, Empathetic Traits, and the Emergent EA Mechanism

The correlational and regression results in Sample 1 unveiled significant negative and positive associations of empathic traits of PD and PT, respectively, with novice TMIND, after controlling for personality trait effects. Furthermore, the novice TMIND's dimensions of NR and NJ were independently interrelated, sans personality traits, given their positive and negative associations with PT and PD, respectively. Therefore, novice TMIND is significantly associated with an enhanced ability to adopt others' perspectives (PT) and a reduction in self-oriented empathic distress (PD). This mechanism was termed as EA, and similar empirical results have been observed in Western samples (Cooper et al., 2020; Fuente-Anuncibay et al., 2019; Kingsley, 2009). This aligned with previous research indicating that mindfulness fosters greater emotional regulation and cognitive flexibility, which are essential for affective empathy (Fulton & Cashwell, 2015; Jones et al., 2019).

Upon post hoc investigation in behavioral-only Sample 1, towards the EA variable curated as "PT minus PD," persistent evidence was observed in correlation and hierarchical regression analyses, the latter controlling for academic choices, personality, and gender factors. Therefore, in these findings, EA emerged as a plausible novel mechanism, associated robustly with novice TMIND, reflecting the empathetic capacity to perspectivize and share others' mental states without becoming emotionally overwhelmed by them. Overall, on the basis of EA's positive association with TMIND, its naming reflected the underlying rationale, wherein *empathic* denotes enhanced perspectivizing, while *affectfulness* captures an attunement to, rather than entanglement with, the concomitant affective distress. Finally, regarding the EA's internal mechanisms, hierarchical regression indicated in Sample 1 a NR-PT-NJ-PD-EA nexus, wherein TMIND's subdimensions of NR and NJ were associated with EA's configuration with a favorable PT and an attenuated PD, respectively.

Novice State Mindfulness, Empathetic Traits, and EA

While SMIND assessed in Sample 2 demonstrated limited predictive power in its analyses, nontrivial patterns emerged that support the idea of momentary mindfulness functioning as a modulator rather than a predictor of empathic responses (Fuente-Anuncibay et al., 2019). Specifically, yet weakly, during the breath-focus stage of the SMIND intervention, TOM was positively correlated with PT, whereas PD was correlated positively and negatively with DOM and overall SMIND, respectively. Despite the feeble results, findings pointed to the idea that elevated empathic traits of PT and PD may have impacted novice SMIND, owing to the overemphasized perspectivation and mental restlessness, respectively (Brahmi et al., 2025b; Diaz et al., 2014). Lastly, EA's negative robust association with DOM was found post hoc, further strengthening its positive correspondence with mindfulness state- and trait-wise, overall, behaviorally. Since a lower DOM is indicative of reduced mind-wandering (Hoseinian et al., 2019). The associations of TOM-PT and DOM-PD, as well as their relationship with EA, thus emphasize the importance of present-centered awareness (K. W. Brown & Ryan, 2003).

Overall, an absence of strong correlational findings in self-reported SMIND may be due to the unstable nature of novice meditative states, as novices frequently exhibit variability in applying their trait-level mindfulness to actual meditation experiences (Baer et al., 2006). Nevertheless, behavioral findings across both samples indicated that novice trait and state mindfulness were moderately yet consistently associated with the empathic dimensions of PT and PD.

The EEG-based SMIND assessment observed feeble yet significant associations: EA's negative relation with PFC beta-gamma powers, PT's negative association with PFC gamma power, and DOM's positive interrelation with PFC beta powers. Besides, gamma enhancement has been traditionally linked to long-term mindfulness expertise, especially for Vipassana-type interventions, similar to the one used herein (Braboszcz et al., 2017; Cahn et al., 2010). Thereupon, a possible explanation could be that a lower empathic perspectivising trait might aid the novice meditators to be more aware of their breaths, since self-report also indicated, albeit weakly, the positive association of TOM and PT. Thus, plausibly hinting that a high PT and EA may entail increased mentalizing in daily life but may be detrimental during meditative focus in novices (Brahmi et al., 2025b). Further, the interrelation of a reduction and an increase in PFC beta powers with EA and DOM, respectively, might entail that a higher EA trait is reflected by lesser cognitive interference and relative ease in disengaging from distractive thought patterns. In literature, the role of PFC beta oscillations is unclear in meditative contexts, however, its decrease has been associated with long-term meditation expertise (Lee et al., 2018). Therefore, given the DOM-EA-PFC beta triangulation in the present sample, these oscillations might indicate a less effortful meditative breath-focus for novices with a higher EA trait.

