

# Integrating EEG and fMRI in naturalistic paradigms: Advances in understanding mental disorders-a decade study in review (2014–2024)

Anam Mehmood<sup>a,b</sup> , Shuyue Xu<sup>a,b</sup>, Sultan Mehmood Siddiqi<sup>c</sup>, Li Zhang<sup>a,b</sup>, Gan Huang<sup>a,b</sup>, Zhen Liang<sup>a,b</sup> and Yongjie Zhou<sup>d</sup>

<sup>a</sup>School of Biomedical Engineering, Medical School, Shenzhen University, Shenzhen, China; <sup>b</sup>Guangdong Provincial Key Laboratory of Biomedical Measurements and Ultrasound Imaging, Shenzhen, China; <sup>c</sup>Graduate School at Shenzhen, Tsinghua University, Shenzhen, China; <sup>d</sup>Department of Child Health, Shenzhen Maternity and Child Healthcare Hospital, Shenzhen, China

## ABSTRACT

**Background:** Integrating electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) with naturalistic stimuli has advanced our understanding of the neural mechanisms underlying mental disorders. Naturalistic paradigms use dynamic, multimodal stimuli that capture complex emotional and cognitive processes more effectively than traditional experimental designs. **Objective:** This review synthesizes research from 2014 to 2024 exploring neural mechanisms of anxiety, depression, and schizophrenia within naturalistic paradigms. **Methods:** Recent EEG–fMRI studies employing naturalistic tasks were examined to identify common and disorder-specific neural alterations across affective and cognitive networks. **Results:** In anxiety, hyperactivity in the amygdala, prefrontal cortex, anterior cingulate cortex, and insula, together with changes in the dorsal attention, default mode, and frontoparietal networks, reflects excessive fear responses and impaired regulation. Depression is characterized by disruptions in default mode and frontoparietal connectivity and altered amygdala–prefrontal interactions, indicating maladaptive introspection and cognitive control. Schizophrenia shows abnormalities in motor and language processing, with aberrant activity in frontal, parietal, and temporal regions including the insula and temporoparietal junction. **Conclusion:** These findings highlight the shared involvement of the amygdala, prefrontal cortex, anterior cingulate cortex, and insula across disorders and demonstrate the potential of naturalistic paradigms for advancing personalized diagnostics and interventions in mental health.

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## 1. Introduction

The human brain, a marvel of complexity, generates multitudinous electrical signals that offer deep insights into an individual's emotional and cognitive processes. These neural biomarkers, another term for brain signals, are crucial for understanding mental states, whether active or passive, and play a key role in diagnosing and treating mental disorders (Abi-Dargham et al., 2023; Chang et al., 2012). The prevalence of mental health conditions like anxiety, depression, and Schizophrenia (SCZ) is not just a statistic but a global challenge that requires our attention. About 264 million people are affected by anxiety disorder, over 300 million (4.4%) face depression, and nearly 1% of the global population suffers from SCZ (Smith and De Torres, 2014; Panday and Abhimanyu, 2024; American Psychological Association, 2000). These disorders often

occur alongside other medical conditions, such as cardiovascular disease and diabetes, making diagnosis and treatment more complicated. As mental health gains recognition as a critical public health issue, research efforts are increasing to understand the complex brain mechanisms behind these disorders.

The advent of neuroimaging techniques has dramatically enhanced our understanding of the neural processes involved in mental health conditions (Lui et al., 2016). Among these methods, electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are essential, each providing unique yet complementary benefits. EEG, a non-invasive technique that records electrical activity produced by neurons, is beneficial for studying quick cognitive processes such as attention, perception, and emotional regulation (Sharma and Meena, 2024; Bell and Cuevas, 2012). EEG has been extensively used to

identify abnormalities in brainwave patterns, supporting the diagnosis of psychological and neurological disorders (Chandra et al., 2017). While fMRI provides details about brain regions and networks involved in complex cognitive functions such as memory, emotional regulation, and language processing, it detects fluctuations in blood flow and oxygenation to offer a comprehensive view of brain activity, elucidating the spatial distribution of neural responses (Logothetis, 2002; Guell et al., 2018). Together, these neuroimaging modalities provide a multifaceted perspective on brain function, shedding light on the intricate neural mechanisms that underlie mental health disorders. Abbreviations used in this manuscript are listed in Table 1.

### 1.1. History of naturalistic paradigms

The study of the human brain and behaviour has traditionally depended on controlled laboratory experiments where basic stimuli like light flashes or auditory tones are used to isolate specific cognitive processes (Sonkusare et al., 2019). However, a compelling new approach to the naturalistic paradigm has emerged. These paradigms use dynamic stimuli that mimic real-world experiences, such as spoken narratives, video clips, television ads, news articles, video games, and virtual reality encounters (Hasson et al., 2004; Lahnakoski et al., 2012; Bartels and Zeki, 2004; Kauttonen et al., 2018). Though often conducted in lab settings, these paradigms closely resemble our daily experiences, earning them the label 'naturalistic'. They activate broader neural networks involved in perception, attention, emotion, and cognition, resulting in consistent and predictable brain responses across individuals. By providing a more ecologically valid framework, naturalistic stimuli help us better understand

how the brain reacts to the complexities of real-world scenarios (Bartels and Zeki, 2004).

The integration of naturalistic stimuli into neuroscience began in 1954 when they were first used in EEG research as a more dynamic alternative to the static stimuli employed in traditional laboratory settings (Gastaut and Bert, 1954). This early shift marked a key move from isolated, controlled environments to more dynamic, real-world contexts, paving the way for a deeper understanding of brain activity in response to complex, multimodal stimuli (Sonkusare et al., 2019). In this evolving field, neuroimaging techniques like fMRI and EEG play a crucial role. These tools offer a more comprehensive and accurate assessment of brain activity, allowing researchers to explore how the brain processes and combines complex, real-world information, thus enabling the development of naturalistic paradigms. Alongside traditional naturalistic stimuli, Stoyanov (2022) has introduced clinical evaluation tools directly into functional neuroimaging paradigms (Stoyanov, 2022). This translational approach aims to bridge the gap between experimental neuroscience and clinical psychiatric assessment, offering a promising path towards better diagnostic accuracy and treatment evaluation.

### 1.2. EEG with naturalistic paradigms

EEG monitors the brain's rapid responses to continuous stimuli in real time and provides crucial insights into how the brain processes complex information during real-world experiences (Niso et al., 2023). By utilising different stimuli in EEG, researchers have revealed how the brain interprets these inputs differently, enhancing our understanding of multisensory integration and speech perception in noisy environments (Hasson et al., 2010). Various EEG studies on mental health disorders have investigated altered brain functions in the context of naturalistic stimuli. Oathes et al. (2008) investigated how individuals with generalised anxiety disorder (GAD) process emotional faces under stress and reported higher levels of gamma activity (Oathes et al., 2008). Similarly, Zhu et al. (2021) explored the effects of music listening on brain oscillatory networks in individuals with major depressive disorder (MDD). They reported that music can alter brain wave patterns in regions associated with emotional regulation (Zhu et al., 2021). Mosabbir et al. (2022) also evaluated the impact of emotionally charged music on depressed people and reported notable changes in frontal theta oscillations and difficulty in regulating emotions (Mosabbir et al., 2022). Babiloni et al. (2014) examined neural synchronisation

**Table 1.** List of abbreviations.

| Abbreviated Terms | Full Terms                            | Abbreviated Terms | Full Terms                  |
|-------------------|---------------------------------------|-------------------|-----------------------------|
| fMRI              | Functional Magnetic Resonance Imaging | ACC               | Anterior Cingulate Cortex   |
| EEG               | Electroencephalography                | DAN               | Dorsal Attention Network    |
| GAD               | Generalised Anxiety Disorder          | SMN               | Sensorimotor Network        |
| SAD               | Social Anxiety Disorder               | DMN               | Default Mode Network        |
| MDD               | Major Depressive Disorder             | FPN               | Frontoparietal Network      |
| UD                | Unipolar Depression                   | AI                | Anterior Insula             |
| BD                | Bipolar Depression                    | TPJ               | Temporoparietal Junction    |
| SCZ               | Schizophrenia                         | STS               | Superior Temporal Sulcus    |
| PFC               | Prefrontal Cortex                     | CBT               | Cognitive Behaviour Therapy |

during face-to-face cooperative tasks in hyper scanning. They reported that SCZ and social anxiety disrupt emotional and social processing in real-world contexts (Babiloni and Astolfi, 2014). Ladouce et al. reported that EEG with real-time feedback can enhance safety measures in activities that require high cognitive engagement (Ladouce et al., 2016). These findings underscore the potential of EEG to reveal the real-time dynamics of emotional and cognitive processing in mental disorders, sparking anticipation for the future of mental health research and the development of more effective interventions and treatments in the field of mental health.

### 1.3. fMRI with naturalistic paradigms

fMRI, within the domain of naturalistic paradigms, has gained significant popularity in recent years, offering valuable insights into the emotional, social, and cognitive factors that play a significant role in the onset and maintenance of mental disorders. These studies, with the potential to stimulate future research, have significantly expanded our understanding of anxiety disorders, underscoring the interplay between the amygdala, prefrontal cortex (PFC), and other brain regions involved in emotion regulation (Li et al., 2020; Kim et al., 2011). Etkin et al. (2007) reported that individuals with anxiety exhibit a notably stronger amygdala response to real-world stress (Etkin and Wager, 2007). Depression and SCZ have also been the focus of fMRI studies, particularly those concerning the reward circuitry of the brain. Gabbay et al. (2020) reported that depressed individuals show reduced activation in both the anterior cingulate cortex (ACC) and the ventral striatum, regions associated with anhedonia (Gabbay et al., 2013). Nummenmaa et al. (2012) reported disturbed activity in the default mode network (DMN) and emotion-processing networks (including the thalamus and ventral striatum), which are characteristic features of SCZ (Nummenmaa et al., 2012). Lepage et al. (2011) reported that brain activity, particularly in the PFC and amygdala, is altered in individuals with SCZ when they view emotionally expressive faces (Lepage et al., 2011). Although these studies face significant challenges, particularly in interpreting complex fMRI data due to the wide variety of emotional and cognitive responses induced by naturalistic stimuli, they have contributed substantially to our understanding of mental health disorders and the advancement of neuroscience.

