Beyond the Baseline: Systematic Review of Task-Based Neural Oscillations in PTSD and Anxiety Disorders

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Contents

Background: Neural oscillations serve as potential biomarkers in understanding the pathophysiology of PTSD and anxiety disorders. Prior studies have focused on frequency band abnormalities during resting state; however, task-based protocols might reveal more about deviations in brain oscillations in these disorders.

Methods: This review adheres to PRISMA guidelines, with a search across PubMed, Web of Science, and Scopus databases. We extracted data on task-based EEG and MEG measurements, focusing on theta, alpha, beta, gamma, and delta oscillations. We examined the differences between adults diagnosed with PTSD or anxiety disorders and healthy controls, aiming to understand the deviations in neural oscillations and their implications for these conditions.

Results: Our findings indicate a possible pattern of alteration in theta and gamma oscillations in individuals with PTSD and anxiety disorders during cognitive tasks. Theta oscillations showed a significant elevation, which correlates with emotional and cognitive dysregulation, while gamma oscillations were primarily associated with memory processing and emotional regulation.

Conclusions: Theta and gamma oscillations exhibit possible distinctive patterns that could inform future diagnostic and therapeutic strategies. There is a need for further research to standardize tasks used for enabling finding an effect.

Keywords: PTSD, anxiety disorders, EEG, MEG, ASReview, brain oscillations

Layman's Summary: Understanding Brain Waves in PTSD and Anxiety Disorders

What is this review about?

This review looks at the differences in brain waves between people who have PTSD (Post-Traumatic Stress Disorder) or anxiety disorders and those who don't. We specifically searched for studies that studied brain waves while people were doing specific tasks, using tools called EEG (Electroencephalogram) and MEG (Magnetoencephalogram) that record brain activity.

Why is this important?

Understanding the brain waves in people with PTSD and anxiety can help us find better ways to diagnose and treat these disorders. Since these disorders can make daily life very challenging, learning more about them can improve how we help people affected.

What did we do?

We looked at research where brain waves were recorded from adults with PTSD or anxiety disorders while they did tasks like remembering things or reacting to images. We compared their brain waves to those of people without these disorders.

What did we find?

We found that people with PTSD and anxiety disorders have potentially different patterns in their brain waves compared to healthy people, especially in theta and gamma waves. This might explain some of the difficulties they experience with fear and memory. Higher activity in gamma waves might also explain why they react differently to stimuli.

What do these findings mean?

These differences in brain waves might one day help doctors identify PTSD and anxiety disorders more quickly and accurately. They might also guide the development of new treatments targeting these brain wave changes.

What are the limits of our findings?

Our results are based on a few studies, and the tasks used vary from one study to another, making it hard to draw robust conclusions. More research using similar tasks across different studies would help confirm our findings.

Beyond the Baseline: Systematic Review of Task-Based Neural Oscillations in PTSD and Anxiety Disorders

As of 2024, global stability is severely undermined by wars in Ukraine (Gulnaz et al., 2023), Sudan (Tutlam et al., 2022), and Palestine (Abudayya et al., 2023). PTSD manifests through persistent symptoms such as intrusive thoughts, heightened alertness, avoidance behaviors, and negative changes in cognition and mood following exposure to traumatic events (American Psychiatric Association, 2013). Present estimates suggest that PTSD affects approximately 3.9% of the general population (Koenen et al., 2017), varies between 3.4% and 26.9% among military personnel (Schein et al., 2021), and reaches around 31% among refugees (Blackmore et al., 2020). The pervasive impact of PTSD on daily functioning (e.g., productivity loss, medically related problems) underscores the critical need for early detection and targeted treatment interventions (Jellestad et al., 2021; Pietrzak et al., 2012; Brunello et al., 2001).

In recent years, there has been a lot of effort to identify important factors for the early detection of PTSD. On a genetic level, a new multi-ancestry meta-analysis of genome-wide association studies (GWAS) identified 80 new significant loci possibly relevant for targeted treatments (Nievergelt et al., 2024). Multiple neuroimaging studies identified possible sub-types in PTSD for targeted therapy, but the found sub-types could not be replicated on the new data (Hinojosa et al., 2024). While genome-wide association and neuroimaging studies provide insights into genetic and neural underpinnings of PTSD, EEG studies offer direct measurement of neural dynamics. They could complement the existing knowledge about possible biomarkers. For instance, in EEG studies, fear networks in the brain were identified as one of the main targets for treatment due to growing evidence that PTSD could be seen as a disorder where normal fear processes are disturbed (Ressler et al., 2022).

PTSD originates from an event that is intensely distressing and fear-inducing. Thus, it may be partially perceived as a disorder of anxiety mismanagement (Ressler et al., 2022). Anxiety is a state of emotion that involves an extended period of enhanced alertness due to the potential and expected threats that lie ahead (Grupe and Nitschke, 2013). It is common for anxiety disorders to occur alongside PTSD (Blackmore et al., 2020; Desmedt et al., 2015), often as a result of traumatic experiences (Koenen et al., 2017). Although PTSD is now identified as a trauma-related disorder (American Psychiatric Association, 2013) and

increasingly considered a memory disorder (Jongedijk, 2021), it retains overlapping diagnostic and treatment aspects with anxiety disorders. Presently, the leading treatment options for PTSD, such as Narrative Exposure Therapy, Cognitive Behavior Therapy (CBT) with prolonged exposure (PE), Eye Movement Desensitization and Reprocessing (EMDR), and Brief Eclectic Psychotherapy (Gersons and Schnyder, 2013), rely on exposure-based strategies (Jongedijk, 2021). These therapeutic approaches are thought to be effective by modifying the neural circuits associated with fear (Ressler et al., 2022). However, current data indicates that as many as half of those treated for PTSD do not adequately benefit from these therapies (Barawi et al., 2020). Consequently, the search for biomarkers for PTSD and associated anxiety disorders is gaining momentum (Al Jowf et al., 2023), with previous systematic reviews indicating that distinctive patterns of neural oscillations may serve as potential biomarkers and treatment targets (Çalışkan and Stork, 2019; Meyer et al., 2015).

Central to understanding PTSD and anxiety disorders is the role of the hippocampus in forming memories and integrating sensory details. The hippocampus manages our innate reactions to anxiety as well as disorders characterized by generalized fear memory, such as PTSD. It is part of a network that includes the amygdala and medial prefrontal cortex, which influence how we process and retain anxious experiences. The hippocampus is also the genesis site for theta and gamma oscillations. Theta oscillations coordinate communication between the amygdala and hippocampus during fear conditioning and mediate the assessment of threats (Çalışkan and Stork, 2019; Trenado et al., 2018). Conversely, gamma oscillations are involved in the cognitive processing of fear, enhancing neural synchrony, which is crucial for managing PTSD and anxiety (Çalışkan and Stork, 2019; Trenado et al., 2018). Theta oscillations aid in the encoding and retrieval of traumatic memories, while gamma oscillations support cognitive functions that can be disrupted in these disorders (Çalışkan and Stork, 2019; Trenado et al., 2018). This ongoing cycle of fear memories makes it more difficult for individuals to move past their traumas, potentially explaining why some people may not respond adequately to treatments that aim to ease these memories (Çalışkan and Stork, 2019).

