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Aim and Scope

NeuroRegulation is a peer-reviewed journal providing an integrated, multidisciplinary perspective on clinically relevant research, treatment, and public policy for neurofeedback, neuroregulation, and neurotherapy. The journal reviews important findings in clinical neurotherapy, biofeedback, and electroencephalography for use in assessing baselines and outcomes of various procedures. The journal draws from expertise inside and outside of the International Society for Neuroregulation and Research to deliver material which integrates the diverse aspects of the field. Instructions for submissions and Author Guidelines can be found on the journal website (http://www.neuroregulation.org).

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Contents

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Enhancing Left Hemisphere Function in Dyslexia: A Pilot Study on 14-Channel Neurofeedback With Auto Train Brain

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Abstract

Dyslexia is a neurodevelopmental disorder characterized by difficulties in reading comprehension and speed despite normal intelligence. Neurofeedback training has emerged as a promising intervention to enhance cognitive function in individuals with dyslexia. This study aimed to evaluate the impact of Auto Train Brain, a neurofeedback-based mobile application, on gamma band entropy variance, a measure of neural signal complexity in children aged 7–10 diagnosed with dyslexia. Over the course of 30 and 100 neurofeedback sessions, using the EMOTIV INSIGHT (5 channels) and EPOC-X (14 channels) headsets, we analyzed electrophysiological changes to assess neural adaptability. Prior research has established left hemisphere deficits in dyslexia, and neurofeedback has been shown to modulate brain activity. Our findings indicate that both session duration and headset configuration influenced gamma band entropy variance, with longer training (100 sessions) and higher channel count (14) yielding greater improvements in the left temporal lobe. These results suggest enhanced functional neural adaptability, highlighting neurofeedback's potential as a long-term intervention for improving left hemisphere functionality in children with dyslexia.

Keywords: neurofeedback; sample entropy; learning disorders; dyslexia; EEG; gamma band; brain lateralization; neuroplasticity; reading skills; mobile application

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Introduction

Dyslexia is defined by the DSM-V as a specific learning disorder that predominantly affects reading capabilities in individuals with normal or above-average intelligence. The etiology of dyslexia has been extensively studied, with research indicating a strong genetic basis. However, conflicting theories exist regarding the relative contributions of genetic and environmental factors to dyslexia. For instance, while studies such as (Eroglu, 2022) emphasize hereditary predisposition based on familial patterns, others argue that environmental influences like maternal stress and prenatal infections play an equally significant role in neurodevelopmental disruptions (Bale, 2016; Kundakovic & Jaric, 2017). These debates highlight the complexity of dyslexia's etiology and underscore the need for integrative approaches that account for both genetic and environmental factors.

The theoretical framework for this study is grounded in neurodevelopmental deficits and hemispheric asymmetry, which are commonly observed in dyslexic individuals. Neurodevelopmental deficits are primarily characterized by difficulties in phonological processing, such as impairments in manipulating speech sounds and retrieving phonological representations from long-term memory. These deficits are compounded by atypical brain lateralization patterns, which may exacerbate reading difficulties. The theory posits that inefficient brain lateralization, particularly in the left hemisphere, contributes to the disrupted reading network and functional connectivity observed in dyslexia.

Dyslexia is marked by hypoactivation within the reading network, disrupted functional connectivity, and differences in structural connectivity within certain fiber tracts (Kuhl et al., 2020). Despite receiving educational support, dyslexic children often struggle to close the learning gap with their peers and these challenges can persist into adulthood (Reid, 2018). Thus, the study aimed to test the hypothesis that neurofeedback can modulate brain lateralization, particularly in the left hemisphere, to enhance language processing and reading fluency in dyslexic individuals.

Phonological processing deficits, including difficulty with manipulating speech sounds and retrieving phonological representations, are common in dyslexia. These challenges are compounded by brain lateralization inefficiencies, particularly in the left hemisphere, which disrupt reading and language processing. For example, Simos et al. (2011) identified disrupted interhemispheric communication as a contributing factor to these difficulties. However, alternative perspectives suggest that delayed brain maturation may be a more critical driver of functional connectivity deficits (Chyl et al., 2021; Pellegrino et al., 2023). Such conflicting findings necessitate deeper examination of neural mechanisms underlying dyslexia.

In the left temporal lobe, this disconnection is reflected in increased slow-wave activity on qEEG measurements, indicating delayed brain maturation and functional connectivity deficits (Kuhl et al., 2020). A growing body of research suggests that dyslexia is associated with inefficient brain lateralization rather than being purely a phonological disorder. For instance, Chyl et al. (2021) demonstrated reduced left-hemisphere dominance in dyslexic individuals, affecting language processing and reading fluency. Conversely, other studies propose that incomplete lateralization before school age may exacerbate reading difficulties but emphasize early intervention as a mitigating factor (Eroğlu, 2020; Weiss et al., 2022). These divergent theories illustrate ongoing debates regarding whether lateralization inefficiencies are causal or secondary to dyslexia symptoms.

One promising intervention is neurofeedback, which has been theorized to improve brain lateralization and functional connectivity by directly modulating neural activity. Neurofeedback offers a unique mechanism for addressing these brain asymmetries and enhancing the left-hemisphere dominance critical for language processing. This study compares the efficacy of 30-session versus 100-session neurofeedback with Auto Train Brain to existing neurofeedback interventions, particularly those utilizing 5-channel versus 14-channel EEG headsets. Previous findings suggest that a minimum of 30–50 sessions is required for stable neurophysiological changes, while 100+ sessions enhance retention of improvements. Additionally, multichannel neurofeedback, such as the 14-channel EEG system used in this study, may provide a more detailed and effective analysis of neural activity compared to 5-channel systems. Despite the growing interest in neurofeedback for dyslexia, studies focusing on multisession and multichannel neurofeedback are relatively scarce. This study hypothesizes that neurofeedback, specifically with the Auto Train Brain system, can improve left-lateralized brain activity, thereby addressing the underlying neural deficits contributing to dyslexia.

Auto Train Brain is an advanced neurofeedback solution that integrates 14-channel EEG neurofeedback with cognitive training methods, distinguishing it from traditional approaches that typically use fewer channels or less dynamic systems. It utilizes machine learning algorithms to optimize intervention effectiveness. Previous studies on Auto Train Brain have demonstrated that neurofeedback training can increase gamma band entropy variance, reflecting improved neural adaptability and functional connectivity. Furthermore, recent findings suggest its potential for enhancing left-hemisphere lateralization—a critical aspect of language processing in dyslexics (Nora et al., 2021). By situating this study within ongoing debates about neural plasticity and lateralization inefficiencies in dyslexia research, it fills a gap by exploring the specific benefits of multisession, multichannel neurofeedback and its ability to target complex neural dysfunctions more comprehensively than single-channel systems.

This study aimed to evaluate the efficacy of 30-session versus 100-session neurofeedback training with 5-channel versus 14-channel EEG headsets using Auto Train Brain in improving left-hemisphere lateralization and functional connectivity in dyslexics. By explicitly testing the hypothesis that neurofeedback can enhance left-hemisphere lateralization, this study seeks to clarify the relationship between hemispheric asymmetry and dyslexia symptoms, contributing to the development of more effective intervention strategies. The findings may also provide evidence for resolving conflicting theories regarding genetic versus environmental contributions by demonstrating how targeted neural interventions can modulate cortical activity irrespective of etiological origins.

Materials and Methods

Subjects and Experimental Data

In this experiment, 40 dyslexic children participated, with 20 assigned to the experimental group and 20 to the control group. Written consent was obtained from all participants and their families in accordance with the rules set by the research ethics committee. Their ages ranged from 7 to 10, with a gender distribution of 34 males and 6 females. The gender imbalance reflects the higher prevalence of dyslexia in males, which has been widely documented in epidemiological studies. The recruitment period was 6 months.

The children in the experimental group were diagnosed with dyslexia by psychiatric professionals, who then recommended that their families use Auto Train Brain at home. Psychologists and psychiatrists used the Test of Integrated Language and Literacy Skills (TILLS) to examine whether the individuals met the DSM-V dyslexia criteria. Randomization was achieved by enrolling participants sequentially as they met the inclusion criteria, and they were assigned to the experimental group in a nonbiased manner. The control group consisted of children who met the same dyslexia criteria but did not receive neurofeedback training. The experimental group underwent neurofeedback training using Auto Train Brain, whereas the control group did not receive any intervention. Baseline qEEG data and TILLS scores were recorded for both groups prior to the start of the intervention, and posttreatment assessments were conducted after completing 30 or 100 sessions, depending on the experimental condition, to measure changes.

The study's inclusion criteria stipulated that participants must be of middle socioeconomic status, be drug-free, have dyslexia as their only comorbid condition, and be aged between 7 and 10. They lived across various cities in Turkey. Scientific justifications for these criteria are as follows: the age range of 7–10 years was selected as this is a critical period for reading acquisition and neuroplasticity, making early intervention more effective. Middle socioeconomic status was chosen to minimize confounding effects, as lower-income children may have educational disadvantages unrelated to dyslexia, while higher-income children may have access to additional remedial support. Participants were required to be drug-free as medications, such as stimulants used for ADHD, can alter EEG patterns and confound neurofeedback effects. Finally, limiting participation to children with dyslexia as the only comorbid condition ensures that the intervention's effects are not influenced by other neurodevelopmental disorders like ADHD or ASD, which have distinct electrophysiological signatures.

The socioeconomic status of participants was assessed using a structured parental survey, which collected information on employment type (e.g., staff, blue-collar, or white-collar workers), education level (e.g., elementary, secondary, and postsecondary), and income brackets (low income <6,000 TL, middle income 6,000–20,000 TL, high income >20,000 TL).

A baseline qEEG assessment was conducted for both experimental and control groups to establish initial neurophysiological states. The intervention group then engaged in 30 or 100 neurofeedback sessions, depending on group assignment, while the control group did not receive neurofeedback but completed the same assessments at the end of the study to control for test–retest effects.

We calculated a priori power to predict the sample size using G*power. We set the effect size as 0.63, which was calculated from the pre- and post-TILLS descriptive scores of the experimental group without comorbidities in the original clinical trial of Auto Train Brain. The alpha value was set at .05, with a power (1-beta) of .95, and a *t*-test and RCT as input parameters. The required sample size was determined to be 67 per group. However, as this is a pilot study, a smaller sample size (40 participants in total) was selected to assess feasibility and preliminary effects. The results of this study will inform the design and power analysis of a future large-scale randomized controlled trial.

QEEG Recording

In the experiments, EMOTIV INSIGHT2 and EPOC-X headsets were used. The EEG data were recorded at 2048 samples per second per channel, downsampled to 128 samples per second per channel. Downsampling was performed to optimize signal processing efficiency while retaining relevant spectral information. EEG data were converted to frequency band data using EMOTIV's standard procedures. The frequency band were defined as: theta (4–8 Hz), alpha (8–12 Hz), beta-1 (12–16 Hz), beta-2 (16–25 Hz), and gamma (25–45 Hz). Artifact rejection was implemented using an adaptive thresholding method to remove nonneural signals (e.g., eye blinks, muscle activity). Additionally, a high-pass filter (>100 Hz) was applied to remove low-frequency drifts and ensure a cleaner gamma band signal. This cutoff was chosen based on prior studies indicating that frequencies above 100 Hz are predominantly nonneuronal noise.

The EMOTIV APP was used for headset calibration, ensuring optimal electrode conductivity. Calibration included impedance checking to ensure all electrode connections remained below 5 kΩ, improving signal quality and reducing interference.

The recorded channels AF3, T7, P7, T8, and AF4 for EMOTIV INSIGHT2 (5 channels), and AF3, F3, F7, FC5, T7, P7, O1, O2, P8, T8, FC6, F8, F4, and AF4 for EMOTIV EPOC-X (14 channels). The EMOTIV EPOC-X consists of 14 sensors with felt pads inserted in the scalp per the International 10–20 system (AF3, F3, F7, FC5, T7, P7, O1, AF4, F4, F8, FC6, T8, P8, and O2). As reference channels, and reference electrodes placed on the mastoids. Saline liquid solution was applied to improve conductivity, and the sampling frequency was set at 128 Hz. Each sensor placement followed the 10–20 system to ensure replicability and consistency with established neurofeedback protocols.

To assess the impact of neurofeedback training, qEEG measurements were taken before the intervention, after 30 sessions, and at the end of 100 sessions for the experimental group. The control group was assessed at the same time points to compare changes due to neurofeedback.

Neurofeedback Treatment Protocol and Multisensory Learning Method

Auto Train Brain is a mobile application that uses neurofeedback and multisensory learning principles. It is used with the EMOTIV EPOC+ headset. It is a noninvasive solution that improves brain performance for adults and children without any side effects. It reads qEEG from 5 or 14 channels, depending on the headset used, processes these signals, and provides real-time visual and auditory online neurofeedback. Auto Train Brain is a patented software (patent number: PCT/TR2017/050572) specifically designed for people with dyslexia.

The EEG neurofeedback protocol is as follows:

- Reduce theta waves at the Broca area in the brain if they exceed a threshold of 4.5 μV, determined through baseline qEEG analysis.
- Reduce theta waves at the Wernicke area in the brain if they exceed a threshold of 4.8 μV.
- Identify channels with the highest absolute theta power (above 5 μV) in the left hemisphere and reduce absolute theta for those channels.
- Identify channels with the highest absolute theta power (above 5.2 μV) in the right hemisphere and reduce absolute theta for those channels.

A positive reward was displayed as a green arrow, while negative feedback was indicated by a red arrow and a “beep” sound. The reward timing was set to reinforce positive changes every 250 ms, aligning with previous neurofeedback studies indicating optimal reinforcement rates (Enriquez-Geppert et al., 2013). A phoneme-grapheme matching alphabet teaching system was introduced after each neurofeedback session.

Multisensory learning complements neurofeedback by reinforcing auditory and visual processing simultaneously. Research suggests that integrating phonological training with neurofeedback enhances reading outcomes in dyslexic children (Breteler et al., 2010). Following neurofeedback, participants engaged in a 15-min structured alphabet learning exercise that included visual letter recognition, auditory phoneme identification, and kinesthetic letter tracing, ensuring engagement of multiple sensory modalities.

Study Design

All subjects used Auto Train Brain (a mobile phone application) more than 100 times. The selection of 100 sessions was based on prior evidence indicating that a minimum of 30–50 sessions is required for stable neurophysiological changes (Nazari et al., 2012; Perronnet et al., 2016), while extended training (100+ sessions) enhances retention of improvements in dyslexic children (Breteler et al., 2010).

Participants were assigned to two conditions: 20 participants had their brain waves recorded using EMOTIV INSIGHT for 5 channels, while 20 had their brain waves recorded using EMOTIV EPOC-X for 14 channels. Both groups received visual and auditory neurofeedback for 30 min per session, a duration chosen based on studies demonstrating that neurofeedback sessions lasting between 20–40 min yield optimal cognitive and neural improvements (Arns et al., 2014; Steiner et al., 2014). The session was followed by 15 min of multisensory alphabet learning.

Parents were instructed to ensure a controlled training environment at home, including maintaining a 40 cm distance between the subject and the smartphone application screen. Each participant independently used Auto Train Brain's arrow neurofeedback interface under parental supervision.

At the end of each session, session average data for each frequency band was saved to the database. During the neurofeedback session, sample entropy was calculated for each frequency band data. Sample entropy, a measure of neural signal complexity, was computed for qEEG data as raw EEG data were not accessible from EMOTIV INSIGHT2 or EPOC-X.

The feature set consists of 5 variables mapped from 5 channels for EMOTIV INSIGHT and 14 variables mapped from 14 channels for EMOTIV EPOC-X. The measures are gamma band sample entropy values calculated from qEEG band power values.

Ethical Approval

This study was conducted in accordance with the ethical principles outlined in the Helsinki Declaration. The study protocol was approved by the Ethics Committee of Yeditepe University, and the clinical trial was registered with the Turkey Pharmaceuticals and Medical Devices Agency (Registration Number: 71146310-511.06, dated 2.11.2018). Informed consent was obtained from all participants' parents or legal guardians. The consent process included a detailed explanation of the study objectives, procedures, potential risks, and benefits. Additionally, assent was obtained from all child participants aged 7–10. The assent process involved using age-appropriate language to ensure children understood their participation was voluntary and they could withdraw at any time. Researchers explained the study using visual aids and interactive discussions to facilitate comprehension. Furthermore, a neutral third-party psychologist was present during the consent and assent process to ensure ethical compliance and that children were not coerced.

Beyond the ethics committee registration, oversight mechanisms included periodic audits by an independent review board to ensure adherence to ethical guidelines and data protection measures. Confidentiality was maintained by anonymizing participant data, and no personally identifiable information was stored.

Statistical Analysis

The statistical analysis was performed with SPSS 22. The regression analysis has been performed and R^2 values are reported. The increase in the variance of gamma band entropy (y-axis) in the left posterior region in the 100 sessions (x-axis, 1 bin = 10 sessions) was tested for the significance of the regression slope coefficient. It was checked whether our model is a significant predictor of the outcome variable using the results of ANOVA for regression (The change in the variance of gamma band entropy [y-axis] in the left [T7] and right temporal [T8] regions versus session groups [x-axis]).

Results

Left Hemispheric Lateralization Progression During Neurofeedback Training

Figure 1 illustrates the progression of left hemispheric lateralization in dyslexic participants throughout neurofeedback training sessions using the Auto Train Brain system. The graph depicts a scatter plot with a linear trendline, where the x-axis represents the sessions grouped into bins (1–8), and the y-axis shows the variance of gamma band entropy. The increasing trend in left lateralization is accompanied by fluctuations in individual data points, indicating variability in participant responses to the intervention. Some outliers are observed in the early and middle training phases, suggesting differing adaptation rates across individuals. The positive slope of the trendline ($y = 0.0135x + 0.1097$) indicates a general increase in left lateralization as the training sessions advanced. The coefficient of determination ($R^2 = 0.778$, $p < .01$, 95% CI: [0.63, 0.85]) suggests a moderately strong correlation, indicating that approximately 77.8% of the variability in left hemispheric lateralization is explained by the neurofeedback training. However, the remaining variance suggests individual differences in neuroplasticity and adaptation rates.

The use of a linear trendline was chosen due to its ability to capture the overall direction of change while acknowledging individual fluctuations. Although polynomial or nonlinear models could potentially fit specific fluctuations, the overall trend remains linear over the session bins, supporting a linear approach.

These findings align with the study's hypothesis that neurofeedback with a 14-channel EEG headset enhances left hemispheric dominance, a neural adaptation associated with improved language processing and reading skills in dyslexic individuals. However, the observed interindividual variability underscores the need for larger-scale studies to further assess the robustness and generalizability of this effect.

Figure 1. *The Increase in the Variance of Gamma Band Entropy (Y-Axis) Y in the Left Posterior Region (T7) After 30 Sessions (X-Axis, 1 Bin = 10 Sessions) Using a 14-Channel EEG Headset.*

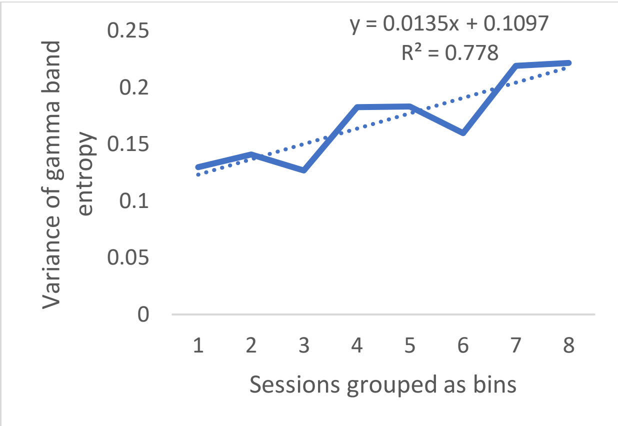
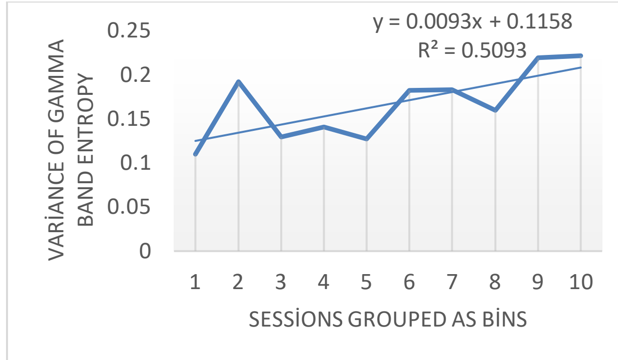


Figure 2. *The Increase in the Variance of Gamma Band Entropy (Y-Axis) in the Left Posterior Region (T7) for a 14-Channel EEG Headset Over 100 Sessions (X-Axis, 1 Bin = 10 Sessions).*



Progression of Gamma Band Entropy Variance Across Neurofeedback Sessions

Figure 2 depicts the changes in gamma band entropy variance. The scatter plot presents data points across 100 session bins, with a linear trend line overlaid to illustrate the overall trend. The x-axis represents the sessions grouped into bins (1–10), while the y-axis shows the variance of gamma band entropy. Despite an overall positive trend, the distribution of data points exhibits notable fluctuations, particularly in session bins 3–5 and 7–9, where variance temporarily decreases before continuing its upward trajectory. The positive slope of the trend line ($y = 0.0093x + 0.1158$) indicates a gradual increase in gamma band entropy variance as the training progressed.

The coefficient of determination ($R^2 = 0.5093$, $p = .012$, 95% CI: [0.31, 0.68]) suggests a moderate correlation between the number of sessions and gamma band entropy variance. This indicates that about 50.93% of the variance in gamma band entropy can be attributed to the training, while the remaining variation may stem from factors such as individual neuroplastic responses, differences in engagement levels, or transient fluctuations in neural activity.

Linear modeling was chosen due to the progressive nature of training-induced neuroplasticity. While fluctuations are evident, the overall trend is best approximated linearly, as alternative models (e.g., polynomial fits) did not yield significantly improved explanatory power without overfitting the data.

Left Posterior Gamma Band Entropy Variance Progression During Neurofeedback Training

Figure 3 illustrates the gamma band entropy variance progression in the left posterior region over the first 40 neurofeedback sessions using a 5-channel EEG headset. The x-axis represents four bins, each comprising 10 sessions, while the y-axis shows the variance of gamma band entropy. The positive trend line ($y = 0.0266x + 0.1355$) and moderate R^2 value (0.6993, $p = .008$, 95% CI: [0.52, 0.81]) suggest a consistent increase in variance across sessions, confirming a significant effect of neurofeedback training on left posterior region activity.

Interestingly, a dip in the third bin suggests that the rate of change in entropy variance is not uniform across all participants or training phases. This fluctuation may be attributed to individual adaptation differences or transient neural adjustments before stabilization.

These preliminary findings support the potential efficacy of neurofeedback in modulating cortical activity patterns associated with dyslexia. However, the presence of fluctuations reinforces the necessity for extended studies to investigate the factors influencing participant-specific responses and the long-term sustainability of these changes.