Nevertheless, the SMIND neurobehavioral results should be interpreted with caution, given their small effect sizes, gender-skewed sample, and exploratory nature, warranting further validation through longitudinal or qualitative-based research designs.

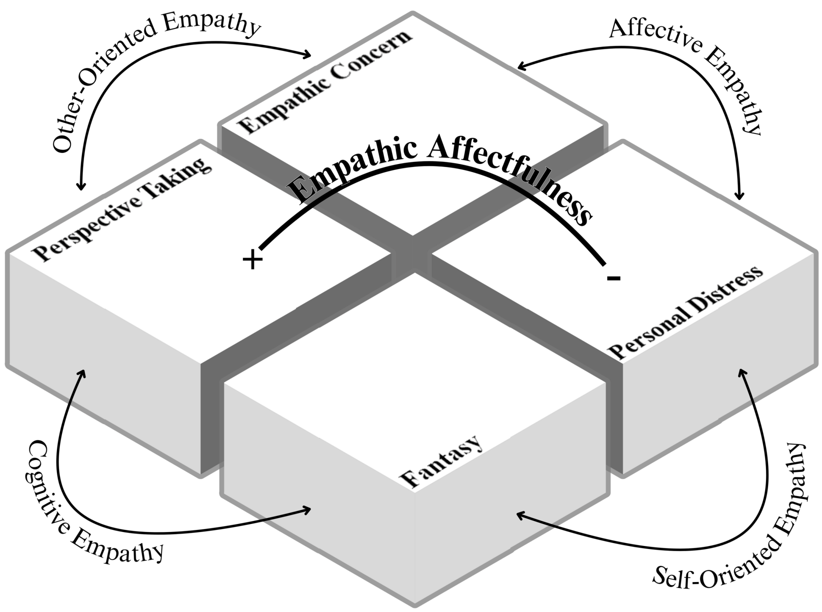
EA: Regulating Empathetic Overdrive

Across both samples, the construct of EA—operationalized as the difference between PT and PD—emerged as a possible stable and meaningful empathic regulatory mechanism in novice mindfulness. Trait-level findings suggested that EA, as a novice mindfulness mechanism, not only supported other-oriented cognitive mentalizing (PT) but also buffered against empathic overdrive in the form of emotional overwhelm (PD). These findings resonate with models of emotional regulation in empathy, such as those proposed by Decety and Jackson (2004), which highlight the role of emotion regulation in empathic engagement. Interestingly, although SMIND showed limited predictive power behaviorally, DOM—a key facet indicating mental fragmentation—was inversely associated with EA both at self-report and EEG levels. The convergence of lower DOM, lower PFC beta activity, and higher EA underscores a possible novice neurocognitive mechanism, wherein EA-based empathic regulation is linked to a less fragmented mental state and reduced frontocortical effort during meditative engagement. However, heightened TOM was observed to be related to a higher PT trait, which in turn triangulated with a greater EA and a lower PFC gamma activity. Thereby, suggesting PT-EA to be related with poorer meditation-focused novice states, owing to TOM-based interference, as meditation is essentially an exercise in mental emptying (Rodriguez-Larios et al., 2020).

The novice mindfulness-empathy functional interdependence, as reported in the trait and state sample, possibly indicated that EA is not a static trait but a dynamic process influenced by momentary cognitive states (Fuente-Anuncibay et al., 2019). Overall, EA offers novel novice mindfulness mechanisms for understanding adaptive empathy, beyond the existing dimensional structure by Davis (1983; Figure 2).

In clinical settings, the concept of EA could be valuable for understanding and mitigating burnout among caregivers, therapists, and educators, who are often exposed to intense emotional experiences (Cooper et al., 2020; Salvarani et al., 2019; Simon et al., 2018). Mindfulness-based interventions thus may be particularly effective in building emotional boundaries while maintaining empathic engagement, promoting both emotional resilience and the capacity for compassionate care (Cheang et al., 2019; Goswami et al., 2024; Hoseinian et al., 2019). EA abilities would also be crucial in professions that require sustained emotional labor, and cultivating EA may serve as a protective factor against PD (Asuero et al., 2014; Verweij et al., 2016).