A systematic review (Lobo et al., 2015) underscores a connection between the severity of PTSD, conceptualized from a dimensional perspective, and alterations in alpha rhythm. Higher PTSD severity levels were associated with increased right-frontal activity, as indexed

by alpha power (Lobo et al., 2015). Compared to healthy individuals, those with PTSD exhibit decreased alpha power in both the posterior default mode network hub (posterior cingulate cortex) and the anterior default mode network hub (medial prefrontal cortex), which suggests alpha deficits in the default mode network (Nicholson et al., 2023; Clancy et al., 2020). Additionally, alpha deficits are potentially present in the visual cortex in PTSD. Alpha power deficits in the DMN and visual cortex correlate with symptom severity of hypervigilance in PTSD (Clancy et al., 2020). Frontal EEG alpha asymmetry, with increased rightward alpha activity indicating heightened withdrawal-related motivation/emotion, is associated with the core symptoms of PTSD and traumatic reactions (Butt et al., 2019).

These days, PTSD diagnosis is based on behavioral observations, self-reports, and interviews conducted by skilled clinicians. Thus, it is a highly subjective process (Rosen and Lilienfeld, 2008). To date, no definitive objective measure for PTSD has been established (Ressler et al., 2022). The recent systematic review indicated that abnormal oscillations could potentially be normalized by brain stimulation, and it could be used as a targeted treatment. Therefore, it is essential to have a deep understanding of deviations in oscillation in PTSD and anxiety disorders, which is lacking at this moment (Trenado et al., 2018). Recent literature reviews (Table 1) include studies with either only resting-state measurements or a mix of resting-state and task-based protocol measurements, which could be seen as not the best way to find abnormalities in neural oscillations (Meyer et al., 2015). It was found that state-dependent asymmetry in alpha during trauma-related tasks provided a more apparent distinction between PTSD patients and healthy controls compared to resting state frontal alpha asymmetry (Meyer et al., 2015). Additionally, there is a need to study EEG profiles in PTSD during cognitive tasks (Bryant et al., 2021). Therefore, this review is the first systematic review to our knowledge that is focused solely on task-based protocols during the examination of neural oscillations across various frequency bands in PTSD and anxiety disorders. By concentrating on task-based protocols, this review seeks to identify potential EEG/MEG-based biomarkers and target treatments that can offer an objective and quantifiable approach to diagnosing and treating PTSD and anxiety disorders.

None of the recent reviews (Table 1) reported data availability, and therefore, it seems to be hard to replicate their results. However, this systematic review is conducted using the active learning software 'ASReview,' enabling 100% reproducibility due to the complete

availability of raw data and detailed documentation of steps taken by both reviewers during the search, selection, and data extraction phases. Full reproducibility is essential because only 1 in 100 systematic reviews could be replicated due to a lack of the reported steps and the absence of raw data (Rethlefsen et al., 2024). Additionally, this systematic review did not have a limitation by using a language filter in search compared to recent reviews (Table 1) due to the knowledge of more than ten languages reviewers. Therefore, articles in different languages were assessed that typically are excluded from the search.

This systematic review aims to explore how neural oscillations across various frequency bands differ in adults diagnosed with PTSD or anxiety disorders compared to healthy controls during task-based protocols in awake-state EEG or MEG studies. We hypothesize that significant differences, primarily in the theta frequency band, will be observed due to its role in memory and fear mechanisms.

Methods

This systematic review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) and the SAFE Procedure (Boetje and van de Schoot, 2024), and was registered prospectively on the Open Science Framework (https://osf.io/nkqsm/files/osfstorage). Deviations from pre-registration can be found (Table 3).

Seach strategy

Four preliminary literature searches were conducted to develop a search script that accurately represents neural oscillations in the context of PTSD and anxiety disorders. The first three searches yielded either too many or too few results. The fourth search produced adequate results, and the search script was approved by all three researchers. These preliminary searches, conducted by Reviewer 1 (SK) from February 12 to March 4, are detailed in the supplementary materials (S01, https://osf.io/gzvje) and preliminary search scripts (S1.1, https://osf.io/jg4ew). Following these, the full literature search was conducted on March 6-7 in three databases: PubMed, Scopus, and Web of Science. The search terms included combinations of 'PTSD,' 'posttraumatic stress disorder,' 'trauma,' 'anxiety,' 'brain oscillation,' 'neural oscillation,' 'EEG,' and 'MEG,'memory task', ' cognitive task' along with relevant variations and Boolean operators, and were performed without filters for date or language. The protocol for the final search (S1.2, https://osf.io/h4j6n) and the full search

script (S1.3, https://osf.io/jqced) are available in the supplementary materials. All results of the final search were saved in the reference manager 'Mendeley' and downloaded as a single .ris file.

Inclusion and exclusion criteria

Inclusion criteria were a peer-reviewed article, use of EEG or MEG methods in awake state during a task-based protocol and report outcomes related to brain oscillations. Additionally, only studies focused on adults (aged 18 years and older) with an official diagnosis of either PTSD or any anxiety disorder were included. Furthermore, only studies containing a comparison control group of healthy adults were include.

Exclusion criteria were a non-empirical article (e.g. case reports, literature reviews, and systematic reviews) and a peer-reviewed article with report only on EEG or MEG during resting states and/or sleep. Additionally, studies examining only event-related potentials (ERPs) without reporting on frequency band power, time-frequency domains, connectivity within frequency bands, cross-frequency coupling, or high-frequency values were also excluded.

Study selection using ASReview and applying SAFE procedure

Study selection was conducted independently by two reviewers (SK, KH) using the active-learning open-source application 'ASReview' (van de Schoot et al., 2021), which aims to enhance the efficiency and transparency of the article screening process (van de Schoot et al., 2021). Reviewer 1 uploaded the search results, stored in a .ris file, to ASReview. A data project file was then created and shared with Reviewer 2, ensuring that both reviewers operated under identical settings and had the same starting point.

Additionally, the guidelines of the 'Stopping Algorithm for Efficiency' (SAFE) were followed (Boetje and van de Schoot, 2024). The SAFE procedure comprises four phases: training data screening, application of active learning, switching to an alternative model, and an evaluation check of excluded articles (e.g., an article could been excluded due to screening fatigue). In the first phase, the 'Term Frequency-Inverse Document Frequency' (TF-IDF) model, in combination with the 'Naive Bayes Classifier' (NB), was selected for screening in ASReview. TF-IDF calculate how often a term is mentioned in the title and abstract, and divides this number by the number of titles and abstracts that does not contain this term while NB classifier helps to determine which title and abstract will be more likely relevant for the reviewer based on the choices she or he made (e.g. each article could be labeled as 'relevant'

or 'irrelevant'). Reviewer 1screened a random subset of the dataset, representing 1% of all records, and the fraction of relevant records was calculated to establish a baseline relevance within the dataset. A dataset with an established baseline relevance was sent to reviewer 2 so that both reviewers had the same dataset, and start to screen it independently. During phase 2, both reviewers were instructed to stop screening abstracts and titles in ASReview once two conditions were met: at least 148 articles had been screened, and 50 consecutive articles were labeled as irrelevant. At the end of phase 2, the articles in the dataset were partially labeled as 'relevant' or 'irrelevant'. After phase 2, there was a meeting between reviewers to discuss the screening process. It was decided to adjust inclusion and exclusion criteria, and therefore partially re-label articles. For more details about deviations in the protocol see Table 3.

In phase 3, a partially labeled dataset served as prior knowledge for a deep learning model 'Bidirectional Encoder Representations from Transformers ' (Sentence BERT) with a 'Random Forest Classifier' (RF). Sentence BERT is a more advanced model than TF-IDF, and is able to understand the context of sentences. RF builds multiple decisions trees and based on them helps to predict what title and abstract would be relevant for the reviewer. Screening in this phase was halted once 50 consecutive articles were marked as irrelevant by both reviewers.

