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A Scoping Review on Integration of Electroencephalogram Neurofeedback Training for Alcohol Use Disorder: Clinical and Neurocognitive Outcomes

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Abstract

Background. The conventional treatment for alcohol use disorder (AUD) consists of dual treatment encompassing pharmacotherapy and psychotherapy. Nonetheless, the impact of these treatments on clinical and neurocognitive outcomes is only low to medium efficacy. Research studies substantiate the integration of electroencephalogram neurofeedback training (EEG-NFT) as an add-on tool with significant improvements in clinical and neurocognitive outcomes. **Methods**. A scoping review of the existing literature on EEG-NFT and AUD, which are open access, including review papers and empirical studies in the English language, and with human subjects are deemed worthy of the scope of this study. The keywords *electroencephalogram neurofeedback training*, *alcohol use disorder*, *stress*, *neurocognition*, and *relapse* were used. The primary sources of the literature search were Science Direct, Scopus, PubMed, and Google Scholar. A total of 35 articles have been included in the scoping review. Studies from the last 15 years were considered for the same. **Results**. This review revealed that EEG-NFT is a promising tool with significant improvements in stress levels, cognitive deficits, and relapse rates for individuals with AUD when used in integration with conventional treatments. **Conclusion**. Chronic alcohol use affects cognitive functions, escalates relapse rate, and increases stress experienced by the individual. The present study highlights the significance of NFT as a potent add-on treatment modality to improve clinical and cognitive outcomes, thereby facilitating abstinence and reducing relapse rates in individuals with AUD.

Keywords: neurofeedback training; alcohol use disorder; stress; response inhibition; relapse

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Introduction

Alcohol use disorder (AUD) is a serious public health concern, with chronic use resulting in 3.3 million deaths worldwide every year, which as a causal factor exceeds global death rates caused by HIV/AIDS or tuberculosis (Althaus et al., 2021; Dousset et al., 2020). Despite the growing number of research on preventing relapse and reinforcing abstinence, AUD has an astonishingly high relapse rate of approximately 80% within a year postwithdrawal, which is why relapse occurring from the consumption of alcohol after prolonged periods of withdrawal is still of interest for understanding addiction (Dacosta-Sánchez et al., 2021; Dousset et al., 2020).

Chronic alcohol use is associated with a wide range of clinical comorbidities, of which stress has been constantly reviewed in the literature. Adverse experiences such as early social deprivation, isolation and abandonment, and parental use of alcohol exceed an individual's coping capacity, increasing his or her risk for AUD (Sebold et al., 2021). By the same token, long-term use of alcohol also dysregulates the brain's effector system such as the hypothalamic-pituitary-adrenal (HPA) axis, leading to the pathophysiology of AUD (Uscinska et al., 2021). Additionally, stress has long been known to increase the risk of relapse among individuals with AUD (Breese et al., 2011). For instance, evidence shows

differences in stress responsivity in individuals with AUD and without AUD, wherein the former demonstrated alterations in stress pathways that could explain the significant contribution of stress-related mechanisms on relapse (Sinha, 2012).

Likewise, chronic use of alcohol also has profound neurocognitive effects mainly affecting executive functions, episodic memory, and visuospatial capacities related to multiple brain lesions (Bernardin et al., 2014). While the literature strongly establishes that chronic use of alcohol leads to cognitive deficits, there have been efforts to understand the relationship between various parameters of alcohol use and associated cognitive deficits (Dacosta-Sánchez et al., 2021). For example, a study analyzed cognitive profiles of patients according to the pattern of substance use and found that there is a significant association between the age of onset of alcohol use (early age of use; before 25 years) and executive dysfunctions, likewise, the duration of alcohol use (more than 10 years) is related to attentional deficits, and quantity of alcohol use increased impairment in working memory (Madhusudhan et al., 2021). The transition to habit theory by Everitt et al. (2008) states that addiction consists of a series of transitions from voluntary and hedonic-driven drinking habits at first to strongly automatized habitual use of the substance that is characterized by compulsive behavior and loss of control, which explains consumption of alcohol despite the negative consequences or relapse (Czapla et al., 2016).

The classic treatment model for AUD consists of a combination of pharmacotherapy and psychotherapy, where the former addresses the neurotoxic effects of alcohol, and the latter deals with the psychosocial dimensions of the disorder. Nonetheless, the efficacy of this dual treatment providing significant changes in the individual is still low to medium with limited impact on drinking behavior and quality of life (Dousset et al., 2020). Furthermore, alcoholism involves the alteration of brain electrophysiology such that researchers and clinicians are considering the alteration of brain rhythmic activity as a viable mode of treatment option for individuals with AUD (Dalkner et al., 2017; Heilig et al., 2019; Rangaswamy & Porjesz, 2014).