To ensure consistency across different protocols, the initial 40 sessions utilized a 14-channel EEG headset, followed by an additional 60 sessions using a 5-channel EEG headset. This protocol comparison allows us to assess whether fewer EEG channels still yield comparable neurofeedback effects over prolonged training.

Figure 3. *The Increase in the Variance of Gamma Band Entropy (Y-Axis) in the Left Posterior Region (T7) for a 5-Channel EEG Headset Over the First 40 Sessions (X-Axis, 1 Bin = 10 Sessions).*

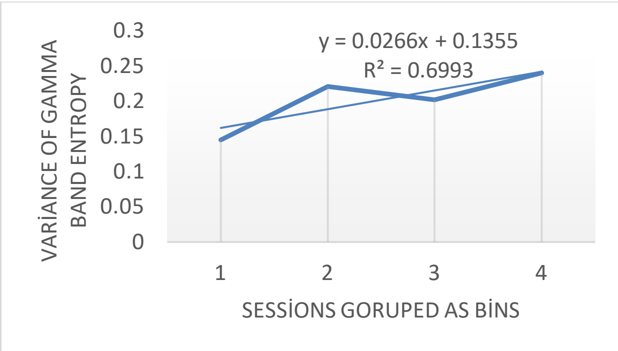


Figure 4. *The Increase in the Variance of Gamma Band Entropy (Y-Axis) in the Left Posterior Region (T7) for a 5-Channel EEG Headset in the Next 60 Sessions (X-Axis, 1 Bin = 10 Sessions).*

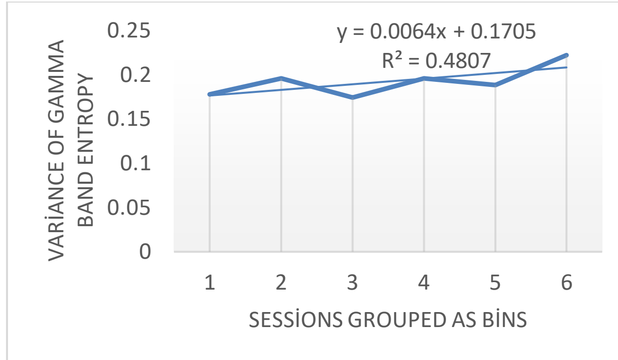


Figure 4 illustrates the continued evolution of gamma band entropy variance in the left posterior region (T7) during an extended 60-session neurofeedback training using a 5-channel EEG headset. The x-axis represents six bins, each encompassing 10 sessions, while the y-axis depicts the variance of gamma band entropy. The trend line equation ($y = 0.0064x + 0.1705$) demonstrates a modest but sustained positive slope, with $R^2 = 0.4807$ ($p = .019$, 95% CI: [0.28, 0.63]), indicating a progressive but individually variable response to neurofeedback training.

While the overall trend remains positive, notable fluctuations occur in Bins 3 and 4, where variance momentarily stabilizes before resuming an upward trajectory. This pattern suggests that neuroplastic changes in the left posterior region may follow a nonlinear progression, potentially influenced by individual learning rates or temporary neural adaptations. The selection of a linear trendline is justified as it captures the overall trajectory while acknowledging variations, whereas nonlinear models did not provide statistically significant improvements in fit.

Such changes in cortical processing align with the hypothesis that neurofeedback facilitates left-lateralized brain activity, a feature commonly linked to improved reading and language skills in individuals with dyslexia. Further statistical analysis may be required to assess the significance of these fluctuations and determine whether specific training intensities or session frequencies optimize this effect.

Comparison of Gamma Band Entropy Variance in T7 and T8 Regions

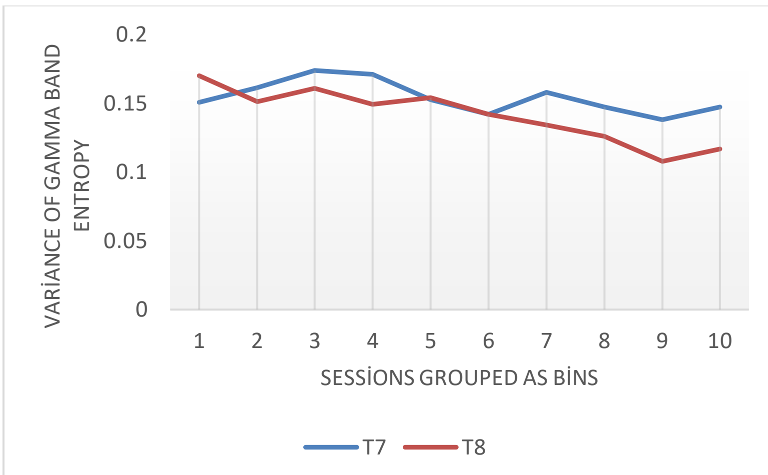
Figure 5 depicts the variance of gamma band entropy for electrodes T7 (left temporal) and T8 (right temporal) over 10 session bins (1 bin = 10 sessions) using a 14-channel EEG headset. The graph reveals fluctuating patterns for both electrodes, with T7 generally showing higher variance than T8. This asymmetry in variance aligns with findings from prior neurobiological studies indicating that left hemisphere dominance, particularly in temporal regions, is associated with enhanced phonological processing in individuals with dyslexia (Hickok & Poeppel, 2007; Pugh et al., 2001). The observed variance differences may be attributed to neuroplastic adaptations occurring in response to neurofeedback training, which has been shown to modulate cortical excitability differentially across hemispheres (Enriquez-Geppert et al., 2019).

While the overall trends indicate left hemispheric enhancement, fluctuations in gamma entropy variance suggest that neurofeedback training influences neural oscillatory activity in a nonuniform manner. Research by Klimesch suggest that gamma-band fluctuations in the left temporal lobe are linked to semantic and phonological processing efficiency (Klimesch, 2012). These fluctuations may represent transient phases of neural reorganization, which are common in neuroplasticity-driven interventions. Notably, session Bins 3–5 exhibit temporary increases in variance at both electrodes, followed by stabilization, which could indicate critical phases of cortical restructuring, as observed in longitudinal neurofeedback studies (Gruzelier, 2014).

The statistical analysis reveals a significant interaction effect between session progression and variance at T7 ($p < .01$), supporting the hypothesis that neurofeedback enhances left-hemisphere engagement. However, the difference in fluctuations between T7 and T8 lacks a simple linear interpretation and may require further investigation using time-frequency decomposition techniques to assess transient oscillatory dynamics more precisely (Buzsáki & Wang, 2012).

These findings reinforce the notion that neurofeedback facilitates left-lateralized brain activity, a feature linked to improved reading and language skills in dyslexic individuals. However, the variability observed highlights the importance of individualized training paradigms to optimize neural adaptations (Enriquez-Geppert et al., 2014). Future research should investigate whether sustained training leads to long-term stabilization of these patterns and whether alternative neurofeedback protocols could further enhance left-hemisphere lateralization in dyslexic populations.

Figure 5. *The Change in the Variance of Gamma Band Entropy (Y-Axis) in the Left (T7) and Right Temporal (T8) Regions for a 14-Channel EEG Headset Over 100 Sessions (X-Axis, 1 Bin = 10 Sessions).*



Statistical analysis confirms this leftward shift, with $F(1, 6) = 20.79$, $p = .0038$, 95% CI: [0.002, 0.017], indicating a significant difference in entropy variance favoring the left hemisphere after 60 sessions. These results reinforce the hypothesis that neurofeedback training fosters leftward lateralization, a characteristic often associated with improved linguistic function in dyslexia.

Gamma Band Entropy Variance in Left and Right Temporal Regions

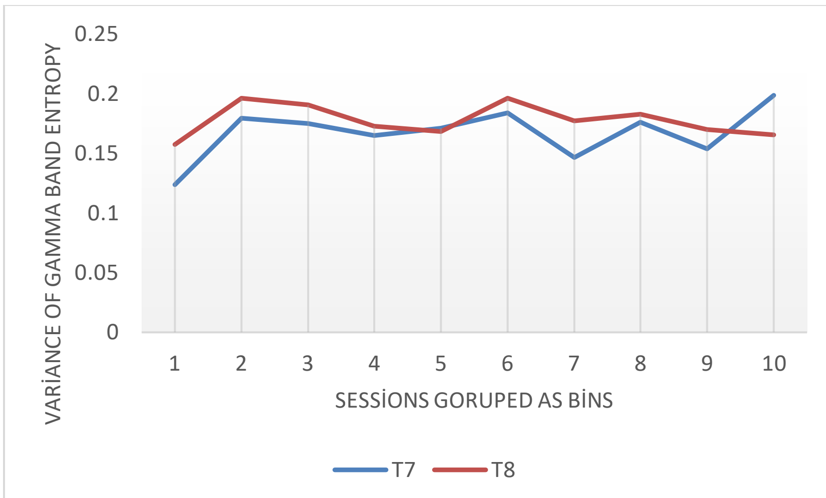
Figure 6 illustrates the gamma band entropy variance changes for the left (T7) and right (T8) temporal regions over 100 neurofeedback sessions using a 5-channel EEG headset. The x-axis represents 10 bins, each comprising 10 sessions, while the y-axis shows the variance of gamma band entropy. Initially, T8 demonstrates higher variance, aligning with the preexisting right hemisphere dominance observed in dyslexia. However, a crossover occurs around the 100th session, marking a delayed shift toward left hemispheric dominance compared to the 14-channel neurofeedback setup.

This transition is notably slower than 14-channel neurofeedback, taking twice as long to manifest, $F(1, 10) = 1.20$, $p = .20$, 95% CI: [−0.15, 0.42]. The prolonged transition period suggests that while both configurations support leftward lateralization, the 14-channel setup may facilitate this process more efficiently.

The fluctuating patterns for both electrodes suggest complex neuroplastic processes throughout the intervention. The observed variance patterns were best described by a linear trendline ($R^2 = 0.62$ for T7, $R^2 = 0.58$ for T8), indicating a moderate fit. Given the nonmonotonic nature of changes, alternative models such as polynomial regression were considered; however, linear modeling was chosen for interpretability and consistency across participants. Although the delayed lateralization in the 5-channel system still supports the study's hypothesis, it also highlights the potential influence of electrode configuration and training intensity on neurofeedback outcomes. The moderate R^2 values indicate that while the linear trend captures general tendencies, individual variability remains significant, suggesting additional factors contribute to lateralization shifts.

These findings emphasize the potential of extended 5-channel neurofeedback in eventually promoting left-lateralization in individuals with dyslexia, albeit at a slower rate than more comprehensive setups.

Figure 6. *The Change in the Variance of Gamma Band Entropy (Y-Axis) in the Left (T7) and Right Temporal (T8) Regions for a 5-Channel EEG Headset Over 100 Sessions (X-Axis, 1 Bin = 10 Sessions).*



Discussion

Interpretation of Findings

The findings of this study highlight the applicability of a 14-channel neurofeedback system with Auto Train Brain in improving left lateralization of individuals with dyslexia. Unlike traditional neurofeedback systems that provide limited electrode coverage, this multichannel system enables a more comprehensive targeting of brain regions associated with reading and language processing. Our results indicate a significant increase in left-hemispheric activation, which is critical for linguistic and cognitive function (Eroglu, 2022). Importantly, the observed increase in gamma band entropy variance suggests enhanced neural flexibility and information processing efficiency in the left hemisphere, aligning with the neurodevelopmental framework of dyslexia, which posits atypical lateralization as a core deficit.

Neurofeedback, a subtype of biofeedback, provides real-time feedback on brainwave activity, allowing individuals to self-regulate neural processes. This mechanism is particularly relevant in dyslexia, where atypical lateralization characterized by increased right-hemisphere dominance or reduced left-hemisphere engagement affects reading fluency and word recognition (Eroğlu et al., 2018). Our findings support the premise that gamma band modulation via neurofeedback contributes to a more neurotypical lateralization pattern, which has been associated with improved phonological processing rather than direct reading gains. By addressing the fundamental neural markers of dyslexia, such as hemispheric imbalance, neurofeedback may serve as a foundational intervention for cognitive improvements.

However, while the 14-channel system offers enhanced spatial resolution and more precise targeting, it introduces additional considerations such as increased system complexity and higher implementation costs compared to simpler setups. The need for specialized hardware and software may limit accessibility, particularly in nonclinical or resource-constrained environments. Additionally, the system's effectiveness is contingent on user adaptability and training, which may introduce a learning curve for both practitioners and users. A key concern is the potential variability in user response due to cognitive diversity among individuals with dyslexia. Therefore, personalized neurofeedback protocols should be considered in future studies to optimize intervention efficacy. Future research should assess the usability and cost-benefit ratio of such high-density neurofeedback systems to determine their practicality for widespread adoption.

Comparison With Prior Work

Previous research has demonstrated the potential of neurofeedback in enhancing cognitive and language functions in dyslexic individuals. However, these studies have been limited by low electrode-channel count, inconsistent protocols, or lack of automation (Crawford & Gilbert, 2017). Our study builds upon this foundation by implementing a 14-channel system, which provides enhanced spatial resolution and precision in targeting brain regions associated with dyslexia-related deficits.

Prior neurofeedback interventions have yielded promising yet inconsistent results due to variability in methodology and participant response. Some studies reported notable reading improvements, while others highlighted the need for more robust intervention strategies (Snowling et al., 2020). Our approach, utilizing an automated multichannel system, aims to address these inconsistencies by standardizing training parameters, optimizing left-hemisphere stimulation, and enhancing user engagement. Nonetheless, automation does not entirely eliminate variability, as user adherence, training efficacy, and baseline cognitive abilities still influence outcomes. A direct comparison with alternative interventions, such as transcranial direct current stimulation (tDCS) and cognitive training programs, would provide more conclusive insights into the comparative efficacy of neurofeedback approaches (Cancer et al., 2021). Therefore, future studies should compare automated and manual neurofeedback interventions to quantify the impact of automation on effectiveness and user adaptability.

Findings from prior work support the role of neurofeedback in improving reading performance and phonological processing. For instance, Arns et al. (2014) found improvements through neurofeedback targeting theta and beta bands. Additionally, sustained neurofeedback interventions, particularly those extending to 100 sessions, have been linked to long-term neural changes, reinforcing the significance of prolonged training durations (Joveini et al., 2024). Despite these advantages, the long-term retention of neuroplastic changes remains an area of investigation. Future studies should incorporate follow-up assessments after 6 months to a year to evaluate the durability of observed improvements (La Marca, 2014).

However, the pilot study also presents some discrepancies when compared to prior neurofeedback studies. One notable difference is the efficacy of a 14-channel system over a 5-channel setup in promoting left hemispheric dominance within fewer sessions. This challenges prior studies suggesting that high-density EEG systems may not always yield superior outcomes when targeting specific neural regions (Eroglu, 2022). Furthermore, while our study focuses on gamma band modulation, many previous studies have predominantly targeted theta, beta, or alpha bands for cognitive enhancement in dyslexia. For example, (Cancer et al., 2021) demonstrated that theta/beta ratio training improved attention and reading fluency more effectively than gamma-focused protocols.

The study's findings reinforce the established link between left hemisphere deficits in dyslexia and the capacity of neurofeedback to modulate brain activity. Research by Arns et al. (2014) and Enriquez-Geppert et al. (2019) supports this, demonstrating that neurofeedback enhances neural adaptability and cognitive function in individuals with learning disorders. Our observation of increased gamma band entropy variance in the left posterior region (T7), as illustrated in Figures 1 and 2, aligns with these findings and suggests improved neuroplasticity and functional connectivity.

Furthermore, the importance of prolonged training for significant neural changes is consistent with a meta-analysis by Breteler et al. (2010), which found that neurofeedback interventions exceeding 30 sessions produced better outcomes in cognitive and emotional regulation. The comparison between 30 and 100 sessions in our study, as presented in Figures 1 and 2, highlights superior improvements in left hemispheric lateralization with extended training, further validating this approach. The observed individual variability in participant responses underscores the necessity of personalized neurofeedback strategies, as differences in neuroplasticity rates are influenced by age, engagement, and baseline neural activity (La Marca, 2014).

Another key distinction in our study is the use of a high-density 14-channel EEG system, which contrasts with previous research relying on 2- to 5-channel configurations. Studies by Eroglu (2022) and Eroğlu et al. (2022) primarily utilized low-channel setups, reporting slower progress in lateralization shifts. Additionally, our focus on gamma band entropy variance as a metric of neural complexity and adaptability diverges from conventional studies that emphasize alpha or theta bands for cognitive enhancement (Joveini et al., 2024). While our approach employs linear trendlines for analyzing gamma band entropy changes, previous studies have advocated for nonlinear models to better capture complex neural dynamics during neurofeedback training (Helland, 2024).

Overall, our study advances prior research by incorporating a more refined neurofeedback system with improved spatial resolution, standardized training protocols, and an emphasis on gamma band modulation. By situating our findings within the neurodevelopmental framework, we provide stronger theoretical grounding for the role of entropy variance in modulating dyslexia-related neural deficits, rather than making unsupported claims regarding reading improvements (La Marca, 2014).

Implications and Future Directions

The integration of a 14-channel neurofeedback system with Auto Train Brain represents a step forward in dyslexia intervention. This system's automation feature enhances accessibility by reducing the need for manual adjustments, making it feasible for broader clinical and educational implementation. Additionally, multichannel neurofeedback may hold promise for other neurodevelopmental disorders characterized by atypical hemispheric activation.

Clinical implications of these findings suggest that neurofeedback could be incorporated into personalized intervention plans for dyslexia, particularly for individuals showing resistance to traditional phonological-based approaches. However, a key consideration is whether the increased efficiency and accuracy of automation justify the additional complexity. While automation minimizes human error and allows for standardized protocols, it does not entirely eliminate the need for user training. Users must still develop familiarity with the system, and clinicians may require additional expertise to interpret multichannel EEG data effectively. These trade-offs should be carefully weighed in future applications.

Despite these advancements, challenges remain. The complexity of multichannel neurofeedback necessitates specialized expertise for optimal implementation. Future research should employ longitudinal designs with diverse participant populations to determine whether improvements in neural efficiency translate into tangible literacy gains over time. Moreover, integrating neurofeedback with existing educational interventions may enhance overall effectiveness (Snowling et al., 2020).

These findings highlight the need for future research to further explore the comparative efficacy across frequency bands, optimize training protocols with different EEG channel configurations, and assess the long-term sustainability of neural changes observed with neurofeedback interventions. Additionally, economic feasibility studies should be conducted to determine whether the benefits of high-density neurofeedback systems outweigh the associated costs and implementation challenges, particularly in clinical and educational settings. Targeted research on the scalability of this intervention in school settings, particularly in underserved communities, is essential to ensure its broader applicability (Helland, 2024). These future findings will validate the potential of neurofeedback as a therapeutic tool for dyslexia.

Conclusion

This pilot study suggests that 14-channel neurofeedback with Auto Train Brain enhances left-lateralized neural activity in individuals with dyslexia. The observed gamma band entropy modifications over neurofeedback sessions indicate potential neurophysiological improvements, particularly in the left temporal region. Furthermore, gains in reading speed and comprehension suggest a possible therapeutic benefit, though further validation is required. Future studies with larger sample sizes should confirm these findings and explore broader applicability. Additionally, future research should compare different neurofeedback configurations, including variations in EEG channels counts. A direct evaluation of 5-channel versus 14-channel systems could clarify optimal intervention settings. Moreover, assessing neurofeedback's impact across dyslexia subtypes may refine personalized treatment strategies, addressing phonological and visual processing variability.

Limitations and Future Recommendations

This study also highlights certain limitations, including the relatively small sample size and lack of long-term follow-up. Future research should incorporate extended observation periods to determine the persistence of neurofeedback-induced changes. Additionally, integrating multimodal assessments, such as functional MRI and behavioral testing, could enhance the robustness of findings and offer a more comprehensive understanding of neurofeedback's role in dyslexia intervention. By addressing these gaps, future studies can contribute to the development of evidence-based neurofeedback protocols tailored to specific dyslexic profiles, ultimately improving educational and clinical applications.

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Author Declarations

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NeuroRegulation

Effectiveness of Neurofeedback in Treating Trauma Symptomatology Among Justice-Involved Adolescents in Residential Treatment

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Abstract

Objective. Adolescents who have experienced complex psychological trauma may incur neurobiological alterations that can be linked to internalizing and externalizing behaviors, while impeding adaptive coping and resolution skills. Scientific advances in the effects of trauma and neuroplasticity in adolescence have the potential to revolutionize interventions for justice-involved youth. The objective of this study was to examine the efficacy of low-resolution electromagnetic tomography (LORETA) *z*-score neurofeedback in decreasing internalizing and externalizing behaviors, as well as trauma symptomatology among justice-involved adolescents with a history of trauma. **Methods.** A secondary analysis of a quasi-experiment was conducted with 41 youth assigned to receive 24 sessions of LORETA *z*-score neurofeedback (LZNF; $n = 20$) or treatment-as-usual (TAU; $n = 21$). **Results.** Individual repeated measures analysis of variance (rANOVAs) reveal LZNF efficacy in decreasing dissociation-fantasy scores. **Conclusion.** Implications highlight the potential of expanding brain-based services within the array of treatment options for traumatized youth across child welfare and justice systems.

Keywords: trauma; juvenile justice; youth; adolescent development; neuroscience

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Introduction

The relationship between complex psychological trauma, chronic stress, and brain architecture is complex. Significant adversity can cause developmental disruptions that lead to lifelong impairments in physical and mental health, educational achievement, economic productivity, and longevity (Abram et al., 2013; Dierkhising et al., 2013; Felitti et al., 1998; Lippard & Nemeroff, 2020; Shonkoff et al., 2012). Up to 90% of justice-involved youth living in residential treatment have experienced complex psychological trauma placing them at greater risk for lifelong negative outcomes (Sprague, 2008). Ford and Courtois (2009) define complex psychological trauma as the result of exposure to severe stressors that are chronic, involve harm or abandonment by a caregiver or other responsible adult, and occur during sensitive developmental periods such as adolescence. The neurobiological changes that occur in the central brain and peripheral autonomic nervous systems as a result of childhood complex psychological trauma are likely to increase stress, anger, and impulsivity, while inhibiting youth from engaging in effective coping and problem solving (Ford et al., 2012). In addition, research demonstrates complex psychological trauma exposure as being significantly correlated with high-risk behaviors (D'Andrea et al., 2012). Consequently, treating the effects of childhood complex psychological trauma is essential to youth outcomes and has the potential to break the cycle of youth involvement in the justice system. Focusing on justice-involved youth is specifically important to society as juvenile crime comprises the largest proportion of all crime, with youth being arrested for 37% of all violent crimes and 43% of all property crimes (Belfield et al., 2012).