In phase 4, an evaluation check of the excluded records was conducted by Reviewer 1. The dataset labeled in phase 3 was downloaded, and in Excel, all unseen records and those labeled as 'relevant' were deleted, leaving only the 'irrelevant' articles. Reviewer 1 removed all previous labels for articles labeled as 'irrelevant,' manually labeled 10 obviously irrelevant articles (for example, articles with Parkinson patients) as such, and uploaded this Excel file to ASReview. The model then used these 10 labeled articles as prior knowledge. Reviewer 1 re-screened the previously labeled 'irrelevant' articles, continuing until another 50 articles were labeled as 'irrelevant' consecutively. A list of all full-reading articles was created; Reviewer 1 read all articles, while Reviewer 2 read 10% of them. After phase 4, a consensus meeting was held to discuss any differences in labeling between the two reviewers based on inter-rater reliability (Figure1; Figure2) to select articles for this review. A third reviewer (FS) was consulted when consensus could not be reached. Additionally, all selected studies were cross-checked in the Retraction Watch Database to verify if they had been retracted.

Data extraction Reviewer 1 performed the data extraction for the selected articles. The main outcomes extracted were data about brain oscillations measured during a task:

changes in power, coherence, time windows, and spectral density of the oscillations in all reported frequency bands. Additionally, description and aims of the performed tasked were extracted. Consequently, behavioral outcomes were extracted (e.g. reaction time, association between symptom severity and brain oscillations). Furthermore, the extracted data included descriptive information about the sample, such as official diagnosis, age, country, sample size per group and number of female per group.

Risk of bias

All included studies were observational compared studies, therefore 'Newcastle-Ottawa Scale (NOS)' (Wells et al., 2011) was used for the assessment of risk of bias (Table 2). This tool is specifically developed for quality assessment of non-randomized studies in three main areas: the selection of study groups, the comparability of groups, and the ascertainment of exposure or outcome. The risk of bias assessment was done by reviewer 1 (SK).The evaluation of each study was based on points system. The maximum amount of points that one study could get is 9. Scores were classified as follows: 8-9 as low risk, 7 as low-moderate risk, and 6 or below as moderate risk. The studies with low risk of bias were considered as more reliable in the data synthesis phase.

Generative AI usage disclosure

For this systematic review, SK developed three custom GPTs within the infrastructure of ChatGPT-4: one for editing English text, another for explaining EEG terms using techniques already familiar to SK (e.g., fMRI, ESM, etc.), and a third for providing feedback based on the Cochrane manual for systematic reviews of written text. All prompts and responses from ChatGPT can be found in the supplementary materials (S4, https://osf.io/8pw9z).

Results

Study selection using ASReview and applying SAFE procedure

The literature search identified 1,827 records. After the removal of duplicates, 1,476 articles remained for screening. Following phases 2 and 3 of the SAFE procedure, the reviewers agreed to include 40 articles for the full-read stage. Details on the disagreements between the two reviewers and information on inter-rater reliability can be found on OSF. A subsequent evaluation check was performed to account for potential fatigue effects in the screening process, adding four more articles to the full-read list. After a comprehensive review,

where reviewer 1 read all 44 articles and reviewer 2 read 10% of them, 15 were ultimately selected for inclusion in this systematic review. A list of all articles excluded and the reasons for their exclusion can be found in the supplementary materials (S2, https://osf.io/s4gvt). The flowchart of the study selection process is presented in (Fig. 3). Additionally, all the included studies were cross-checked in the Retraction Watch Database, and no matches were found.

The 15 included studies included 771 participants. The average sample size per study was 25 (SD = 7.6). The weighted average age of all participants was 32.9 (SD = 7.6), with 53 % male and 47% female. Notably, several studies included only one gender: only female participants (Mennella et al., 2017) and only male participants (Khanna et al., 2017; T. J. McDermott et al., 2016; Popescu et al., 2023). None of the studies reported on transgender or non-binary participants. One-half of the included studies were with patients with PTSD (k=8) (Table 5), and the other half of the included studies were with patients with anxiety disorders (k=7) (Table 6). The complete overview of the descriptive characteristics of the included studies can be found in the table 4.

Results of the risk of bias assessment

After the assessment of the risk of bias with NOS, several studies (k=7) were labeled as having a 'low' risk of bias (Gan and Li, 2023; Shim et al., 2022; Reuveni et al., 2022; Waldhauser et al., 2018; Mennella et al., 2017; Gerez et al., 2016; de Carvalho et al., 2015). Only one study had a 'moderate' level risk of bias (Khanna et al., 2017), mostly scoring low in providing detailed information about the control group (in the following domains of NOS: 'Representiveness of the cases', 'Selection of Controls').

Several studies (Popescu et al., 2023; De La Rosa et al., 2020; Cavanagh et al., 2017; Cohen et al., 2013; Gordeev, 2008) were labeled as having a 'high risk of bias' in the domain of 'case definition.' This indicates that the description of the clinical group and the procedure for identifying an official diagnosis were described vaguely, and concrete details (e.g., structural interviews conducted by psychologists) were omitted. For example, in the study by De La Rosa et al. (2020), only 'phone screening' without any further details was mentioned. Furthermore, the included studies varied mainly in the 'Comparability.' Studies that received two '**' indicating a very low risk of bias in this domain extensively reported on controlling for confounding variables (e.g., depression, time after a traumatic event, amount of the same traumatic events, gender, etc.). For instance, in the study of Waldhauser et al. (2018), clinical

and control groups were formed with a control for the self-reported same amount and types of experienced traumatic events. The total bias assessment can be found in Table 2.

Gamma Band Oscillations in PTSD and Anxiety Disorders

In the domain of gamma-band oscillations across task-based protocols, multiple studies (k=4) reveal nuanced differences between patients with PTSD (Waldhauser et al., 2018; Reuveni et al., 2022; Popescu et al., 2023) or anxiety disorders (Di Giorgio Silva et al., 2017) and healthy controls. Elevated gamma power was observed in PTSD during tasks involving memory suppression and trauma imagery, while findings in anxiety disorders noted a heightened gamma coherence during an attention-driven task.

Waldhauser et al. (2018) conducted a study using a think/no-think task (S3, https://osf.io/6gmha) in which 11 refugees diagnosed with PTSD and 13 without PTSD were analyzed. This task involves three phases: initial training to memorize image pairs, a task phase where participants inside a MEG are cued with an image of a door either to recall (think) or suppress (not think) the memory of an associated pair for 1250 ms, and a final recognition test assessing memory for suppressed and recalled items. The study found distinct differences in brain activity in the gamma frequency band (70-120 Hz) during the suppression attempts. In the no-think phase, intended for memory suppression, the PTSD group exhibited high gamma activity during two specific post-stimulus time windows: 700-1200 ms and 1350-1750 ms. In contrast, the control group showed a decrease in alpha activity. Behaviorally, the PTSD group did not show a significant reduction in memory recall for No-Think items in comparison to the control group.

Reuveni et al. (2022) explored gamma oscillations using a task during MEG measurement that included listening to trauma-related and neutral narratives followed by a phase of mental imagery (S3, https://osf.io/6gmha). Patients with PTSD (n=12) and trauma-exposed control group (n=14) first listened to a 30-second narrative script, either of a personalized traumatic event or a standard neutral scenario, then engaged in a 30-second imagery phase, visualizing the script with sensory details, and ended with a 30-second rest period. During both the narrative listening and the imagery phases, an elevation in high-gamma power (80-150 Hz) was observed in the PTSD group relative to the baseline neutral condition, as well as in comparison to the trauma-exposed control group. Source localization analyses of MEG data suggest this increase is particularly pronounced in the

cuneus region. Unlike the PTSD group, the control participants did not show a similar significant variance in high-gamma power when exposed to trauma versus neutral scripts, indicating a stable response across both conditions. In the gamma band (30-80 Hz), a similar trend of differential responses was noted, with the PTSD group exhibiting greater gamma power in the left inferior and middle occipital gyri in response to traumatic scripts as opposed to neutral ones—a contrast not detected within the control group.