Thus, the main objective of the present paper is to review the merits of neurofeedback training (NFT) as a tool that has been gaining momentum for its efficiency-cum-effectiveness in clinical and research areas (Marzbani et al., 2016). This article highlights the evidence that is in favor of the application of electroencephalogram neurofeedback training (EEG-NFT) as an add-on tool for altering the deficient brain wave patterns of AUD patients with significant improvements in clinical such as reduced stress levels and relapse rates and enhanced neurocognitive abilities to maintain long-term abstinence when used in combination with other forms of treatments.

Methods

The primary aim of the review paper is to present arguments in favor of the application of EEG-NFT neurofeedback as an add-on tool for the treatment of AUD with other adjunct therapies such as psychotherapy and pharmacotherapy. A scoping review of the existing literature on NFT and AUD, which are open access, including review papers and empirical studies in the English language, and with human subjects are deemed worthy of the scope of this study. The keywords *electroencephalogram neurofeedback training*, *alcohol use disorder*, *stress*, *neurocognition*, and *relapse* were used to identify relevant publications. The primary sources of the literature search were Science Direct, Scopus, PubMed, and Google Scholar. A total of 35 articles have been included for scoping review. Studies from the last 15 years were considered for the same.

Results and Discussion

EEG Function in AUD

Literature shows that both acute and chronic use of alcohol results in significant brain wave alterations that are observable with quantitative electroencephalogram (qEEG). The qEEG reports in AUD patients mainly describe brain wave alterations that are mainly within the alpha, theta, and beta bands (Sokhadze et al., 2008). For example, a higher theta (4–8 Hz) power has been reported in alcoholics when compared with control subjects indicating a reduction or blocking capability of the individual to encode new information (Mumtaz et al., 2018). The abnormal elevation of theta in the posterior region is also associated with deficient inhibition and excitation (Mohan & Rajeshwaren, 2015). Additionally, a decrement in alpha (8–12 Hz) oscillatory powers especially in the occipital regions of AUD patients is an indication of impaired memory and attention, in addition to dysregulated stress response (Mumtaz et al., 2018).

In like manner, elevated beta (12–30 Hz) band power is observed in the whole brain of AUD patients and such abnormal elevations at the posterior region can predict relapse in alcoholics (López-Caneda et al., 2017). Hence, chronic use of alcohol leads to

increased activity of the autonomous nervous system, resulting in increased physical and psychological stress and anxiety marked by decreased alpha and increased high beta respectively, which are clinically important as they are related to the severity and relapse of AUD (Ko & Park, 2018). These altered brain wave patterns and associated impairments compromise the treatment outcome in favor of individuals by hampering good decision-making, and further accelerating cognitive and behavioral dysfunctions heightening the propensity to relapse in the face of drug and drug-related stimuli (Le Berre et al., 2017).

EEG Neurofeedback Training in AUD

Yonah (2023) mentions the efficient-cum-effective use of NFT for various psychological and neuropsychiatric disorders. Neurofeedback is a noninvasive, self-regulation technique that utilizes a brain-computer interface (BCI) to facilitate neural plasticity and neural efficiency (Cannon, 2015). It provides feedback to the individual on the localized brainwave activity with a specific frequency range (Cannon, 2015). The feedback here is similar to the feedback provided in other modes of treatment, which empowers the person to make necessary changes in their behavior that often results in therapeutic gains (Russo et al., 2023). Neurofeedback of the operant conditioning type consists of EEG activity to hit the threshold fixed before the feedback is delivered (Cannon, 2015; Yonah, 2023).

The major advantage of neurofeedback is that it safely harnesses internal brain processes, facilitates voluntary control of brain oscillations, and enhances long-term induction of brain plasticity (Ros et al., 2014). Also, EEG-NFT is purely endogenous in nature and the reorganization of oscillations is facilitated by the system itself based on the conscious feedback signals unlike pharmacotherapy (Dousset et al., 2020; Ros et al., 2014). Thus, repeated training of the specific brain oscillations further strengthens the synaptic connections (“neurons that fire together, wire together”), encouraging them to produce the same pattern in an open environment. It means that NFT enables implicit volitional control of covert brain activity inducing enhanced attention and motor cortical activation yielding coherent and stimulus-specific brain activity than an unregulated mental practice (Ros et al., 2014).

