ORIGINAL ARTICLE

EEG Variabilities in Diagnosis of Schizophrenia, Bipolar Disorder, and PTSD: A Literature Review

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ABSTRACT

Clinically significant disturbances in a person's cognition, emotional regulation, or behavior are the hallmarks of mental health disorders, which are debilitating psychiatric conditions. This review is being conducted to investigate whether the present literature regarding electroencephalography (EEG) patterns in individuals diagnosed with either schizophrenia, bipolar disorder (BD), or post-traumatic disorder (PTSD) show diagnostic biomarkers of the aforementioned mental health (MH) disorders. While the data from selected studies reported a relative level of variation, EEG activity and asymmetry were suggested in specific brain areas that potentially correlate with these MH disorders.

Mean synchronization in the alpha band decreased in BD patients, with the most significant decreases in fronto-central and centro-parietal connections. Furthermore, BD patients' clustering coefficient and global efficiency decreased, whereas the characteristic path length increased. Although the studies emphasizing the relationship between PTSD and EEG all pinpoint brain areas of increased activation in individuals diagnosed with PTSD, there is variation between specific areas of interest: the left frontal lobe, right frontal lobe, and the centro-parietal lobe. Despite the complexity of the MH disorder, abnormal EEG patterns found in schizophrenic patients have been shown across studies that demonstrate elevations of slow wave activity and deficits in alpha band frequency.

INTRODUCTION

Mental health disorders are debilitating psychiatric conditions that are characterized by clinically significant disturbances in an individual's cognition, emotional regulation, or behavior. Post-traumatic stress disorder, schizophrenia, and bipolar disorder are common forms of mental health disorders [1]

(Kalin, 2020). Neurologists and psychiatrists frequently request an EEG from diagnosed individuals to assess a patient's brain activity in various states [2].

The National Institute of Mental Health (NIMH) defines schizophrenia as a complex mental health disorder encompassing symptoms ranging from disruptions of thoughts and behaviors to psychotic symptoms involved in visual hallucinations, auditory hallucinations, and delusions due to disturbances in brain functioning. Due to the complex symptomatology, accurate prevalence rates have been challenging to assess, but individuals diagnosed with schizophrenia experience high mortality rates, comorbidities, and additional external stressors [3].

Bipolar disorder (BD) is characterized as a psychiatric mood disorder with disabling impacts on the outlook of life, therefore affecting daily living [4]. The effects of BD are crippling despite pharmacological advancements and an increase in drug options. Nearly 50% of individuals diagnosed with BD experience at least one episode every two years, and 73% of diagnosed individuals experience a BD episode at least once every five years [5]. Determining an ideal treatment plan for each individual can considerably decrease patient care and pharmacoeconomics. The identification of biomarkers to enhance the treatment of bipolar disorders thus requires a deeper understanding of the action mechanisms of existing diagnostic measures.

Post-traumatic stress disorder (PTSD), another chronic and debilitating neuropsychiatric disorder, can develop after experiencing a traumatic event. Symptoms of PTSD include persistent intrusive recollections such as nightmares and flashbacks to inciting events and the avoidance of trauma-related stimuli. Additional signs include alterations in cognition and mood, such as difficulty concentrating and alterations in arousal and reactivity, which can manifest in aggression, destructive behavior, and problems sleeping. An estimated 3.6% of U.S. adults experienced PTSD in the past year, which was more prevalent in females (5.2%) than males (1.8%) [3].

Electroencephalography (EEG) is a non-invasive medical test that records the cerebral cortex's electrical activity and potential differences generated by pyramidal cells [6]. EEG measurements use electrodes placed directly on the scalp to record electrical signals accurately. The international 10-20 system is a standardized method of scalp electrode placement to corresponding brain regions for accurate testing purposes [7]. EEG data has been utilized to discover altered temporal features of functional EEG microstates during depressive episodes. Armitage (2007) notes that EEG can provide insight into neural activity investigation and specific waveforms in individuals with varying psychological disorders like schizophrenia, BD, and PTSD [2].

Though difficult when considering the comorbidities of conjunctive mental health issues, the central objective of this literature review is to examine the previous research regarding EEG variance between individuals diagnosed with Schizophrenia, Bipolar, and PTSD when compared to normal controls in hopes of identifying fundamental EEG biomarkers of mental health disorders.