Research has found the prevalence of complex psychological trauma in youth in residential treatment is high, with rates estimated between 50–71% (Bettmann et al., 2011; Jaycox et al., 2004). Further, Sprague (2008) found that 75% of juvenile justice-involved youth have experienced complex psychological trauma, whereas other studies indicate that 90% of these youth have experienced at least one complex psychological traumatic event (Abram et al., 2013; Dierkhising et al., 2013). Many of these youth have been polyvictimized, meaning they have been affected by multiple traumatic stressors on multiple occasions (Abram et al., 2013; Briggs et al., 2012; Charak et al., 2018; Ford et al., 2013; Musicaro et al., 2019). According to Briggs and colleagues (2012), 92% of youth had been polyvictimized; while Abram et al. (2013) found that 56.8% of youth in juvenile detention have been exposed to traumatic stressors six or more times. Unfortunately, complex psychological trauma may continue in intensive residential treatment or juvenile facilities, as the environment (e.g., staff abuse, peer violence, restraints) may re-expose youth to traumatic stressors (Dierkhising et al., 2014; Mendel, 2011).

By gender, female children experience higher rates of PTSD symptoms compared to male children after experiencing complex trauma (Wamser-Nanney & Cherry, 2018). This remains consistent across the life span, as lifetime PTSD prevalence is higher among women (Kimerling et al., 2018).

Internalizing and Externalizing Behaviors and Complex Psychological Trauma

Research has found a strong positive correlation between trauma exposure and complex psychopathology (Ford et al., 2010; Spinazzola et al., 2018), with many children experiencing symptoms consistent with multiple internalizing and externalizing disorders (Cook et al., 2005; Ford et al., 2009; van den Huevel et al., 2023). Further, adverse childhood experiences (ACEs) research has found that children with four or more ACEs were 36.2 times as likely to have learning or behavior problems compared to those with no ACEs (Burke et al., 2011). Emotional, behavioral, and cognitive dysregulation can lead to internalizing and externalizing symptoms and behaviors, with affect dysregulation being common in both trauma symptomatology and juvenile delinquency (Ford et al., 2006). As adolescents are already at risk of emotional dysregulation given normal adolescent brain development, complex psychological trauma can exacerbate dysregulation leading to worse outcomes.

Neurobiological Impact of Complex Psychological Trauma in Adolescence

Complex psychological trauma that occurs in sensitive developmental periods such as adolescence can have significant impacts on the brain causing loss of brain cells, damage to brain cell connectivity, enlargement or shrinking of certain parts of the brain, and hyperactivity of certain parts of the brain such as the amygdala, hippocampus, and prefrontal cortex—all areas which undergo normal development during adolescence (Blanco et al., 2015; Giedd, 2008; Herringa, 2017). In Teicher and Samson's (2016) review of neurobiological effects of childhood abuse and neglect, they discuss how structural and functional abnormalities previously associated with psychiatric illness may instead be a direct consequence of abuse. Childhood complex trauma can inhibit or delay certain aspects of brain maturation and development, disrupt attachment patterns (Cook et al., 2005), affect reward and motivation (Teicher & Samson, 2016), executive systems (Ford et al., 2013), and diminish the ability to self-regulate (Ford et al., 2005). A dysregulated brain has a diminished ability to respond to specific demands, and the discontinuity of brainwaves can lead to faulty processing and communication between the brain and the nervous system (Hill & Castro, 2009).

Neuroimaging studies on aggressive and violent offenders suggest that violent offenders who have engaged in impulsive acts have lower brain function in the prefrontal cortex (PFC) and medial temporal regions in the brain, which are areas associated with affect and emotion regulation (Bufkin & Luttrell, 2005). Their findings support that negative emotion regulation may lead to an increased risk for externalizing behaviors of aggression and violence.

Further, childhood complex psychological trauma has been found to interfere with arousal and stress-management systems resulting in individuals feeling like they are constantly under threat (Cannon & Hsi, 2016). Research has shown that chronic trauma exposure influences hypothalamic-pituitary-adrenal (HPA) axis functioning and can result in persistent alterations in stress responsivity later in life. When an individual's stress response is chronically activated, the HPA feedback loop can be disrupted resulting in negative changes to psychological, behavioral, biological, and physiological functioning as the body may produce excessive amounts of cortisol leading to inappropriate behavioral responses to small or minor threats (Gunnar & Vasquez, 2006; Lawrence & Scofield, 2024; Schumacher et al., 2019).

The complex effects of adverse experiences and the environment have significant influence on our developing and maturing neural circuits (Bick & Nelson, 2016; Keuroghlian & Knudsen, 2007; Knudsen, 2004; Knudsen et al., 2006; Majdan & Shatz, 2006; McLaughlin et al., 2014). Neuroplasticity or the brain's ability to adapt to past experiences or changes in the environment can occur through reorganization, formation of new neural networks, or changes in the strength of connections (Sharma et al., 2013). One of the most promising aspects of the adolescent brain is the flexibility of its circuitry to adapt and form new connections after experiencing adversity (Giedd, 2015; Kanwal et al., 2016). Thus, targeted interventions based in neuroplasticity that can increase cognitive control and enhance neural regulation, especially in the limbic lobe and PFC, may be effective in treating the dysregulation caused by complex psychological trauma.

Neurofeedback Intervention

An innovative potential intervention is neurofeedback, a form of electroencephalogram (EEG) biofeedback that measures the electrical activity in the brain and can change unwanted patterns that may be contributing to poor physical and mental health (Hill & Castro, 2009). Neurofeedback helps regulate arousal levels and resync a dysregulated brain through real-time, operant conditioning at specific sites of the brain (Pop-Jordanova & Zorcec, 2004), with the amplitude of specific brainwaves being altered to improve speed and functioning (Marzbani et al., 2016).

Neurofeedback has been found to improve neurological functioning (Hill & Castro, 2009). During neurofeedback training, the brain gradually moves out of "park" with the ability to self-regulate after treatment is completed (Hill & Castro, 2009). According to Marzbani et al. (2016), neurofeedback is effective in treating ADHD, schizophrenia, insomnia, learning disabilities, drug addiction, autism, epilepsy, depression, anxiety, and pain management. Other studies have examined the effectiveness of neurofeedback in treating posttraumatic stress disorder (PTSD) symptomatology (Askovic et al., 2023; Bell et al., 2019; du Bois et al., 2021; Foster & Veazy-Morris, 2013; Gapen et al., 2016; Leem et al., 2021; Nicholson et al., 2020; Noohi et al., 2017; Smith, 2008; van der Kolk et al., 2016; Walker, 2009). As neurofeedback focuses on neural regulation and stabilization, its effects in treating PTSD may be more effective than other evidence-based treatments that primarily target processing the trauma narrative and associated emotions (van der Kolk et al., 2016). Prior research shows neurofeedback may be beneficial for those who have been traumatized and are experiencing anxiety (Walker, 2009), dissociation, dysregulation, depression, and other PTSD symptomatology (Bell et al., 2019; Foster & Veazey-Morris, 2013; Gapen et al., 2016; Smith, 2008; van der Kolk et al., 2016).

In van der Kolk et al.'s (2016) study, 24 sessions of neurofeedback led to statistically significant improvements in PTSD symptomatology in adults for which 6 months of trauma-focused psychotherapy had been ineffective. Rogel and colleagues (2020) examined neurofeedback on children with developmental trauma and histories of severe abuse and neglect and found that 24 sessions led to statistically significant decreases in PTSD, internalizing and externalizing behaviors, and improved executive functioning. Similarly, Huang-Storms et al. (2006) study of children aged 6–13 with histories of abuse and neglect found significant results in internalizing and externalizing behaviors, social problems, aggressive behaviors, cognitive dysfunction, delinquent behavior, anxiety and depression, and attention problems after an average of 38 neurofeedback sessions over a time period of 2–8 months. Although neurofeedback has shown promise for PTSD treatment, scant research has explored its effects with adolescents.

Low-Resolution Electromagnetic Topography (LORETA) Z-Score Neurofeedback. LORETA *z*-score is a type of neurofeedback that allows clinicians to target cortical and subcortical structures, providing a comprehensive view of brain functioning. With LORETA *z*-score neurofeedback (LZNF), dysregulation of core neurocognitive networks and patient symptomatology can be linked to a specific anatomical location to train through EEG source localization (Thatcher, 2011; Thatcher et al., 2019). In 2004, Applied Neuroscience, Inc., developed a real-time comparison of EEG to a normative database using LZNF and Gaussian distributions (Thatcher et al., 2019), which allows for a single metric to standardize EEG analyses. The development of the normative database has helped refine neurofeedback protocols. Simply reinforcing brainwaves toward $z = 0$ becomes the common goal, regardless of whether the dysregulation is above or below $z = 0$. Based on which functional hubs or Brodmann areas are dysregulated, neurofeedback can be optimized to increase regulation and network connectivity within those areas, which in turn could reduce PTSD symptoms.

Some studies have shown LZNF can reduce the number of sessions needed for positive clinical outcomes (Wigton, 2013), leading to less financial burden for clients and improvement in symptoms in a shorter amount of time. More research is needed to substantiate these claims (Coben et al., 2019; Reiter et al., 2016). However, if increased studies found LZNF to be more effective in less time than traditional neurofeedback protocols, this form of neurofeedback may be more accessible for clinical populations, especially those who are underserved.

As LZNF aims to reduce dysregulation symptoms and arousal levels caused by alterations in the brain, it may be an effective intervention in reducing internalizing (i.e., anxiety, depression) and externalizing behaviors (i.e., attention, rule-breaking, aggression) among trauma exposed, justice-involved youth with histories of complex psychological trauma. The primary research question was: Is LZNF as treatment for justice-involved adolescents with complex psychological trauma effective in reducing internalizing and externalizing behaviors and trauma symptomatology compared to treatment-as-usual? This question was tested through three main hypotheses for each dependent variable.

1) There will be significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of internalizing behaviors.
2) There will be significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of externalizing behaviors.
3) There will be significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of trauma symptomatology

Methods

This research conducted a secondary data analysis on a quasi-experimental designed dataset with a naturalistic, pretest, multiple posttests sample. Based on the secondary, deidentified analysis, this study was exempt from IRB review. Study participants were justice-involved adolescents receiving evidence-based standard treatment in an intensive residential treatment center (RTC) accredited by the Joint Commission. Informed consents were administered at the RTC at intake. Standard programming includes group, individual, and family therapy, recreation therapy, on-campus education, 24/7 nursing, psychiatric consultation, and life skills. As part of standard care, youth remained on any medications that they were prescribed and had weekly medication management check-ins through the facility. Youth in the control group received standard programming along with qEEG assessments at four measurement time points: baseline, session 12, session 24, and 1-month follow-up. Youth in the treatment group received standard programming, qEEG assessments, and 24 LZNF sessions.

Inclusion Criteria

Youth were 11–18 years old, had a clinically significant history of trauma as measured by the cutoff scores on the Trauma Symptom Checklist for Children Screening Form (TSCC-SF) and psychosocial history, had a history of justice involvement, and had the ability to speak, read, and understand English sufficiently well to consent and complete all study procedures. In addition, youth had to be in the custody of a parent or guardian who could provide informed consent. This age range was chosen for inclusion as adolescence is a critical developmental age for intervention due to the plasticity of the brain during this period (Giedd, 2015). Neuropsychiatric services (NPS) lab staff helped administer the TSCC-SF to determine if youth had clinically significant trauma symptoms and intake staff determined history of traumatic events using the psychosocial history in the electronic health record (EHR). Intake staff also helped identify youth with a history of current or past juvenile justice involvement.

Exclusion Criteria

Youth who were in state custody, who had an anticipated release from the residential program within the next 3 months, or those who displayed current psychotic symptoms or severe developmental disabilities were excluded from participation.

Deidentified data sent to the PI included treatment group (coded with 0 = TAU, 1 = treatment), gender, age, race, all raw and *z*-score metrics for the TSCC and Youth Self-Report (YSR), and brain maps for each time point. Data not provided to the PI included information regarding their medications (type, dosage, etc.) or details of their justice involvement (reasons why, any charges, how long their involvement has been, etc.). If eligible, participants were matched by age, gender, and ethnicity and assigned to either standard programming (n = 21) or standard programming plus LZNF (n = 20). The

TSCC and YSR were administered by NPS lab staff at all time points.

Measures

Biofeedback Certification International Alliance (BCIA)-certified neurofeedback technicians administered standardized behavioral measures, EEG, and neurofeedback interventions in the NPS lab.

Demographics. Demographic data included age, gender (coded as 0 = *male*, 1 = *female*), and race (0 = *African American*, 1 = *White*, and 2 = *Asian*).

Trauma Symptom Checklist for Children (TSCC). The TSCC Screening Form (Briere, 1996) cutoff scores were used to determine inclusion criteria for clinically significant trauma symptoms. The TSCC-SF includes 20 items and two subscales: general trauma (GT; 12 items) and sexual concerns (SC; 8 items). Cutoff scores are based on age (8–12) and gender groups (13–17) for each subscale (Briere, 1996): for males ages 8–12: GT scores ≥16 and SC scores ≥5; males ages 13–17: GT scores ≥14 and SC scores ≥6; females ages 8–12, GT scores ≥16 and SC scores ≥3; females ages 13–17, GT scores ≥18 and SC scores ≥4. Internal consistency is in good-to-excellent range and test-retest reliability was r = .80 for each scale. The full TSCC (Briere, 1996) was used across each measurement time points which is a 54-item self-report measure of posttraumatic stress for children 8–16 years. Youth are asked to rate the frequency of certain thoughts and behaviors on a 4-point scale (0 = *never*, 1 = *sometimes*, 2 = *lots of the time*, and 3 = *almost all the time*). The TSCC includes two validity scales (under-response and hyper-response), six clinical scales (anxiety, depression, anger, posttraumatic stress, dissociation, and sexual concerns), and eight critical items. Subscales for dissociation measure overt-dissociation and dissociation-fantasy. Overt-dissociation involves observable disruptions in memory, identity, or perception, and can include depersonalization (feeling detached from oneself) or derealization (feeling like the world is not real; Choi et al., 2017). Dissociation-fantasy is a more subtle form of dissociation often characterized by excessive daydreaming or pretending to be someone or somewhere else (Dalenberg et al., 2012; Giesbrecht & Merckelbach, 2006). Sample items include “worrying about things” and “feeling mad.” Cronbach’s alpha for the TSCC was α = .732.

Youth Self-Report (YSR). The YSR (Achenbach & Rescorla, 2001) consists of 112 items designed to measure internalizing behaviors such as anxious depressed or withdrawn depression, and externalizing behaviors such as rule-breaking, aggressive behavior and DSM-oriented scales (e.g., oppositional defiant and conduct problems). Items are scored on a 3-point Likert scale (0 = *absent*, 1 = *occurs sometimes*, 2 = *occurs often*). A sample item on the YSR is “Hangs around with others who get in trouble.” The internalizing subscale of the YSR has a Cronbach’s alpha of α = .60 and the externalizing subscale of the YSR has a Cronbach’s alpha of α = .59. As this was a preliminary study, only the internalizing, externalizing, and total YSR scores were analyzed to reduce the risk of false positives.

EEG Acquisition and Neurofeedback Intervention

The NPS director, a BCIA-certified fellow, analyzed all EEG metrics and developed individualized neurofeedback protocols for participants. BrainMaster Discovery 24 amplifiers were used to collect EEG data with NeuroGuide being used for editing EEG and developing qEEG findings. The reference for normality in NeuroGuide is based on other participants of that age. BrainMaster Atlantis 2x2 was used for neurofeedback sessions. An individualized LZNF protocol was developed for each subject based on their baseline EEG to identify the area(s) of the brain exhibiting the most atypical activity and the specific brainwaves that needed to be trained towards normality (z = 0). For all subjects, the common 10/20 system combined with qEEG findings was used. The most common training sites included Cz, F3/F4, Fz, Pz, and C3/C4, with common protocols involving (a) uptraining alpha (8–12 Hz) and downtraining beta (12–30 Hz) activity and (b) downtraining theta (4–8 Hz) and uptraining beta (12–30 Hz) activity.

During neurofeedback, the subject chose games developed through the brain-computer interface in BrainMaster that provided both auditory and visual feedback when the brainwaves matched the thresholds set in each protocol. An example of a game is an animated race where the participant’s car only moved when their brain signals were operating within the limits set in their protocol. Thus, the participant learned how to control and interact with the game as their brain waves adjusted to the thresholds. Subjects received three 30-min sessions per week, for a total of 24 neurofeedback sessions. Youth in the study did not report any adverse reactions from the intervention.

Statistical Analysis

Data from standardized behavioral measures was securely stored on a password protected computer in an encrypted Excel sheet for deidentified analysis. EEG data were deidentified, coded, and provided to the PI on a flash drive. IBM SPSS v.29 was used for all statistical analyses. Descriptive statistics and bivariate analyses with demographic variables and pretest scores were conducted. For multivariate analyses, repeated measures analysis of variance (RANOVA) was chosen as it allows the researcher to measure the occasion effect (within-subjects effect), group effect (between-within-subjects effect), and the interaction effect (occasion by group effect). RANOVA has several advantages as it controls for errors due to differences between-subjects, which in turn extracts within-subjects variation, and reduces the error variance, and thus, increases the power in testing the null hypothesis (Abu-Bader, 2016). For any pretest scores significantly different between groups, RANCOVAs were conducted with pretest scores as covariates. Missing data was handled by multiple imputation.

Results

Descriptive Statistics

In the treatment group, 10 youth (50.0%) were 11–13 years old and 10 youth (50%) were 14–16 years old. In the control group, 15 youth (71.4%) were 11–13 years old, and six youth (28.6%) were 14–16 years old. There were 11 females (55.0%) and 9 males (45.0%) in the treatment group. In the control group, there were 13 females (61.90%) and 8 males (38.10%). Half of the participants in the treatment group, (*n* = 10, 50.0%) identified as white. In the control group, over half (52.38%) identified as African American, and nearly half youth (47.62%) identified as white (see Appendix: Table A1 for descriptive statistics). In the treatment group, there was a 100% retention rate at posttest, but a 76% retention rate at 1-month follow up due to five youth discharging prior to study completion. In the control group, there was a 100% retention rate at all four time points. All youth met inclusion criteria with clinically significant TSCC-SF cutoff scores (see Appendix: Table A1).

Individual *t*-tests were conducted to examine any gender differences in pretest TSCC-SF, TSCC, and YSR scores. There was a statistically significant difference by gender for depression scores at baseline ($t = -3.310$; $p > .05$). Females reported higher depression scores at baseline ($\bar{X} = 74.21$, $SD = 10.16$) than males ($\bar{X} = 65.47$, $SD = 6.73$). There was a statistically significant difference by gender for sexual concerns scores at baseline ($t = 6.75$; $p > .001$). Males reported higher sexual concerns scores ($\bar{X} = 21.59$, $SD = 3.54$) than females ($\bar{X} = 14.38$, $SD = 3.25$). One-way ANOVAs were conducted to examine any differences in pretest TSCC and YSR scores by race/ethnicity and no significant differences were found.

Independent *t*-tests were conducted to examine any differences between group regarding the general trauma and sexual concern subscales of the TSCC-SF and all baseline measures for the TSCC and YSR. There was a statistically significant difference by group for externalizing behavior scores at baseline ($t = -3.221$; $p > .05$). Those in the treatment group reported higher externalizing behavior scores ($\bar{X} = 70.0$, $SD = 4.26$) than those in the control group ($\bar{X} = 64.86$, $SD = 5.88$). There was a statistically significant difference by group for sexual concerns scores at baseline ($t = 2.244$; $p > .05$). Those in the control group reported higher sexual concerns scores ($\bar{X} = 67.62$, $SD = 7.39$) than those in the treatment group ($\bar{X} = 62.20$, $SD = 8.07$). Due to the pretest differences for these two scales, ANCOVAs were run with the pretest as a covariate to determine intervention effects. For both sexual concerns and externalizing behaviors, there was no significant intervention effects over time when controlling for pretest scores.

RANOVA Interaction Effects. The results of the two-way RANOVA tests of within-subjects effects showed significant interaction effects for the dissociation-fantasy subscale of the TSCC ($F_{(df = 3, 102)} = 7.083$, $p < .001$, $\eta^2 = 0.172$). See Appendix: Figure A1 depicting interaction effects.

Table 1
Summary Statistics for YSR Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η^2
Internalizing Behaviors			.499	.684
Pretest	64.10 (6.92)	66.90 (4.48)		
Midpoint	64.90 (7.17)	65.48 (5.21)		
Posttest	65.30 (6.85)	67.86 (6.51)		
Follow-up	62.60 (5.23)	64.19 (6.26)		
Externalizing Behaviors			.129	.060
Pretest	70.00 (4.26)	64.86 (5.88)		
Midpoint	69.30 (4.55)	65.05 (4.80)		
Posttest	65.35 (4.31)	66.14 (4.36)		
Follow-up	64.07 (4.51)	64.62 (4.48)		
YSR Total Score			.332	.033
Pretest	67.90 (4.14)	66.62 (6.02)		
Midpoint	65.35 (5.66)	67.38 (5.89)		
Posttest	63.50 (5.92)	65.05 (6.70)		
Follow-up	61.80 (5.33)	64.67 (5.33)		

Table 2
Summary Statistics for TSCC Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η^2
Anxiety			.083	.063
Pretest	71.10 (13.28)	69.67 (9.22)		
Midpoint	68.30 (10.00)	69.67 (10.24)		
Posttest	66.90 (8.58)	69.71 (8.64)		
Follow-up	65.47 (8.43)	68.71 (7.18)		
Depression			.311	.034
Pretest	72.55 (11.12)	68.74 (8.24)		
Midpoint	69.60 (9.04)	68.95 (11.39)		
Posttest	66.35 (8.29)	67.76 (9.95)		
Follow-up	64.73 (7.77)	65.05 (8.25)		

Table 2
Summary Statistics for TSCC Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η²
Anger			.053	.072
Pretest	68.45 (8.45)	68.74 (8.24)		
Midpoint	65.45 (8.20)	68.95 (11.39)		
Posttest	64.45 (5.74)	67.76 (9.95)		
Follow-up	63.60 (5.18)	65.05 (8.25)		
Posttraumatic Stress			.191	.048
Pretest	70.15 (13.09)	68.43 (9.65)		
Midpoint	67.60 (11.16)	71.51 (10.86)		
Posttest	66.20 (10.10)	69.95 (10.37)		
Follow-up	66.08 (10.61)	69.00 (8.85)		
Dissociation			.305	.035
Pretest	69.30 (13.62)	68.76 (8.07)		
Midpoint	67.80 (9.42)	69.62 (12.56)		
Posttest	66.35 (8.99)	70.90 (12.17)		
Follow-up	63.93 (7.77)	67.05 (10.44)		
Dissociation-Overt			.355	.033
Pretest	67.65 (11.13)	71.81 (11.71)		
Midpoint	66.00 (9.10)	71.00 (8.78)		
Posttest	65.30 (8.86)	65.48 (7.90)		
Follow-up	65.46 (10.15)	64.95 (7.34)		
Dissociation-Fantasy			.001*	.173
Pretest	70.95 (9.67)	65.29 (9.17)		
Midpoint	68.60 (8.49)	68.14 (10.22)		
Posttest	65.25 (6.81)	67.19 (9.72)		
Follow-up	64.07 (7.07)	66.71 (8.50)		
Sexual Concerns			.684	.014
Pretest	62.20 (8.07)	67.62 (7.39)		
Midpoint	61.30 (6.45)	66.0 (7.64)		
Posttest	61.55 (6.20)	66.62 (9.84)		
Follow-up	59.47 (5.84)	66.81 (9.97)		

Table 2
Summary Statistics for TSCC Subscale Interaction Effects

Subscales	Treatment Group Mean *T* Score (*SD*)	Control Group Mean *T* Score (*SD*)	*p*	η^2
Sexual Concerns-Preoccupation			.896	.006
Pretest	64.75 (7.50)	65.95 (7.95)		
Midpoint	65.45 (7.25)	65.43 (7.83)		
Posttest	65.85 (8.31)	66.19 (6.85)		
Follow-up	65.47 (8.43)	67.14 (8.97)		
Sexual Concerns-Distress			.909	.005
Pretest	67.50 (9.99)	68.67 (8.21)		
Midpoint	67.05 (8.74)	67.10 (10.68)		
Posttest	66.10 (7.82)	67.43 (8.73)		
Follow-up	63.53 (6.01)	64.57 (8.67)		

Note. * = $p < .010$.