The two neurofeedback protocols that are commonly used in the treatment of AUD are the Peniston-Kulkosky (alpha/theta protocol) and Scott-Kaiser modification (beta/sensorimotor rhythm [SMR]) protocol. Literature shows that neurofeedback protocols are designed to reduce anxiety and stress levels through the alpha-theta protocol, and impulsivity, through the beta-SMR protocol, with significant results in maintaining abstinence (Russo et al., 2023). Study shows that the application of the Peniston-Kulkosky protocol induced a profound state of relaxation for the participants with AUD (Sokhadze et al., 2008). It was seen to amplify the effect of psychotherapy by enhancing self-efficacy and personal insight, and by inducing a sense of control among patients diagnosed with AUD (Dalkner et al., 2017).

Hence, training alcohol-dependent individuals to increase their alpha and theta rhythms is associated with a decrease in alcohol intake and relapse (Mohan & Rajeshwaren, 2015). Furthermore, unlocking the direct control of the brain also induces changes at the neurochemical level by increasing beta-endorphins (a stress index), which is related to the stress of abstinence (Ross, 2013). Research demonstrates that the baseline alpha brainwaves increased substantially after the first five sessions of the Peniston-Kulkosky training, which called for the need for multiple sessions of NFT to elicit lasting changes in the EEG metrics of the individual. Accordingly, 15 sessions of the Peniston-Kulkosky training showed significant positive changes in the overall quality of life and long-term abstinence among individuals with AUD (Ross, 2013).

Together with the Peniston-Kulkosky protocol, the Scott-Kaiser modification is found to show substantial improvements in attention, reduction in hyperactivity, and impulsivity in facilitating thalamic inhibitory mechanisms, thus helping individuals to override automatic behaviors facilitated by the drug-wanting system such as ventral striatum, and further strengthening the drug-denying system governed by the prefrontal cortex (Rangaswamy & Porjesz, 2014). Over the course of learning via neurofeedback, the individual gains control over the physiological process which also used to be in automatic action schemata mode (Ros et al., 2014). Thus, participants report improved confidence and reduced emotional stress, feelings of inadequacy, and insecurity, which are potential dispositional factors that are used to increase the risk of relapse among AUD patients (Dalkner et al., 2017).

Correspondingly, alcoholism is also characterized by a lack of control over drinking patterns despite negative consequences; such abnormal behavioral patterns may be attributed to structural and functional abnormalities of the prefrontal cortex responsible for decision-making (Fein & Cardenas, 2015).

Accumulation of evidence shows that EEG-NFT enhances cognitive functions by facilitating brain plasticity through structural and functional changes over the course of learning (Loriette et al., 2021). A meta-analysis on neurofeedback affirms that all neurofeedback protocols have shown improved activation of the striatum, which is responsible for reinforcement learning, and increased volume of putamen indicating an ability to integrate learned behaviors and benefit from the training (Emmert et al., 2016). The neural network held by neurofeedback consists of both cortical and subcortical structures in which basal ganglia play an important role, in addition to dopaminergic and glutamatergic synapses that play an essential role in the neurobiology of AUD (Yonah, 2023).

Participants learn to associate the feedback provided during training with the behavior they are producing, initiating direct activation of specific brain regions underlying the behavior (Loriette et al., 2021). EEG-NFT has yielded positive behavioral outcomes such as reduced intensity of adverse symptoms and improved specific cognitive functions. For example, a case study on the efficacy of neurofeedback on AUD patients showed that as the sessions progressed, the patient showed improvements in working memory index and executive functions, in addition to decreased intake of alcohol and improved quality of life with improved assertiveness and self-confidence (Ghosh et al., 2014).

Integration of EEG Neurofeedback

A large number of data have shown EEG alterations in addition to impaired quality of life among AUD patients. The low to moderate efficacy of conventional treatments with significantly high relapse rates call for interventions that address the neuropsychophysiological conditions of the disorder from the point of view of Rostami and Dehghani-Arani (2015). Similarly, Dousset et al. (2020) emphasize the importance of a novel treatment modality that is multimodal in nature, suggesting that the typical psychological and pharmacological treatments need to be complemented with neuromodulation techniques considering the viability of neural networks to reduce symptoms.

Dalkner et al. (2017) show that alpha/theta training has shown beneficial effects on AUD pathology such as decreased stress-related craving, fear of relapse, and depressive symptoms, in addition to changes in clinical personality traits and that the beta-SMR protocol has improved the cognitive deficits experienced by individuals, which can be further maintained with the help of adequate psychological interventions. The improvements in AUD pathology facilitate a neurocognitive shift that enhances an individual's capability to deal with stressors in a healthy way (Feldstein Ewing, Filbey, et al., 2011).