METHODS

Specific EEG methods and analyses differed among the studies used in the current review. However, Kam et al. (2013) analyzed resting state EEG power and coherence among diagnosed schizophrenic and bipolar patients. Specific methods used in the study will be explained, and additional methodology utilized in other studies will be noted in the discussion [8].

Following all initial exclusion criteria, consent, and preliminary tests, three-minute eyes-closed EEG recordings were obtained from all participants. Researchers placed electrodes on each participant's scalp using the international 10-20 system. All electrode impedances were below 10 kΩ before and throughout each recording session. Thirty-two channels of EEG recordings were obtained through silver/silver chloride electrodes, and a common reference was placed on each participant's nose. The sampling rate was set to 1000 Hz with a 0.10 Hz high-pass filter and 200 Hz low-pass filter. Additional vertical and horizontal electrooculograms (EOG) assessments were completed during each recording to track the participant's eye movement [8].

Following the initial recording, EEG data was processed through software to remove additional artifacts. Any possible low-frequency artifacts were removed by passing data through a 0.5 Hz high-pass digital filter, and other noise artifacts were also removed through a 60 Hz notch filter. Additional blink artifacts greater than 100 μV were removed from each data set before further analyses [8] (Kam et al., 2013) to be accurately compared among schizophrenic and bipolar patients.

RESULTS

Schizophrenia: Area of Interest - Slow Wave Elevations & Alpha Deficits

Elevations of slow wave delta, slow wave theta, and alpha power deficit have been prominent conclusions following eyes-closed resting state EEG recordings of schizophrenic patients. These findings align with previous literature not studied in this review.

No significant differences were identified between the first episode and chronic schizophrenic patients. However, both groups differed from healthy controls across EEG frequency composition [9]. Univariate tests based on electrode site Cz demonstrated significant elevations of delta and theta bands and significant alpha deficits. No differences were noted across beta frequencies.

Additional research from Sponheim et al. (2000) expanded these findings to identify specific disorder symptomatology and brain morphologies of patients by replicating methods and found similar supporting evidence for slow wave activity [10]. Researchers also concluded that these abnormal EEG patterns can be

correlated with negative schizophrenia symptomatology, larger variations of brain morphology, and reduced ocular motor function.

Quantitative EEG data was collected by Kim et al. (2015) to locate specific brain regions and electrode locations that presented abnormal EEG frequency power [11]. The highest power was found in the parieto-occipital region when looking at all frequency bands. Aligning with previous literature, absolute delta was elevated in frontal, central, temporal, and occipital electrodes, and absolute alpha was low in right frontal, right central, and parietal electrodes across schizophrenic patients.

Donati et al. (2021) also conducted research regarding self-paced movement in patients diagnosed with schizophrenia and their corresponding EEG activity [12]. Compared to healthy subjects, there is a reduction in C1 – FC1 beta band frequency and Readiness Potential (RP). Takahashi et al. (2010) aimed to investigate the variational disorder in EEG signal complexity across patients diagnosed with drug naïve schizophrenia [13]. Researchers emphasized multiple time scales, and results suggested that an increased complexity at lower frequencies (higher time scales) in anterior (frontal, central, and temporal) regions occurred in patients diagnosed with schizophrenia when compared to healthy counterparts.

Further research regarding EEG's potential to diagnose schizophrenic symptoms was conducted by both Shor et al. (2021) and Taylor et al. (2021). Shor et al. (2021) concluded that their novel EEG analytic system effectively diagnosed certain neurocognitive and neuropsychiatric disorders, which include schizophrenia [14-15]. Taylor et al. (2021) also analyzed EEG data via machine-learning regression methods. For Event-Related Potentials (ERPs), Taylor et al. (2021) suggest that spatiotemporal EEG profiles are predictive of psychotic schizophrenic symptoms when compared to healthy controls [15].

Bridging the gap between mental health disorders, Kam et al. (2013) reviewed resting EEG power and EEG coherence between schizophrenia and bipolar disorder. Researchers concluded greater delta coherence within hemispheres and greater theta coherence across hemispheres in schizophrenic patients [8].

Bipolar Disorder: Area of Interest - Elevated Beta, Gamma, & Alpha Waves

Kam et al. (2013) further revealed higher beta and gamma activity and additional intra-hemispheric coherence at the beta band level [8]. A rise in rapid alpha activity was also noted across patient groups. In contrast, a study with patients with euthymic bipolar disorder in a medication-free sample found that the spontaneous alpha activity was significantly decreased [16].