Discussion

This study explored the use of neurofeedback in treating trauma symptomatology among traumatized youth with histories of justice involvement in intensive residential treatment. All youth in the study had clinically significant trauma symptoms as measured by the TSCC-SF cutoff scores. By gender, there were higher rates of depression among females than males. It was surprising that the PTS subscale was not significant by gender as prior research supports females experience higher rates of PTSD symptoms (Wamser-Nanney & Cherry, 2018). Additionally, we found that males reported higher rates of sexual concerns than females, which was in contrast to previous studies (Wamser-Nanney & Cherry, 2018) and surprising as males typically under-report sexual concerns compared to females (Holmes & Slap, 1998). The lack of gender differences in these results may be attributed to the small sample size.

The primary objective of the study was to test the hypothesis that there is significant occasion (pretest, midtest, posttest, and follow-up) by group (treatment and TAU) interaction effects on levels of internalizing behaviors, externalizing behaviors, and trauma symptomatology. This study found significant interaction effects for one TSCC subscale, with the treatment group showing significantly decreased dissociation-fantasy scores over time compared to the TAU group. The interaction between group and time accounted for 17.2% of the variance in dissociation-fantasy scores. This result suggests that LZNF may help traumatized youth cope without resorting to fantasizing. In Flaherty's (2017) study, youth offenders with crimes against persons had significantly higher rates of dissociation-fantasy scores than those with crimes against property or drug offenses. Their study highlights the importance of treating fantasy subtypes of dissociation as a prevention strategy for criminal behaviors.

There were no significant interaction effects for internalizing or externalizing behaviors. Although the effects were not statistically significant for externalizing behaviors, and the anxiety and PTS subscales of the TSCC, there was an overall reduction in these scores for the intervention group but not for TAU. The failure to achieve statistical significance may be due to low power given the small sample size, wide variability in scores, and the loss of some treatment participants to follow-up.

Previous literature has cited positive effects of neurofeedback on many PTS symptoms (Huang-Storms et al., 2006; Rogel et al., 2020; van der Kolk et al., 2016). However, protocols used in the studies differed from the LORETA *z*-score training employed in this study. Rogel et al. (2020) and van der Kolk et al. (2016) both employed sequential placement of electrodes with active sites at T4 with reference at P4 for adults, whereas Huang-Storms et al. (2006) employed individualized protocols with children. Given these differences, future research with larger sample sizes should compare effects based on protocols and the type of neurofeedback modality used.

Limitations

This study has several limitations. First, the study design lacks a randomized control group, which is challenging as it is unethical to deny treatment to any youth within the care of the facility. However, matching was used based on admission criteria and criteria for brain-based services to control for any confounding variables or differences that may be present in the groups. In addition, there was a small sample size limiting our ability to fully examine differences by gender identity and ethnicity. Although the study sample was diverse with 54% identifying as White, 43% identifying as African American, and 0.5% identifying as Asian, prior research demonstrates the overrepresentation of minority groups in residential facilities and the juvenile justice system (Hockenberry, 2020). Thus, future research needs to draw on larger, more diverse samples and should seek to intentionally recruit more than these three race/ethnicities to better identify and represent the true population in these settings. Using strategies derived from community-based participatory research, such as incorporating the youth at every stage of the planning and development, may increase buy-in and willingness of these marginalized groups to engage in research (Collins et al., 2018).

Future studies may want to include more specific screening measures of mental health symptomatology such as depression and anxiety using the Patient Health Questionnaire for Adolescents (PHQ-A) or Generalized Anxiety Disorder-7 (GAD-7) scales. Although the PHQ-A and GAD-7 are limited screening tools, they can provide more detailed symptomatology information compared to the subscales of the YSR and are still accessible and easy to administer within community-based settings.

Implications and Recommendations

This study promotes collaborative and interdisciplinary research that integrates neuroscience, development, psychology, and social work. Findings suggest that neurofeedback may be an additional intervention for justice-involved youth with complex psychological trauma histories who are in residential treatment. Future research should employ randomized controlled trial designs with this population. Additionally, qualitative data from both the researchers' and staff's observations throughout the study could provide a different and unique perspective to the observed changes in clients.

Longitudinal studies are also warranted to examine how the manifestation of delinquent behaviors, mental health disorders, and trauma symptomatology changes from onset of trauma through early adulthood. This longitudinal data could help provide increased support and adaptation of the trauma coping model (Ford, 2002; Ford et al., 2006; Ford et al., 2009). Future studies should adapt the number of neurofeedback sessions conducted as well as the follow-up measurement to assess for the sustainability of effect and assess recidivism rates.

Increased research is needed comparing the clinical efficacy of various types of neurofeedback (i.e., LORETA neurofeedback vs. traditional methods of neurofeedback) and the training protocols administered for each. Although some researchers suggest LORETA neurofeedback can lead to less sessions, making it a more affordable option for clients (Wigton, 2013), very few rigorous studies exist testing the efficacy of LORETA neurofeedback with clinical populations. A systematic review by Coben et al. (2019) found only three research studies evaluating the effects of LORETA neurofeedback with clinical populations and appropriate comparison groups and concluded that these methods need to be replicated in different populations with rigorous superiority trials conducted to determine its clinical efficacy.

Further, incorporating neuroscience techniques such as neuroimaging and neurofeedback by researching them within the greater context of adolescent development with the addition of biomarkers (i.e., stress hormones) and behavioral markers (i.e., treatment adherence) can provide a more comprehensive view of overall brain functioning and allow clinicians to target specific cortical and subcortical areas of the brain with various behaviors.

Conclusion

This study examined the effects of neurofeedback on justice-involved youth's trauma symptomatology and internalizing and externalizing behaviors. Although exploratory in nature, preliminary results of the study identified that neurofeedback was efficacious in treating dissociation-fantasy scores of justice-involved youth in residential treatment. More rigorous empirical evidence with a larger sample size is needed to support the expansion of neurofeedback as a potential intervention for traumatized youth in child welfare and juvenile justice systems.

Author Disclosure

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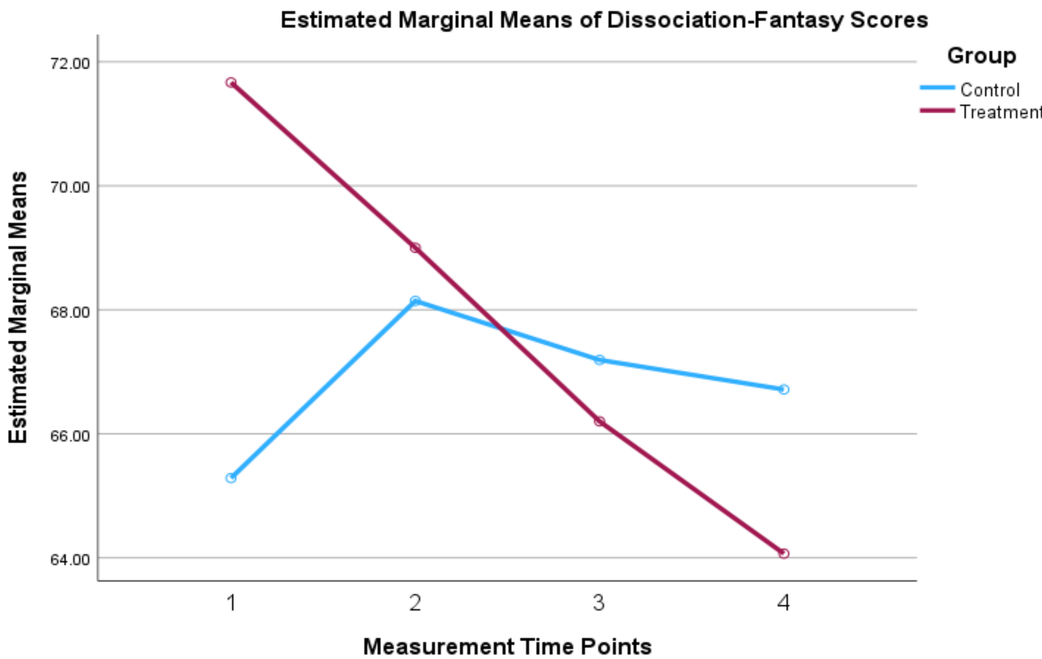
Appendix

Table A1
Descriptive Statistics of Sample

Variables	Treatment Group		Control Group	
Age				
11	3		5	
12	2		6	
13	5		4	
14	4		3	
15	3		1	
16	3		2	
(11–13)	10		15	
(14–16)	10		6	
Mean (*SD*)	13.55 (1.64)		12.76 (1.56)	
Gender				
Female	11		13	
Male	9		8	
Race/Ethnicity				
African American	8		11	
Asian	2		0	
White	10		10	
TSCC-SF Raw Scores General Trauma	**Age 8–12**	**Age 13–17**	**Age 8–12**	**Age 13–17**
Female	16.67 (4.93) (*n* = 3)	21.25 (2.71) (*n* = 8)	24.67 (7.26) (*n* = 6)	26.0 (3.46) (*n* = 7)
Male	25.0 (1.41) (*n* = 2)	22.14 (4.38) (*n* = 7)	22.0 (3.16) (*n* = 5)	19.67 (0.58) (*n* = 3)
Sexual Concerns				
Female	12.33 (3.51) (*n* = 3)	15.0 (2.51) (*n* = 8)	14.83 (3.97) (*n* = 6)	14.14 (3.63) (*n* = 7)
Male	21.0 (1.41) (*n* = 2)	21.71 (4.19) (*n* = 7)	21.6 (4.10) (*n* = 5)	21.67 (3.51) (*n* = 3)

Figure A1. *Interaction Effect: TSCC Dissociation Fantasy Subscale.*



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A Clinical Perspective on Neurofeedback Integrated With Acceptance and Commitment Therapy (ACT)

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Abstract

The integration of neurofeedback (NF) with acceptance and commitment therapy (ACT) describes a multimodal intervention that provides access, noninvasively, to real-time information and feedback of client-relevant biological behavior set within an evidence-based psychotherapeutic behavioral context. It is advanced that the integration of therapies considers the range of contextual and learning factors that influence NF, which are supported by advancements in contextual behavioral theory and practice. This paper frames NF as a repeated experiential exercise that supports psychological flexibility processes relevant to acceptance, defusion, self-as-context, and contact with the present moment, while engaging values-based committed action. This clinical perspective offers that NF can be flexibly integrated and blended within an evidence-based psychotherapeutic context and applied as a transdiagnostic, process-based intervention that may provide a broad scope for meaningful change.

Keywords: ACT; psychotherapy; neurofeedback; neuromodulation; multimodal

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Introduction

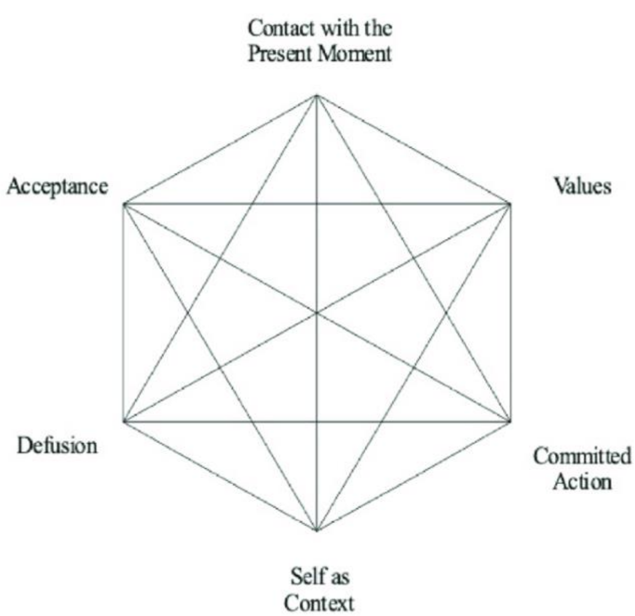
Flexibility is viewed from various perspectives widely across the study of the human mind, brain, and behavior. This includes but is likely not limited to psychological, behavioral, social, cognitive, cortical, neural, and network flexibility—each referring to adaptive change in changing contexts. Humans modulate behavior, that is, exert a modifying influence through environmental and language interactions from self and with others. However, behavior can also be influenced by other means, such as chemically, electrically, and electromagnetically. The aim of the present perspective is to consider the multimodal integration of a specific psychotherapeutic orientation, acceptance and commitment therapy (ACT), with technology that also provides a means for neuromodulation (i.e., neurofeedback [NF]), to offer a context for cultivating flexible change in a personalized, meaningful direction.

ACT has been described as part of the third wave of cognitive behavioral therapy (CBT), increasingly acknowledged as a process-based therapy (PBT; Hayes & Hofman, 2021). The foundation of ACT is firmly grounded in the scientific philosophy of functional contextualism and behavioral psychology, as well as developed alongside as a clinical application of an extended modern behavioral analytic theory of human cognition and language, relational frame theory (RFT; Hayes et al., 2012). ACT has accumulated an impressive evidence base with over 1,000 published randomized control trials to date (Hayes & King, 2024). There is demonstrated efficacy across a wide range of clinical presentations and settings, including but not limited to depression (Bai et al., 2020), anxiety disorders (Haller et al., 2021), chronic pain (Ma et al., 2023), obsessive compulsive disorders (Soondrum et al., 2022), substance use disorders (li et al., 2019), psychosis (Tonarelli et al., 2016), and insomnia (Salari et al., 2020), although the evidence base extends well beyond DSM diagnosable presentations (Hayes & King, 2024).

In a meta-analysis of meta-analyses across a broad range of mental health conditions, Gloster et al. (2020) showed small to medium effect sizes in favor of ACT over both active and inactive controls.

ACT is a flexible process-based model that takes a skills-based experiential approach to promoting health and growth through fostering psychological flexibility, that is, the ability to contact the present moment more fully as a conscious human being without defense and based on what the situation affords—to change or persist in behavior to serve valued ends (Hayes & Strosahl, 2004). The functional contextual approach of ACT directs focus on function over form of behavior, where function is defined in relation to context, then considered in terms of workability (Harris, 2019). Building skills in psychological flexibility are developed through six core interrelated processes of acceptance, defusion, present-moment awareness, self-as-context, values, and committed action (see Figure 1). The ACT model of psychopathology therefore conceptualizes that the inverse processes of psychological inflexibility are central to the development and maintenance of psychological suffering (Luoma et al., 2007).

Figure 1*. The ACT Hexaflex.*



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NF is a form of biological feedback that provides individuals with real-time information about their brain activity, most commonly measured via electroencephalography (EEG). This feedback is typically delivered through visual or auditory cues and reflects specific desired brain events, such as the presence of a targeted brain frequency at a predetermined power threshold (i.e., frequency band NF) or a slow shift in cortical excitation or inhibition (e.g., slow cortical potential [SCP]). NF is grounded in principles of learning theory, particularly classical and operant conditioning, wherein the reinforcement of desired brain states increases the likelihood of their recurrence (Sherlin et al., 2011). However, it is widely acknowledged that NF outcomes are influenced by multiple factors beyond simple conditioning. As Strehl (2014) notes, "the equipment is a tool within this interaction, NF is a method of behavior therapy" (p. 6), underscoring the importance of the therapeutic context. NF has demonstrated clinical efficacy across a range of populations, with the strongest empirical support in attention-deficit/hyperactivity disorder (ADHD; Van Doren et al., 2019). Additional evidence supports its use in conditions such as epilepsy (Tan et al., 2009), insomnia (Lambert-Beaudet et al., 2021), posttraumatic stress (Askovic et al., 2023), anxiety (Russo et al., 2022), depression (Fernández-Álvarez et al., 2022), chronic pain (Patel et al., 2020), and performance enhancement in nonclinical populations (Brito et al., 2022).

Neurofeedback-Integrated ACT: The Case for NF as an Experiential Exercise

It is offered that NF occurs on at least two different levels, that is, at the biophysiological level of brain-wave conditioning and an experiential level. While the integration of ACT and NF highlights the latter, there are several important factors that are argued to contribute to the worthy integration of these therapies. Foremost, behavior learning theory is foundational to both NF and ACT, and it is forwarded that the theoretical foundations of ACT, such as RFT, may assist in further appreciating some of the multifactorial mechanisms of change observed in NF. Secondly, it is argued that psychological flexibility processes may blend synergistically with NF practice rather than simply providing additive effects of pairing different modalities, as much as to frame the act of NF as a repeated experiential exercise when delivered within an ACT context and stance. At the level of experience, NF corresponds to flexibly allocating and sustaining attention to real-time brain behavior in the present moment with openness of experience in the service of moving in the direction of valued action. Finally, given that ACT is a transdiagnostic, process-based model, the combination of therapies may provide greater scope for the clinician and individual in terms of meaningful change with use of psychological, behavioral and physiological processes simultaneously.

Considering the Multifactorial Mechanisms of Change

Despite the established clinical efficacy of NF, the literature continues to suffer from considerable methodological heterogeneity, small sample sizes, a lack of standardization in NF protocols and practice across clinicians, and a mixed evidence base despite decades of inquiry. NF opponents raise issues of inadequately controlled studies with lack of clarity in the mediators of change, often attributing the reported benefit arising from both nonspecific general and NF-related nonspecific treatment effects, such as technique and therapy expectations, the therapeutic interaction with the clinician, and effects of repeatedly sitting still and focusing with reinforcement, not otherwise directly resultant from specific brain wave reinforcement (Thibault & Raz, 2017). Although there are now controlled and adequately powered studies indicating nonsuperiority of active compared to sham NF, despite the clear clinical effectiveness of the highly active sham conditions (Arnold et al., 2021; Schönenberg et al., 2017), the validity of controlled studies that do not adhere to foundational operant conditioning learning principles (e.g., very high or automatic reward thresholding) has been questioned (Pigott et al., 2021).

For example, there is evidence from a recent well-powered (i.e., 144 children with ADHD), double-blind placebo-controlled randomized NF study from Arnold et al. (2021), including 25-month follow up (Arnold et al., 2023), which shows the clear, sustained clinical benefits of such stated nonspecific effects. In this study, both groups received counseling on sleep and nutrition, while the control group condition used prerecorded EEG signals to determine rewards while retaining live electromyography (EMG) biofeedback. It was found that both the active control and NF groups resulted in significant and sustained reduction in ADHD symptoms, indicating a majority psychotherapeutic/behavioral effect. For context, the highly active control group showed large and sustained clinically meaningful effect sizes for reduction in ADHD symptoms (e.g., Cohen's $d > 1$). While not statistically significant, there was a trend suggesting that more of the control group required medication compared to the active NF group at follow-up, alluding to the long-term and relevant benefits of the active, brainwave conditioning effect.

In studies where the attentional training component is controlled by comparing active NF to cognitive training, findings have shown superiority of the NF group in reducing ADHD symptoms in children (Gevensleben et al., 2009; Steiner et al., 2014), although this effect is not consistently demonstrated (Minder et al., 2018). As with Arnold et al. (2021), Steiner et al. (2014) also found that the active NF group did not require changes in medication, whereas the control groups saw increases in medication dose at 6-month follow-up. Consider that repeatedly training awareness to reinforcement that is importantly linked with changing biological function, whether measurable or perceived, may broadly train one's sensitivity to available contingencies, as opposed to direct attention training without biological feedback.

In addition to the literature attempting to compare active to sham NF, it is important to address trials showing nonsuperiority of NF over standard cognitive and behavioral type therapies (Abbasi et al., 2018; Kwan et al., 2022; Moreno-García et al., 2019; Schönenberg et al., 2017) when considering the value of a combinatorial, integrative approach rather than direct comparison. There has been one quasi-experimental trial comparing NF (i.e., 30 half-hour alpha reward sessions, three sessions per week), ACT (i.e., a dozen 1-hr weekly sessions), and a nonactive control group in women with anxiety disorders in Iran (Soleymani et al., 2020). The findings demonstrated significant reduction in anxiety at postintervention and follow-up for both the NF and ACT groups, albeit with significantly higher reduction of anxiety in the ACT group. Future studies may however explore whether the integration of NF within ACT augments and/or extends outcomes for particular clinical contexts.

Given NF is resource-intensive and hard to access, it is seldom used as a fine-line intervention and is typically considered after other therapies or medications have had limited success (Tsuji-Lyons & White, 2023). For example, as an adjunct therapy to trauma counseling where previous counseling had poor response, Askovic et al., (2020) followed 13 individuals with chronic PTSD at a tertiary trauma in clinic in Sydney Australia who underwent personalized NF, compared to a waitlist control group continuing only trauma counseling. Results of this preliminary retrospective study found that the adjunct NF group showed significantly reduced symptoms of trauma, anxiety, and depression, such that 12 of the 13 individuals were below PTSD diagnostic threshold at posttherapy. In individuals with medication refractory epilepsy, SCP NF has been integrated within a wider behavior therapy framework to increase context sensitivity to seizure-related antecedents and reinforcing contingencies, resulting in significant reduction in severity of seizures relative to a pretraining phase (Kotchoubey et al., 1996). While not specifically ACT, these examples highlight the value of integrative psychotherapy with NF in a treatment-resistant population. Alternatively, the integration of mindfulness and acceptance skills via ACT with biofeedback technology, such as heart rate variability (HRV) training, has been well articulated clinically (Ehrenreich, 2024; Khazan, 2015), and it was recently further discussed in a chapter by Dr. Richard Gevirtz in *Integrating Psychotherapy and Psychophysiology* (Gevirtz, 2024). The latter application describes an example of psychotherapy integrated with biofeedback; however, it is appreciated that there is no existent literature on the integration of ACT with EEG-based biofeedback.