Figure 2. *Empathic Affectfulness as a Novel Mechanism Within Davis' Dimensional Structure of Trait Empathy (1983).*



Conclusions, Limitations, and Future Work

This study examined the interrelationships between trait empathy and novice mindfulness using neurobehavioral measures. Trait mindfulness—particularly NR and NJ—was positively associated with PT and negatively with PD, respectively, independent of personality traits. SMIND showed weaker associations: DOM correlated positively with PD and prefrontal beta activity, while TOM correlated positively with PT. Overall, PD showed negative associations with both trait and state mindfulness, whereas PT was positively linked in the trait context but showed inverse associations in the state mindfulness context. As PT itself was also linked to reduced prefrontal gamma activity, suggesting that while PT facilitates mentalizing, it may interfere with novice meditative focus. Post hoc trait-level analysis identified EA—the difference between PT and PD—as a potential mechanism of emotionally conscious empathy. Even though its link to SMIND was not very strong, EA was connected to lower prefrontal beta activity and DOM, suggesting its association with focussed meditative states. Crucially, EA showed substantial predictive validity, since it was evident in both trait and state mindfulness samples, underscoring the plausible role of novice mindfulness in fostering affect-conscious empathy.

Further, these results contribute to a growing understanding of mindfulness not only as a facilitator of empathy but also as a buffer against empathic overarousal, even in novices. Both design-wise and empirically, the study has several limitations that warrant caution, since it espouses an exploratory mechanism. Firstly, the construct of EA is novel and operationalized post hoc; its validity and boundaries require further theoretical refinement and empirical validation. Next, the use of novice meditators, limited gender diversity in the EEG sample, and a cross-sectional design limited generalizability and causal inferences towards EA. Further, SMIND was assessed using a brief, single-session intervention that may not adequately capture the complexity of meditative states in real-world practice; however, the intervention did include workload induction, apriori to its onset. Besides, the EEG results, though promising, were exploratory with small effect sizes and should be interpreted accordingly. Additionally, replications across cross-cultural samples, contemplative traditions, and population subgroups (as clinical and care-giving contexts) are essential to assess EA's generalizability, although similar results have been reported in Western samples before (Cooper et al., 2020; Fuente-Anuncibay et al., 2019; Kingsley, 2009). Lastly, the integration of additional neuroimaging techniques, synchronization- and source-based EEG analyses may offer a more comprehensive understanding of the neurophysiological basis of EA.

Overall, the present study offered an initial conceptual and empirical framework for EA, encouraging its continued investigation as a potentially meaningful mechanism at the intersection of mindfulness and empathy.

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Author Declaration

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NeuroRegulation

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.

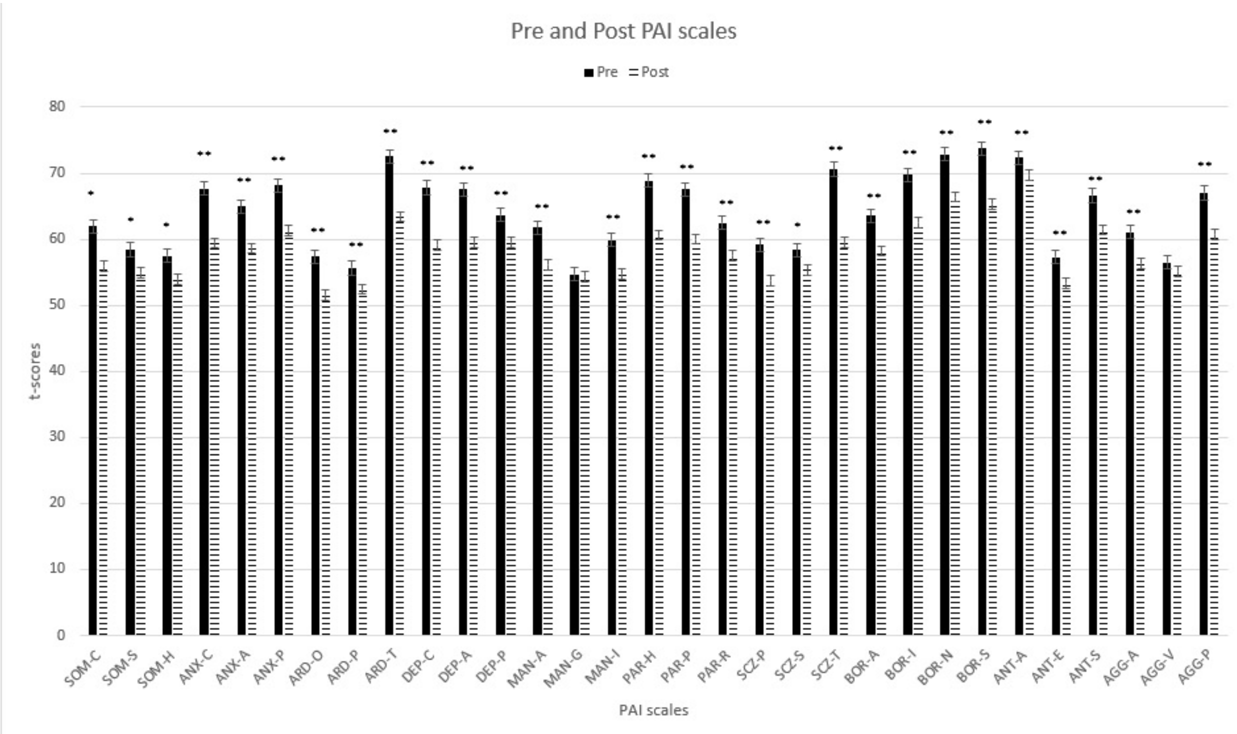
Table 2 shows the results for the sLORETA post > pre-EOB contrast results. In the table from left to right are the frequency in terms of CSD, BA and hemisphere (right, left, or middle), neuroanatomical label, t-value for the result and the probability of the t-value. The data illustrate notable changes 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							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	*t*	*df*	Sig. (2-tailed)
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.*