According to the spontaneous EEG study by Atagun (2007), schizophrenic and bipolar patients had enhanced frontocentral slow beta oscillations, like their relatives, according to the results of a second spontaneous EEG investigation [5]. Furthermore, adding to previous literature, researchers concluded that fast alpha activity rose in the bipolar illness group.

There were no appreciable age or educational attainment variations between the patient and control groups. Both groups had very low mean ratings for the symptoms of mania and depression, and there was no discernible difference between the two groups. The STAI's state and trait scales scored BD patients more highly [5].

Area of Interest - Microstates

The study provides the first proof of abnormal resting-state EEG microstate dynamics in euthymic patients with BD. At the time of the experiment, patients were stable and did not significantly vary from HCs in terms of their manic or depressed symptomatology. Despite this, individuals displayed abnormally high levels of microstates, with some groups corresponding with the level of anxiety [4]. Additionally, the associations between clinical-neurocognitive assessments or EEG network indices and antipsychotic and mood stabilizer dosage were examined [11]. The dose of mood stabilizers and nodal CCs in the left orbital gyri, left polar plane of the superior temporal gyrus, and left anterior segment of the circular sulcus of the insula showed significant positive correlations in schizophrenia patients ($r = 0.327$, $p = 0.045$; $r = 0.328$, $p = 0.045$; $r = 0.321$, $p = 0.049$). There were no discernible relationships between antipsychotic dosage and either EEG measures or symptoms. Also, there were no discernible relationships between medication dosages and EEG characteristics or symptoms in patients with bipolar illness.

Post Traumatic Stress Disorder (PTSD)

Based on the evaluations from this review, EEG has the potential to both diagnose and reveal biomarkers of PTSD. Although the studies emphasizing the relationship between PTSD and EEG all pinpoint brain areas of increased activation in individuals diagnosed with PTSD, there is variation between specific areas of interest: the left frontal lobe, right frontal lobe, and the centro-parietal lobe.

Area of Interest- Left Frontal Lobe

Among the reviewed PTSD studies, multiple studies determined that left frontal EEG frequency asymmetry correlated to PTSD symptoms. Rahmani et al. (2018) calculated a significant difference in the Hurst exponent of PTSD-diagnosed individuals in EEG channel F3 when compared to normal controls [17]. The Hurst exponent is primarily used to identify long-term patterns in a series, the rate of repetition, and the series' tendency to either regress or aggregate in any specific direction.

Zotev et al. (2018) suggested that after learning a real-time fMRI neurofeedback (rtfMRI-nf) method to modulate the interactions between the amygdala and the prefrontal cortex [18]. PTSD-diagnosed combat veterans showed a reduction in PTSD-related symptoms. PTSD symptoms were rated before and after the

training using the Clinician-Administered PTSD Scale (CAPS). After training, the PTSD group showed significant reductions in total CAPS scores and simultaneous reductions in EEG activation of the left dorsolateral prefrontal cortex and the left lateral orbitofrontal cortex regions.

Area of Interest- Right Frontal Lobe

Conversely, similar studies were identified in this review that pinpoints right frontal EEG frequency asymmetry that correlated to PTSD symptoms. Lobo et al. (2015) utilized a systematic review of PTSD-EEG correlated studies [19]. They found that many of the total studies included right frontal activation as a marker of PTSD symptoms. Specifically, PTSD severity was found to be often associated with related changes in right-frontal alpha rhythms [19].

Additionally, a literature review organized four years following Lobo et al. (2015) and Butt et al. (2019) found that within the EEG frequency domain, right frontoparietal and parietal asymmetry in alpha band power is the most promising marker of PTSD symptoms, when compared to left frontoparietal and parietal asymmetry [19-20].

Meyer et al. (2016) applied an experiment of trauma-related image exposure to three groups of individuals: those diagnosed with PTSD, individuals who had experienced traumatic events but were not diagnosed with PTSD, and a control group of individuals who had not experienced any traumatic events [21]. Based on EEG recordings during image exposure, results showed that right-sided frontal asymmetry correlated with increased PTSD psychopathy and related symptoms within tested groups.