Neurofeedback and Relational Frame Theory (RFT)

Considering the complex means by which humans learn through language and cognition may help to appreciate the translation and transfer of repeated NF practice into meaningful changes in daily life. Further exploration through ACTs theoretical grounding, RFT, may help to elucidate some of the nonspecific psychotherapeutic effects that emerge from NF. As expressed in RFT, humans have the remarkable capacity to relate anything to anything else based on nonarbitrary properties of stimuli as well as arbitrarily defined relations (Torneke, 2010). Learning in humans is vast and complicated, extending beyond contingency-based learning through classical and operant conditioning; that is, humans hold the ability to learn through deriving relations without any direct learning experience through arbitrarily applicable relational responding. Although this capacity provides undeniable advantages to reflect, plan, organize, communicate, and anticipate consequences, rigid patterns of verbal rules dominating awareness can act to narrow behavior and limit sensitivity to available contingencies leading to psychological suffering (Villatte et al., 2015). Through derived relational responding, the psychological functions of stimuli and events can transform stimulus functions through relational frames based on contextual cues (Torneke, 2010). NF-related nonspecific effects leading to meaningful change beyond the therapy room may describe an individual's changing relationship with their context through a transformation of stimulus functions; context in NF considers the interaction with the therapist as well as the technology, feedback, and setting combined with their unique learning history and changing private experiences.

For instance, and even in "sham" NF conditions, experiential exercises based on repeated attentional training in the presence of a trained mental health behavior clinician can facilitate derived relational responding and transformation of stimulus functions. Consider the primary argued NF mechanism of operant conditioning of target brain waves, such as the occurrence of a brain event at a predetermined threshold (e.g., sensorimotor rhythm [SMR]) followed by positive reinforcement (e.g., presence or movement of desired visual and/or auditory stimulus), thereby increasing likelihood of such brain event reoccurring. There is also an arbitrary applied relational frame of coordination between the presence of the feedback with provided language (i.e., SMR = feedback = "relaxed attention"). In addition, there are many other likely recurring psychological events present or accessed during the exercise, including thoughts, feelings, sensations, and memories, including but certainly not limited to boredom, tiredness, alertness, busyness, anxiety, excitement, engagement, and so on. If such repeated psychological events such as boredom, tiredness, "I can't do this," or "I want to do something else" can be noticed and present without changing or shifting task, and they are related to the experience of "relaxed attention" and task engagement, this may in turn assist in a transformation of stimulus functions from aversive to appetitive in relevant contexts. When boredom then shows up during work-related tasks, it functions as less aversive now related to "relaxed attention" and has been experienced without task disengagement, thereby widening a previously narrow behavioral repertoire (e.g., boredom as an aversive resulting in experiential avoidance and task disengagement).

Indeed sham-controlled NF conditions represent a highly active intervention that demonstrates meaningful psychotherapeutic effects, such that derived relational responding may occur without feedback of any "real" live EEG activity through repeated experiential practice, exposure, and language, with acknowledgment that the individual receiving sham feedback is successfully blinded and therefore likely believes the feedback reflects their own biological function. However, the inclusion of operant conditioning of relevant brain events within the exercise remains worthwhile (Pigott et al., 2021), especially when considering some of the potential differences in long-term effects (Arnold et al., 2021; Steiner et al., 2014) between defined NF learners and nonlearners (Kolken et al., 2023; Krepel et al., 2022). It is forwarded that it is the combination of underlying operant conditioning principles of physiological function interacting with a complex interpersonal language and relational learning context, as applied to a specific individual's context that works to guide flexible and sustained self-regulation. In this context, the term self-regulation refers to the role of attention and awareness processes to modulate behavior that is consistent with one's needs, values, and interests (Brown & Ryan, 2003).

Neurofeedback in a Process-Based Clinical Context

As outlined above, the focus of the present perspective is at the experiential level, and it is not within the scope of this paper to discuss the range of brain behavior targets and NF protocols available. Considering this, the practice and experience that informs this view emerged through working within the confines of the standard, well-researched, protocols including single channel reinforcement of SMR, theta-beta ratio, alpha-reward, and SCP NF (Arns et al., 2014; Marzbani et al., 2016) with sessions exclusively clinician-facilitated in clinic or via telehealth. These protocols relate to well-described and measurable biological processes functioning within the arousal-based vigilance model (Arns & Sterman, 2019). The appropriate NF protocol is guided in the context of clinical history, current presentation, and formulation through the clinician's standard clinical intake, in addition to integration of formal assessment with standardized symptom questionnaires as well as preintervention quantitative EEG (qEEG). Most critically, the NF protocol is aligned with the individual's primary concerns for seeking intervention (e.g., attention difficulties, affective dysregulation, etc.) and related to their therapy goals with attention to measurable behavioral goals.

Moreover, the current paper provides a narrative integration informed by clinical experience; it is but one perspective on an integrative psychotherapy approach in neuromodulation and it is not a systematic review of the literature. Importantly, the current position is not that the combination of therapies will necessarily result in an augmentation of specific clinical outcomes over monotherapy approaches, as there is not empirical data to support this, rather that the integration has the potential to reach wider in its effects, extending beyond symptom reduction.

The present paper also explores the integration of NF within an ACT framework transdiagnostically, and it is therefore not in reference to any specific clinical population. With that in consideration, much of the clinical experience that has informed this integration has come from those primarily seeking support for ADHD, along with the commonly occurring psychiatric and behavioral "comorbidities." There is an evidence base supporting the use of cognitive behavioral interventions to support the day-to-day impact on functioning from ADHD symptoms, including deficits in focused and sustained attention, inflexibility, behavioral problems, as well as related problems of depression, anxiety, psychological adjustment, and quality of life (Kretschmer et al., 2022). More specifically, mindfulness-based interventions have shown efficacy on improving core ADHD symptoms (Xue et al., 2019), and a scoping review by Munawar et al. (2021) suggested the use of ACT for ADHD is feasible, flexible, and promising; however, further well-controlled trials are required.

It is forwarded that multimodal interventions that are transdiagnostic and process-based, such as ACT and NF, may have additional utility in certain clinical contexts, such as ADHD and PTSD, where the majority are more likely than not to meet criteria for another diagnosable mental health disorder (Brady et al., 2000; Gnanavel et al., 2019). When supporting disorders of arousal-based dysfunction, there is the dual benefit of targeting psychological and behavioral processes while simultaneously supporting relevant biophysiological processes pertaining to sleep, arousal, and vigilance regulation within the same experiential exercise. Furthermore, there is often advantage in adapting mindfulness-based exercises in populations whose use of traditional mindfulness-meditation exercises may be particularly challenging to engage without modifications (e.g., as in ADHD; Janssen et al., 2020) or trigger aversive trauma responses (Lindahl et al., 2007).

Additionally, it is acknowledged that the existent body of intervention studies, including ACT, often shares limitations in the underrepresentation of certain demographic groups (Misra et al., 2023). As a result, it may work to limit the generalizability of such an integration of models which requires careful consideration when applied in diverse clinical populations. For example, much of the language used in this integration is in reference and drawn from work with adolescents and adults. It is necessary to adapt the language when working with children, for example, using the adapted Kidflex model (Black, 2022). Working effectively with children means working with their parents, with consideration taken to teaching flexibility processes for parents to model at home and applying effective behavioral therapy techniques.

In this capacity, the integrated therapeutic work can function within a PBT model, that is, an overarching integration of evidence-based therapies that carefully considers selected mediators of change for the individual, organized across dimensions of function according to evolutionary adaptive processes of variation, selection, and retention in context across biophysiological and sociocultural levels (Hayes & Hofman, 2021). In NF practice when operating in the arousal model, attentional and affective dimensions can be targeted at the biophysiological level while simultaneously and synergistically addressing relevant psychological and behavior change processes through language-based and psychosocial interactions that are personalized and targeted to the individual. As a clinical example, consider an individual seeking intervention who presents with chronic difficulties with allocating and sustaining attention to tasks, loss of contact with the present moment, experiential avoidance of fatigue, boredom, and anxiety resulting in task disengagement and procrastination, alongside evidence of a vigilance impairment at brain level in the form of hypoarousal and elevated midline slow-wave theta activity. A process-oriented therapy may consider a repeated exercise of present moment awareness, with openness of experience and a flexible sense of self, while simultaneously guiding brain states towards mental alertness with acknowledgement of lowered arousal through operant conditioning, in the service of health, a sense of vitality, productivity, and efficiency.

Practically, NF practice delivered as an experiential exercise in clinical practice operates within standard approximate hour-long sessions, and the exercise duration typically lasts around 20–30 min, taking place usually at least on a twice weekly basis to facilitate learning. Therefore, in practice, there is still time spent before and after feedback to practice psychotherapy (Fisher et al., 2016; Tsuji-Lyons & White, 2023), such as ACT (please see the numerous available transdiagnostic treatment manuals for more information which has informed the current view, such as Harris, 2019; Luoma et al., 2007; Polk et al., 2016; Twohig et al., 2020; Villatte et al., 2015). The next section will consider the integration of each psychological flexibility process within NF practice. See Table 1 for an example protocol for ACT-based NF completed on an approximate twice weekly basis over approximately 20–30 sessions.

Table 1
Example Transdiagnostic Protocol for NF-Integrated ACT

Week	Session	Approximate Therapy Outline for ACT-Based NF Sessions *Each session comprises 20–30 min experiential NF practice and 20–30 min talk therapy*
1–2	0–4	Psychoeducation on biophysiological processes relevant to qEEG-guided NF protocol (e.g., arousal regulation, SMR, cortical flexibility, etc.). Permission to offer a different perspective by collaboratively exploring use of the ACT matrix (Polk et al., 2016). This perspective can set up useful noticing language to revisit throughout therapy, such as toward and away moves, senses, and mental experiencing. It also provides a clear platform to identify internal barriers and unworkable actions, and reveal motivations and values along with targets for behavioral change. Revisiting this perspective when introducing psychological flexibility processes can be useful. Orienting to the feedback mindfully, ***contacting the present moment.*** Flexible attention training through the NF experiential exercise is practiced in every session of NF-integrated ACT. ***Committed action*** for healthy sleep-wake behavior. Revisited regularly throughout intervention and often related to the biophysiological target processes (e.g., SMR, SCP, etc.).

Table 1
Example Transdiagnostic Protocol for NF-Integrated ACT

Week	Session	Approximate Therapy Outline for ACT-Based NF Sessions *Each session comprises 20–30 min experiential NF practice and 20–30 min talk therapy*
3	5–6	Creative hopelessness, undermining the control agenda through metaphor and other experiential exercises. Introduce experiential ***acceptance*** as an alternative to control. Facilitate open, nonjudgemental awareness of feedback. Practice gentle acknowledgement, accommodation, allowance, and appreciation of what is present and what is not under voluntary control (e.g., brain state compared to volitionally continuing to remain seated and engaged with the task).
4	7–8	Explore the process of ***defusion*** through metaphor and experiential exercises. Practice defusion techniques on private experiences showing up during NF exercises by noticing, naming, and expanding awareness. Physicalizing exercises, dropping anchor, placing thoughts on flowing feedback (e.g., puzzle pieces, moving bar), and metaphors using “waves” (e.g., wave surfing, boat on the water, etc.) can be particularly valuable to consider practicing during NF. Invite the client to practice defusion skills in daily life through behavioral commitments.
5	9–10	The ***self-as-context*** process is embedded within NF by attending to perspective-taking on one’s brain activity. Invite the client to notice from what perspective are they able to notice the feedback and highlight the constancy of the self-as-context perspective with changing experience and brain function (e.g., NF as the self-as-context metaphor). Further explore any fusion with self-as-content through memories, roles, labels, and evaluations, and ask questions to take perspective across time, person, and place. Formally review progress at the 10th session. Clinical interview, formal questionnaires of relevant symptoms and processes.
6	11–12	Following the review and decision to continue with therapy, revisit and formally explore ***values*** as an intrinsic source of ongoing motivation that can be accessed in and outside of sessions to augment sources of reinforcement. Link values with relevant valued life domains where qualities of behavior (e.g., being open, aware, curious, loving, etc. at school, work, or home) can be engaged in within sessions and during NF practice, and then transferred to ***committed actions*** in daily life.
7–10	13–20	Review out of session practice, set and track behavioral commitments, flexibly revisit and address psychological flexibility processes as required. Work to integrate and transfer NF mindfulness skills into daily life. At the end of the 20th session, complete another formal review with questionnaires and any relevant behavioral or physiological measures (e.g., sleep-wake actigraphy watch).
11+	21–30	Depending on the client’s progress and presentation, consider discontinuing therapy or continuing sessions to facilitate consolidation of therapy gains.

Note. The above protocol illustrates one example of a therapy protocol integrating ACT with NF. In practice, the order of processes addressed in therapy varies depending on the case conceptualization, functional assessment, and context, flexibly as needed. Please see the numerous available transdiagnostic treatment manuals for more information which has informed the current view, such as Harris, 2019; Luoma et al., 2007; Polk et al., 2016; Twohig et al., 2020; Villatte et al., 2015.

Psychological Flexibility Processes and Neurofeedback

Acceptance

Experiential acceptance refers to the open receiving of one's inner experience as it is, without attempts to remove or control it, with the inverse corresponding to experiential avoidance (Luoma et al., 2007). In practice, acceptance is often introduced as an action of willingness; that is, willingness reflects an active behavior to contact unpleasant or painful experience; to acknowledge, allow, accommodate, and appreciate inner experience; and to do so in the service of acting in accordance with one's values (Harris, 2019). The process of experiential acceptance is not readily appreciated within the aims of NF, a practice that is seemingly an attempt to control and influence brain activity in a targeted direction as an active attempt to change, reduce, or increase brain behavior through consequences. This aim is quickly met with "but how do I make my brain do what we are asking it to do?!"—at times along with frustration, disappointment, and self-judgement. Further, it can inadvertently send the message of a dysfunctional brain that needs to be fixed or normalized. Consider, however, that despite targeting specific brain events over repeated sessions, such as in frequency band training, pre–post testing of brain function in the direction of training is not always reliably found in specific neurophysiological measures at group level (Arns et al., 2012), and it is often not even evaluated in NF studies (Wigton & Krigbaum, 2015). This is not at all to say that brain changes are not occurring throughout NF, rather that brain activity and behavior are complex and dynamic, and aiming to simplify such complexity can be reductive met with inconsistency or unreliability in measurement on an individual basis.

To illustrate complexity in brain changes following NF, in a study of alpha reward NF for tinnitus, Vanneste et al. (2018) showed that there were distal functional connectivity changes as a result of decreasing cross-frequency coupling between beta and gamma synchrony with alpha activity, resulting in significant reduction in tinnitus-related distress. The authors discussed a possible means by which the coupling of slow and fast frequencies may influence changes in brain network communication, lending evidence to support complex interactional brain changes not otherwise noted in the targeted training frequency (e.g., alpha activity). There are other NF studies showing changes in event-related potentials (ERPs) at group level following NF (Kropotov et al., 2005; Strehl et al., 2011). Nevertheless, identification of client-relevant biological processes through a personalized qEEG-informed approach can inform standard NF protocols, as in ADHD, and enhance the multimodal treatment efficacy and likelihood of response (Pimenta et al., 2021). Although defining "learners" in NF is not necessarily straightforward (Strehl, 2014; Strehl et al., 2017), it remains essential that NF practice strictly adheres to the learning theory that it is founded on if any direct brain conditioning effects are to take place (Pigott et al., 2021; Sherlin et al., 2011). Given the recognized multifactorial mechanisms of change and complexity involved, meaningful change can still occur in the absence of demonstrated neurophysiological learning effects when evaluating therapy effectiveness on an individual basis.

Accordingly at the level of experience, the proposed perspective of ACT-integrated NF departs from the approach of normalizing brain waves to reduce the severity of symptoms. Alternatively, consider the functional contextual approach of removing any evaluative notions of good/bad of normal/abnormal brain behavior. Rather, it is inherent to the human condition to experience a full range of emotion. Similarly, it is inherent to display the full range of brain frequencies albeit with differences in measurable power within and across individuals depending on context. When there is observation of brain behavior through feedback, one notices oscillations and this up/down, ebb/flow, excitation/inhibition is the case for everyone. Within the framework of functional contextualism, the function of brain activity is interpreted within the individual's context and the aim of NF is to increase awareness and condition activity that is related to more workable behavior for the client.

Context has always been vital to the interpretation of electrical brain activity. If the behavior of the brain (i.e., EEG activity) in a particular context is not serving the individual and is misaligned with the individual's needs and goals at the time (e.g., the presence of slow-wave theta or alpha activity during times of task engagement and mental alertness), it can lead to challenges for the individual (Strehl, 2014). When brain activity is not flexibly in line with the changing context, this may be viewed as a form of cortical inflexibility. Acceptance through NF may be reflected in a simple statement such as acknowledging that "this is my brain as it is working in this moment." Although the person is not in direct voluntary control of their electrical brain activity at any specific moment, they can notice and respond to it in the service of living a valued life. The use of mindful language to frame the context of the experiential practice can promote the acceptance process, such as “allowing,” “guiding,” “permitting,” and “letting be” what is noticed (Khazan, 2015).

Defusion

Cognitive fusion refers to entanglement with symbolic relations that dominate awareness which, while adaptive in many contexts, can work to limit context sensitivity and result in psychological rigidity and inflexibility. Fusion is often described as being “hooked” or buying into the content of thoughts as literal truths (Harris, 2019). Cognitive defusion is thereby the process of disentangling from and changing the relationship with thoughts to observe them as they are—symbolic relations in the mind—from a distance (Luoma et al., 2007). The act of taking internal experiences, such as arousal and attention, then correlating such processes with more complex behaviors, cognitions, and affect involved in topographic symptoms, derived from measurable brain activity, and relating it to concrete, nonsymbolic fluctuations, can facilitate defusion. Put simply, NF is an opportunity to witness painful or challenging experiences as squiggly lines, moving bars, and beeps—distilling something into a partial representation of its electrophysiological correlate. Moreover, the inner world does not stop showing up when someone attends to and notices their brain activity in real time; that is, language and cognition do not cease during NF. The verbal human is endlessly languaging, weighing in on what is in the here and now with evaluations, judgements, rules, reasons, self-statements, and narrations. During ACT-integrated NF we practice noticing, naming, and making room for cognitions that show up and dominate awareness, and we gently redirect attention to the here-now senses experience of the feedback.

SCP NF is a form of brain feedback involving learned cortical self-regulation of slow brain potentials. The target and experience in SCP are somewhat different to traditional frequent band training. SCP feedback is focused on slow electrical shifts in brain activity reflecting underlying cortical activation and inhibition. Activation refers to increased excitation of the underlying cortex whereas inhibition represents a decrease in neuronal firing related to inhibition (Mayer et al., 2012). The context of SCP feedback often evokes thoughts of confusion and self-judgement, although these are certainly not unique to SCP. Thoughts such as “I don’t get it,” “I suck at this,” “my brain is broken,” “my brain isn’t listening to me,” or “I don’t have any control,” all commonly show up and do so especially in the early learning phase of therapy. It was initially thought that cognitive strategies employed during NF may facilitate learning; however, the literature and clinical experience suggest otherwise (Kober et al., 2013; Strehl, 2014). Strategies may be helpful for some people, some of the time; however, consistent use of the same strategy will often prove ineffective across changing context. Adopting the same strategies without sensitivity to context in a rigid and inflexible way conforms with the control agenda, and they will not infrequently be met with seemingly random signals, moving in unpredictable directions and giving rise to the above-mentioned experiences of frustration, confusion, and a perceived lack of control. A common clinical observation of flexibility in training cortical excitation and inhibition over the course of sessions tends to emerge alongside an open and flexible stance, with expanded awareness of noticing inner and perceptual experiences. In other words, the cortically flexible client often appears open, aware, and engaged. There is acknowledgement when their signal moves in some desired direction, and there is open acceptance and curiosity when noticing departures.

There are numerous exercises and metaphors to help facilitate defusion which often starts with experimenting with and modeling language which encourages and facilitates observation and effective tracking of experience. For example, “dropping anchor” is a powerful technology which can be helpful to introduce early into psychotherapy combined NF sessions (Harris, 2019). The ACE formula for dropping anchor-related exercises of Acknowledge (i.e., acknowledge your inner world), Connect (i.e., connect with your body), and Engage (i.e., engage in what you’re doing), as described by Harris (2021), can be nicely adapted within and during NF sessions as a defusion tool amidst distraction and disengagement. Importantly, the intention is not to introduce cognitive-emotional content and mental activity during NF that may then interfere with the conditioning process but rather to build tools in effectively responding to the content that inevitably shows up.

Self-as-Context

The process of noticing oneself as the container of one’s experiences, from above and distinct from the experience itself, contacts the process of self-as-context or is sometimes referred to as flexible perspective taking (Harris, 2019). Alternatively, when self is viewed from the perspective of one’s experiences, informed by the collection of thoughts, beliefs, narratives, roles, and memories, typically in the form of “I am” statements, it is referred to as the conceptualized self. If attachment to a rigid and inflexible conceptualized self results in unworkable behavior, learning to shift perspectives to contact self-as-context can foster a more psychologically flexible perspective that transcends the verbal mind. From clinical experience, a common client description of changes noticed from NF follows an individual stating that they have increased awareness of their attention and arousal from a hierarchical relation to self (i.e., “I notice my attention more”).

NF facilitates an opportunity to view the brain from a different perspective. It is an experiential exercise that invites the person to engage with the noticing or observing an aspect of experience contained within self in a physical and concrete way. The self-as-context process considers deictic relations across person (“I-you”), place (“here-there”) and time (“now-then”) to view anyone and anything from a perspective of I-here-now (Torneke, 2010). Therefore, during NF one notices that they can notice their brain as it is working in real time. It offers the perspective of I-here-now can notice my brain working there, now. For some entering therapy with long histories of prior intervention, they may have developed an unhelpful frame and relationship with their brain and self, sometimes embedded in the mechanistic and medicalized model of psychiatry that can provide some sense of naming and distancing from pathology, however replaced with fusion to the conceptualized self (e.g., my ADHD/depressed brain is bad, useless, or broken, etc.). NF may facilitate a transformation of function in the way an individual relates to self by providing a platform to observe one’s brain function from a different perspective (e.g., “I-here-now notice my ADHD brain working over there”). Of interest, Hawkins (2014) postulated that physiological self-regulation through biofeedback may reflect an illusion of self-control and that improvements in health and behavior are understood as a function of an improved sense of coherence through an RFT perspective.

Contact With the Present Moment

In behavioral terms, attention training is the process of learning how to voluntarily broaden or narrow stimulus control (Villatte et al., 2015). Allocating and sustaining purposeful attention to the real-time brain activity feedback provided in the here-now can provide a particularly rich experience through the lens of ACT. The experience of noticing brain activity involves directing attention purposively towards visual and/or auditory representations—attending carefully to moving details on a monitor and/or changes in sound (e.g., pitch, volume, speech, etc.). The stance is open, curious, and nonjudgmental. While there is a focus on acknowledgement of reward in the presence of target features (e.g., hearing a beep or seeing something happen on the screen is a wanted and desired action), performance is secondary to the act of observation. Attention invariably fluctuates during NF from a senses experience, noticing bodily sensations and arising internal experiences of thoughts, feelings, images, and memories. When attention wanders, the individual is asked to notice and acknowledge it, then gently return their attention and integrate their internal experience with the feedback provided in the present moment. It is not only feedback of brain activity that facilitates present moment awareness but also orientation to slight changes in movement and muscle activity through EMG and EOG (electrooculography) biofeedback that provides valuable real-time information on the body. Indeed, active control groups that provide EMG biofeedback in NF studies still show significant sustained clinical outcomes (Arnold et al., 2021; Schönenberg et al., 2017; Strehl et al., 2017).