Anxiety, a mental health condition of global significance, ranks ninth in terms of disease burden (Baxter et al., 2014). It is characterised by persistent

nervousness, stress, and unease in response to perceived threats and serves as an adaptive emotional response essential for survival. However, when these feelings become disproportionate or persistent, they can lead to dysfunction, marking the onset of anxiety disorders, including agoraphobia, panic disorder (PD), social anxiety disorder (SAD), GAD, and specific phobias (Foa et al., 2017). Specific phobias and GAD are more commonly observed in childhood or adolescence (Guha, 2014; Lijster et al., 2017). Neuroimaging studies have shed light on the neural mechanisms underlying anxiety disorders. A key finding is the consistent hyperactivity in the amygdala among individuals with anxiety disorders, which is often coupled with decreased connectivity to the PFC in response to fear-inducing stimuli (Etkin and Wager, 2007).

Additionally, anxiety disorders are frequently associated with altered activity in several brain regions involved in emotional regulation, including both limbic and cortical structures (Sun et al., 2020). Studies have demonstrated abnormal functional connectivity within the DMN, dorsal attention network (DAN), bilateral precuneus, and right fusiform gyrus in individuals with SAD. When exposed to emotional stimuli, these individuals also exhibit heightened activation in the bilateral amygdala and left medial temporal lobe (Liu et al., 2015). Similarly, GAD is linked to irregular functional connectivity between the amygdala and key regions such as the PFC, ACC, and insula, with elevated beta oscillations in the frontal cortex indicative of heightened states of hyper vigilance and arousal (Zhang et al., 2017). On the other hand, panic disorder is associated with increased activation in threat-related brain regions, including the subgenual cingulate, ventral striatum, amygdala, and midbrain periaqueductal gray area (Lueken et al., 2016). These findings collectively suggest a neural imbalance in the circuits that govern emotion and risk perception, which may underlie the exaggerated fear responses and emotional dysregulation observed in anxiety disorders. In addition to fMRI, EEG research has provided significant insights into the neural activity associated with anxiety. Knyazev et al. (2005) reported elevated beta oscillations in the frontal cortex of individuals with GAD, a marker of hyper vigilance and heightened arousal (Knyazev et al., 2005). A deeper exploration of these brain correlates not only enhances our understanding of anxiety but also holds the potential to inform more targeted diagnostic tools and therapeutic interventions.

Depression, a widespread mood disorder, has significant impacts on both physical and mental health, contributing to cognitive impairment and an increased risk of neurological disruptions, including

dementia (Gururajan et al., 2016). Approximately 50% of individuals worldwide suffering from depression do not receive treatment, primarily because of the absence of objective diagnostic guidelines (Fernández et al., 2010). fMRI studies have provided valuable insights into the neural mechanisms underlying depression. Sheline et al. (2010) reported that rumination and emotional regulation in depression are associated with aberrant connectivity between the DMN, PFC, and amygdala (Sheline et al., 2010). Similarly, Belov et al. (2023) reported that hyperactivity within the DMN may serve as a biomarker for depression severity and, importantly, as a predictor of treatment response (Belov, 2023). EEG studies have also contributed to our understanding of depression, mainly through the detection of frontal alpha asymmetry, which is closely linked to negative emotions and depression severity. Yatsenko et al. (2010) reported increased activity in the alpha, theta, and beta bands in the occipital and parietal regions of the brain in individuals with depression (Grin-Yatsenko et al., 2010). More recent studies have demonstrated that antidepressant treatments, particularly ketamine, can rapidly restore regular connectivity between the PFC and amygdala, thereby alleviating depressive symptoms (Murrough et al., 2015). These findings underscore the potential of neuroimaging techniques as valuable tools for assessing treatment effectiveness and improving diagnostic accuracy.

Schizophrenia (SCZ) is a severe, persistent mental disorder that significantly affects a person's thoughts, behaviour, and emotions. Initially, termed 'dementia praecox', meaning 'early dementia', it was one of the top 15 leading causes of disability worldwide (Kraepelin, 1971). Over 55% of patients with SCZ exhibit significant negative symptoms that significantly impact their ability to form and maintain social relationships and affect occupational functioning and overall quality of life (Bobes et al., 2010; Rosenheck et al., 2006). According to fMRI studies, SCZ is associated with disruptions in communication between the thalamus and PFC (Chen et al., 2019; Wang et al., 2015). Furthermore, various studies have demonstrated that SCZ is linked to hyperactivity in the DMN (Jang et al., 2011; Hu et al., 2017). Kraguljac et al. (2016) used connectome analysis to map large-scale functional network dysfunctions in SCZ patients. They reported disturbed connectivity of the DAN, executive control network, salience network, and DMN (Kraguljac et al., 2016). An EEG study by Basar-Eroglu et al. (2007) revealed that gamma impairments affect the processing of sensory information, leading to

symptoms such as chaotic thought patterns and hallucinations in SCZ (Basar-Eroglu et al., 2007). The need for further research in these areas is crucial for improving assessment precision and implementing better treatments, offering hope for those affected by this disorder.

#### 1.4. Review purpose

This review explores the integration of naturalistic paradigms in neuroimaging to study mental health disorders in detail. To date, no review has extensively examined studies on mental disorders within the naturalistic paradigm. This review focuses on anxiety, depression, and schizophrenia because they are highly prevalent, widely studied with naturalistic EEG and fMRI over the past decade, and share both overlapping and distinct disruptions in key neural circuits such as the amygdala, PFC, and ACC. Although reward-system dysfunction is also a factor in addictions, a balanced synthesis was not possible due to the small number of naturalistic studies in this field. This study highlights key neural biomarkers, types of stimuli, and patterns that can lead to more accurate diagnostic and therapeutic strategies. The findings underscore the potential of naturalistic paradigms to significantly improve the ecological validity of mental health research and advance treatment approaches for mental disorders.

## 2. Methodology

An extensive literature search was conducted across various electronic databases, including Google Scholar, Research Gate, PubMed, Scopus, and Embase. This search was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a systematic and transparent method for the literature review. To collect a full range of existing research on the topic, a wide variety of keyword combinations were utilised with the 'AND' operation. These included 'EEG neuroimaging', 'fMRI neuroimaging', 'naturalistic paradigms', 'audio-visual stimuli' (e.g., pictures, video clips, and audio), 'mental disorders', 'schizophrenia', 'anxiety', and 'depression'. The time range window was set from 2014 to 2024 for searching published research.

### 2.1. Inclusion criteria

This review included only original research articles published in English and available in full text. Eligible studies employed EEG or fMRI as the primary

neuroimaging technique; incorporated naturalistic paradigms; addressed anxiety, depression, and schizophrenia; and provided measurable brain function outcomes. These strict inclusion criteria were designed to ensure the precision and accuracy of our review process.

## 2.2. Exclusion criteria

Studies were excluded if they employed EEG or fMRI with controlled laboratory-based stimuli, used resting-state fMRI or EEG, did not identify key brain areas affected by the disorder, or were not published in English. Review articles, meta-analyses, preprints, survey reports, or conference papers lacking primary data were also excluded.

## 2.3. Search and selection process

A total of 287 articles were identified from multiple electronic databases. After guardedly removing duplicates and non-English language articles, 216 articles remained for screening. This screening process further narrowed the pool to 46 full-text articles. These 46 articles were then rigorously reviewed against the pre-defined inclusion criteria and included in the review, providing a comprehensive overview. The PRISMA flow diagram in Figure 1 illustrates the detailed selection process.

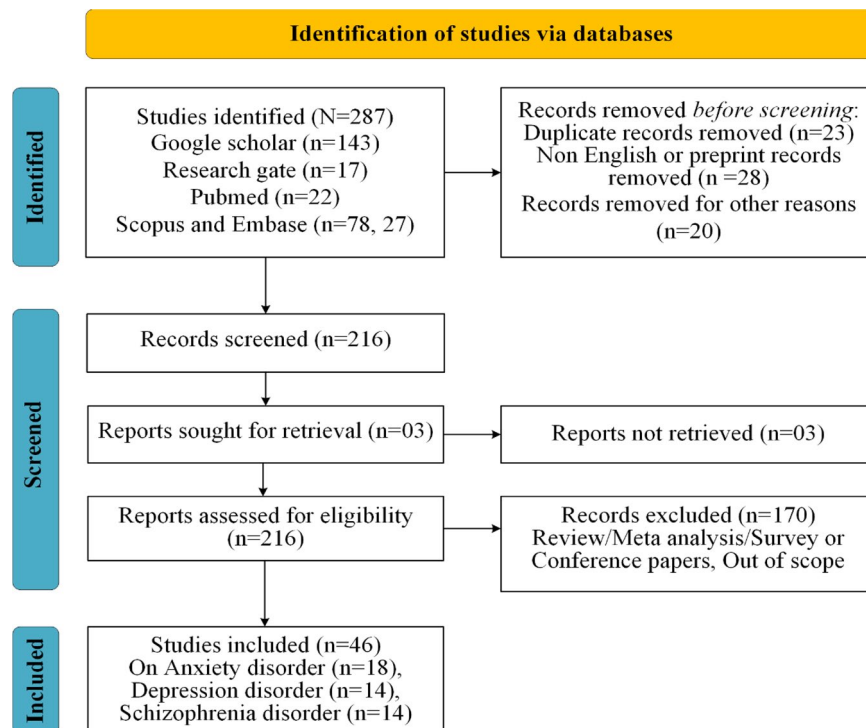
## 3. Results

### 3.1. Findings about anxiety disorder

Studies from countries such as the USA, China, Germany, Japan, the UK, the Netherlands, and Switzerland have significantly illuminated the brain processes underlying anxiety disorders. The reviewed studies offer critical insights into the neural mechanisms underlying anxiety, emphasising the role of various brain regions involved in emotional regulation, social cognition, and threat processing. Most studies employed fMRI, with sample sizes ranging from small cohorts to large-scale studies (18–163 participants), including individuals diagnosed with various anxiety disorders alongside healthy control groups. The authors' details, study purposes, sample characteristics, imaging modalities, naturalistic stimuli, key findings, and brain areas affected are summarised in Table 2.