Area of Interest- Antero-Frontal Lobe & Centro-Parietal Lobe

As opposed to identifying specific frontal lobe asymmetry, another study of interest suggests PTSD biomarkers in two distinct brain regions. Wang et al. (2019) attempted to study EEG abnormalities of PTSD diagnosed in combat veterans while sleeping [22]. EEG readings were taken over two nights, and results showed that PTSD-diagnosed individuals experienced increased anterior frontal gamma activity during both non-REM and REM sleep when compared to combat-exposed men without PTSD. Furthermore, this study recognized decreased centro-parietal delta activity during non-REM sleep.

DISCUSSION

Schizophrenia

While there were experimental variations in EEG data collection, the most utilized was a 64-channel EEG system (Donati et al., 2021; Taylor et al., 2021) according to the international 10-20 standard [12,15]. In the two studies mentioned above, sampling rates were set to 5000 Hz and 1024 Hz, respectively, and down-

sampled and filtered for artifact removal. Much of the examined literature used resting state EEG tests to examine abnormal frequencies across mental disorders.

Kim et al., 2015 utilized QEEG measures to analyze resting EEG data further. Researchers ran the data through MATLAB 7.0.1 (MathWorks, Natick, and MA, USA) and EEGLAB toolbox before being down-sampled to 250 Hz and passed through a 1 Hz-high-pass filter and a 60 Hz notch filter [11].

Due to a lack of support for differences between the first episode and chronic schizophrenic patients, researchers alluded that the abnormal EEG patterns are not due to treatment or disorder duration. Instead, this abnormal pattern is a possible trademark in the identification of schizophrenia [10]. The researcher further identified enlarged ventricle sizes as a prominent feature in schizophrenic individuals. The increase in intracranial pressure may add additional pressure against the thalamus, playing a critical role in EEG abnormalities.

Bipolar Disorder

At the network level, anomalies in structural and functional connections have been linked to two mental illnesses analyzed in this review: bipolar disorder and schizophrenia. EEG research shows that individuals diagnosed with schizophrenia and bipolar disorder have been found to have disrupted resting-state networks [5]. Broadly reduced synchronizability was discovered by Jalili and Knyazeva et al. (2010) in several frequency bands, including the theta, alpha, beta, and gamma bands. Global and nodal topological abnormalities were seen in the brain network structure of individuals diagnosed with schizophrenia during resting-state fMRI studies [23].

Although most of the research shows that depression is associated with both impaired EEG rhythms and sleep homeostasis, the effects of gender and age on sleep disruptions were notable. Decreased slow-wave activity was substantially linked with melancholic depression symptoms in depressed males. Regardless of the presence of melancholic traits, they had little effect on the temporal coherence of sleep EEG rhythms in depressed women [2].

Kim et al. (2020) concluded that individuals diagnosed with depression have heightened alpha and beta activity as they sleep, which is consistent with their increased hyperarousal and fragmented sleep patterns. These results correspond with PET brain imaging studies showing a less pronounced decline in relative regional cerebral glucose metabolism from pre-sleep to NREM sleep [2]. However, other research implies that primary insomnia may exhibit higher levels of beta activity than depression. Alternately, waking EEG investigations also support the finding of increased rapid frequency EEG activity in depression. Nevertheless, there is supplementary proof that depression impairs the synchronization of EEG activity during sleep. EEG data from depressed adults and adolescents show considerably lower levels of temporal coherence during sleeping EEG activity recorded from the right and left hemispheres. Also, lower levels of

temporal coherence are shown in the synchronization of fast and slow-frequency EEG. The assessment of awake EEG activity and electrode site coherence produced similar results.

Post Traumatic Stress Disorder (PTSD)

Methodological Discussion

While the method described in the above section is a commonly used EEG procedure, additional studies subject to examination in this review deviated from those methodological procedures.

Rahmani et al. (2018) conducted a study where EEG readings were taken from six individuals diagnosed with PTSD and six healthy controls (mean age = 27 ± 5 years, all male) to track differences in EEG waves between groups. In their EEG processing, 31 channels were utilized, with a sampling rate of 5000 samples per second and a resolution of 0.1μV [17]. Afterward, the EEG template subtraction method was utilized to remove artifacts. Regarding Zotev et al. (2018), PTSD-diagnosed individuals in an experimental group (n = 20, all male) learned to use a real-time functional MRI neurofeedback (rtfMRI-nf) during a positive emotion induction task [18]. EEG recordings were administered simultaneously with fMRI. The Clinician-Administered PTSD Scale (CAPS) was used to assess pre-experimental and post-experimental PTSD severity. EEG recordings were performed simultaneously with fMRI using a 32-channel EEG system. EEG data was recorded with 0.2 ms temporal and 0.1 μV measurement resolution (16-bit 5 kS/s sampling).