The following script was adapted from the Music Mindfulness and Defusion exercise (Stoddard & Afari, 2014). This exercise facilitates both purposeful attention to the feedback and observing the complexity of any internal experiences that shows up during the feedback. This script allows the individual to notice the distinction between their senses and mental experience during NF and can complement integrating perspective work with the ACT matrix (Polk et al., 2016). It can be adapted to frame the context for a NF round, typically lasting around 5 min, followed by debriefing on the client’s experience.

Before we start the next round of feedback, I invite you to experiment with observing the place where you can witness your experience gently and without judgment. I’d like you to pay particular attention to visual elements on the screen, holding and noticing the details that you see related to movement, color, shape, and content (e.g., notice the bars moving up and down; really attend to when the bar fills above or below the threshold line; hold attention on the car as it moves; focus on empty space within the puzzle, etc.). In your own time, flexibly move your attention around the screen to another feature and hold your focus there, again noticing movement, color, and content with open curiosity. You may move your attention to the sounds that you hear, noticing any changes in pitch or frequency. You may move your *attention from what you see and hear and take notice of sensations in the body, such as breath, pulse, temperature, tension, pressure, and other physical sensations. Continue to flexibly move your attention around to focus on what you see, hear, feel, and touch, with an open stance.*

As you acknowledge the feedback of your brain activity, I want you to pay attention to your unique experience of noticing your brain as it is working. As you continue to attend, consider this: the experience of you noticing your brain activity may provoke sensations, thoughts, emotions, experiences, evaluations, and judgments. This is just what our minds naturally do—this is our mental programming, and it is happening all the time. Notice any thoughts, emotions, evaluations, or judgments you are having about the feedback. Become aware of how you are currently relating to the experience.

[Once the round has ended] Now gently bring your awareness to the present moment by taking a moment to look around the room and attend to any other sounds present. Notice the sensation of pressure in your body where it contacts the chair and the floor. In your mind's eye, picture yourself in the room.

EEG and Mindfulness

Mindfulness is captured through psychological flexibility processes of present moment awareness with an open, accepting, nonjudgmental, and flexible sense of self (Luoma et al., 2007). There is a body of research that has explored the role of brain activity, including EEG effects, of mindfulness practice as well as NF and mindfulness that is of relevance to this discussion (e.g., Treves et al., 2024). EEG studies across healthy and clinical populations have revealed increased synchronized alpha and theta power associated with mindfulness meditation practices, relative to an eyes-closed resting state (Lomas et al., 2015). Increased synchrony in the gamma EEG frequency band has also been found as enhanced in a small group of long-term meditators during meditation, in addition to increases in theta and alpha activity (Lutz et al., 2004). Moreover, NF protocols rewarding alpha power have shown benefits in mindfulness-related outcomes (Navarro Gil et al., 2018), and combining mindfulness with alpha reward NF has demonstrated augmented benefits to psychological and emotional outcomes as compared to mindfulness with sham NF (Lee et al., 2024).

As a flexible process-based therapy, ACT can be practiced in a myriad of ways, involving the use of direct and indirect mindfulness-based practices, as well as experiential exercises and metaphors contacting specific processes, or by combining and organizing processes in different and creative ways. Thus, while mindfulness practices play a central role in ACT, specific processes are contacted through nonmeditative style experiential exercises and depending on the integration, it may not require or recruit sensitive, specific, or readily measurable brain-wave correlates (e.g., alpha, theta, or gamma activity) in such a changing context. The distinction between this line of research and the current perspective is that, in the former NF, technology is primarily used as a tool to augment the specific mindful-meditation practice, as opposed to delivering NF within a wider ACT-based psychotherapeutic context that flexibly integrates mindful and acceptance processes.

Values

Values are about knowing what truly matters to a person, with the "what" relating to the important qualities of behavior one strives to embed in their actions on an ongoing basis (Luoma et al., 2007). Values vary across life domains, such as those we hold close in relationships, work, education, leisure, spirituality, health, and so forth. For those who have not witnessed or experienced NF, the experience varies between people and also within individuals over the course of their therapy, session to session, and even moment to moment. It can be highly introspective, stimulating, engaging, and interoceptive. Alternatively, by nature it is extremely repetitive, simple, routine, and therefore boring! Moreover, the practice of watching one's brain activity can be abstract and difficult to relate to real-world processes and target behaviors of change. It is extremely common for people to experience thoughts such as "how is this supposed to help me?", "what has this got to do with my life and problems?", and certainly "what's the point?!" Although relevant biological processes are linked with client experiences, reinforcers are augmented by clearly identifying and returning to how the work serves the person and who or what it brings them closer to thereby providing underlying motivation and direction for meaningful behavior change.

Identification of therapy goals and values tends to take place from the clinical intake; however, it is then helpful to often engage in "valuing" behavior during sessions thereby fueling motivation for engagement in session and augmenting the learning process. It can be helpful to begin sessions by reviewing any noticing practice since the previous session, or a choice-point, values bullseye, or ACT Matrix sort (Harris, 2019; Polk et al., 2016).

Committed Action

Committed action is an overt behavior change process, that is, to exert choice in one's behavior, establish goals, and make action plans to create meaningful change in one's life in the direction of their values despite the presence of obstacles. NF is a short-term and intensive intervention, often at a frequency of twice per week, aimed at building automatized skills for long-term sustained effects to help live a more effective life. There is the foremost commitment to attend sessions with regularity and consistency, which is especially essential in the initial phase of intervention; this is where committed action starts. Behavioral values-based goals are formed and reviewed during each session, as appropriate. There is a focus on evaluating changes and responses to identified behaviors as indicators of therapy response. As in the case of attentional and arousal-based struggles, there is goal setting and careful monitoring around whether the individual is demonstrating increased awareness and sensitivity to changing context and whether they are then able to respond more effectively to shifts in attentional focus, to flexibly redirect attention in a way that helps them live in line with what matters to them.

For a common example of committed action in NF, we can attend to the role of sleep-wake behavior. Sleep, arousal, and NF are inextricably linked (Arns, & Kenemans, 2014). Sleep function and quality are well known to influence electrical brain activity and behavior both in the short and long term. Brain behavior targets in NF will commonly have relations to sleep function (e.g., the network relation between SMR and sleep spindle circuitry; Hoedlmoser et al., 2008), and sleep quality has an established impact more broadly on the brain's ability to learn and consolidate new information and relations. Sleep-wake behavior and direct attention to sleep hygiene practices are strongly followed alongside NF and are commonplace amongst mental health support and psychotherapy more widely, commonly reflecting values within domains of health and a general sense of vitality. Sleep function more broadly is another critical transdiagnostic feature (Arns et al., 2021).

Recommended sleep hygiene practices are usually introduced into sessions as suggestions through psychoeducation to help facilitate valued living. With consideration to values and committed action, individuals are encouraged to practice and experiment with behaviors that may assist them with their sleep quality, wake feeling more refreshed, and set them up to respond effectively to what shows up that day. In other words, they make behavioral commitments to establishing consistent sleep-wake behavior and habits that are workable for them in their context. While there is considerable overlap between cognitive behavioral therapy for insomnia (CBT-i), a gold-standard intervention for insomnia (Muench et al., 2022) and ACT-i, the latter also has demonstrated effectiveness (Salari et al., 2020) and may be useful for those who do not respond to CBT-i (Shin et al., 2023).

Future Directions and Concluding Remarks

The proposed integration of ACT with NF introduces a notable potential caveat: the concurrent use of active cognitive and emotional processes during NF may interfere with the operant conditioning mechanisms that underlie effective learning. Specifically, there is a risk that cognitive loading could disrupt stimulus-reward contingencies, reduce the precision of reinforcement learning, or lead to unanticipated verbal associations. These potential concerns suggest that the timing and structure of the integration warrants careful consideration and flexibility in clinical practice with diligence to frame the experiential NF context, as to not weaken the operant neurophysiological conditioning. Further empirical research is needed to explore the impact of embedded versus sequential delivery of therapy modalities on NF efficacy and clinical outcomes.

To examine the clinical effectiveness of an integrated approach, future trials will need to consider treatment arms with active and sham NF both with combined ACT, as well as monotherapy NF and ACT to assist in elucidating augmentation of outcomes from a combined model and understanding any mechanisms of change. It is important to assess clinical outcomes over follow-up time points to capture more sensitive underlying changes with active NF conditions. Regardless, there is benefit in future NF literature including secondary measures related to psychological flexibility and mindfulness processes, for example, including but certainly not limited to the Acceptance and Action Questionnaire (AAQ-2; Bond et al., 2011) or the Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2008), which may assist in revealing empirically the capacity of NF to more broadly promote psychological flexibility processes. Finally, other more fine-grained experimental designs within individuals receiving NF over time may investigate the impact of combined ACT processes during NF through tracking of biological and idiographic psychological or behavioral measurements taken over time.

Despite decades of research showing meaningful clinical benefits of providing real-time feedback of an individual's brain behavior through NF, there is continued uncertainty in the causal mechanisms, with claims that much of the clinical benefit is attributed to the nonspecific psychotherapeutic effects. Rather than discounting the clinical benefits of NF due to multifactorial mechanisms of change, recognizing the benefits of a noninvasive brain-based intervention while embracing the wider psychotherapeutic and behavioral context through a robust, evidenced-based, model of psychotherapy may provide an effective step forward. An NF-integrated ACT approach considers the whole individual addressing brain and behavior function simultaneously at biophysiological and psychosocial levels. The multimodal intervention can be implemented within a widely established individualized and process-based psychotherapeutic framework, and direct empirical investigation is invited.

Author Declaration

Steven Wickens and Trevor Brown are both employed by Neurocare Group (Melbourne, Australia) who offer psychological services and neuromodulation treatment and training services within their clinics. The authors otherwise declare that they have no conflict of interest or declarations.

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The Impact of Invalidating Family Environments and Emotional Dysregulation on Mentalization Abilities: A Study of Electrodermal Activity

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Abstract

Mentalization, the ability to understand and interpret mental states, is central to successful social interactions. Impairments in mentalization, manifesting as either hypomentalization or hypermentalization, are often linked to challenges in empathy, executive functioning, and relationships. Although such deficits are frequently associated with borderline personality disorder (BPD), studying them in nonclinical populations provides valuable insight into the mechanisms of emotional regulation and social cognition. This study explores the relationship between mentalization, emotional dysregulation, and childhood invalidation in a nonclinical sample under stress. Twenty participants completed stress-induction tasks, including the Movie for the Assessment of Social Cognition (MASC) and the Mannheim Multicomponent Stress Test (MMST), while electrodermal activity (EDA) and self-reported emotional arousal (SAM) were recorded. Results revealed significant correlations between better MASC performance and increased physiological activation, as well as between invalidating family environments and emotional dysregulation. Notably, maternal invalidation was strongly linked to heightened emotional dysregulation, while a validating family environment was associated with hypermentalization tendencies. These findings suggest that early family dynamics, particularly invalidation, play a critical role in mentalization impairments and emotional regulation. The study underscores the importance of addressing childhood environmental factors to foster healthy emotional and cognitive development.

Keywords: mentalization; emotional dysregulation; invalidating family environment; electrodermal activity

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Introduction

Mentalization and Its Role in Social Interactions

Mentalization refers to the capacity to understand and interpret one's own and others' mental states such as beliefs, desires, and emotions (Baron-Cohen et al., 1985; Luyten et al., 2020). This ability plays a crucial role in social interactions (Pineda-Alhucema, 2017) enabling individuals to navigate complex interpersonal situations by predicting and responding to the behavior of others (Jara-Ettinger, 2019). An impairment in mentalization abilities has been related with problems in empathy (Decety & Jackson, 2004; Repacholi et al., 1998), executive functions (Perner & Lang, 2000), and, consequently, interpersonal relationships (Premack & Premack, 1995). Mentalization can be disrupted in two distinct ways: hypomentalization and hypermentalization. When hypomentalization occurs, individuals rely solely on observable data as their source of information, finding it difficult to consider alternative perspectives. As a result, the desires, feelings, and mental states of others are equated with observable behaviors (Luyten et al., 2012; Sharp, 2014). In contrast, hypermentalization involves an excessive and often erroneous inference of others' mental states, disconnected from observable reality. This sociocognitive process entails making assumptions unsupported by concrete evidence, leading to misunderstandings and confusion (Sharp et al., 2013; Sharp & Sieswerda, 2013). The individual may engage in prolonged and repetitive analysis, overemphasizing irrelevant details, further complicating social interactions (Li et al., 2020; Luyten et al., 2012).

Mentalization in Borderline Personality Disorder

Mentalization is particularly relevant in the context of borderline personality disorder (BPD), a condition characterized by pervasive instability in affect regulation, self-image, and interpersonal relationships. Individuals diagnosed with BPD experience dysregulation across multiple areas, such as interpersonal relationships and behavior. However, the central feature of the disorder is thought to be generalized emotional dysregulation (ED). This concept is defined as a difficulty in responding adaptively and managing emotions effectively (Carpenter & Trull, 2013), and it involves several components, including heightened emotional sensitivity, negative emotional states, ineffective regulation strategies, and maladaptive coping mechanisms.

Individuals with BPD often exhibit impairments in mentalization (Sharp & Vanwoerden, 2015) which further contribute to their difficulties in forming and maintaining stable and healthy relationships. Impaired mentalization makes it challenging for individuals with BPD to accurately interpret others' emotions and intentions, leading to interpersonal misunderstandings and conflicts. Vahidi et al. (2021) found significant associations between mentalization deficits, difficulties in emotion regulation, and borderline personality features, suggesting that the ability to mentalize is intricately tied to emotion regulation capacities in this population. Similarly, Salsman and Linehan (2012) demonstrated a robust link between ED and BPD, as measured by the Difficulties in Emotion Regulation Scale (DERS; Gratz & Roemer, 2004).

Although mentalization deficits could be studied in individuals with BPD, exploring mentalization in populations without BPD allows a broader understanding of how mentalization functions in the general population in relationship with ED. Studying non-BPD individuals can help identify the general mechanisms of emotional regulation and mentalization, offering opportunities to develop interventions that can be beneficial across various populations, not just those with clinical diagnoses.

Furthermore, Linehan and Kehrer's biosocial theory (1993) asserts that an invalidating family environment—marked by dismissive, punitive, or trivializing responses to a child's emotional experiences—plays a crucial role in the development of BPD. Subsequent research, including a study by Keng and Wong (2017), has consistently supported this theory. Furthermore, Musser et al. (2018) conducted a comprehensive systematic review revealing that growing up in such invalidating environments can significantly impede the development of mentalization skills. This impairment in mentalization abilities could be a key factor contributing to the interpersonal difficulties often observed in individuals with BPD. The Invalidating Childhood Environment Scale (ICES; Mountford et al., 2007; Puddington et al., 2017) is an instrument developed to retrospectively assess exposure to parental invalidation. The ICES additionally offers insights into invalidating experiences from each caregiver with separate assessments for the mother and father. This allows for tracking these invalidating experiences regardless of diagnosis or levels of ED. Given these findings, future research should further investigate how ED and an invalidating childhood environment specifically contribute to the mentalization deficits seen in BPD.

The Role of Stress in Mentalization Impairments

Stress is a physiological response triggered by the perception of aversive or threatening situations. It affects the properties of brain cells and can influence multiple bodily systems, altering both behavioral and cognitive processes (Carlson & Birkett, 2014; Pruessner et al., 2007). One of the systems activated by stress is the autonomic nervous system (ANS). When the ANS is engaged, sweat glands fill, leading to an increase in skin conductance (Ferreira, 2019).

Previous studies suggest that the dysfunctions in stress-regulation systems observed in BPD patients may be linked to their impaired mentalization abilities (Fonagy & Bateman, 2007; Schwarzer et al., 2022). To investigate this relationship further, it is essential to assess participants' stress levels during mentalization tasks. This can be accomplished using self-report tools like the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) or physiological measures such as skin conductance level (SCL).

The present study aims to investigate how mentalization abilities are affected by emotional regulation difficulties and childhood invalidating environments under stressful conditions. The objective is to elucidate how these variables independently and collectively contribute to mentalization difficulties. This study may help to understand the underlying mechanisms behind the mentalization impairments often observed in individuals with BPD.

Materials and Methods

Participants

The study included 27 subjects that were assigned to either a stress group (13 participants, 9 females; *M* = 22.5 years, *SD* = 2.0) or a control group (14 participants, 12 females; *M* = 22.7 years, *SD* = 3.1). Participants were recruited through convenience and snowball sampling methods. Initial participants, primarily university students, were recruited on campus and invited to refer peers to expand the sample.

The research protocol for this study received ethical approval (Protocol # 003220622) from the Ethics Committee of the Faculty of Psychology and Psychopedagogy, Universidad del Salvador. Informed consent and demographic information (e.g., age, education, and sociocultural background) were obtained from all participants in line with this approval. All procedures were conducted in accordance with the ethical standards of this committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Participants also completed the DERS (Hervás & Jódar, 2008) and the ICES to assess emotional regulation and childhood invalidation, respectively.

Stress Group Protocol

Stress Induction. Participants completed the Mannheim Multicomponent Stress Test (MMST; Kolotylova et al., 2010), a standardized protocol for stress induction. This involved performing the Paced Auditory Serial Addition Test (PASAT; Lejuez et al., 2003) while exposed to progressively increasing white noise played through headphones (ranging from 20 to 65 dB). In the PASAT, participants performed arithmetic operations on sequentially presented pairs of digits under time pressure.

Social Cognition Assessment. After stress induction, participants completed the MASC to evaluate mentalization and social cognition abilities.

Control Group Protocol

MMST Modification. Instead of performing arithmetic, participants repeated numbers aloud as they were presented. No white noise was applied.

Social Cognition Assessment. Control participants also completed the MASC (Dziobek et al., 2006; Lahera et al., 2014) task after this nonstressful protocol.

Skin conductance was measured in both groups at four time points: before the MMST, during the MMST, before the MASC, and during the MASC. Additionally, the SAM was administered before and after the MMST to evaluate self-reported valence and arousal.

Skin Conductance Preprocessing

Skin conductance response was measured using a constant voltage device, specifically the NeuLog Galvanic Skin Response Logger Sensor (NUL-2017). The data was sampled at a rate of 5 cycles per second using a 16.0-bit resolution analog-to-digital converter (Idesis et al., 2018). Electrodes were placed on the middle phalanx of the fourth and fifth fingers of the nondominant hand. Skin conductance was measured at four key time points: before the MMST, during the MMST, before the MASC, and during the MASC. Each phase included baseline measurements taken over 30-s intervals (LB and LB_MMST) and the last 5 min of the MMST period.

To analyze electrodermal variations in skin conductance, we utilized the NeuroKit2 library (Makowski et al., 2021) in Python. The primary goal was to extract the SCL, representing the tonic component of the signal. The preprocessing steps included the following:

- ***High-Pass Filtering.*** We applied a high-pass filter with a cutoff frequency of 0.05 Hz to separate the tonic and phasic components of the EDA signal. This step is crucial for isolating the slow, sustained fluctuations in skin conductance from the more transient, rapid changes.
- ***Tonic Activity Calculation.*** After filtering, we averaged the tonic activity over specified intervals to determine the SCL. This provides a measure of the level of skin conductance, which reflects long-term changes in arousal.

Results

Out of 27 participants, 7 (4 experimental) performed below a criterion of 80% correct responses in the MASC attention verification task and they were not included in the final data analysis. As a result, our sample size was reduced, as control measurement effect sizes were reported. We used data from a total of 20 subjects (16 females), with ages ranging from 20 to 31 years old (M = 23.1 ± 2.6). The task performance as well as the SCL measurements between the two groups showed no significant differences when compared using the Mann-Whitney test.

Group Comparisons

DERS scores ranged from 35 to 96 points, which fall within the normal population distribution based on local norms (Villarrubia et al., 2023). No significant differences were noted in the DERS scores or its subscales between the groups, nor in the scores for invalidating family responses, indicating that the groups were homogeneous in terms of ED and family invalidation.

Regarding the SAM measurements, a nonsignificant trend was observed for valence at the start of the study (U = 24, p = .08, μ = 0.4545), with the control group showing slightly lower valence scores compared to the stress group. At the end of the stress task, a significant difference was found in arousal levels (U = 19, p = .041, μ = 0.5682), with the control group displaying lower arousal compared to the stress group. In terms of effect sizes, they ranged from moderate to large (Cohen, 1988).

Correlations

We calculated correlations utilizing Spearman's correlation matrices with a 95% confidence interval.

Electrodermal Activity in MASC Task

We compared the increase in electrodermal activity in the MASC task with correct responses in MASC, hypo-TOM, and hyper-TOM (Table 1). A significant correlation was found between the number of correct answers on the MASC and the increase in electrodermal response during the task (ρ = 0.466, p = .038), suggesting that better performance on the MASC is associated with a greater increase in physiological activation.

Table 1
Correlation Between Electrodermal Activity and MASC Task Performance

	MASCcorrect	Hyper-TOM	Hypo-TOM	MMST-LB	MASC-LBMASC
MASCcorrect	-				
Hyper-TOM	−0.522*	-			
Hypo-TOM	−0.685***	0.019	-		
MMST-LB	0.349	−0.169	−0.169	-	
MASC-LBMASC	0.466*	−0.241	−0.250	0.257	-

Note. * = p < .05; ** = p < .01; *** = p < .001.

We also compared the increase in electrodermal activity during the MASC task with the DERS variables, including the total score, emotional clarity, emotional awareness, impulse control, and emotional nonacceptance. Specifically, emotional inattention correlated negatively with the increase in baseline physiological activation during the MASC task (ρ = −.452, p = .045), indicating that lower emotional awareness is associated with a smaller increase in physiological activation.

We further compared the increase in electrodermal activity during the MASC task with variables related to invalidating family environment. A negative correlation was observed between emotional neglect and the increase in physiological activation during the MASC task (ρ = −.452, p = .045), indicating that higher levels of emotional neglect are associated with a smaller increase in physiological activation.

Electrodermal Activity in MMST Task

The increase in activation was calculated as the difference between physiological activity at the beginning and the end of the MMST task. Both the increase in electrodermal activity and the baseline activity at the beginning of the task were then correlated with several variables. No significant correlations were found with the DERS scores.