Popescu et al. (2023) analyzed gamma oscillations during a cued rule-switching task (S3, https://osf.io/6gmha), where 29 service members with PTSD and 30 without PTSD responded to geometric figures on a screen based on cues (the word 'color' or 'shape') that instructed them to match figures while being in the MEG-chamber. The study reported only a general trend of decrease in gamma power after the cue onset compared to the pre-cue phase of the task, without comparison between groups. This attenuation persisted through the late cue-test stimulus interval and the interval following the test stimuli. However, the occipital regions were an exception based on the source localization analysis of MEG data, displaying significant bilateral increases in gamma power that began from 150 ms to 1050 ms post-cue onset.

Lastly, Silva et al. (2017) investigated gamma coherence in Panic Disorder (PD) patients (n=9) and a control group (n=10) who underwent once an anxiety-inducing computer stimulation (a first-person perspective animation of a bus journey) and then participated in a visual oddball paradigm (S3.1, https://osf.io/f576t). The task was completed during measurement with EEG, and participants were required to distinguish between frequently and infrequently presented stimuli (circles and squares). The task aims to measure attention and response to unexpected stimuli. Participants underwent a single session involving a sequence of a 3-minute rest, an oddball task, another 3-minute rest, 4 minutes of computer simulation, 3 minutes of rest, a second oddball task, and a final 3-minute rest. The study found significant variations in gamma coherence between frontal and parietal EEG channels during the task. Specifically, the study observed a statistically significant main effect for time on the gamma coherence between the F3 and P3 electrodes, with post-hoc analysis revealing higher gamma coherence in the later stages of the task (0.5s post-stimulus visual oddball 2) compared to earlier stages (0.5s pre-stimulus visual oddball 1, and 0.5s post-stimulus visual oddball 1). Behavioral data from the study supported these physiological findings, showing that PD

patients responded faster on average than healthy controls during the task.

Beta Band Oscillations in PTSD and Anxiety Disorders

Within the domain of beta band oscillations, seven studies have documented how these oscillations differ between individuals with PTSD and those with anxiety disorders during various task-based protocols. Among the PTSD-focused research (Shim et al., 2022; Reuveni et al., 2022; Popescu et al., 2023; Cohen et al., 2013), altered beta activity was noted during tasks such as auditory processing, trauma imagery, and cognitive switching. For anxiety disorders (de Carvalho et al., 2015; Gordeev, 2008, Gerez et al., 2016), studies highlighted changes in beta power during simulations of anxiety-inducing situations and an attention-driven task.

Shim et al. (2022) explored beta oscillations in an EEG study with a PTSD group (n=53) and a control group (n=39) during an auditory oddball paradigm (S3, https://osf.io/6gmha). This task involved participants responding to tone stimuli designed to test attention and auditory processing. No significant differences were found in the connectivity strength, clustering coefficient, or path length within low (12-22 Hz) and high beta (22-30 Hz) frequency bands between PTSD and the control group.

Furthermore, Reuveni et al. (2022) performed a MEG study with a PTSD group (n=12) and a trauma-exposed control group (n=14) involving tasks with personalized trauma or standard neutral scripts followed by an imagery phase (S3, https://osf.io/6gmha). It was observed that PTSD patients demonstrated altered beta power during various script exposures compared to the control group. Expressly, lower beta power was noted during exposure to neutral scripts and heightened power during trauma-related imagery. Localization source analysis of the MEG data revealed that altered beta power was detected in the following brain regions: the right and left parahippocampal gyri and the right insula.

Additionally, Popescu et al. (2023) found that during a cued rule-switching task (S3, https://osf.io/6gmha), where participants viewed two geometric shapes on a screen and determined if they matched based on color or shape, there was a generalized decrease in beta power across the cortex during task switches in PTSD participants compared to the control group. The matching rule could change between trials, requiring participants to switch their judgment criteria from color to shape or vice versa. Notably, when the task was repeated without switching rules, individuals with PTSD showed an atypical pattern: they had less

reduction in beta power in specific brain regions, namely the left posterior temporal lobe and frontal lobes. This was determined using source localization analysis of the MEG data.

In a study of emotional processing, Cohen et al. (2013) studied a PTSD group (n=14) and a control group (14) exposed to emotion-provoking images (S3, https://osf.io/6gmha). These images were categorized into three emotional valences—positive, negative, and neutral. The study found that the PTSD group exhibited a continuous elevation of beta activity across all emotional contexts, which was not modulated by frontal theta activity compared to a control group, where beta activity was modulated by frontal theta activity. Furthermore, source localization of EEG data revealed that the PTSD group exhibited widespread beta activation extending to the prefrontal cortex.

Turning to studies on anxiety disorders, De Carvalho et al. (2015) observed patients with Panic Disorder and Agoraphobia (PDA) (n=24) and healthy controls (n=21) during an anxiety-inducing computer simulation task (S3.1, https://osf.io/f576t). Participants watched an animation simulating a bus journey from a first-person perspective, simulating high and low anxiety situations while being measured with EEG. The study found a higher absolute beta-power in PDA patients across several frontal electrode locations (F7, F8, Fp1, Fp2) relative to the healthy controls under the same conditions. Behaviorally, De Carvalho et al. (2015) reported that high PTSD symptom severity was associated with increased reaction times.

Similarly to De Carvalho et al. (2015), Gordeev (2008) compared beta oscillations in PDA patients (n=51) and healthy controls (n=28) measured with EEG but during an oddball paradigm (S3.1, https://osf.io/f576t). The task involved random auditory stimuli where rare (target) tone clicks at 2000 Hz and frequent (non-target) tone clicks at 1000 Hz were used. An elevated beta spectral power density was found in patients with PDA compared to healthy controls, especially in the frontal and parietal regions.

Lastly, Gerez et al. (2016) analyzed beta power in a General Anxiety Disorder (GAD) group (n=53) and a control group (n=30) during an oddball paradigm (S3.1, https://osf.io/f576t) measured with EEG, reporting an increase in beta power in GAD patients relative to a control group.

Alpha Band Oscillations in PTSD and Anxiety Disorders

Within the domain of alpha-band oscillations, six studies have documented how these

oscillations differ between individuals diagnosed with PTSD (Shim et al., 2022; Reuveni et al., 2022; Popescu et al., 2023; T. J. McDermott et al., 2016) and those with anxiety disorders (Mennella et al., 2017; Gordeev, 2008) during various task-based protocols.

Shim et al. (2022) conducted an EEG study with a PTSD group (n=53) and a control group (n=39) during an auditory oddball paradigm (S3, https://osf.io/6gmha). In this paradigm, participants respond to randomly ordered pure tone stimuli, consisting of 15% target tones (1,500 Hz) and 85% standard tones (1,000 Hz), each lasting 100 ms with 10 ms rise and fall times. Upon hearing the target tones, participants pressed a response button to assess their attention to these auditory stimuli. A trend toward decreased overall connectivity strength was noted within the alpha frequency band for PTSD patients compared to healthy controls. Additionally, the clustering coefficient within the alpha band indicated a non-significant reduction.