#### 3.1.1. Brain areas involved in anxiety disorder

The amygdala, a key player in processing emotions, particularly fear, is highly important in the study of anxiety disorders. Robinson et al. (2014) reported that individuals with anxiety disorders displayed heightened amygdala activity when exposed to fearful faces, with the level of activation directly correlated with self-reported anxiety symptoms (Robinson et al., 2014). Price et al. (2014) and Bas-Hoogendam et al. (2020) also reported increased amygdala reactivity to socially threatening or



**Figure 1.** PRISMA flow diagram showing the overall process from identification to inclusion of studies.

**Table 2.** Exploration of anxiety disorder with neuroimaging and naturalistic stimuli.

| <i>Authors (Year)</i>       | <i>Affiliated Country</i> | <i>Study Purpose</i>                                                                                                                                                                      | <i>Sample Characteristics</i>                                                                                                           | <i>Imaging Modality</i> | <i>Naturalistic Stimuli</i>                                 | <i>Key Findings</i>                                                                                                                                                                                                                                                 | <i>Brain Areas Affected</i>                                                                                                                |
|-----------------------------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Robinson et al. (2014)      | USA                       | Investigate the role of the dmPFC/ACC-amygdala circuit in the pathological manifestation of anxiety disorders                                                                             | <b>Participants:</b> 45 unmedicated participants (22 with GAD, SAD, and 23 HC), age: 28±8                                               | fMRI                    | A set of shuffled photographs (Emotion identification task) | Increased circuit coupling and positive correlation between circuit coupling and self-reported anxiety symptoms                                                                                                                                                     | Amygdala, dmPFC, ACC                                                                                                                       |
| Price et al., (2014)        | USA                       | Explore neural activation patterns in anxious youth during the dot-probe task, particularly focusing on threat disengagement                                                              | <b>Participants:</b> 121 youth (90 with GAD, SAD, Social Phobia, and 31 HC), age: 9–13                                                  | fMRI                    | Photographs (Fearful and neutral faces in a dot-probe task) | Anxious youth showed decreased activity in rdACC during incongruent trials (neutral face replaced by a dot) and reduced connectivity between the rdACC and parahippocampal/hippocampal regions                                                                      | rdACC, Bilateral parahippocampal, Hippocampal regions                                                                                      |
| Zilverstand et al. (2015)   | Netherlands               | Investigate whether fMRI neurofeedback can facilitate anxiety regulation through cognitive reappraisal in spider phobics                                                                  | <b>Participants:</b> 18 female spider phobics (randomized, controlled, single-blinded study), age: 21.7±2.1                             | fMRI                    | A set of shuffled photographs (Spider photos)               | Neurofeedback lowers anxiety levels, downregulates insula activation, and long-term anxiety reduction predictions based on changes in insula                                                                                                                        | Left dlPFC, right insula                                                                                                                   |
| Pichon et al. (2015)        | Switzerland               | Investigate emotional inertia and amygdala reactivity to threat stimuli                                                                                                                   | <b>Participants:</b> 25 volunteers, age: 23.2±4.5                                                                                       | fMRI                    | Movie clips                                                 | Negative movies enhance amygdala activation, while positive movies attenuate it                                                                                                                                                                                     | Amygdala                                                                                                                                   |
| Burklund et al. (2017)      | USA                       | Investigate neural responses to rejection and their ability to predict CBT outcomes for SAD                                                                                               | <b>Participants:</b> 87 participants (70 with SAD and 17 HC), age: 28.05±6.93                                                           | fMRI                    | Film clips                                                  | SAD group showed greater amygdala activation to neutral stimuli, the HC group showed more activation in rejection-related regions. Both groups reported greater distress to rejection stimuli                                                                       | ACC, Amygdala, AI                                                                                                                          |
| Heeren et al. (2017)        | USA                       | Investigate social exclusion's neural correlates in SAD using virtual tasks                                                                                                               | <b>Participants:</b> 46 participants (23 SAD, 23 HC); Age: 18–30                                                                        | fMRI                    | Virtual game (Cyberball)                                    | Increased amygdala and mPFC activation in SAD patients during exclusion, suggesting altered social perception                                                                                                                                                       | Amygdala, mPFC, dACC, Insula                                                                                                               |
| Bas-Hoogendam et al. (2020) | Netherlands               | Investigate amygdala hyper reactivity to conditioned faces as an endophenotype for SAD                                                                                                    | <b>Participants:</b> 105 participants from 8 families (multiplex, multi-generational study on SAD), age: children 8–21 and adults 25–55 | fMRI                    | Shuffling images                                            | Bilateral amygdala hyper reactivity to conditioned faces co-segregated with social anxiety                                                                                                                                                                          | Bilateral amygdala                                                                                                                         |
| Tei et al. (2020)           | Japan                     | Investigate the brain and behavioural alterations in individuals with SAD dominated by empathic embarrassment                                                                             | <b>Participants:</b> 23 subjects with SAD, with empathic embarrassment, age: 21.3±1.2                                                   | fMRI                    | Images/Videos (Emotionally charged stimuli)                 | Increased activity in brain areas associated with empathy during social interaction tasks and heightened activity in the amygdala related to fear processing, Behavioural inhibition and avoidance tendencies were observed                                         | mPFC, AI, ACC, Amygdala                                                                                                                    |
| Hildebrandt et al. (2021)   | German                    | Explore how brain activation during social cognition (empathy, compassion, Theory of Mind) predicts perspective-taking in everyday social interactions by ecological momentary assessment | <b>Participants:</b> 122 participants, age: 18–57                                                                                       | fMRI                    | Video clip                                                  | Brain activation during social cognition tasks correlates with real-life perspective-taking                                                                                                                                                                         | mPFC, AI, aMCC, dmPFC, VS                                                                                                                  |
| Huang et al. (2021)         | China                     | Investigate the effects of music listening (neutral and happy) on state anxiety and the underlying brain mechanisms                                                                       | <b>Participants:</b> 62 participants; age: 23.33±0.16                                                                                   | EEG                     | Audio-video clips                                           | Neutral music alleviates state anxiety via reduced occipital lobe power spectral density and increased connectivity between occipital and frontal lobes, Happy music reduces state anxiety via enhanced connectivity between the occipital and right temporal lobes | Occipital lobe (power spectral density reduction)<br>Frontal lobe (increased connectivity)<br>Right temporal lobe (increased connectivity) |

(Continued)