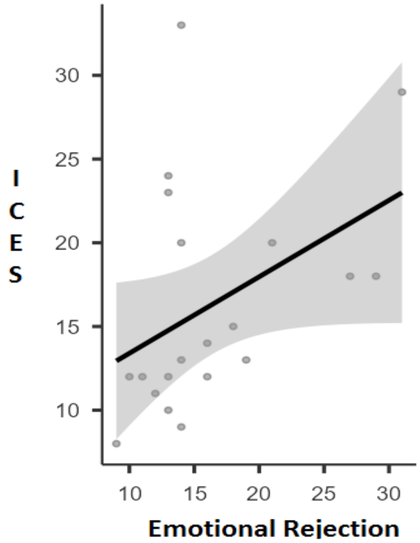
However, within the context of an invalidating family environment, the mother's negative responses were negatively correlated with baseline physiological activation at the start of the MMST (ρ = −.483, p = .03), suggesting that more negative maternal responses are associated with lower baseline activation. Both the mother's (ρ = .539, p = .014) and the father's (ρ = .613, p = .004) negative responses were positively correlated with the increase in physiological activation during the MMST, indicating that negative parental responses are associated with a greater increase in activation during the task.

Behavioral Data

ICES Scores and MASC Accuracy. A positive correlation was found between hyper-TOM and family validation (ρ = .474, p = .035), suggesting that higher levels of family validation are associated with greater hypermentalization.

DERS and ICES Scores. Further analysis uncovered significant correlations related to invalidating family responses. Specifically, the mother's negative invalidating responses were positively correlated with the total DERS score (ρ = .570, p = .0009), indicating that more negative maternal responses are associated with greater ED. No significant correlations were found with DERS subscales. Similarly, the father's negative invalidating responses were positively correlated with emotional rejection (ρ = .516, p = .02), suggesting that more negative paternal responses are linked to greater emotional rejection. No significant correlations were observed with other DERS subscales or the total dysregulation score.

Figure 1. *Correlation Between Fathers' Negative Invalidating Responses and Emotional Rejection.*



SAM Correlations. No significant correlations were found between DERS scores and SAM activation, nor between SAM activation and MASC accuracy. However, initial SAM valence was negatively correlated with a lack of support from both the mother (ρ = −.573, p = .01) and the father (ρ = −.463, p = .04). Additionally, final SAM valence was negatively correlated with a lack of support from the father (ρ = −.463, p = .04).

Discussion

The present study aimed to explore the relationships between mentalization, emotional regulation, and invalidating childhood environments under stressful conditions, in a nonclinical sample. Notably, our subjects did not exhibit abnormal levels of ED. This context enhances the significance of our results, as it suggests that even in the absence of extreme Scores, the interplay between these factors still has a substantial impact on mentalization impairments.

Our study revealed a discrepancy between self-reported emotional activation and physiological measures. While participants reported heightened stress on the final SAM, these self-reports did not consistently align with significant increases in SCL. This inconsistency might indicate that, as previous studies suggested, subjective emotional experiences do not always accurately reflect physiological arousal (Cuve et al., 2023).

However, our results demonstrated that subjects experienced stress as a response to task-related cognitive demands, as indicated by the correlation between greater physiological activation and better performance on the MASC task. These results are consistent with previous literature indicating that stress can be elicited by cognitively demanding tasks (Sandi, 2013).

One of the most compelling findings of this study is the significant correlation between invalidating family environments and ED. Consistent with Linehan and Kehrer's biosocial theory (1993) and more recent studies (Chapman, 2019), our findings highlight that negative parental responses, particularly from the mother, are strongly associated with ED.

Interestingly, the study also found that a more validating family environment was associated with an increase in hypermentalization tendencies. While hypermentalization involves over-attributing mental states to others, often leading to erroneous interpretations, the correlation with validating environments suggests that these individuals might be more attuned to others' mental states, albeit in a potentially maladaptive way. However, literature shows that an invalidating environment disrupts emotional regulation and affects mentalization abilities (Németh et al., 2018; Sharp et al., 2011; Sharp & Vanwoerden, 2015). Our results seem to suggest that all degrees of environmental validation influence how individuals perceive the emotions of others. For this reason, future research should aim to assess the specific qualitative differences between hypermentalization related with validating and invalidating childhood environments.

The fact that these results were found in a nonclinical population is noteworthy for two main reasons. First, the data imply that invalidating family environments might serve as a more potent predictor of poor mentalization abilities than ED alone. While emotional regulation difficulties are undeniably a significant factor, the impact of a childhood marked by invalidation seems to be a more critical underlying mechanism in the mentalization deficits and emotional reactivity observed. Early experiences, then, would serve as important modulators for both emotional behavior and social cognition skills. Second, these findings offer valuable insights for developing preventive strategies such as psychoeducation, aimed at addressing these issues in the general population before they potentially escalate into serious clinical conditions.

One significant limitation is the cross-sectional design of the study, which precludes the ability to establish causality. Longitudinal studies are needed to explore how these factors interact over time and contribute to the development and maintenance of mentalization impairments especially in the BPD population.

As addressed before, despite the fact that the MASC performance criteria reduced the sample size, our results present strong to moderated effect sizes, a reliable confidence interval, and adequate signification levels. In conclusion, this study provides important insights into the complex interactions between stress, emotional regulation, and invalidating childhood environments when undergoing a mentalization task. The findings underscore the need for a holistic approach to understanding and treating mentalization difficulties, considering the critical role of early family dynamics. By continuing to explore these relationships, we can develop more effective strategies to support individuals with psychopathologies such as BPD in their social interactions and overall mental health.

Author Disclosure

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KEYNOTE PRESENTATIONS

The Neuroscience of Deep Brain Reorienting (DBR): Healing of the Shock at the Core

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Deep brain reorienting (DBR) is a trauma psychotherapy based in an understanding of the brainstem mechanisms for orienting and defense. It introduces the idea of preaffective shock, an activation arising in the brainstem that can produce arousal of the cortical EEG, with many attendant subjective phenomena; intensification of subsequent affective responses; disruption of sleep; enhanced vigilance; and disruption of memory processing. DBR aims to treat traumatic shock and its sequelae in a way which is not overwhelming and does not precipitate dissociative responses.

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Endogenous Neuromodulation at Infra-Low Frequencies

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Even as we were engaged with the classic operant conditioning paradigm early in our neurofeedback work, results were better and faster to manifest than could be accounted for within that model. The brain was benefiting from the EEG dynamics to which it was exposed. This nonprescriptive aspect is appropriately termed endogenous neuromodulation. The brain was benefiting from a richer information stream and thus responding more globally. Clinically relevant change could be effected quite rapidly, calling for vigilance on the part of the clinician. This shifted the role of the clinician to a more observational mode. Attending to the subtleties of brain response led to the discovery in the late 90s that we respond best to very specific frequencies, referred to as optimal response frequencies. Identifying such frequencies for each client led to a net migration to ever lower frequencies. In 2006, that led us to enter the infra-low frequency range, the domain of state regulation that sets the context for the EEG regime.

With entry into the low-frequency domain, the discrete rewards were no longer meaningful and were abandoned. The modality had become pure endogenous neuromodulation in pursuit of improved state regulation. Going forward, we were now guided by control system theory, which governs the regulatory hierarchy, as well as by the developmental hierarchy and the frequency hierarchy. In control system theory the foundational requirement is for unconditional stability. Instabilities are characterized by sudden shifts into dysfunctional states. This category includes migraine, epilepsy, panic, vertigo, asthmatic episodes, bipolar mood swings, schizophrenia, narcolepsy, episodic suicidality, tinnitus, nystagmus, fibromyalgia, irritable bowel syndrome, hallucinations, dissociation, and dysautonomia. Also, it includes paroxysmal sleep disorders such as sleep apnea, nocturnal myoclonus, restless leg syndrome, nightmares, night terrors, sleepwalking, sleep-talking, and sleep paralysis.

It was found that the entire class of instabilities is responsive to training interhemispherically at homotopic sites, provided that the training is done at the client's optimal response frequency. Frequency rules were found by which the placements differed in terms of optimal response frequency.

Going ever lower in frequency took us to the foundations of the developmental hierarchy, which gave us access even to early childhood trauma that is necessarily physiologically encoded. With respect to protocols, we were guided by functional neuroanatomy. The focus on core state regulation in all of its aspects (e.g., tonic arousal, interoception, affect regulation, autonomic regulation, and executive function) can be seen as a generalization of the agenda of the traditional biofeedback modalities where the focus is on autonomic regulation.

The broad and inclusive clinical footprint that we are demonstrating with infra-low frequency neuromodulation makes the case for state regulation as the foundational focus in clinical work. It follows that the traditional biofeedback modalities should be recruited into our neurofeedback work, as these reveal state shifts in real time, thus aiding the clinician in the optimization procedure. Rendering the state shifts visible also promotes a sense of participation and of ownership of the process on the part of the client.

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A Multidisciplinary Approach to Neurodevelopmental Delay

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Neurodevelopmental delay (NDD) is the persistence of primal reflexes impacting the central nervous system and further delay of the maturing nervous system. Prenatal brain development is influenced by many factors, such as maternal and paternal health history, in-uterine movement, and pregnancy events which only identify a few. Reflexes provide the unborn child with the ability to move and protect its own life when stressed. Primitive reflexes are automatic, stereotyped movements controlled by the brain stem and driven without cortical involvement. Primitive reflexes precede the development of sensory motor development. At birth the child is met with a bombardment of sensory stimuli. Due to many events reflexes may persist which interrupts the typical developmental progression. Interruptions result in neurodevelopmental delay. The developmental history and a neurodevelopment assessment at any age identifies the timeline of potential interruptions. Early intervention is key in order to compliment the developmental windows. For example, crawling between 6–8 months for a period of 6 months exercises the brain to allow both sides of the brain to communicate. The management plan should address the earliest interruptions and provide steps that allow the lower brain to surrender, pushing the higher brain to take its rightful place directing the child's abilities in motor function, social, communication, adapting, and learning. Interventions should be well-rounded, including movement, neuroimmune function, and the identification of network development and dysfunction through quantitative electroencephalography (qEEG) analysis, while further research is needed to consider a multidisciplinary approach to NDD. In addition, expanding pediatric qEEG databases will assist the provider in understanding the varying brain patterns illustrated during childhood. A child's brain is an open window of development.

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PLENARY SESSION PRESENTATIONS

Virtual Neurofeedback: Implementation and Examination of Effectiveness

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In March 2020, as the ADD Centre shut down our in-person services due to the pandemic, we decided to provide a remote solution for our neurofeedback and biofeedback clients. As our senior staff had experience using GoTo Meeting virtual meeting software to run mentoring sessions for professionals learning neurofeedback, we decided to try rolling out a completely remote single-channel neurofeedback and biofeedback training program using procomp2 devices and peripherals manufactured by Thought Technology. The aim was to make the virtual program as similar as possible to our in-person CZ training program (Thompson, 1998; Thompson et al., 2010). Training included heart rate variability training and training in metacognitive strategies (Economides, 2020).

In 2022, we decided to analyze the data from our progress assessments to determine if virtual neurofeedback training was as effective as in-person training sessions. It would be essential to compare to a control group, as this had not yet been done in the literature (Philippe, 2022). We applied and received a grant from the Foundation for Neurofeedback and Neuromodulation Research (FNNR) for the analysis. This presentation will discuss how we integrated virtual neurofeedback and biofeedback training into our practice and will also review the first 22 cases of remote neurofeedback training who completed a course of 40 sessions. We will compare this to 23 clients who completed 40 in-person training sessions during the same period. The following pre- and postmeasures will be reviewed: CNS vital signs neurocognitive test battery, self-rating questionnaires, diagnostic information, and single-channel EEG data taken at CZ.

As expected, the results of our analysis showed there was no significant difference between the two groups. With all clients included in the study (n = 45), we found significant improvement on measures related to cognition and anxiety ($p < .05$) after being Bonferroni corrected. The results also indicate clinical significance because the Cohen's d effect size was larger than .8 for most of the results. As our sample size was very small, further research with larger sample sizes should be done before drawing broader conclusions.

Now that we have entered 2025, clients have grown accustomed to the flexibility of working and accessing services from the comfort of their homes. We expect to continue to offer hybrid services well into the future and look forward to analyzing the effectiveness of all our programs and sharing this knowledge with our neurofeedback community.

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The Stress Phenotyping Framework: A Multidisciplinary Biobehavioral Approach for Assessing and Therapeutically Targeting Maladaptive Stress Physiology

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We are facing concerning increases in mental and physical illnesses such as depression, anxiety, suicide, addictions, obesity, diabetes, asthma, and cardiovascular disease. A growing body of research is finding that adverse childhood experiences (ACE) are critical contributing factors. Indeed, the prolonged, excessive, or repeated activation of the stress response from ACEs and other stressors including racism, discrimination, and poverty, especially during childhood when the brain is still developing, has been termed toxic stress. Without support, coping strategies, and healing interventions, toxic stress is associated with long-term neurologic, endocrine, immune, metabolic, and genetic regulatory disruptions that can lead to poor health outcomes. More specifically, toxic stress can lead to dysregulation across numerous biological systems including somatosensory processing, arousal, energy and attention, reward processing, autonomic nervous system, hypothalamic pituitary adrenal (HPA) axis and endocrine, immune, and cognitive function, as well as relational health. These biological changes can set patterns that persist into adulthood, increasing the risk for chronic health conditions across the lifespan such as asthma, heart disease, diabetes, and mental health disorders.

Biomarkers hold the promise to provide a mechanism for diagnosing toxic stress, an opportunity to direct treatment, and the ability to monitor intervention effectiveness over time. Biomarkers such as inflammatory markers, cortisol levels, and epigenetic modifications provide objective measures of physiological dysregulation associated with toxic stress. These biomarkers not only confirm the biological basis of toxic stress but also offer valuable tools for early diagnosis, monitoring, and the potential for targeted interventions. The ability to measure the impact of toxic stress at a molecular and physiological level enables clinicians to move beyond psychological or behavioral assessments to a more comprehensive, multidisciplinary, biologically-informed approach to care. While much research still needs to be done, there is a vast amount of scientific research detailing mechanistic pathways, emerging biomarkers, and health consequences that are ready for translation into improved assessment and treatment of toxic stress.

However, although dysregulated stress biology is becoming increasingly recognized as a key driver of lifelong disparities in chronic disease, we presently have no validated biomarkers of toxic stress physiology; no biological, behavioral, or cognitive treatments specifically focused on normalizing toxic stress processes; and no agreed-upon guidelines for treating stress in the clinic or evaluating the efficacy of interventions that seek to reduce toxic stress and improve human functioning. We address these critical issues by (a) systematically describing key systems and mechanisms that are dysregulated by stress; (b) summarizing indicators, biomarkers, and instruments for assessing stress response systems; and (c) highlighting therapeutic approaches that can be used to normalize stress-related biopsychosocial functioning. We also present a novel multidisciplinary stress phenotyping framework that can bring stress researchers and clinicians one step closer to realizing the goal of using precision medicine-based approaches to prevent and treat stress-associated health problems.

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Clinical Impact of Infra-Low Frequency Neurofeedback on Combat Veterans With Concussion

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Introduction. Given that 20–40% of combat veterans who experienced concussions during recent military operations suffer chronically from headaches, insomnia, and attention dysfunction (Agimi et al., 2024), this study's purpose is to determine impact of infra-low frequency neurofeedback (ILFNFB) on chronic postconcussive symptoms. The literature review revealed two studies which had investigated ILFNFB and postconcussive symptoms that resulted in a statistical and clinical significant change in symptoms (Carlson & Ross, 2021; Legarda et al., 2022). Two studies focused on headache, one that resulted in a decrease in migraine frequency and a stabilization of the psychological state (Dobrushina et al., 2017) and the second on tension-type headache that resulted in a reduction in headache frequency (Arina et al., 2022). Given its relationship with mild traumatic brain injury (mTBI), there was an ILFNFB study demonstrating its effectiveness with depression (Grin-Yatsenko et al., 2018). There are also several publications on the efficacy of ILFNFB in clinical settings related to these symptoms (Grin-Yatsenko & Kropotov, 2020; Kirk & Dahl, 2022; McMahon, 2020; Shapero & Prager, 2020). This study will provide additional research evidence as to whether ILFNFB might be an effective treatment option for chronic postconcussive symptoms.

Methods. Eighty-seven participants were enrolled in this randomized controlled trial, with 36 completing the intervention (20 1-hr sessions of ILFNFB and four assessment sessions) and 38 completing the control procedures (8 weekly 15-min health-related discussions and four assessment sessions). Both groups continued treatment as usual throughout participation in study. Data were analyzed on intention-to-treat principle.

Results. The participants were 86% male and 14% female; mean age was 45 for both groups. When comparing baseline to end of treatment measures, findings were clinically and statistically significant for headache (<.001, Cohen's *d* 1.29), sleep (<.001, Cohen's *d* 1.58), and attention (.002, Cohen's *d* 0.68). Additional variables of interest, including quality of life, depression, and posttraumatic stress disorder, were also significantly improved following ILFNFB at end of treatment.

Discussion. These findings demonstrated the consistent efficacy of the ILFNFB intervention across multiple outcome measures, with statistically significant differences indicating improvements in postconcussive symptom physiological measures as well as psychological and quality-of-life metrics. This may be an effective intervention for combat veterans with concussion for whom effective treatments have been difficult to identify (Agimi et al., 2024). In conclusion, ILFNFB holds promise to be a safe and effective intervention for those who suffer with postconcussive symptoms of chronic headache, sleep, and attention disorders and other relevant symptoms. This noninvasive, low risk intervention should be made available to all veterans to enhance their recovery from chronic postconcussive symptoms.

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Using Machine Learning to Enhance the EEG Screening Review by Prescreening the EEG

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One cannot view a news cycle lately without hearing a story of how artificial intelligence (AI) is beginning to dominate the medical field in assisting medical professionals with patient care, diagnosis, and treatment. This ability to assist physicians and improve communication between doctors and their patients is becoming an important part of the patient care process.

The purpose of this paper is to show how a subset of AI, machine learning (ML), is being used to prescreen raw EEGs to determine how “typical” the raw EEG is and to identify certain phenotypes that may be evident. The authors are using ML to improve the quality review screening report by introducing a new analysis panel that mimics similar panels found in a physician’s report, which we call the “brain panel.”

The brain panel will be viewed by the screening team prior to any visual inspection of the EEG or any qEEG analysis that may be made. The brain panel may provide an indication as to whether the EEG should be sent out for clinical review. Our approach is to interpret raw EEG that has been minimally processed using independent component analysis (ICA). We incorporate *z*-scores in our analysis, but we do not compare a person’s EEG to a “normative” database; rather, we use *z*-scores to quantify the neurometrics and show whether they are within limits established by our ML set rules. Using *z*-scores in this way not only serves to enhance the quality review of the EEG but also produces a useful report that mimics a physician’s report, based on the quantitative findings derived from the metric analysis of an AI/ML-enhanced EEG quality review machine or system. The new brain panel includes more metrics for consideration when evaluating EEGs to provide, what we believe to be a more thorough approach to the EEG screening process.

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Individualized *Z*-Scores for Assessment and Training

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Learn from master practitioners on how to use the power of sLORETA and individualized *z*-scores for clinical outcomes and how to use individualized *z*-scores to provide a more informed analysis than a normative database can provide.

This interactive workshop will provide the science behind how individualized *z*-scores are created, how they are different than a normative database, and how they can be used to show individual improvement from therapeutic approaches when little may be seen when using a normative database comparison. The workshop will show how sLORETA can work in tandem with individualized *z*-scores to provide a more thorough analysis of a person's underlying dysregulation of their EEG. The presenters will provide case studies of how powerful these tools are for quality assessments.

Live demonstrations will be performed to show real-time analysis of current therapies such as photobiomodulation (PBM) and pulsed electromagnetic fields (PEMF) and how these analysis tools can show even subtle changes in a person's EEG when little change can be observed using normative tools. Demonstrations will be given showing how one can pinpoint dysfunctional EEG activity to specific ROI's and even individual voxels. The presenters will show how these tools can be used to show how meditation practices can affect a person's brainwaves, how pain is suppressed, and many more applications where one may not think it would be possible to observe any changes. These tools can be used to support clinical practices in mental, medicine, peak performance training, and wellness clinics.

The presenters are all experienced practitioners and have done research using individualized *z*-scores and sLORETA. This interactive workshop will be providing ample opportunity for everyone to witness the power of this type of analysis, to see in real time how to zero in where dysregulation is occurring and provide for a stimulating and fun question and answer session throughout the workshop.

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Applying Progressive Return to Activity for Concussions to Neurotherapies

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The science of managing concussions continues to evolve, but expert consensus for client care currently consistently directs the use of a progressive return to activity (PRA) protocol such as return to learn or return to play. These protocols dictate a graded increase in activities overtime in the absence of symptom provocation. Though these recommendations have existed for nearly a decade, the balance of postconcussion rest and activity has not yet been widely adopted in a unified manner. Additionally, though neurotherapists have direct interest in brain injury care, current literature appears to neglect discussion of best practices for applying progressive return to activity to relevant postconcussive interventions. Though many clinicians seem to loosely apply this model through clinical intuition, the lack of explicit education for clinicians in progressive return to active has been demonstrated to significantly impact patient recovery outcomes. For example, patients treated for an acute concussion after providers received PRA training had greater overall symptom reduction at 1 week, 1 month, and 3 months after injury. Patients treated by physicians trained in a PRA model had a majority (82%) of their symptoms normalized at 1 month, while those very same clinicians prior to PRA training only 36% of patient's symptoms normalized at 1 month. With the growing public interest and increased client accessibility of neurotherapy, it's important that practitioners are educated in effective concussive recovery protocols both to aid in client and patient education and to direct their clinical care to support the best outcomes for clients. This training will apply the stages of PRA model to acute and persistent postconcussive care, and then analyze potential application of different neurotherapy interventions for stages of concussion recovery. Lastly, presenters will discuss the use of a PRA lens for the application of neurofeedback, photo biomodulation, and transcranial stimulation through the use of clinical case studies.

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Psychopathology: Through the Triple Network Lens

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Recently, the brain has been conceived by neuroscientists as a prediction machine involved in reducing uncertainty in a changing environment. The successful navigation of surprising events in our environment requires healthy interactions between three cardinal networks: the default mode network (DMN), the salience network (SN), and the central executive network. Any insult to the dynamic coordination of these domain-specific control networks interferes with predictive processes, leading to distortions of reality that interfere with our ability to meet diverse cognitive, emotional, and environmental demands. When no new information can be attained by the senses due to the poor function of triple network processes, the brain can no longer accurately predict current reality. It resorts to memory to resolve uncertainty, limiting the individual to past, less than optimal strategies. Poor predictive capacity is the root of many psychopathologies including anxiety, depression, PTSD, and developmental trauma

Applied neuroscience in the form of three-dimensional analysis of deeper structures in cortex is central to this new understanding of brain function. The network-centered approach guides analysis to address the distortions produced by a poor functioning triple network model. The framework unites older neuroscience findings with newer results that reduce the siloed diagnostic categories of traditional mental health. It augurs for a spectrum of dysfunctions in the triple network model that explains the comorbidity of symptoms across diagnostic categories. The restoration of aberrant activity in large scale behavioral networks may be accomplished through many different modalities. However, they should address specific regions within the networks that influence autonomic behavior. Additionally, technology should provide strategies related to activation and that address the relationships between the three cardinal networks in psychopathology.