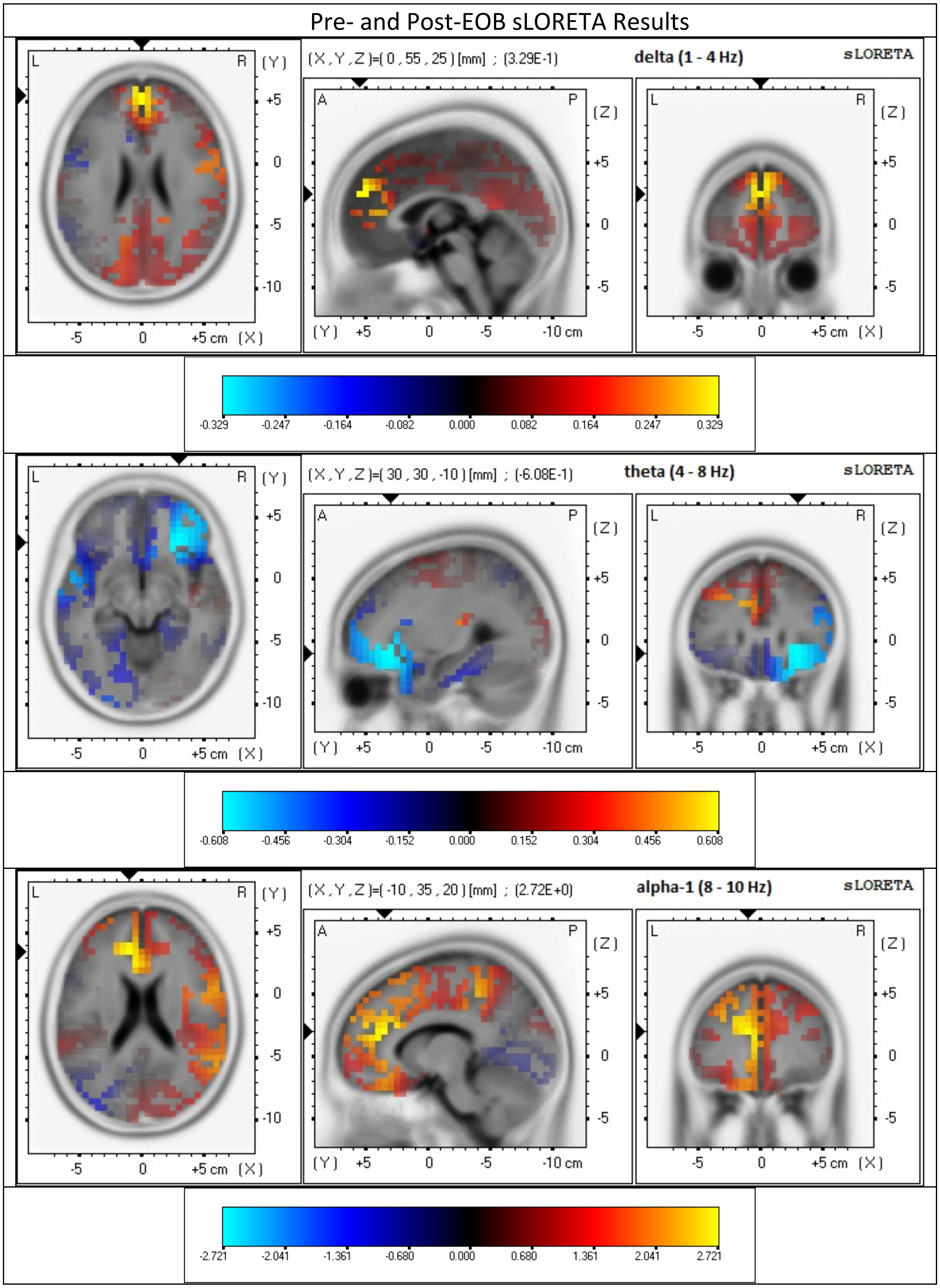
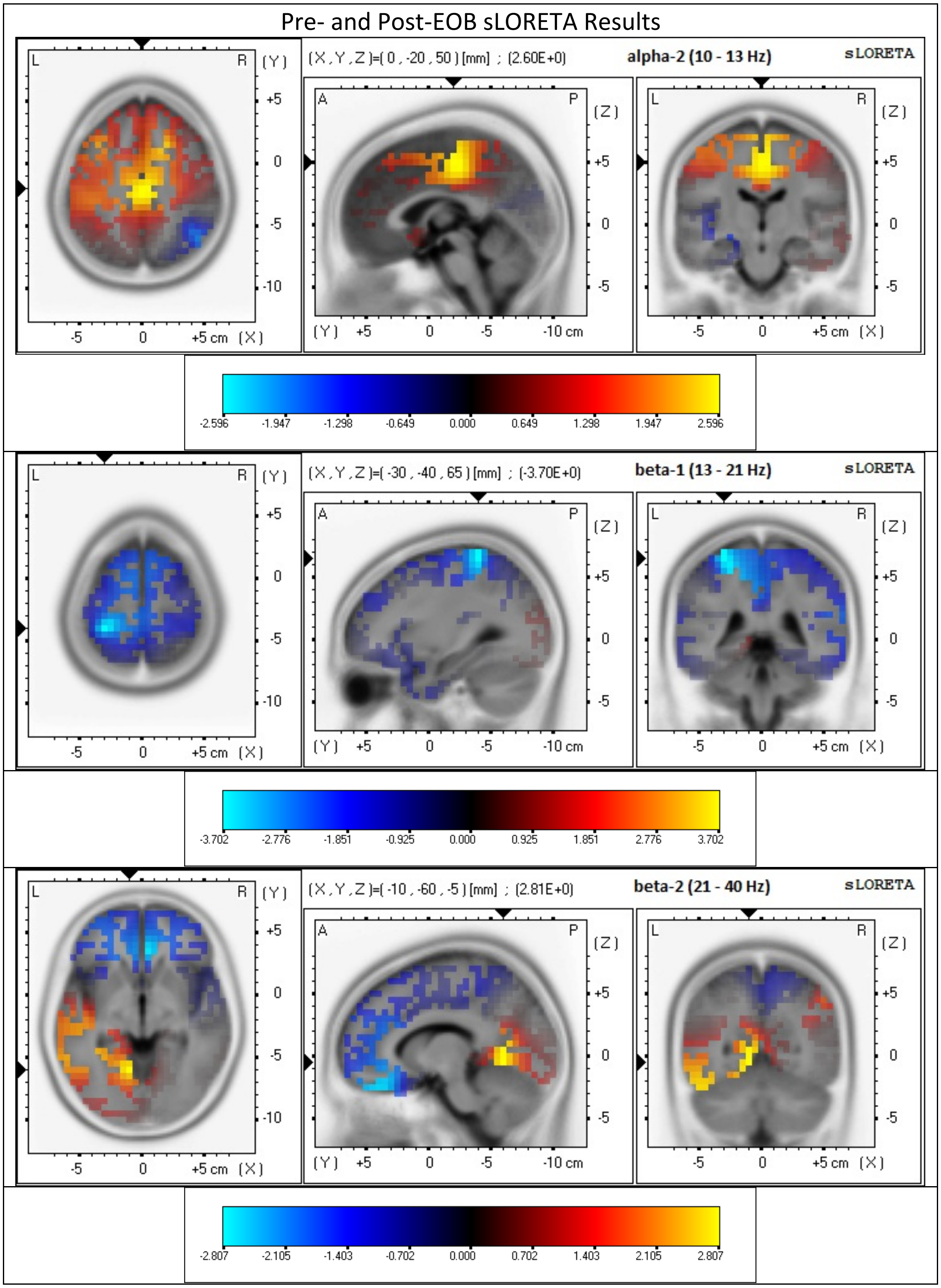


Figure 2. *Shows the sLORETA Images Corresponding to Table 2.*



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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