Subsequently, Reuveni et al. (2022) observed in a MEG study a contrast in alpha responses to traumatic (narrative and imagery) versus neutral conditions (S3, https://osf.io/6gmha). PTSD patients showed higher alpha power during traumatic conditions (narrative and imagery), which diverged from the pattern in the control group, which exhibited lower alpha power under similar conditions.

Further expanding on task-specific brain responses in PTSD, Popescu et al. (2023) observed during a cued-rule switching task (S3, https://osf.io/6gmha) notable differences in the suppression of alpha-band activities in a PTSD group during repeat trials compared to switch trials. This decrease in alpha power, relative to the baseline, was recorded immediately after the cue (the word ‘color’ or ‘shape’) onset from 0 to 150 ms, which continued through the late cue-test stimulus interval between 300 to 600 ms, and extended following the onset of the test stimuli from 750 to 1050 ms. A source localization analysis of MEG data revealed these differences in the left hemisphere’s frontal, temporal, and parietal regions and the bilateral anterior cingulate. No significant differences in baseline power were detected between the conditions for the alpha frequency band.

Moreover, Dermott et al. (2016) focused on a working memory task (S3, https://osf.io/6gmha) involving veterans with PTSD (n=27) and a control group (n=24) using MEG. The task involved observing a crosshair and a grid display of six letters for two seconds. After disappearing, the grid stayed visible for three seconds without letters. Then, a

single probe letter appeared for 900 milliseconds, requiring participants to respond if it matched one of the initial letters. The study found that veterans with PTSD exhibited a significant alpha desynchronization in the right inferior frontal gyrus when compared with controls. This desynchronization occurred in the encoding phase's initial 200-600 ms. Although this effect diminished slightly in the subsequent 600-1000 ms window, it re-emerged and remained consistent in the 1000-1400 ms period, extending to the right supramarginal gyrus and superior and middle temporal gyri. This pattern of alpha desynchronization, indicative of heightened neural processing, was sustained through the latter half of the encoding phase into the transition to maintenance (1000-2200 ms). During the maintenance phase, specifically from 2200-2600 ms, the differences between groups continued, particularly in the right IFG and supramarginal regions. Furthermore, these differences were maintained late into the maintenance phase, with disparities becoming evident in the additional areas such as the right occipitotemporal notch, inferior and ventral temporal regions, and the right cerebellar cortices in the 4200-5000 ms time window. A significant relationship was identified between PTSD symptom severity and neural activity. As PTSD symptoms increased, there was greater alpha desynchronization in the right supramarginal gyrus and weaker alpha synchronization in the parieto-occipital cortices during the maintenance phase.

Additionally, Menella et al. (2017) examined alpha power with EEG during an emotional go/no-go task (S3.1, https://osf.io/f576t) in individuals with blood phobia (BP) (n=20) and a control group (n=20). An emotional go/no go task assesses how individuals respond to different emotional stimuli. Participants were shown images, which included various categories such as threats, mutilations, neutral scenes, and pleasant visuals. Each image was displayed with a pink or blue frame and appeared in both 'go' and 'no-go' trials. Increased alpha power was discovered during no-go mutilation trials in individuals with blood phobia; it was not observed in the control group.

Lastly, Gordeev (2008) analyzed alpha oscillations in patients with PDA using an auditory oddball paradigm (S3.1, https://osf.io/f576t). The study observed lower spectral power density in the PDA group, especially at the F8 electrode location, indicating reduced cortical activation in response to auditory stimuli.

Theta Band Oscillations in PTSD and Anxiety Disorders

Several studies (k=10) measured theta band oscillations, namely six studies done with

individuals diagnosed with PTSD (Shim et al., 2022; Reuveni et al., 2022; Popescu et al., 2023; De La Rosa et al., 2020; Cohen et al., 2013; Khanna et al., 2017) and two studies with individuals diagnosed with PD(A) (Mennella et al., 2017; Gordeev, 2008). Other studies focused on SAD (Gan and Li, 2023) and GAD (Cavanagh et al., 2017).

Shim et al. (2022) involved participants diagnosed with PTSD and healthy controls undergoing an auditory oddball paradigm (S3, https://osf.io/6gmha). PTSD patients exhibited significantly reduced cortical spectral powers in the theta frequency band, particularly around the 300 ms time frame across all four major brain lobes (frontal, parietal, temporal, and occipital) compared to the group without PTSD. At the global level network, PTSD patients showed reduced strength and clustering coefficient but increased path length in the theta frequency band compared to a control group. Significant differences were found at the nodal level in the theta band. PTSD patients demonstrated notably reduced nodal strengths and clustering coefficients, primarily in the parietal-temporal-occipital regions, compared to the control group based on EEG source localization analysis. Additionally, significant negative correlations were found between the nodal clustering coefficients in the theta band and psychiatric symptom scores such as 'Impact of Event Scale-Revised' (This is an instrument used to assess the subjective distress caused by traumatic events), 'Beck Depression Inventory' (This is an instrument for measuring the severity of depression) and 'Beck Anxiety Inventory' (This is an instrument that assesses the severity of anxiety symptoms).

Further emphasizing task-specific responses in PTSD, Reuveni et al. (2022) observed an increased theta power in the PTSD group during exposure to personalized trauma scripts compared to neutral ones, particularly in superior and medial frontal regions during a MEG study. This contrasted with control participants, who exhibited lower power under similar conditions. Conversely, Popescu et al (2023) reported a significant a significant increase in theta power across all brain regions immediately after cue (the word 'color' or 'shape') onset in the PTSD group compared to the control group.

De la Rosa et al. (2020) focused on the implicit visual threat semantic memory recognition task (S3, https://osf.io/6gmha) and measured with EEG. The task involved identifying whether an image (n=256) was real or scrambled. Images were categorized as threatening or non-threatening. PTSD veterans (n=29) exhibited a significant reduction in

peak theta power at electrode FPZ when presented with combat-related threatening imagery, compared to combat-exposed veterans without PTSD (n=13). Conversely, there was no significant difference in theta power responses to non-combat-related threatening items (weapons). Additionally, slower reaction times were reported for threatening stimuli in veterans with PTSD compared to those without, with significant reductions in theta power for threatening combat scenes. This reduction correlated negatively with hyperarousal symptoms.

Cohen et al. (2013) found that PTSD patients showed significant increases in event-related synchronization for negative emotional stimuli compared to healthy controls, localized by source localization analysis of EEG data to prefrontal and anterior cingulate cortices.

Khanna et al. (2017) conducted a study with an emotional Stroop task (S3, https://osf.io/6gmha) in an MEG study with veterans with PTSD (n=26) and without PTSD (n=16). During the task, participants were presented with words that varied in emotional content—combat-related, general threat, and neutral—while their brain activity was monitored. The task aimed to explore how emotional interference affects cognitive processes by requiring participants to name the color of the words, thereby diverting attention from their meaning. During the processing of combat-related words, veterans with PTSD showed significantly weaker theta-frequency responses compared to the control group. Based on source localization analysis, weak theta-frequency responses were localized in the right ventral prefrontal cortex and superior temporal cortices during specific time windows of 0.4–0.6 s and 0.6–0.8 s. During the processing of general threat words compared to neutral words, veterans with PTSD showed an increased theta activity compared to the control group. An increase in theta activity was localized in the left hippocampus and amygdala during the time window of 0.6–0.8 s. Veterans with PTSD demonstrated longer color-naming latencies for combat-related words compared to neutral and general threat words. Veterans without PTSD did not show significant differences in response times across word types.