**Table 2.** Continued.

| <i>Authors (Year)</i> | <i>Affiliated Country</i> | <i>Study Purpose</i>                                                                                                                        | <i>Sample Characteristics</i>                                                       | <i>Imaging Modality</i> | <i>Naturalistic Stimuli</i>                      | <i>Key Findings</i>                                                                                                                                                                                        | <i>Brain Areas Affected</i>                         |
|-----------------------|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| Kirk et al. (2022)    | UK                        | Investigate the relationship between anxiety and amygdala-prefrontal connectivity during movie-watching                                     | <b>Participants:</b> 86 right-handed participants; age: 18–58                       | fMRI                    | Video clip (Ecologically rich movie)             | Anxiety correlated with increased face-dependent parietal activation and decreased auditory cortex activation, but did not show anxiety-dependent connectivity                                             | Superior parietal cortex, auditory cortex, amygdala |
| Perino et al. (2021)  | USA                       | Investigate attentional bias in paediatric anxiety and its association with brain activity                                                  | <b>Participants:</b> 129 children (75 girls, Half with anxiety disorder), age: 8–12 | fMRI                    | Photographs in reordering                        | Higher anxiety correlated with greater capture of attention by non-emotional, salient stimuli; brain activity increased in the FG and VAN                                                                  | IFG, VAN                                            |
| Brandt et al. (2021)  | German                    | Investigate how negative interpersonal experiences influence neural mechanisms during social interaction                                    | <b>Participants:</b> 33 volunteers, age: 27.52 ± 6.78                               | fMRI                    | Video clip                                       | Negative interpersonal experiences led to prolonged affective changes and increased neural responses in social interactions, particularly in regions involved in social cognition and emotional regulation | mPFC, TPJ, STS, Precuneus, ACC, IFG                 |
| Nan et al. (2022)     | United States             | Explore how the ISC in EEG during emotional video viewing relates to anxiety and mood                                                       | <b>Participants:</b> 163 healthy adults, age: 39.80 ± 22.65                         | EEG                     | Video clip ( <i>The Lion Cage</i> )              | ISC in alpha and beta bands inversely related to anxiety symptoms                                                                                                                                          | Superior Parietal Cortex (Centro-Parietal Region)   |
| Wang et al. (2023)    | China                     | Examine neural connections that play a significant role in anxiety                                                                          | <b>Participants:</b> 20 adults; age: 27 ± 2.7                                       | fMRI                    | Movie clip ( <i>The Butterfly Circus</i> )       | Arousal modulates reciprocal amygdala-insula connectivity, enhancing understanding of emotional processing                                                                                                 | Amygdala, insula                                    |
| Koban et al. (2023)   | USA                       | Examine social learning of self-perception in SAD through public speaking feedback                                                          | <b>Participants:</b> 44 adults (21 SAD, 23 HC), age: 18–35                          | fMRI                    | Feedback (Social feedback after public speaking) | SAD patients displayed stronger responses to negative feedback, reinforcing negative self-perception                                                                                                       | Frontoparietal brain areas, AI                      |
| Fu et al. (2024)      | China                     | Acute behavioural and neural effects of a single intranasal oxytocin administration of subjective fear experience in a naturalistic context | <b>Participants:</b> 67 healthy adults, age: 21.03 ± 1.95                           | fMRI                    | Video clips                                      | By influencing both subjective fear and brain activity, oxytocin shows promise as a potential treatment for conditions such as SAD. Oxytocin enhanced communication between DAN, FPN, and DMN              | DAN, DMN, FPN                                       |
| Watve et al. (2023)   | Switzerland               | Investigate real-time fMRI neurofeedback using dynamic emotional faces to modulate amygdala activity and emotion regulation                 | <b>Participants:</b> 64 healthy adults, age: 18–64                                  | fMRI                    | Feedback (Dynamic emotional faces)               | Significant downregulation of amygdala activity in the fear-down group, with task-dependent changes in connectivity                                                                                        | Amygdala, FFA, mOFC                                 |

Note: GAD - generalised anxiety disorder, SAD - social anxiety disorder, fMRI - functional magnetic resonance imaging, HC - healthy control, dmPFC - dorsomedial prefrontal cortex, ACC - anterior cingulate cortex, rdACC - rostral-dorsal anterior cingulate cortex, rdACC - dorsal anterior cingulate cortex, dlPFC - dorsolateral prefrontal cortex, AI - anterior insula, mPFC - medial prefrontal cortex, aMCC - anterior middle cingulate cortex, ToM - theory of mind, VS - ventral striatum, IFG - inferior frontal gyrus, VAN - ventral attention network, FG - fusiform gyrus, TPJ - temporoparietal junction, STS - superior temporal sulcus, FFA - fusiform face area, mOFC - medial orbitofrontal cortex, EEG - electroencephalography, DAN - dorsal attention network, DMN - default mode network, FPN - frontoparietal network.

emotionally evocative stimuli in anxiety disorders (Price et al., 2014; Bas-Hoogendam et al., 2020).

This hyperactivity in the amygdala is often paired with disruptions in its connections to other brain areas, such as the PFC and ACC. The PFC, which includes the mPFC, dlPFC, and dmPFC, plays a vital role in controlling emotions, decision-making, and social understanding. Heeren et al. (2017) reported that people with SAD often show reduced connectivity in these regions during tasks involving cognitive control, social judgement, and emotion regulation, highlighting the potential for treatment strategies targeting the PFC (Heeren et al., 2017). The ACC, on the other hand, is a key part of neural circuits that manage conflict monitoring, emotional regulation, and social cognition. It is often involved in anxiety-related research, with changes in activity in this area linked to increased emotional reactivity and social anxiety. Burklund et al. (2017) demonstrated that people with SAD showed greater ACC activation in response to rejection cues (Burklund et al., 2017). Additional research underscores the importance of the ACC in neurofeedback and social learning settings (Zilverstand et al., 2015; Koban et al., 2023). Price et al. (2014) observed decreased activity in the rdACC of anxious youth, suggesting that problems with threat disengagement happen in this region, which is also involved in emotion regulation and decision-making (Price et al., 2014).

The insula, another essential node in processing interoceptive signals, emotional awareness, and anxiety regulation, offers potential for targeted treatments. Zilverstand et al. (2015) demonstrated that neurofeedback focusing on insula activation reduces anxiety in spider phobics (Zilverstand et al., 2015). Other studies by Hildebrandt et al. (2021) and Wang et al. (2023) showed that changes in amygdala-insula connectivity were linked to emotional processing during exposure to anxiety-provoking stimuli, further emphasising the role of these regions in integrating emotional and sensory information (Hildebrandt et al., 2021; Wang et al., 2023). These findings highlight the potential for targeted treatments that focus on the insula in managing anxiety disorders.

Building on the understanding of neural dysfunctions, it is crucial to examine how these abnormalities appear in social cognition and self-perception in individuals with anxiety disorders.

### **3.1.2. Self-perception and social cognition**

Studies have investigated how anxiety and social cognition influence social feedback processing and emotional expression. Brandi et al. (2021) reported

that negative interpersonal experiences during interactions lead to long-lasting affective changes and modify neural responses in brain areas involved in social cognition (Brandi et al., 2021). Similarly, Koban et al. (2023) reported that individuals with SAD show increased neural reactivity to negative feedback, which reinforces negative self-perception (Koban et al., 2023).

### **3.1.3. Neural mechanisms underlying empathy and theory of mind (TOM)**

The ability to understand others' perspectives (ToM) and engage in empathy is often altered in individuals with anxiety disorders. Hildebrandt et al. (2021) investigated the neural correlates of empathy and ToM and reported that brain activation during social cognition tasks was related to real-life perspective-taking ability (Hildebrandt et al., 2021). Brain regions such as the PFC, AI, ACC, and amygdala are involved in processing social information and regulating emotional responses in social contexts. Tei et al. (2020) also highlighted embarrassment in SAD patients, observing activity in these same brain regions during social interaction tasks involving emotionally charged stimuli (Tei et al., 2020), suggesting that individuals with SAD may be hypersensitive to social cues, which contributes to their anxiety.

Given the impact of neural and social processing impairments, various therapeutic interventions have been explored to regulate these dysfunctional brain systems and reduce anxiety symptoms.

### **3.1.4. Impact of therapeutic interventions on brain activity**

Therapeutic interventions, particularly CBT and neurofeedback, have shown promising results in regulating brain activity in individuals with anxiety disorders (Chen et al., 2014). Burklund et al. (2017) reported that CBT reinforces emotional regulation in SAD patients by increasing functional connectivity in the ACC and amygdala (Burklund et al., 2017). Zilverstand et al. (2015) revealed that neurofeedback reduced amygdala activation in spider-phobic individuals, resulting in a long-lasting decline in anxiety (Zilverstand et al., 2015). Similarly, Watve et al. (2024) reported that real-time fMRI neurofeedback handled amygdala activity during exposure to dynamic emotional faces and improved emotion regulation, which aligns with Koban et al. (2023) (Koban et al., 2023; Watve et al., 2023). These findings support neurofeedback as an effective intervention for reducing anxiety, especially with real-time brain monitoring.

### 3.1.5. Neural synchrony and connectivity

Neural synchrony, which involves the coordination of brain activity in emotion processing, is a promising research area. Nan et al. (2022) confirmed that inter-subject correlations (ISCs) in the alpha and beta bands during emotional video viewing were inversely related to anxiety symptoms (Nan et al., 2022). This discovery opens new possibilities for future studies, especially in understanding the role of specific brain regions, like the superior parietal cortex, which shows altered connectivity in anxiety and may offer treatment options.

### 3.1.6. Non-traditional interventions-music and oxytocin

Huang et al. (2021) explored non-traditional interventions like music for anxiety regulation. Their findings showed that neutral music, unexpectedly, decreased state anxiety by lowering occipital lobe power spectral density and speeding up connectivity between the occipital and frontal lobes. Conversely, happy music was found to reduce anxiety by increasing connectivity between the occipital and right temporal lobes (Huang et al., 2021). These findings not only emphasise music's potential as an easy yet effective tool for regulating brain activity but also inspire hope and optimism in anxiety research.

Fu et al. (2024) investigated the effects of oxytocin on fear processing and neural connectivity. Their results showed that oxytocin increased connectivity among brain networks involved in attention and emotion regulation, including the DAN, FPN, and DMN (Fu et al., 2024). These findings not only suggest that oxytocin could have therapeutic benefits for SAD but also open new possibilities for treating social and emotional impairments in anxiety disorders.

## 3.2. Findings about depression disorder

Naturalistic paradigms in depression research have diversified our knowledge of the brain processes underlying depression disorders. The global impact of these studies is evident, with significant contributions from the USA, China, Australia, Taiwan, Denmark, and Germany. Studies on unipolar (UD) and bipolar (BD) depression were considered in this review. Although they are distinguished by categorical nosology, both are taken into account in many naturalistic neuroimaging investigations under the more general heading of depressive disorders. Although we acknowledge that there may be differences in the neurological changes between UD and BD, we included both to give a thorough review. Researchers have utilised various

naturalistic stimuli, including emotional images, autobiographical recall, and audio-video clips, using neuroimaging to study brain responses related to emotional processing, empathy, and self-reflection. Sample sizes vary, with participants ranging from 12 to 65 years of age. These different studies offer valuable information about how depression affects specific neural circuits, as described in Table 3.