Among the most important relationships between large scale behavioral networks involve the DMN and the SN. The DMN underlies a sense of self, while the SN determines what is important. This relationship is central to healthy functioning that includes effective predictive mechanisms. A dysfunctional relationship between these two networks is central to distortions of reality that involve self-identity. In psychopathology, a dysfunctional relationship between SN and DMN amplifies memory over sensory data dooming individuals to reflexive, historical behavior rather than optimal behavior driven by current circumstances.

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Review of Dipole Source Localization Using Electrophysiological Source Localization and Importance of Accurate Positioning of EEG Sensors

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Electroencephalographic (EEG) source localization (ESL) is one of the well-established techniques to estimate where epileptic activity might originate and how it propagates. ESL is usually based on modeling using several methods, such as equivalent current dipoles (ECD); distributed source imaging like low-resolution brain electromagnetic tomography (LORETA), sLORETA, and other LORETA variations; beamforming, multiple signal classification (MUSIC), and other similar forward and inverse modeling techniques. For focal epilepsy source localization, ECD, MUSIC, and sLORETA modeling are most common. These methods have their advantages and limitations, which will be reviewed in the study. EEG sensor position digitizing is one method that contributes to the accuracy of the ESL. Precise localization of surface EEG electrodes is important for accurate epilepsy source localization because determining the exact origin and propagation of epileptic activity is essential for neurosurgery planning. Misplaced EEG electrode location may affect accuracy of ESL. There are only 19 surface EEG electrodes in the standard 10/20 model; however, in epilepsy monitoring, additional electrodes are added, particularly bilateral electrodes in the temporal areas. Number of electrodes (e.g., 19, 32, 64, 128) affects spatial resolution, which is higher with more sensors, though it may complicate monitoring patients for several days in hospital settings. Regardless of the number of EEG sensors during recording, accurate electrode placement is important for better differentiation between brain structures and is necessary for improving the identification of the epileptogenic zone for informed clinical decisions, including planning implantation of stereo-EEG electrodes for more precise localization of epileptic onset zone. Methods of digitizing EEG electrodes position employ various approaches. Among these methods are electromagnetic digitization, when electromagnetic sensors are used to measure the 3D coordinates of each EEG electrode using six degrees of freedom (DOF) relative to a reference point (e.g., nasion, inion, preauricular points, where other sensors are, while handheld digitizing pen is used to mark each EEG sensor; Polhemus Fastrak device); photogrammetry (e.g., EGI GPS) that uses frames with many high-resolution photo cameras to record subject's head with EEG electrodes and define their location; optical digitizing systems like Polaris and Brainsight that use infrared optical tracers; ultrasound-based methods; and directly measuring EEG electrodes positions using scanning of applied sensors position with MRI/CT, which is less practical for a common use. For clinical applications in epilepsy source localization, high-precision methods like electromagnetic digitization, optical infrared digitizing, or photogrammetry are typically preferred. It should be noted that precise digitizing of EEG electrode location is important in neurofeedback methods that use sLORETA to target training sites. This presentation will provide a comparative review of current dipole source localization methods and will describe most popular digitizing methods for more accurate positioning of the EEG electrodes in clinical research and applied neuroscience.

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Review of Stereoelectroencephalography (sEEG) Data Analysis Methods in Epilepsy

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Analysis of implanted intracranial EEG (iEEG), including stereoelectroencephalography (sEEG), plays an important role in epilepsy surgery planning and neurosurgical procedures. Identifying the epileptogenic zone (EZ), the brain region responsible for generating seizures, and understanding seizure activity propagation are essential. Traditionally, trained epileptologists visually inspect raw sEEG traces to identify interictal (between seizures) and ictal (during seizures) activity, helping locate the EZ. More advanced quantitative EEG (qEEG) methods use time-frequency analysis, including fast Fourier transform (FFT) and wavelet transformations, to detect high-frequency oscillations (HFOs, 80–500 Hz ripples), which serve as biomarkers of the epileptogenic seizure onset zone (SOZ). Spectral analysis using FFT assesses the power spectrum of sEEG signals to identify abnormal EEG patterns. Additionally, sEEG is employed for epilepsy source localization using inverse modeling techniques such as standardized low-resolution brain electromagnetic tomography (sLORETA), though its spatial resolution in sEEG remains limited. A crucial approach in sEEG analysis is functional connectivity analysis, which examines statistical relationships between sEEG signals from different electrode contacts to identify seizure-generating networks and their propagation patterns. This review highlights the most widely used connectivity analysis methods in sEEG, providing insight into brain region interactions in epilepsy. There are three recognized types of connectivity: structural, functional, and effective connectivity. Structural connectivity analyzes white matter tracts using diffusion tensor imaging (DTI), tractography, and more precise techniques like MRTrix3. Functional connectivity analysis measures relationships between sEEG activity from different brain regions using methods such as coherence, phase locking value (PLV), cross-correlation, imaginary coherence, and/or weighted phase lag index (wPLI). Lastly, effective connectivity targets identification of causal or directed influences between brain areas through techniques like Granger causality, direct transfer function (DTF), partial directed coherence (PDC), transfer entropy (TE), and phase slope index (PSI). More advanced modern methods include graph theory analysis, where the brain is modeled as a network of nodes (regions) and edges (connections), and neurometrics such as degree centrality, clustering coefficient, path length, and other similar indices are used to study network properties. Graphical visualizations aid in interpreting these results. In some cases, with implanted sEEG electrodes, SOZ identification is possible as some of the electrode contacts may show the earliest ictal activity to identify the SOZ. It is also common to use analysis of sEEG interictal spikes that look like abnormal discharges between actual seizures. Other methods of sEEG analysis are based on electrical stimulation through implanted electrodes to map functional brain areas (e.g., language, motor, etc.), to provoke seizures or to evoke corticocortical potentials for connectivity assessment in epilepsy. Recent advancements integrate machine learning (ML) and artificial intelligence (AI) to detect sEEG patterns associated with EZ or SOZ. Additionally, qEEG methods are integrated with neuroimaging to

improve brain anatomical correlation. Modern epilepsy neurosurgery planning integrates visual inspection and computational methods. From spectral and connectivity analysis to ML and AI, these approaches provide deeper insight into seizure dynamics and brain network interactions. As research continues to refine these methodologies, the field can move toward a more precise and accurate seizure localization.

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Bridging Relational-Cultural Theory and QEEG: Toward a Neuroaffirming Model of Connection

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Rooted in feminist and multicultural understanding, relational cultural theory (RCT; Miller, 1976) posits that growth-fostering relationships are the cornerstone of psychological well-being. This postmodern approach diverges from the traditional perspective of centralizing autonomy and suggests that mutual empathy and empowerment within relationships foster intrapersonal resilience and healing (Miller, 1976). Researchers continue to explore the salience of RCT in clinical practice. For example, within mental health counseling, the model attends to mitigating psychological distress for concerns such as traumatic stress (Hershberger, 2021) and anxiety (Sapiro & Quiroz, 2022) disorders. Further, RCT addresses the various and unique stressors of underrepresented cultural groups (Avent Harris et al., 2023). Despite the positive therapeutic implications of an individual's perception of connection, further empirical evidence is warranted to infer RCT's usefulness in areas including case conceptualization, clinical phenomena, and intervention (Lenz, 2016).

Neuroscience advancements are transforming mental health care as affiliated research affirms the efficacy and validity of therapeutic approaches and recommendations (Beeson & Field, 2017). Quantitative electroencephalography (qEEG) affords practitioners and researchers a noninvasive avenue for measuring brainwave activity. With high temporal and spatial resolution, qEEG recordings offer detailed information of brain activity relating to cerebral location and cognitive implications (Fingelkurts & Fingelkurts, 2022). This modern type of electroencephalography continues to be compounded with other therapeutic modalities (i.e., neurofeedback) to address mental health concerns including anxiety (Gregory et al., 2023) and stress (Hafeez et al., 2019). Understanding how neuroscience informs client development encourages best practices for integrating brain-based elements into mental health wellness values (Spears et al., 2024).

This presentation will introduce a framework that aligns essential RCT outcomes (e.g., authenticity and mutuality) with measurable changes in qEEG patterns. Presenters will hypothesize how variations in brainwave markers may occur throughout relationally-focused therapy, potentially providing empirical support for its therapeutic effectiveness.

The researchers hope that by connecting relational and neurological frameworks, the conceptual work advocates for a more integrative and evidence-based approach to understanding human connection in mental health care.

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EEG-Based Source Localization (ESL) of Epilepsy Spikes Onset Zone Using Interictal Activity in Pediatric Case Series

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Background. Monitoring pediatric epilepsy patients with 19-channel EEG remains the gold standard in presurgical evaluation for capturing interictal and ictal events. Compared to other neuroimaging methods, EEG-based source localization (ESL) offers two key advantages: the ability to monitor patients for extended periods in clinical settings and high temporal resolution, which enables tracking the propagation patterns of epileptogenic activity within brain networks (Eom, 2023; Lee, 2023). However, EEG interpretation in most comprehensive epilepsy centers still relies on visual analysis of EEG traces, and ESL is not routinely performed. Recent surveys indicate that fewer than half of epilepsy neurosurgery centers incorporate ESL into presurgical evaluations (Gavvala & Ebersole, 2024). While visual EEG analysis remains essential for initial assessment, ESL provides greater precision and objectivity, facilitating integration with advanced neuroimaging—making it a valuable tool for presurgical epilepsy evaluation (Cox et al., 2021). Nevertheless, accurately identifying EEG signal sources with only 19 electrodes can be challenging due to limited spatial resolution, particularly in temporal lobe epilepsy (TLE; Verhellen & Boon, 2007). This study aimed to assess the clinical utility of ESL in presurgical evaluations by comparing it with MEG-based source localization and postsurgical outcomes.

Methods. This retrospective study analyzed interictal EEG spike data from eight pediatric patients (mean age: 15.5 ± 3.11 years; 5 female, 3 male) who achieved seizure freedom or significant improvement following neurosurgical intervention. All patients underwent Phase I/II evaluations, including scalp EEG, MEG, MRI, CT, and stereo-EEG (sEEG). Using Compumedics CURRY9 software, we applied equivalent current dipole (ECD) modeling and sLORETA-based current density mapping within a boundary element method (BEM) head model to localize the onset and propagation zones of interictal discharges. ESL analyses were based on interictal scalp EEG data, incorporating relevant anatomical references and landmarks.

Results and Discussion. ESL findings demonstrated acceptable concordance with MEG and sEEG results, though minor discrepancies were observed in localizing subtemporal and basal temporal epileptogenic activity, particularly in focal mesial TLE cases. Mesial temporal sources often produce dipoles oriented tangentially to scalp electrodes, making them more difficult to detect than radially oriented sources, which ESL typically identifies more reliably (Lantz et al., 2003). Temporal lobe epileptogenic activity, especially mesial temporal spikes, may not project clearly to scalp electrodes limited to the 10–20 system, increasing the risk of mislocalization. These findings support previous recommendations (Ebersole, 2000) to augment standard EEG with additional temporal electrodes (T1/T2, T9/T10) to improve spatial resolution and dipole modeling accuracy in TLE. Even with a limited number of electrodes, EEG-based source localization (e.g., dipole modeling, sLORETA) offers several advantages over purely qualitative EEG interpretation in epilepsy workup.

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Phase Lag and Neural Synchrony in Early Brain Development: Insights From QEEG Brain Metrics in Children With Autism

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Neural synchrony, governed by phase-lag relationships between oscillatory signals across brain regions, plays a critical role in early brain development and the formation of functional neural networks. This study investigates phase-lag abnormalities in children diagnosed with autism spectrum disorder (ASD) using quantitative EEG (qEEG) metrics. A dataset comprising 38 clinically confirmed ASD cases was analyzed, focusing on *z*-scored deviations across nearly 6,000 neurophysiological variables. Only metrics with absolute mean *z*-scores greater than 2 were retained for interpretation, all of which pertained to phase-lag measurements in high-beta and beta frequency bands across frontal, central, and parietal cortical regions.

Results revealed a consistent pattern of reduced phase-lag, indicative of excessive neural synchrony, predominantly across frontal and central midline electrode pairs. These findings parallel previous research using the debiased weighted phase lag index (dbWPLI), which demonstrated increased synchrony in high-risk infants who later developed ASD. The most affected pairwise phase-lag connections in this sample involved regions supporting executive function, motor planning, and attention, all of which are domains commonly impaired in individuals with ASD. Negative mean *z*-scores in these phase-lag variables reflect less temporal delay between regions, suggesting premature or rigid synchrony that may impede typical neurodevelopmental processes such as pruning, differentiation, and integration of cortical networks.

Theoretical implications suggest that abnormal phase-lag dynamics, manifesting as early hyperconnectivity, may disrupt the refinement of long-range communication networks and contribute to the emergence of restricted, repetitive behaviors and cognitive inflexibility seen in ASD. These neurophysiological disruptions may stem from accelerated maturation of white matter or imbalances in excitation and inhibition that alter the trajectory of typical brain development. Furthermore, these findings underscore the potential of phase-lag metrics as early biomarkers for ASD and raise the possibility of targeting temporal coordination through interventions such as neurofeedback or noninvasive brain stimulation.

Future directions include longitudinal tracking of phase-lag patterns from infancy to adolescence, exploring metrics like phase-lag entropy to capture connectivity diversity, and assessing the efficacy of therapeutic interventions aimed at modulating oscillatory synchrony. By elucidating the role of timing-based neural communication, this study contributes to the growing body of evidence linking neural oscillatory dynamics to the core features of autism and opens new avenues for early identification and targeted intervention.

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Neuroregulation in Virtual Reality

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Neuroregulation (NR) of the electroencephalographic (EEG) alpha rhythm has proven effective in supporting mental health and well-being. Similarly, virtual reality (VR) integrated therapies have been shown to induce greater positive affect than equivalent tasks delivered in standard two-dimensional (2D) formats. This overlap in therapeutic potential has generated interest in combining NR and VR, with preliminary research indicating that the use of VR may enhance the effects of NR. However, existing studies are limited by methodological issues, such as inconsistent use of visual stimuli across formats, leaving key questions unanswered about the combined effects of NR and VR. Addressing limitations of prior research by using consistent visual stimuli, the current study explores the psychological and physiological effects of combining NR of the EEG alpha rhythm with VR.

In this single session experiment, 120 participants were randomized to either upregulate or downregulate their EEG-alpha power across both 2D and VR viewing formats. Psychological outcomes were assessed using self-reported emotion ratings, while physiological outcomes were measured using EEG (measures of amplitude and coherence across frequency bands) and electrocardiography (ECG; measures of heart rate and heart rate variability). Results demonstrated that participants successfully modulated their EEG-alpha amplitude in the targeted direction in both the 2D and VR conditions. Moreover, changes in amplitude and coherence of EEG alpha and other frequency bands (e.g. theta, beta, and gamma) occurred depending on training direction (upregulation vs. downregulation) and viewing format (VR vs. 2D). No differences were seen for ECG outcomes based on training direction nor viewing format. Greater positive affect was reported during NR in VR compared to the NR in the 2D format. These findings support the feasibility and effectiveness of delivering EEG-alpha NR in both 2D and VR formats, with differential effects occurring based on training direction and format. These results may guide future interventions combining NR and VR for treating mental health disorders and supporting well-being.

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The Efficacy of Neurofeedback for Anxiety

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Introduction. Anxiety disorders are one of the most prevalent mental health conditions worldwide, with over 300 million cases reported globally and a 50% increase in prevalence since 1990 (Yang et al., 2019). Current treatment approaches frequently rely on psychotropic medication and psychotherapy, which may not be effective or desirable for all individuals. Neurofeedback, a noninvasive technique that trains individuals to self-regulate brain activity, provides a promising alternative. This study investigates the efficacy of neurofeedback in reducing activity within the anxiety network in a controlled laboratory setting.

Methods. Thirty participants (aged 18–30, male and female) were recruited via screening surveys. Inclusion criteria required right-handedness and the absence of psychotropic medication use, neurological disorders, or brain injury. Eligible participants were randomly assigned to either the experimental group, targeting the anxiety network, or the control group, targeting the mirror neuron system. A single-blind design ensured that participants were unaware of their group assignment. Baseline EEG data were collected using an ElectroCap 24-electrode wet cap under standard conditions in a lab. Participants then completed six *z*-score neurofeedback sessions using NeuroGuide software and a DSI-24 Dry Cap system, after which posttreatment EEGs were recorded under the same conditions. In addition to EEG measures, participants completed a self- reported "treatment confidence survey." EEG recordings consisted of a minimum of 2 min of artifacted data. Data analyses were conducted using NaviStat statistical and NeuroNavigator neuroimaging software to measure deviations from mean activity in Brodmann areas associated with anxiety.

Results. Preliminary results indicate that participants had an above-average level of treatment coincidence at a score of 6 from the survey given, following six sessions of neurofeedback. Further analyses to be conducted when our larger cohort is reached, it is hypothesized that the experimental group will show a statistically significant reduction in the resting baseline nonexposure activity within the anxiety network when comparing the pre- and posttreatment EEG recordings. No significant change is expected in the control group. These changes are anticipated to reflect decreased hyperactivation of brain regions implicated in anxiety processing, supporting the efficacy of neurofeedback as an intervention.

Discussion. If findings align with expectations, this study will provide evidence supporting neurofeedback as an effective, noninvasive, and medication-free treatment for anxiety disorders. While assessing specific neurophysiological changes, reductions of hyperactivity within the anxiety network may indicate broader applicability to generalized anxiety and other related disorders. Given the growing global burden of anxiety, neurofeedback could represent a viable treatment alternative for individuals seeking nonpharmacological options. Future research may expand to larger, more diverse populations with longer treatment durations and explore long-term treatment outcomes.

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Neurofeedback for Arachnophobia a Randomized Controlled Clinical Trial of the Anxiety Neural Network and of Spider Phobia: Preliminary Results

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Neurofeedback is a harm-free technique that trains the brain to regulate itself in real time based on feedback from brainwave activity. Surface electrodes on the scalp measure electrical activity, and feedback or reward is provided to the user when brain activity is moved in the desired direction (e.g., relaxation, focused attention, or emotional regulation). This approach has been applied in therapeutic and research environments to alleviate anxiety-related networks, phobias, and other disorders defined by dysregulated neural activity. This study investigated the effect of two neurofeedback protocols on the alleviation of arachnophobia and the regulation of power in the anxiety neural network (ANN). Participants were randomly assigned to either one of the protocols in a treatment-blinded design for the purpose of impartial findings. Every participant underwent two baseline quantitative EEG (qEEG) recordings: a resting eyes-open, overall neural activity measurement and a spider-viewing recording, neural response measurement for phobia. These were used as a baseline from which changes after neurofeedback training would be measured.

Following baseline measurement, participants underwent six sessions of neurofeedback training with no apparent exposure to spiders. During training, they were provided with feedback intended to facilitate associated neural patterns of decreased anxiety and enhanced emotional regulation. Following completion of the neurofeedback training sessions, participants completed the initial tests again, including qEEG recordings and corresponding questionnaires, to assess fear responses, neural activity related to anxiety, and emotional reactivity changes. Power spectral *z*-score analysis was used to assess the degree of change in neural activity within the targeted networks. Early results indicate that both neurofeedback interventions significantly lessened spider fear differentially modulating ANN power between conditions. Notably, MNS participants exhibited a slight but significant decrease on the personal distress subscale of the interpersonal reactivity index (IRI), as they reported less emotional reactivity along with less phobia-specific fear.

These findings provide initial evidence that neurofeedback therapy is capable of selectively inhibiting fear and anxiety-associated neural systems. Through inhibition of the hyperactivity of the ANN and enhancement of emotional control, neurofeedback may prove to be an effective treatment for phobias and other anxiety disorders. The differential effects between protocols also highlight the potential for tailoring neurofeedback therapies to individualized neural and behavioral patterns and suggest potential future areas for customized applications and research.

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Toward a Universally Applicable Self-Report Measure of Interoception: Developing the Invariant MAIA-SF Across Health-Related Background Characteristics

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Ensuring we assess clients and study participants with valid psychological measures lies at the heart of rigorous research and good clinical practice. To achieve optimal validity of a scale, the interpretive meaning of all items on the tool must be equivalent across groups of people with varying identities. The concept of measurement invariance (MI) emerged to test this fundamental assumption (Putnick & Bornstein, 2016). Though MI is a prerequisite for valid group comparisons and avoiding bias when estimating associations between variables, recent reviews of the literature suggest an alarming oversight of the MI assumption in psychological science (e.g., Maassen et al., 2025).

Interoception—defined as the integration of body-to-brain signals—is central to neuroregulation approaches such as HRV biofeedback, EEG neurofeedback, and mindfulness-based neuromodulation, which aim to improve self-regulation of physiological and emotional states. Yet, most outcome measures in these fields emphasize physiological signals alone. The Multidimensional Assessment of Interoceptive Awareness (MAIA) is widely used in clinical and mind-body research contexts (Mehling et al., 2012, 2018). However, its length and recent evidence of bias across populations with varying experiences of body and health-related marginalization limit its utility as an outcome measure (Mensinger et al., 2025). Lack of MI suggests that differences in scores may reflect measurement bias and not trait-level differences. Thus, MI is a critical assumption for the development of universally applicable self-report tools that can assess mental health risks and intervention outcomes across diverse populations. To address these challenges, we validated a new invariant 24-item short form

(MAIA-SF) optimized for psychometric robustness and cross-group comparability.

Using two independent samples of adults (*N* = 2000), we combined the original 37-item MAIA-2 with nine new pilot items to create an item pool for invariance testing. We conducted multigroup confirmatory factor analyses (MGCFA) in Mplus with the robust maximum likelihood estimator to evaluate MI across six variables: gender, age, eating disorder status, body mass index, exposure to childhood trauma, and experiences of weight stigma. Items were retained based on factorial validity, local fit indicators, and parameter stability across groups (Kline, 2024; Meade et al., 2008).

Results supported excellent global fit statistics for the final MAIA-SF model, χ^2 = 689.4(224); RMSEA = .032; CFI = .977; SRMR = .027. We replicated the original eight-factor structure with three items (including 21 original items and 3 new items) on each MAIA subscale: noticing, not distracting, not worrying, attention regulation, emotional awareness, self-regulation, body listening, and trusting. We also found strong evidence for configural, metric, and scalar invariance across all six background characteristics (CFI changes ≤ .003). Final item selection favored those demonstrating the most consistent loadings and intercepts across groups while maintaining theoretical content coverage, internal consistency reliability (McDonald's omegas range .69–.90), and validity of each subscale (standardized loadings range .62–.93).

The new MAIA-SF offers a practical, psychometrically sound tool that can complement physiological markers by assessing whether neuroregulation translates into enhanced subjective interoceptive sensibility. Its demonstrated invariance across diverse populations ensures comparability of outcomes, making it well-suited for both clinical applications and research trials of biofeedback and neuromodulation interventions.

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