In a study by Menella et al. (2017), 20 participants were diagnosed with BP, and 20 healthy controls participated in an 'emotional go/no-go task' while being measured with EEG. A more excellent theta synchronization was reported for no-go compared to go trials, with a significant main effect. Theta synchronization was also more pronounced at central midline sites compared to frontal. Furthermore, the group modulated a significant category effect,

with the control group showing more theta synchronization for threatening compared to neutral stimuli. In comparison, the blood phobia group exhibited significantly greater theta synchronization for mutilation compared to neutral and pleasant stimuli and marginally significantly compared to threatening stimuli. The analysis of reaction times showed that individuals with blood phobia responded slower to go trials compared to the control group, with a more significant effect for mutilation pictures compared to all other content categories. In no-go trials, accuracy was lower for mutilation pictures than for all other picture contents.

In the study by Gordeev (2008), 51 patients diagnosed with PDA were compared to 28 healthy controls who participated in an 'oddball paradigm' while being measured with EEG. Theta power densities in F8, T4, and T6 electrode locations were significantly higher in patients with PDA than healthy controls.

In the study of Gan et al. (2023), 26 individuals diagnosed with SAD and 24 healthy controls assessed the emotional content of the following stimuli: unimodal faces, voices, and their bimodal combinations. They were measured with EEG. In the SAD group, there was a decreased power in frontal theta ERS in response to bimodal stimuli compared to voices alone during specific time windows of 120–280 ms in angry trials and 120–260 ms in neutral trials at 6 Hz. This decrease was also observed in the HC group but in slightly different time windows, namely in a cluster during 160–280 ms in angry trials and a cluster during 100–340 ms in neutral trials at 6 Hz. The study also reported increased power in occipital theta oscillations in response to bimodal stimuli compared to faces alone. This increase was observed in angry and neutral trials within defined time windows at 4–6 Hz for both the SAD and HC groups. Furthermore, there was an increase in the power of frontal theta oscillations in the SAD group in response to bimodal stimuli compared to faces in both angry (120–320 ms) and neutral trials (60–380 ms) at 4–6 Hz compared to the control group, where the effect was noted in 260–380 ms at 4–6 Hz in angry trials and 300–420 ms at 6 Hz in neutral trials. No significant differences were observed between the SAD and HC groups regarding the accuracy and reaction times for the emotional categorization of the stimuli.

In a study by Cavanagh et al. (2017), 39 individuals diagnosed with GAD and 52 healthy controls participated in a 'Flanker task' while being measured with EEG. Individuals with GAD exhibited enhanced theta power during conflict and error conditions compared to the control group. This enhancement was localized to the mid-frontal region and was evident

without significant group differences in intertrial phase consistency. In examining the correlations between GAD status and neural measures related to error processing and conflict, the study found that GAD was significantly correlated with more significant error-related negativity and conflict N2 amplitudes and increased theta power during error-related and conflict-related activities. Unlike the control group, the GAD group exhibited an increased theta predicting RT speeding post-error, where an increased mid-frontal theta power was associated with response time (RT) slowing post-error. A regression analysis with the predictors error-related negativity, ERN, and theta power and additional theta band network features (theta inter-trial phase clustering, ITPC; theta-response time, RT correlation; and intersite phase clustering, ISPC) accounted for 23% of the variance between GAD and control groups, revealed that the theta-RT correlation emerged as a significant predictor of GAD status beyond ERN and theta power alone.

Delta Band Oscillations in PTSD and Anxiety Disorders

Only two studies measured delta band oscillations, namely one study with individuals diagnosed with PTSD (Reuveni et al., 2022) and the other one with individuals diagnosed with Blood Phobia (BP) (Mennella et al., 2017).

In a study by Reuveni et al. (2022), the PTSD and control group processed personalized trauma or standard neutral scripts, followed by an imagery task (S3, https://osf.io/6gmha) in the MEG chamber. PTSD patients exhibited higher delta power in response to trauma scripts compared to neutral scripts, particularly over the bilateral superior temporal and prefrontal cortex. Trauma-exposed control participants did not show such a power response. PTSD patients showed increased delta power in response to trauma scripts compared to neutral scripts, predominantly over the bilateral superior temporal and prefrontal cortex. This differential response was not observed in the trauma-exposed control group.

Conversely, Menella et al. (2017) investigated delta band oscillations in individuals with blood phobia and healthy controls during emotional go/no-go tasks (S3.1, https://osf.io/f576t) while being measured with EEG. The study reported only the general trend in the delta band oscillations without group specifications. It reported an increase in delta synchronization during no-go trials compared to go trials and a more pronounced delta event-related synchronization at the central scalp site compared to the frontal site. Additionally, mutilation stimuli elicited more excellent delta synchronization than pleasant

stimuli. The study noted an increase in delta synchronization during no-go trials compared to go trials, with pronounced event-related synchronization at the central scalp site over the frontal site. Additionally, mutilation stimuli elicited more excellent delta synchronization than pleasant stimuli.

Discussion

This systematic review set out to investigate how neural oscillations across various frequency bands differ in adults diagnosed with PTSD or anxiety disorders compared to healthy controls during task-based protocols in awake-state EEG or MEG studies. Our hypothesis that significant differences, particularly in the theta frequency band, would be observed was partially supported. Theta oscillations were significantly different, particularly in PTSD. However, the findings also uncovered complex patterns across multiple bands. Gamma band oscillations revealed elevated power in PTSD during memory suppression and trauma imagery, and heightened coherence in anxiety disorders during attention-driven tasks. Beta band patterns showed variability, with PTSD participants displaying altered power in response to different script types and conditions. Alpha band findings were less uniform but indicated desynchronization in PTSD during cognitive tasks. Delta band oscillations were not extensively covered but showed increased power in PTSD during an emotional engagement.

Patterns of Neural Oscillations by Frequency Bands

The findings of theta band oscillations in PTSD and various anxiety disorders highlight specific contexts where theta activity is either upregulated or downregulated, suggesting differential neural processing and potential diagnostic markers. Several studies indicate a reduction in theta power in PTSD patients during various tasks. Several studies indicate a decrease in theta power in PTSD patients during multiple tasks. For example, For instance, Shim et al. (2022) observed a broad decrease in theta power across all major brain lobes in PTSD patients during an auditory oddball task, suggesting a generalized deficit in cognitive functions in PTSD. This is in line with previous studies indicating potential theta involvement in attention and memory processing in PTSD (Sopp et al., 2019; Meyer et al., 2015;Eidelman-Rothman et al., 2016). Similarly, De la Rosa et al. (2020) reported reduced theta power in PTSD veterans when presented with combat-related threatening imagery. Conversely, Reuveni et al. (2022) noted increased theta power in PTSD patients when exposed to personalized trauma scripts, particularly in the frontal regions, which may reflect an

enhanced engagement or reactivity to personally relevant emotional stimuli. This contrasting response in theta activity could be important for understanding PTSD's complex pathology. The decrease in theta power might reflect a disrupted or dysregulated baseline state of neural activity (Meyer et al., 2015). At the same time, the increase during personalized emotional tasks could indicate a hyperactivation linked to the re-experiencing symptoms of PTSD. Similar dynamics are observed in anxiety disorders but with different contextual triggers and regional specificity. For example, Gordeev (2008) reported increased theta power in panic disorder during an oddball paradigm, highlighting heightened vigilance or abnormal attentional processes towards novel stimuli. Popescu et al. (2023) reported an increase in theta power across all brain regions in response to generic cues in anxiety disorders, indicating a generalized heightened alertness that is less specific to trauma and more indicative of an overall anxious state. In GAD, increased theta during conflict and error conditions. Cavanagh et al. (2017) suggests a hyperarousal state during cognitive control tasks, potentially as a neural correlate of the disorder's characteristic excessive worry and anticipation of threats. This variability indicates that theta oscillations could be a nuanced biomarker sensitive to specific task demands and emotional contexts rather than a one-size-fits-all marker given the condition that future studies would focus on using similar types of experimental tasks.