### 3.2.1. Key brain areas involved in depression disorder

The amygdala plays a crucial role in emotional processing and is often altered in individuals with depressive disorders. Chen et al. (2014) reported asymmetric activation in the right and left amygdala during emotional processing in MDD patients treated with escitalopram, focusing on emotional processing asymmetry (Chen et al., 2014). Similarly, Guo et al. (2016) reported disruptions in the amygdala and PFC during emotional film viewing in patients with melancholic depression (Guo et al., 2016). Adolescents with MDD also exhibited heightened bilateral amygdala activation in response to fearful faces, as Hall et al. (2014) reported, underscoring the amygdala's role in emotional reactivity (Hall et al., 2014).

The PFC also shows decreased activation in individuals with depression. Peña-Arteaga et al. (2021) reported reduced activation in the vlPFC during emotion regulation tasks in MDD and BD patients (De la Peña-Arteaga et al., 2021). Conversely, Stewart et al. (2014) noted heightened functional connectivity of the PFC in MDD patients (Bürger et al., 2017). Altered ACC activity is frequently linked to depressive disorders, as studies by Lepping et al. (2016), Liu et al. (2021), and Hall et al. (2014) demonstrated abnormal ACC activation in response to negative stimuli (Gruskin et al., 2020; Liu et al., 2021; Zappa et al., 2019).

The hippocampus, which is critical for memory and emotional processing, is also abnormal in individuals with depression. Young et al. (2017) and Li et al. (2016) highlighted increased hippocampal activation in drug-naïve female MDD patients with a history of SLEs (Li et al., 2016; Young et al., 2017). The insula, another key region, has been implicated in disrupted emotional processing, as noted by multiple studies (Henningsson et al., 2015; Hall et al., 2014).

These alterations in brain function also manifest in disrupted emotional processing and social cognitive deficits, which are central features of depressive disorders

### 3.2.2. Social cognition and emotional processing

Depression significantly impacts the neural mechanisms underlying social cognition and emotional feedback

**Table 3.** Exploration of depression disorder with neuroimaging and naturalistic stimuli.

| Authors (Year)                   | Affiliated Country | Study Purpose                                                                                                                                                    | Sample Characteristics                                                                                                                                          | Imaging Modality | Naturalistic Stimuli                                           | Key Findings                                                                                                                                   | Brain Areas Affected                                                                                                                                                                            |
|----------------------------------|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Chen et al. (2014)               | Taiwan             | Examine amygdala asymmetry in MDD patients during emotional processing with antidepressant treatment                                                             | <b>Participants:</b> 20 depressed patients, treated with escitalopram, age: 28–55                                                                               | fMRI             | Photographs (Different emotional pictures in shuffling)        | Differential activation in the right and left amygdala, indicating emotional processing asymmetry with treatment-related effects               | Right and left amygdala                                                                                                                                                                         |
| Henningsson et al. (2015)        | Denmark            | Investigate the impact of sex-hormone manipulation on emotional processing and depressive symptoms                                                               | <b>Participants:</b> 56 healthy women; baseline (follicular phase) and 16±3 days post-GnRHa intervention, age: 24.3±5.0                                         | fMRI             | Photographs (Emotional faces in shuffling)                     | GnRHa manipulation increased depressive symptoms, which is related to heightened emotional responses in AI and amygdala                        | AI, amygdala                                                                                                                                                                                    |
| Li et al. (2016)                 | China              | Investigate differences in brain activation under negative emotional picture stimuli in drug-naïve female patients with and without SLEs before depression onset | <b>Participants:</b> 33 females (18 female patients with SLEs, 15 female patients without SLEs; all drug-naïve with first major depressive episode), age: 18–55 | fMRI             | Photographs in shuffling (Negative emotional pictures)         | Patients with SLEs showed increased activation in brain regions associated with emotion processing, memory, and perception                     | Bilateral superior temporal gyrus, Left middle temporal occipital gyrus, Left medial frontal gyrus, Right inferior frontal gyrus, bilateral thalamus, Hippocampus, Precentral/postcentral gyrus |
| De la Peña-Arteaga et al. (2021) | Spain              | Investigate the neural correlates of emotion regulation deficits in BPD and MDD                                                                                  | <b>Participants:</b> 19 BPD patients, 20 MDD patients, 19 HC, age: 21–63                                                                                        | fMRI             | Photographs (Negative images in shuffling)                     | Both BPD and MDD showed decreased activation in the right vPFC during emotion regulation; MDD showed additional deficits in prefrontal regions | vPFC, Left dlPFC, Bilateral orbitofrontal cortices, Temporal regions (visual ventral stream)                                                                                                    |
| Bürger et al. (2017)             | Germany            | Examine neural activation differences between BP and UP depression in response to emotional faces                                                                | <b>Participants:</b> 36 UD patients, 36 BD patients, 36 controls, age: 41.33±6.05                                                                               | fMRI             | Photograph in shuffling (Emotional faces)                      | Differences in ACG response between BD and UD; higher FC in UD for emotion processing regions                                                  | ACG, amygdala                                                                                                                                                                                   |
| Stewart et al. (2014)            | USA                | Investigate the capability model of EEG asymmetry during resting and emotional challenge conditions in depression                                                | <b>Participants:</b> 306 (143 individuals with lifetime MDD, 163 without lifetime MDD), age: 17–34                                                              | EEG              | Real-time Facial emotion task                                  | EEG asymmetry during emotional challenges was more indicative of MDD than resting asymmetry                                                    | PFC (alpha asymmetry regions)                                                                                                                                                                   |
| Young et al. (2017)              | USA                | Investigate real-time fMRI neurofeedback in MDD                                                                                                                  | <b>Participants:</b> 36 unmedicated adults with MDD, age: 18–55                                                                                                 | fMRI             | Neurofeedback (Real-time using autobiographical memory recall) | Amygdala neurofeedback enhanced response to positive memories, improving depressive symptoms and recall of positive autobiographical memories  | Amygdala, hippocampus, OFC                                                                                                                                                                      |
| Lepping et al. (2016)            | USA                | Examine how neural processing of emotional musical and non-musical stimuli differs in people with MDD compared to HCs                                            | <b>Participants:</b> 19 MDD patients, 20 never-depressed (ND) controls, age: 18–59                                                                              | fMRI             | Audio video clip                                               | MDD patients showed altered activation in ACC compared to ND controls, especially in response to negative stimuli                              | ACC, Striatum                                                                                                                                                                                   |
| Gruskin et al. (2020)            | USA                | Investigate depressive symptoms' link to brain responses in naturalistic emotional processing in youth                                                           | <b>Participants:</b> 112 participants, age: 17–21                                                                                                               | fMRI             | Movie Clip ('Despicable Me')                                   | Adolescents show atypical brain responses, stronger symptom-profile links, and developmental brain changes                                     | Left dlPFC, medial temporal lobe, left OFC, hippocampus, mPFC, PCC                                                                                                                              |
| Guo et al. (2016)                | Australia          | Examine disrupted neural activity in emotional circuitry during film viewing in melancholic depression                                                           | <b>Participants:</b> 30 adults with melancholic depression, age: 20–50                                                                                          | fMRI             | Video clip (Emotional content)                                 | Disrupted neural synchrony in emotional processing networks, particularly in individuals with melancholic depression                           | Amygdala, PFC                                                                                                                                                                                   |
| Liu et al. (2020)                | China              | Investigate frequency-specific FC in MDD during music perception                                                                                                 | <b>Participant:</b> 19 healthy adults, age: 24–65, 20 MDD patients, age: 23–58                                                                                  | EEG              | Audio clip (Music-modern tango piece by Astor Piazzolla)       | Increased connectivity in the delta band and decreased connectivity in the beta band in MDD                                                    | Delta band: Right central, right temporal, and left parietal regions. Beta band: Frontal areas and frontal parieto-occipital connections                                                        |

(Continued)

**Table 3.** Continued.

| Authors (Year)     | Affiliated Country | Study Purpose                                                                                | Sample Characteristics                                                            | Imaging Modality | Naturalistic Stimuli                                           | Key Findings                                                                                                                                                                                                                                                      | Brain Areas Affected                                                                        |
|--------------------|--------------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------|----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| Hall et al. (2014) | USA                | Examine brain function in response to emotional faces in adolescents with MDD and HCs        | <b>Participants:</b> 32 unmedicated adolescents with MDD, 23 HC, age: 12–18       | fMRI             | Photographs (Happy and fearful faces in clips)                 | Adolescents with MDD had greater bilateral amygdala activation, reduced activation in the right hemisphere in insula and temporal region in response to fearful faces, Subgenual anterior cingulate cortex activity inversely correlated with depression severity | Amygdala (bilateral), Insula, Superior/middle temporal gyrus, Heschl's gyrus, Subgenual ACC |
| Zhu et al. (2021)  | China              | Explore frequency-specific brain networks during music listening in HCs and MDD participants | <b>Participants:</b> 20 healthy adults, 20 MDD participants, age: $42.8 \pm 10.7$ | EEG              | Audio clip (Music-Tango piece Adios Nonino by Astor Piazzolla) | The MDD group showed reduced SMN and visual network activation and increased lateral visual network activity                                                                                                                                                      | Left angular gyrus, SMN, Auditory network, Medial visual network                            |
| Liu et al. (2021)  | China              | Explore hyperconnectivity and hypoconnectivity networks in MDD during music listening        | <b>Participants:</b> 20 MDD patients, 19 HC, age: 18–65                           | EEG              | Audio clip (Music by Tango piece 'Adios Nonino')               | MDD exhibited hyperconnectivity in DMN regions and delta-modulated auditory networks; hypoconnectivity in FPN                                                                                                                                                     | DMN (mPFC, PCC, precuneus), auditory cortex, FPN                                            |

