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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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