As stress levels decrease, individuals learn better coping mechanisms with the help of treatments such as psychotherapy governed by the hippocampus, extended amygdala, reduced activation of the HPA axis, and subsequently lower cortisol levels. Psychotherapies such as motivational interviewing (MI) have been successfully used among individuals with AUD, as motivation and change talk (individuals using languages of change from the current state) indicate a neurocognitive shift and inhibition of impulsive responses to drug related-cues (Feldstein Ewing, Filbey, et al., 2011; Ewing, Yezhuvath, et al., 2014).

Such change in perception of alcohol use indicates activation of the prefrontal cortex over the motivational and reward circuitry of the brain which can be further amplified with the help of neurofeedback protocols such as beta-SMR that facilitates top-down processing that dominates over sensory information such as craving responses of the individual (Feldstein Ewing & Chung, 2013). The importance of interpersonal context in group psychotherapy reduces hopelessness and stress levels which in turn enhances the efficacy of alpha-theta protocol on stress reduction and improved relaxation with better coping in the face of stress (Feldstein Ewing & Chung, 2013). Furthermore, NFT involves gaining control over physiological processes which is likely to enhance self-confidence and reduce emotional stress, feelings of inadequacy, insecurity, and fear among patients (Dalkner et al., 2017).

Conclusion

An integrative and multimodal approach is needed, for AUD has been proven difficult to treat with psychological or pharmacological interventions alone. Nonetheless, it would be unfair to believe that alteration of brain waves alone would be sufficient, considering the psychosocial context of the disorder. Therefore, EEG-NFT can be considered a promising add-on tool for the treatment of AUD in addition to medication and psychotherapy. EEG-NFT would facilitate a symbiotic interplay of biopsychosocial aspects of the disorder when used in conjunction with other treatment modalities.

To conclude, given the complexity of substance use disorder in general and AUD in particular, any one form of treatment will seldom work for the individual considering the multiple dynamics associated with AUD. Although evidence strongly states that EEG-NFT is efficacious in reducing the symptomatology associated with AUD, there is still the need for additional counseling/psychotherapy to address the psychosocial factors that can impact an individual's setbacks in the journey of recovery. The focus of the study is to understand the effective utility of EEG-NFT as an add-on treatment tool for addressing the neurophysiological factors that are found in individuals with AUD. EEG-NFT acts as an additional course of action to support clients' long-term recovery addressing clinical and neurocognitive outcomes related to AUD. The inclusion of EEG-NFT could prove to be beneficial and may align with the biopsychosocial model of addiction.

Limitations and Future Scope

This article attempts to explain the application of NFT that mostly involves electroencephalogram neurofeedback, as it is widely preferred by researchers for the treatment of AUD due to its affordable, noninvasive, and high temporal resolution (= 1 ms), and convenience compared to other modes (Mumtaz et al., 2018). The main objective of this scoping review is to focus on the merits of EEG-NFT. Nonetheless, NFT has widespread other interfaces such as functional magnetic resonance imaging neurofeedback (fMRI-NF), which is also used among AUD and relies on real-time processes, localizing brain signals to specific regions of the brain in response to specific stimuli and has not been reviewed intensively due to the limited scope of the study (Dousset et al., 2020).

Future research should focus on the functional specificity of EEG-NFT by delving into the trainability (desired changes in the trained brain wave oscillations), independence (lack of changes in untrained bands), and interpretability (differences in the treatment group only; Gadea et al., 2020). Research shows that a substantial population of participants (almost one-third of the nonresponders) does not benefit from EEG-NFT as the success of EEG-NFT is heavily dependent on the participant's ability to actively control their brain activity based on the given feedback (Loriette et al., 2021). Having clarity on trainability, independence, and interpretability will help clinicians understand the nonresponders and design protocols according to the individual characteristic needs that might help reduce the percentage of nonresponders (Yonah, 2023).

It is equally important to check the training effect of neurofeedback beyond laboratory conditions through systematic evaluations such as follow-ups similar to psychotherapy, to ensure that the improvements produced are not state-dependent (Gadea et al., 2020). Prospective studies with a larger sample size are also recommended to further generalize the transition effect produced by EEG-NFT (Dalkner et al., 2017; Loriette et al., 2021). Most importantly, the scope of EEG-NFT as a preventive tool can also be explored as the majority of the evidence is based on clinical samples compared to early-stage problem drinkers, who are far more numerous than dependent drinkers (Subramanian et al., 2021). Last but not least, a meta-analysis on the efficacy of integrated NFT adjunct to psychotherapy and/or pharmacotherapy will help clinicians to understand individual differences in the treatment outcome and also the effectiveness of a multimodal approach for the treatment of AUD.

Author Disclosure

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