Note: MDD - major depressive disorder, fMRI - functional magnetic resonance imaging, AI - anterior insula, SLEs - stressful life events, dlPFC - dorsolateral prefrontal cortex, MDD - major depressive disorder, UD - unipolar depression, BD - bipolar depression, HC - healthy control, ACC - anterior cingulate gyrus, EEG - electroencephalography, PFC - prefrontal cortex, OFC - orbitofrontal cortex, ACC - anterior cingulate cortex, mPFC - medial prefrontal cortex, PCC - posterior cingulate cortex, vlPFC - ventrolateral prefrontal cortex, dACC - dorsal anterior cingulate cortex, VLPFC - ventral prefrontal cortex, SMN - sensorimotor network, DMN - default mode network, FPN - frontoparietal network.

processing. Henningsson et al. (2015) reported accelerated emotional responses in the AI and amygdala under sex hormone manipulation in women with depression, which correlated with increased depressive symptoms (Henningsson et al., 2015). Gruskin et al. (2020) reported abnormal brain responses during emotional processing tasks in youth with depression, suggesting that developmental changes in neural function contribute to social impairments (Gruskin et al., 2020). Furthermore, deficits in emotion regulation are reflected in reduced activity in the amygdala, ACC, and PFC. Peña-Arteaga et al. (2021) noted significant emotion regulation deficits in MDD patients, particularly in the right vlPFC (De la Peña-Arteaga et al., 2021).

Recognising these neural and emotional dysregulations, emerging therapeutic approaches such as neurofeedback and targeted interventions have been developed to improve outcomes in depression.

### 3.2.3. Neurofeedback, emotion regulation, and altered neural synchrony

Therapeutic interventions targeting brain activity offer promising results for depression management. Young et al. (2017) reported that real-time fMRI neurofeedback focusing on the amygdala and ACC improved emotion regulation and reduced depressive symptoms (Young et al., 2017). These findings underscore the potential of neurofeedback in the treatment of depression. Liu et al. (2020) further demonstrated altered neural connectivity patterns in MDD patients, which could guide neurofeedback protocol designs (Liu et al., 2021).

Stewart et al. (2014) reported that EEG asymmetry during emotional challenges indicates more MDD than does resting asymmetry, suggesting disruptions in prefrontal and limbic area communication (Stewart et al., 2014). Burger et al. (2017) reported greater functional connectivity in the ACC and amygdala in UD patients than in BD patients (Bürger et al., 2017).

### 3.2.4. Musical stimuli in depression

Recent studies have explored the impact of musical stimuli on depression. Liu et al. (2020, 2021), Zhu et al. (2021), and Lepping et al. (2016) reported altered neural activation in response to emotional musical stimuli in MDD patients (Oathes et al., 2008; Lepping et al., 2016; Liu et al., 2021). These findings suggest that music can influence brain regions involved in emotional regulation, including the DMN, FPN, SMN, ACC, medial visual network, and auditory cortex. These findings position music as a potential non-pharmacological intervention for depression.

### 3.3. Findings about schizophrenia disorder

In this decade, naturalistic paradigms have been widely used in SCZ research, resulting in integrated knowledge of the multifaceted effects of the disorder on sociability and cognition. Indeed, Germany, Spain, the United States, and China have made massive contributions to this effort. Studies have explored how people with SCZ react to settings resembling daily experiences. The sample sizes of these studies vary with age and range between 18 and 70 years. Remarkable key findings from these studies are presented in Table 4 and discussed below.

#### 3.3.1. Key brain areas involved in schizophrenia disorder

The SCZ induces complex changes in brain regions that control cognitive functions, emotional regulation, and sensory processing. Motor-linguistic coordination is often disrupted, leading to disordered speech and motor symptoms. Zappa et al. (2019) reported lower synchronisation in motor-linguistic coordination, reflecting abnormalities in the brain networks responsible for movement and speech (Cuevas et al., 2022). Dysfunctional PFC connectivity impairs cognitive control and social processing, as highlighted by He et al. (2021) (He et al., 2021). Ciaramidaro et al. (2015) reported reduced vMPFC activation and increased activation for physical information processing (Ciaramidaro et al., 2015). Mishra et al. (2022) identified alterations in frontal and parietal regions in SCZ patients (Mishra et al., 2022). Cuevas et al. (2022) noted that co-speech gestures normalise responses to complex semantic stimuli, activating the middle frontal and inferior parietal regions (Cuevas et al., 2022). Dysfunctional pSTS connectivity is linked to impaired social cognition, as the pSTS processes social cues such as facial expressions and emotions. Dietz et al. (2020) reported increased connectivity between V5 (motion-sensitive area) and the pSTS, exacerbating positive symptoms and impairing social processing (Roa Romero et al., 2016). Similarly, Patel et al. (2021) reported decreased activation and connectivity between the right TPJ and pSTS, particularly in the middle TPJ, further impairing social cognition (Patel et al., 2021). ACC dysfunction contributes to emotion regulation deficits and negative symptoms, as noted by Cordes et al. (2015) (Cordes et al., 2015). DMN dysregulation impairs self-reflection and perspective-taking, creating challenges in balancing self-referential thinking with external task demands in SCZ patients, as reported by Iglesias-Parro et al. (2023) (He et al., 2021).

Building upon these neural disruptions, it is essential to explore how SCZ affects emotional regulation and real-world functioning.

#### 3.3.2. Neurofeedback and emotion regulation

Cordes et al. (2015) used neurofeedback to explore how patients with SCZ regulate ACC activity (Cordes et al., 2015). Mishra et al. (2022) studied emotion processing in patients with SCZ and reported altered brain connectivity, particularly in the right frontal and parietal lobes (Mishra et al., 2022). Dietz et al. (2020) explored brain connectivity in first-episode SCZ patients and reported difficulty in distinguishing social stimuli from non-social stimuli, indicating disrupted emotional processing in social contexts (Dietz et al., 2020). Yang et al. (2020) focused on early SCZ detection via emotional content and reported reduced brain synchronisation in SCZ patients, affecting areas such as the temporal and frontal lobes (Yang et al., 2020). Improving the functions of these disturbed areas can help address the social impairments associated with SCZ.

Beyond social and emotional impairments, SCZ also involves profound disruptions in sensory processing and network synchrony, which further contribute to clinical symptoms.

#### 3.3.3. Sensory processing and neural synchrony

Disruptions in sensory processing and network connectivity have been observed in SCZ patients. Xiang et al. (2019) reported increased entropy in the frontal cortex during a sensory processing task, which may be related to positive symptoms, indicating that impaired sensory gating plays a role in the disorder (Šimić et al., 2021). Romero et al. (2016) reported that while audio-visual incongruence in the auditory cortex was detected in both the SCZ and control groups, the SCZ group presented lower frontal theta-band oscillations, indicating a deficit in multi-sensory processing (Roa Romero et al., 2016). Fuentes-Claramonte et al. (2022) studied linguistic deixis processing in SCZ patients with and without AVH and reported altered brain activity in the temporal and parietal regions (Fuentes-Claramonte et al., 2022).

## 4. Discussion

This review focuses on notable breakthroughs in combining naturalistic paradigms with EEG and fMRI, as well as the brain processes underpinning anxiety, depression, and SCZ. By using ecologically valid stimuli, this study bridges the gap between controlled