Alpha Band Oscillations were frequently associated with attentional control and memory processes (Meyer et al., 2015; Lobo et al., 2015; Çalışkan and Stork, 2019; Trenado et al., 2018). The results from Shim (2022) and McDermott (2016) highlight a trend of reduced connectivity strength and significant alpha desynchronization, particularly in PTSD patients. These findings suggest a disruption in the typical inhibitory role of alpha oscillations during cognitive tasks, potentially reflecting altered attentional and memory processing mechanisms in PTSD (Dayan et al., 2016). This desynchronization, particularly noted in the right inferior frontal gyrus and extending to other cortical areas underlines a heightened neural processing that could be related to the hyperarousal symptoms often reported in PTSD (Meyer et al., 2015). Also, Decreased alpha power, indicating active cognitive engagement, was noted during cognitive tasks in PTSD subjects (Shim et al., 2022; Popescu, 2023), reflecting possible compensatory mechanisms to maintain task performance despite psychopathological disturbances (Lobo et al., 2015). In contrast, Reuveni et al. (2022) reports an increase in alpha power in PTSD patients when exposed to traumatic versus neutral

stimuli. This could represent a neural mechanism of emotional regulation or disengagement, where heightened alpha activity serves as a protective inhibition of processing trauma-related content (Meyer et al., 2015), contrasting the lower power observed in controls under similar conditions. In anxiety disorders, the studies indicated an inconsistency in alpha responses (Mennella et al., 2017; Gordeev, 2008), suggesting variable impacts on attentional resources across different anxiety states (Newson and Thiagarajan, 2019; Clancy et al., 2020).

Beta oscillations have shown considerable variability in their modulation across task-based protocols in both PTSD and anxiety disorders, indicating their potential role in distinct cognitive and emotional processes within these conditions. Among PTSD studies, Shim et al. (2022) identified no significant differences in beta connectivity strength during an auditory oddball task, suggesting that, unlike other frequency bands (Meyer et al., 2015, Newson and Thiagarajan, 2019), beta oscillations may not be as sensitive to auditory stimulus differentiation in PTSD. In contrast, Reuveni et al. (2022) found altered beta power in PTSD during trauma-related imagery, with increased power suggesting a neural mechanism for heightened emotional response or recall of traumatic events. These findings highlight the task-specific nature of beta oscillations and their potential to reflect different aspects of PTSD pathology, such as impaired emotional regulation or heightened sensory processing (Dayan et al., 2016). In anxiety disorders studies, Gordeev (2008) and Gerez et al. (2016) reported increased beta power in panic disorder and generalized anxiety disorder during oddball and attention-driven tasks, respectively. Specifically, Gordeev (2008) observed elevated beta power at frontal and parietal sites, aligning with the neural correlates of heightened vigilance and disrupted executive control mechanisms typical in anxiety states.

Gamma band oscillation results showed a possible pattern that may reflect neural processing dynamics associated with PTSD and anxiety disorders. Across different task-based protocols, there is a notable trend of elevated gamma power in PTSD compared to healthy controls, particularly during cognitive tasks that involve memory suppression (Waldhauser et al., 2018) and trauma imagery Reuveni et al., 2022). This elevation in gamma activity, especially in high-gamma ranges (70-150 Hz), suggests an intensified neural response during specific cognitive demands associated with PTSD. For instance, during memory suppression tasks, the PTSD group showed significant gamma activity during attempts to suppress memories, contrasting with control groups who exhibited decreased activity in other frequency

bands like alpha. Similarly, Reuveni et al. (2022) study highlighted increased gamma power during both the listening and imagery phases of trauma-related narratives, pointing towards an enhanced engagement or possible neural hyperarousal when processing trauma-relevant information. Comparatively, in anxiety disorders, the pattern differs slightly; Silva et al. (2017) findings on increased gamma coherence during attention-demanding tasks in Panic Disorder suggest that gamma activity may also be implicated in heightened vigilance or attentional control mechanisms (Moon et al., 2018). This is unlike the PTSD-specific response where gamma activity seems more linked to emotional and memory-related processing (Durand et al., 2019).

Limitations of the evidence included in this review

The systematic review identified common study limitations, particularly in sample selection, demographic specificity, and comparability. For example, several PTSD studies included only male participants (Popescu et al., 2023; T. J. McDermott et al., 2016,) whereas some studies on anxiety disorders exclusively featured female participants (Mennella et al., 2017; Di Giorgio Silva et al., 2017. Although the number of women in the military—and consequently in combat situations—is increasing, less is known about PTSD in women (M. C. McDermott et al., 2024; Spanovic Kelber et al., 2021). Additionally, most of the included studies had only two gender profiles, namely female and male, without reporting any information about whether transgender or non-binary people were included or reporting reasons why these groups were not included in the study design even though all studies that did include only one gender reported reasons for this choice. Transgender and non-binary people are mainly absent in neurophysiological research. However, the high prevalence of anxiety disorders within this population ranges from 17% to 68% (Millet et al., 2017), and PTSD rates are around 17.5 to 45% compared to 5% in the general population in the USA (Tebbe and Budge, 2022). Moreover, all included studies featured relatively small sample sizes and utilized cross-sectional designs, which limits the statistical power and robustness of the conclusions that can be drawn. There was also underreporting regarding the healthy control groups, specifically how they were selected (Gordeev, 2008) and their characteristics, including tests for comorbidities (Cavanagh et al., 2017; Gerez et al., 2016; Di Giorgio Silva et al., 2017; Cohen et al., 2013). The scarcity of information about control groups, often described merely as groups of healthy volunteers, complicates comparisons between groups. This is because it

becomes challenging to establish initial differences between them, and heterogeneity in control groups makes it difficult to compare studies (Levack et al., 2019).

Limitations of the review processes used

One of the main limitations of this review was the inclusion of studies that conducted different types of tasks (from cued rule-switching tasks to oddball tasks) aimed to measure various kinds of processes (from cognitive flexibility to response to auditory stimuli). The outcomes of these tasks could not be compared, so a meta-analysis was not performed. Even though some small patterns emerged in different frequency bands, the question remains whether these deviations in oscillations were a characteristic of the task or whether these deviations were a characteristic of PTSD or anxiety disorder. In this systematic review, it was impossible to identify why certain oscillation deviations occurred. Additionally, this systematic review also had methodological limitations. Namely, the risk of bias assessment and data extraction were conducted only by one reviewer, which increases the chance of inconsistencies.

Strong points of this review

The most vital part of this systematic review was its methodological rigor and application of Open Science techniques. All raw data and completed steps during a systematic review are documented and openly available on the Open Science Framework. Even though a transparent process does not guarantee the absence of inconsistencies, it enhances trust in the scientific results and makes it possible to find and fix inconsistencies (Rethlefsen et al., 2024). Additionally, the article search process used no language or time filters. This made the spectrum of the articles more representative compared to the most common scenario of filtering exclusively for English-written articles. Even though it was impossible to identify a robust pattern in oscillations across different tasks, studies with different tasks provided an extensive overview of what could be done in future studies to make systematic investigation possible.

Implications for future research

The implications of this systematic review are related predominantly to future research and not to practice or policy. For future research, it is essential to consistently use similar or similar types of tasks to identify patterns in neural oscillations during task-based protocols. The usage of similar or the same kind of tasks would make it possible to compare studies with each other and to observe whether there is a pattern in the oscillation abnormalities in PTSD

and anxiety disorders. It is also essential to report all outcomes (even those not significant) related to all brain oscillations measured (e.g., in the supplementary materials).