Wang et al. (2019) utilized a 64-channel EEG system but also involved 78 combat-exposed men, which included thirty-one individuals diagnosed with PTSD and forty-seven without a PTSD diagnosis [22]. Meyer et al. (2016) included 39 trauma survivors (24 of whom were diagnosed with PTSD) and 15 healthy participants in this study. An emotional provocation task was utilized by presenting one of each image, neutral, positive, negative, and trauma specific. EEG recordings were tracked during these tests according to the International 10-20 system at 22 channel locations and then band-pass filtered (0.1–35 Hz) [21].

Although six individual pieces of literature of interest are the focus of our PTSD-related review, two (33.3%) of the total are either systematic or literature reviews. Lobo et al. (2015) performed a systematic review set to investigate the range of the PTSD/Post post-traumatic stress symptoms (PTSS) spectrum, from normal to pathological, solely citing EEG experiments that utilized dimensional analyses between PTSD and EEG [19].

Butt et al. (2019) applied a systematic review to identify patterns of EEG signals identified that are associated with PTSD and interrelated symptoms [24]. While the researchers did not include a distinct methodology section, their data includes 42 studies of interest. Of the studies, the researchers created three distinct groups of interest: studies centralizing on EEG frequency band studies of trauma/PTSD, studies centralizing on auditory ERP and PTSD, and studies centralizing on visual ERP trauma and PTSD. Butt et

al. compared the results of these divergent methodologies and foci to find emerging similarities in the findings [24].

General Discussion

Of the regions of interest that the Schizophrenia and Bipolar Disorder studies identified, the most prominent areas of EEG abnormal variation occurred in the frontal, central, and temporal lobes, with the most frequent variation occurring at electrode C1. Significant fluctuations in alpha, beta, delta, and theta bands in patients diagnosed with MH disorders were also concluded across most of the studies. Though Shor et al. (2021) and Taylor et al. (2021) did not utilize nor identify frequency bands of interest, both recognize additional quantum and systematic methods in symptom analysis [14-15]. Of the regions of interest the six PTSD studies identified, two identified left frontal lobe asymmetry, three identified right frontal lobe asymmetry, and one identified Antero-frontal asymmetries and Centro-parietal asymmetry. The frontal brain region is directly responsible for executive function and emotion recognition. Moreover, the frontal lobe involves judgment, planning, sustained attention, inhibition of responses, verbal episodic memory retrieval, problem-solving, sequencing, and reasoning skills [21]. Regarding sleep, decreases in REM sleep and increases in frontal-lobe arousal during sleep can lead to compressive reductions in restorative sleep. Verweij et al. (2014) found that sleep deprivation leads to a loss of functional connectivity of prefrontal brain regions and related functions [25]. Parietal asymmetry is also linked to biological and physical arousal that may impact concentration and filtering of environmental distractors, potentially leading to a decrease in daily functioning.

LIMITATIONS

One limitation of this literature review is the search databases used and related inaccessibility to other studies that could have potentially fit within the inclusion criteria. Another limitation is some lapses in methodology transparency, as some studies included in this review detailed their EEG methodology more compressively than others. Furthermore, the presence of experiments containing small sample sizes could affect the results of an experiment, and other studies included a lack of potential generalizability to the total Mental Health population.

CONCLUSION

Currently constituted, discovering distinct biomarkers of singular mental illnesses may present as complex, especially when regarding the high level of comorbidities of multiple mental health disorders. Regardless, a baseline framework has the potential to be identified when analyzing the individual band differences in

EEG readings of these mental health disorders. While the totality of our studies found variation between specific areas of interest, the indication of areas of interest highlights the potential use of EEG to serve as objective markers of these mental health disorders and the associated severity. EEG's relatively inexpensive data collection costs make it an apt method to investigate and identify these decisive biomarkers while maintaining non-invasiveness and general portability. Due to the several brain systems affected by mental health disorders, treatment is often complicated. Though there are no guarantees for treatment, commonly accepted treatments include psychotherapy, psychiatric medications, and coping mechanism utilization (National Institute of Mental Health, 2019). In addition to identifying mental health diagnostics, future directions of MH-PTSD studies could also gain cooperative implementations with treatment to record the longitudinal decreases in MH symptoms.

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