**Table 4.** Exploration of schizophrenia disorder with neuroimaging and naturalistic stimuli.

| Authors (Year)                                             | Affiliated Country | Study Purpose                                                                                                                                       | Sample Characteristics                                                                           | Imaging Modality | Naturalistic Stimuli                                                                                                              | Key Findings                                                                                                                                                                                                                                                                                                                                                               | Brain Areas Affected                                                                                                                                                                                                                  |
|------------------------------------------------------------|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|------------------|-----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Zappa et al. (2019) (Zappa et al., 2019)                   | USA                | Examine motor and linguistic processing in a VR setting to simulate real-life actions in SCZ.                                                       | <b>Participants:</b> 40 SCZ patients and HC, age: 18–45                                          | EEG              | Virtual Reality (Motor and linguistic tasks)                                                                                      | Impaired motor-linguistic coordination in SCZ with reduced synchrony in virtual actions                                                                                                                                                                                                                                                                                    | Motor cortex, language-associated areas                                                                                                                                                                                               |
| Mishra et al. (2022) (Mishra et al., 2022)                 | India              | Examine the dynamic FC of emotion processing in SCZ with naturalistic stimuli                                                                       | <b>Participants:</b> 40 participants, age: 23.3 ± 3                                              | EEG              | Video clips (Emotional video)                                                                                                     | Connectivity patterns in the upper beta band differentiated emotion, temporal variability in DFC is related to emotional arousal and dominance, Hubs in the functional networks were found across the right frontal and bilateral parietal lobes                                                                                                                           | Right frontal and bilateral parietal lobes                                                                                                                                                                                            |
| Iglesias-Parro et al. (2023) (Iglesias-Parro et al., 2023) | Spain              | Examine neural connectivity in SCZ using task-based EEG and graph theory                                                                            | <b>Participants:</b> 45 adults, age: 38.8 ± 11.8                                                 | EEG              | Video clips                                                                                                                       | Reduced neural synchronisation and altered connectivity in DMN                                                                                                                                                                                                                                                                                                             | DMN                                                                                                                                                                                                                                   |
| Cuevas et al. (2022) (Cuevas et al., 2022)                 | German             | Analyses SCZ patients' responses to semantic complexity and gestures                                                                                | <b>Participants:</b> 16 patients, 18 HC, age: 34 ± 12.18                                         | fMRI             | Video clips                                                                                                                       | Cospeech gestures normalised responses to complex semantic stimuli                                                                                                                                                                                                                                                                                                         | Middle frontal, inferior parietal regions                                                                                                                                                                                             |
| Tu et al. (2019) (Tu et al., 2019)                         | Taiwan             | Investigate neural responses to humour processing in SCZ patients                                                                                   | <b>Participants:</b> 29 SCZ patients (age: 38.2 ± 8.2) and 29 HC (age: 35.7 ± 9.1)               | fMRI             | Movie clips (Comedy)                                                                                                              | SCZ patients showed lower ISC than HC during humour processing, higher clinical severity correlated with lower ISC in frontal and temporal regions, and higher ISC in visual areas                                                                                                                                                                                         | Higher ICS in bilateral lateral occipital, bilateral superior frontal, left supramarginal, right lateral orbito-frontal cortices; lower ISC in left superior temporal sulcus, bilateral supramarginal, and inferior parietal cortices |
| Dietz et al. (2020) (Dietz et al., 2020)                   | Denmark            | Investigate abnormal brain connectivity during social cognition in SCZ, focusing on how it relates to positive symptoms                             | <b>Participants:</b> 24 first-episode SCZ patients (FES), 25 HC, Average age: 25.21              | fMRI             | Video clips (Animated geometric shapes moving in coordinated social motion or random non-social motion)                           | FES patients less accurate in distinguishing social from non-social stimuli, increased feed-forward connectivity from motion-sensitive V5 to pSTS in FES patients, higher positive symptoms correlated with increased disinhibition within pSTS                                                                                                                            | Motion-sensitive area V5, pSTS                                                                                                                                                                                                        |
| He et al. (2021) (He et al., 2021)                         | German             | Investigate modality-specific dysfunctional neural processing of social-abstract and non-social-concrete information in SCZ                         | <b>Participants:</b> 17 patients with SCZ or schizoaffective disorder, 18 HC, age: 33.12 ± 12.35 | fMRI             | Video clip (an actor speaking or gesturing, unimodal, and both speaking and gesturing, bimodal) about social or non-social events | Reduced activation in mPFC for social-abstract content only during the gesture condition in patients, decreased activation in the left postcentral gyrus and right insula for non-social-concrete content during the speech condition, improved task performance and comparable activation in bimodal conditions for patients                                              | mPFC, left postcentral gyrus, right insula                                                                                                                                                                                            |
| Cordes et al. (2015) (Cordes et al., 2015)                 | German             | Investigate cognitive and neural strategies during ACC control via fMRI neurofeedback in patients with SCZ                                          | <b>Participants:</b> 11 patients with SCZ, 11 HC, age: 38.9 ± 9.3                                | fMRI             | Neuro feedback                                                                                                                    | Both patients and controls learned to control ACC activity, but used different neural strategies; patients activated the dorsal ACC, and controls activated the rostral ACC                                                                                                                                                                                                | ACC (dorsal and rostral subdivisions)                                                                                                                                                                                                 |
| Ciaramidaro et al. (2015) (Ciaramidaro et al., 2015)       | German             | Investigate neural evidence supporting the hypo-hyper intentionality hypothesis in SCZ and autism spectrum disorder (ASD) during a mentalizing task | <b>Participants:</b> 23 individuals with ASD, 18 with paranoid SCZ, 23 HC, age: 14–32            | fMRI             | Photographs (Picture sequencing task)                                                                                             | Both SCZ and ASD groups showed reduced brain activation during intentional vs physical information processing, SCZ showed reduced activation in left pSTS and vmPFC, with increased activation for physical information processing, and ASD showed reduced activation in right pSTS for intentional processing, opposed connectivity patterns between right pSTS and vmPFC | Left and right pSTS, vmPFC                                                                                                                                                                                                            |

(Continued)

Table 4. Continued.

| Authors (Year)                                                     | Affiliated Country | Study Purpose                                                                                                                                         | Sample Characteristics                                                              | Imaging Modality | Naturalistic Stimuli                                                                                       | Key Findings                                                                                                                                                                                                                                                             | Brain Areas Affected                                                                                                                                                                                                   |
|--------------------------------------------------------------------|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------|------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Romero et al. (2016) (Roa Romero et al., 2016)                     | German             | Investigate cross-modal prediction error (PE) processing in SCZ                                                                                       | <b>Participants:</b> 17 SCZ patients (age: 35.24 ± 7.73) and 17 HC (age: 36 ± 8.29) | EEG              | Video clips (actress uttering syllables/Pa./La./Ta./Ga./Fa/with real audiovisual onset asynchrony)         | Intact audiovisual incongruence detection in auditory cortex in both groups, SCZ shows a lack of frontal theta-band oscillations enhancement in response to high-predictive stimuli, a deficit in top-down multisensory processing in the SCZ group                      | Auditory Cortex (incongruence detection), Frontal Cortex (theta-band oscillations)                                                                                                                                     |
| Xiang et al. (2019) (Xiang et al., 2019)                           | China              | Investigate the abnormal modulation of entropy in EEG signals of SCZ patients during an auditory paired-stimulus paradigm, focusing on sensory gating | <b>Participants:</b> 61 SCZ inpatients (age: 37 ± 1.25), 55 HC (age: 41 ± 1.59)     | EEG              | Audio clip (Two auditory stimuli, S1 and S2, were presented in quick succession to measure sensory gating) | The SCZ group showed higher entropy values in the frontal and occipital regions, HC showed a significant reduction in entropy values during S1 and less variance in S2, SCZ showed a more minor decrease in entropy values during S1, suggesting impaired sensory gating | Frontal Cortex (increased entropy, related to positive symptoms), Occipital Cortex (abnormal entropy modulation, related to compensatory visual processing)                                                            |
| Patel et al. (2021) (Patel et al., 2021)                           | USA                | Examine the role of the right TPJ in social cognition impairments in SCZ                                                                              | <b>Participants:</b> 27 SCZ patients (age: 38.2 ± 8.2), 21 HC (age: 35.7 ± 9.1)     | fMRI             | Movie clip: (The Good, the Bad and the Ugly)                                                               | SCZ patients exhibited impaired social cognition with reduced TPJ-pSTS activation and connectivity, especially in TPJ middle (TPJm)                                                                                                                                      | TPJ, pSTS, TPJm                                                                                                                                                                                                        |
| Yang et al. (2020) (Yang et al., 2020)                             | China              | Develop an individualised imaging methodology combining naturalistic stimuli to improve diagnosis and early detection of SCZ                          | <b>Participants:</b> 72 first-episode drug-naïve SCZ patients, 54 HC, age: 16–40    | fMRI             | Movie clips (Cognitive, social, and emotional content)                                                     | SCZ patients exhibited less synchronised brain activity compared to HCs, with an accuracy of 71%–78% in recognising SCZ patients                                                                                                                                         | Temporal, parietal, and dorsal frontal lobes, left superior frontal gyrus, right middle frontal gyrus (BA6 and BA8), right precuneus, right supramarginal gyrus, right cerebellum (uvula), left inferior frontal gyrus |
| Fuentes-Claramonte et al. (2022) (Fuentes-Claramonte et al., 2022) | Spain              | Explore processing of linguistic deixis in individuals with SCZ, with and without auditory verbal hallucinations (AVH)                                | <b>Participants:</b> 23 AVH+ patients, 27 AVH– patients, 25 HC, age: 18–70          | fMRI             | Audio clip (Recording)                                                                                     | AVH+ and AVH– groups did not differ in deictic processing, but there was altered activity in the SCZ group compared to the HC                                                                                                                                            | Bilateral middle temporal gyri, temporal poles, inferior parietal cortex, precuneus, midline regions                                                                                                                   |

**Note:** VR - virtual reality, FC - functional connectivity, SCZ - schizophrenia, EEG - electroencephalography, fMRI - functional magnetic resonance imaging, HC - healthy control, DMN - default mode network, V5 - motion-sensitive area, pSTS - posterior superior temporal sulcus, mPFC - medial prefrontal cortex, ACC - anterior cingulate cortex, vMPFC - ventral medial prefrontal cortex, pSTS - posterior superior temporal sulcus, TPJ - temporoparietal junction, BA - Brodmann area, AVH+ - auditory verbal hallucinations positive, AVH– - auditory verbal hallucinations negative, TPJm - middle temporoparietal junction.

laboratory experiments and real-world experiences, providing profound insights into the intricacies of brain activity in mental health problems. This review also examines how diverse research approaches, such as realistic stimuli, real-time neurofeedback, and various imaging modalities, contribute to our understanding of the neurological substrate of disorders, offering hope for future advancements in mental health treatment.

#### **4.1. Overview of anxiety disorder studies**

This study focused on the complexities of anxiety disorders and their neurological origins. These findings indicate that brain areas such as the amygdala, PFC, and ACC play essential roles in accelerating the emotional reactions that define anxiety. The amygdala, which is frequently hyperactive in people with anxiety disorders, is particularly susceptible to fear-inducing stimuli. Its malfunction, particularly in terms of connectivity with the PFC, appears to affect the regulation of emotional reactions (Basar-Eroglu et al., 2007; Bas-Hoogendam et al., 2020). This may explain the hyper vigilance to perceived threats that is a hallmark of anxiety. In contrast, Šimić et al. reported that reduced connectivity between the amygdala and PFC contributes to difficulties regulating emotions and managing stress (Šimić et al., 2021). This explains the poor coping mechanisms often observed in individuals with anxiety.

Additionally, the findings suggest that anxiety disorders are closely linked to social cognition difficulties, particularly in the processing of negative social feedback. Increased activation in brain areas related to social perception, such as the mPFC, STS, and TPJ, demonstrates how individuals with anxiety tend to overreact to social cues, leading to feelings of social rejection or fear (Tei et al., 2020; Huang et al., 2021; Perino et al., 2021). This can reinforce anxiety and avoidance behaviours, perpetuating the cycle of the disorder. Furthermore, neurofeedback and other interventions are promising for correcting these neural dysfunctions (Price et al., 2014; Wang et al., 2023; Hammond, 2005; Dehghani et al., 2023).

CBT, as a therapeutic tool for modulating brain activity, particularly in regions such as the amygdala and PFC, has shown potential in reducing anxiety symptoms (Pichon et al., 2015). Many previous studies have focused on CBT as a treatment for anxiety-related disorders (Marom and Hermesh, 2003; Springer et al., 2018). Oxytocin is emerging as a promising option for reducing symptoms of SAD (Koban et al., 2023). As a 'love hormone', oxytocin has been shown to enhance

social functioning and improve emotional regulation in social contexts (Algoe et al., 2017; Carter, 2022). However, there might be a risk of individuals becoming reliant on it to manage their anxiety rather than developing more sustainable coping strategies, which could hinder the effectiveness of long-term therapy approaches. Additionally, the effects of oxytocin can vary between individuals, and more research is needed to understand its long-term impact on SAD. Anxiety disorders are deeply rooted in neural abnormalities, but both behavioural and neuropsychological interventions hold promise for managing these disorders effectively.

#### **4.2. Overview of depression disorder studies**

The incorporation of naturalistic paradigms into depression research has significantly improved our understanding and focused on identifying how specific brain regions are altered in MDD patients in response to emotional stimuli, emotion regulation, and treatment interventions. The reviewed studies provide consistent evidence that several key brain regions are involved in MDD, with the amygdala, PFC, insula, ACC, and hippocampus playing central roles.

Notably, altered amygdala activity has been observed across multiple studies, consistently showing heightened reactivity to emotional stimuli, which may reflect an exaggerated emotional response in MDD patients (Chen et al., 2014; Bürger et al., 2017). Elevated bilateral amygdala activation in adolescents was observed in response to fearful faces and was inversely correlated with depression severity (Hall et al., 2014). Prefrontal regions, especially the vlPFC, dlPFC, and mPFC, were found to have reduced activation, implicating impairments in emotion regulation and cognitive control (De la Peña-Arteaga et al., 2021; Gruskin et al., 2020). In contrast, the hippocampus is frequently observed to exhibit dysfunction, particularly in individuals with a history of SLEs (Li et al., 2016), which is consistent with previous findings (Donofry et al., 2016). These findings suggest that stress-related neurobiological changes may exacerbate depressive symptoms. The PFC, responsible for the top-down regulation of emotional reactivity, works in coordination with the amygdala to modulate emotional intensity (De la Peña-Arteaga et al., 2021; Bürger et al., 2017). Dysfunction in the PFC-amygdala circuit in MDD patients leads to difficulty in controlling negative emotions. Findings across studies are generally consistent in implicating the amygdala and PFC in MDD; some studies presented contrasting results. Similarly, Bürger et al. (2017) reported improved functional connectivity

between the ACC and amygdala in UD patients, contrasting with findings from other studies indicating reduced connectivity in MDD patients (Bürger et al., 2017). These inconsistencies may arise from differences in the participants' population or the nature of the stimuli used in the tasks. These differences underscore the complexity of depression and suggest that the neural changes associated with the disorder may vary depending on the subtype or stage of the illness. Studies by Liu et al. (2020, 2021) and Zhu et al. (2021) employed music perception tasks and identified altered patterns in the delta and beta bands among individuals with MDD (Oathes et al., 2008; Liu et al., 2020; Liu et al., 2021). This highlighted a dual pattern of hyper-connectivity in the DMN and hypoconnectivity in the FPN. This interplay between overactive introspection and reduced regulatory control sheds light on the neural underpinnings of depression.

Neurofeedback techniques have shown promise in enhancing emotional regulation and improving depressive symptoms. Studies using these techniques have demonstrated how real-time brain activity modulation could be a potential avenue for treatment (Young et al., 2017; Zotev et al., 2016). These findings align with those of previous studies (Mehler et al., 2018). Compared with standard lab-based tasks, using naturalistic stimuli, including emotional images, film scenes, and autobiographical recall, has provided a richer understanding of how MDD patients process emotional information. Elevated levels of sex hormones have also been identified as potential factors influencing depression (De la Peña-Arteaga et al., 2021). Previous studies have also noted the impact of sex hormones on depressive symptoms (Morssinkhof et al., 2020).

### 4.3. Overview of schizophrenia disorder studies

The reviewed studies highlight the intricate neural dynamics of SCZ, particularly emphasising disruptions in brain connectivity across key regions involved in cognitive control, emotional regulation, and sensory processing. A recurring finding across studies is dysfunction in areas such as the motor cortex, PFC, pSTS, ACC, TPJ, DMN, and frontal and parietal lobes. These regions are essential for motor coordination, social cognition, and emotion control; these regions are disturbed in SCZ patients. Zappa et al. (2019) and Mishra et al. (2022) reported that SCZ patients display abnormal connectivity and neuronal synchronisation, notably in the motor cortex and emotional processing area, emphasising motor linguistic coordination impairments and emotional reactivity disturbances (Cuevas et al.,

2022; Tu et al., 2019). Dietz et al. (2020) and He et al. (2021) reported how changes in pSTS connectivity impact social cognition and perception in SCZ patients (Roa Romero et al., 2016; Xiang et al., 2019). In addition, reduced neural synchronisation in the DMN was observed by Iglesias-Parro et al. (2023), which was supported by previous studies (Iglesias-Parro et al., 2023; Das et al., 2022; Das and Menon, 2023). The role of the ACC in emotion regulation, as demonstrated by Cordes et al. (2015) (Xiang et al., 2019), is in line with the findings of previous studies (Menon and Uddin, 2010; Salgado-Pineda et al., 2014). Sensory processing deficits, as noted by Xiang et al. (2019) and Fuentes-Claramonte et al. (2022), focus on the role of impaired sensory gating in the manifestation of positive symptoms, which is aligned with previous studies, suggesting a need for therapies targeting sensory integration and neural synchrony to mitigate these symptoms (Fuentes-Claramonte et al., 2022; Keil et al., 2016). Early detection of SCZ via individualised imaging methodology combined with naturalistic stimuli has proven beneficial, has shown high accuracy, and aligns with previous studies (Yang et al., 2020; Lieberman et al., 2019).

In recent years, the triple network model (the Salience network, the DMN, and FPN) has emerged as a promising framework to understand the neural mechanisms underlying various mental health conditions, including anxiety, depression, and SCZ. These networks interact to facilitate adaptive cognitive and emotional processing (Cai et al., 2021; Cai et al., 2016). Disruptions or dysregulations within these networks are thought to contribute to the pathophysiology of psychiatric disorders.

### 4.5. Research focus and future directions

This review's main goal was to examine how naturalistic paradigms reveal both disorder-specific changes (such as motor-linguistic deficits in schizophrenia and hyperconnectivity of the DMN in depression) and transdiagnostic mechanisms (like amygdala-PFC dysregulation across various disorders). Comparative naturalistic studies will be essential for understanding how these treatments alter connectivity differently across disorders, ultimately aiding in developing more personalised treatment approaches. The integration of findings from different disorders in this review illustrates how naturalistic paradigms can support transdiagnostic frameworks and tailored interventions for specific conditions. Future research should investigate how these neural markers can be targeted with interventions. For instance, neurofeedback might be particularly effective for transdiagnostic emotional dysregulation,

while CBT could better address disorder-specific cognitive distortions.

#### 4.6. Limitations

Despite significant advancements in understanding neural mechanisms, several limitations persist in current research. A key issue is the reliance on single neuroimaging techniques, either fMRI or EEG, which provide valuable insights into brain activity but are limited by relatively low temporal and spatial resolution. Additionally, many studies still use passive stimuli, which fail to capture the complexity and unpredictability of real-world interactions fully. While ecological validity is generally improved through VR-based tasks, these tasks still fall short of replicating the dynamic nature of everyday experiences. Moreover, the prevalence of cross-sectional designs limits the ability to establish causal relationships between neural activity and the progression of mental health disorders. The small sample size further restricts the generalisation of the findings. Finally, variability in individual responses to treatment remains underexplored, and more research is needed to personalise interventions based on neural profiles and consider age-related differences in disorders such as SCZ. Future studies should prioritise multimodal approaches, combine EEG and fMRI with interactive paradigms, and incorporate more diverse, longitudinal populations to improve the findings' ecological validity and impact.

#### 5. Conclusion

Naturalistic paradigms have offered vital insights into the neural basis of anxiety, depression, and SCZ disorders, particularly in understanding the roles of key brain regions such as the amygdala, PFC, and insula. These regions are crucial for emotional regulation, cognitive processing, and social interaction, which are central to these disorders. Future research should integrate multiple neuroimaging techniques, diverse participant populations, and longitudinal designs to improve personalised diagnostic tools and therapeutic strategies. Neurofeedback, CBT, and music therapy were chosen for the therapeutic intervention as these approaches have unique strengths in the study of neural mechanisms or have demonstrated therapeutic potential.

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#### ORCID

Anam Mehmood  <http://orcid.org/0000-0001-7129-5967>

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