Conclusion

This systematic review has uncovered nuanced patterns of neural oscillations across various frequency bands in individuals diagnosed with PTSD and anxiety disorders. These patterns provide small insights into these disorders' specific neural mechanisms underlying symptomatology and cognitive processing differences. Additionally, this systematic review uncovered the need to use similar or the same type of task in research about oscillations in PTSD and anxiety disorders to find an effect of oscillations.

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Table 1

An overview of the recent reviews about brain oscillations in PTSD or Anxiety Disorders

Authors	Main Aim	EEG/ MEG	Main Conclusion	Language Filter Used	Data Availability
Meyer et al., 2015	review the literature on frontal asymmetry as a potential objective indicator of PTSD symptoms	resting-state, task-based	trauma-relevant tasks lead to asymmetric frontal activation	yes	not reported
Lobo et al., 2015	review the literature on EEG abnormalities in PTSD to identify biomarkers of PTSD	resting-state, task-based	there is a relationship between alpha frequency and severity of PTSD	yes	not reported
Trenado et al., 2018	reviewed literature on oscillations correlates for fear conditioning and extinction	resting-state, task-based	modulation of alpha activity was not linked to fear conditioning but to the valence of the stimuli	not reported	
correlateCaliscan et al., 2019	reviewed the literature on how oscillations in the hippocampal network are engaged in threat assessment	resting-state; task-based	oscillations are connected to the process of fear regulation and memory extinction	not reported Newson et al., 2019	review the literature on abnormalities in frequency bands in psychiatric disorders
resting-state	for the PTSD group, the difference in the power spectrum was absent	not reported	not reported		
Al Ezzi et al., 2020	review literature on connectivity estimators in SAD	resting-state, task-based	neural biomarkers detected during traumatic situations are potentially effective for early detection of SAD	not reported	not reported

Note. PTSD - Posttraumatic Stress Disorder, SAD - Social Anxiety Disorder.

Table 2

Risk of Bias Assessment

Authors	Case def.	Rep.	Sel. of Controls	Def. of Controls	Comparability	Ascertainment of Exposure	Method consistency	Non-Response Rate	Risk of bias
Gan & Li, 2023	*	*	*	*	*	*	*	*	low
Popescu et al., 2023	-	-	*	*	**	*	*	*	low-moderate
Shim et al., 2022	*	*	*	*	**	*	*	*	low
Reuveni et al., 2022	*	*	*	*	*	*	*	*	low
De La Rose et al., 2019	-	*	*	*	*	*	*	*	low-moderate
Waldhauser et al., 2018	*	*	*	*	**	*	*	*	low
Cavanagh et al., 2017	-	*	*	*	*	*	*	*	low-moderate
Menella et al., 2017	*	-	*	*	**	*	*	*	low
Silva et al., 2017	*	-	*	*	*	*	*	*	low-moderate
Khanna et al., 2017	*	-	-	*	*	*	*	*	moderate
Gerez et al., 2016	*	*	*	*	**	*	*	*	low
de Carvalho et al., 2015	*	*	*	*	*	*	*	*	low
Mc Dermott et al., 2015	*	-	-	*	**	*	*	*	low-moderate
Cohen et al., 2013	-	*	*	*	*	*	*	*	low-moderate
Gordeev, 2008	-	*	*	*	*	*	*	*	low-moderate

Note. Case def. - case definition, Rep. - Representativeness of the cases; Sel. of controls - selection of controls; Def. of controls - definition of controls.

High-quality studies in all domains except 'Comparability' were identified with one '*.' Only in the 'Comparability' domain could a study receive two '**.' Studies with a high risk of bias in a specific domain are labeled '-.'

Table 3

Deviations from the protocol

Type of deviation	Description	Reason	Influence on review
Partial re-screening and re-labeling	During phase 2 of the SAFE procedure, following the 1st consensus meeting, it was decided to partially re-screen articles	The initial screening revealed that the exclusion criteria needed to be more precisely defined	Following exclusion criteria were added: ERPs studies, mixed clinical group, resting state EEG/MEG, sleep EEG
No intervention studies	During the consensus meeting, after full-read phase, it was decided to exclude longitudinal studies	Due to time restriction of conducting this review, abscence of exact reporting about brain oscillations and attempt to make this systematic review more focused	The review contains only comparative observational studies and longitudinal component is absent. Therefore, pre-registered research question 2 was not asessed
Different risk of bias tool	ROBINS-I was a pre-registered risk of bias assessment tool	Longitudinal studies were excluded, and therefore NOS was a better and validated choice for comparative observational studies	The assessment of bias was more tailored for the selected articles
Effect sizes	Initially, the plan was to calculate effect size (d) of the included studies	Due to insufficient information for this calculation across all selected studies	The results are presented in a more descriptive manner

Note. ROBINS-I - Risk Of Bias In Non-randomized Studies - of Interventions; NOS - Newcastle-Ottawa Scale.

Table 4

Descriptive characteristics of the comparative observational studies

Authors	Diagnosis	Diagnosis based on	EEG/ MEG	Clinical group (n)	Clinical group age (M, SD)	Clinical group f (n)	Control group (n)	Control group age (M, SD)	Control group f (n)
Gan & Li, 2023	SAD	if LSAS > 60, clinical interview	EEG	26	21.77 (SD=2.05)	20	24	22.38 (SD=3.09)	14
Popescu et al., 2023	PTSD	PCL-5>=35	MEG	29	48.8 (SD=9.9)	0	30	43.2 (SD=5.7)	0
Shim et al., 2022	PTSD	psychiatrist assessment	EEG	53	42.86 (SD=10.49)	29	29	38.74 (SD=9.05)	21
Reuveni et al., 2022	PTSD	clinical interview	MEG	12	40.83 (SD=12.77)	1	14	36.6 (SD=13.89)	2
De La Rose et al., 2019	PTSD	phone screening	EEG	29	32.24 (SD=7.38)	2	13	32 (SD=5.7)	3
Waldhauser et al., 2018	PTSD	clinical interview	MEG	11	23.41 (SD=7.5)	2	13	20.83 (SD=6.58)	3
Cavanagh et al., 2017	GAD	MASQ	EEG	39	26.56 (SD=10.07)	37	52	25.29 (SD=8.46)	44
Menella et al., 2017	BP	if MQ > 18, clinical interview	EEG	20	22.5 (SD=1.6)	20	20	21.8 (SD=1.4)	20
Silva et al., 2017	PD	official PD diagnosis	EEG	9	48.8 (SD=11.16)	9	10	38.2 (SD=13.69)	10
Khanna et al., 2017	PTSD	CAPS and F1/I2 rule	MEG	26	33.94 (SD=9.03)	0	16	32.34 (SD=7.72)	0
Gerez et al., 2016	GAD	official PD or GAD	EEG	53	34.3 (SD=13.66)	26	30	32 (SD=11.1)	15
de Carvalho et al., 2015	PDA	interview with M.I.N.I. 5.0	EEG	24	38.75 (SD=10.09)	8	21	40.52 (SD=12.47)	17
Mc Dermott et al., 2016	PTSD	CAPS and F1/I2 rule	MEG	27	32.5 (SD=7.12)	0	24	30.6 (SD=7.9)	0
Cohen et al., 2013	PTSD	CAPS score > 80	EEG	14	32.2 (SD= 10.68)	4	14	26.1 (SD=3.3)	5
Gordeev, 2008	PDA	offcial PDA diagnosis	EEG	51	not reported	not reported	28	30.7 (SD=2.5)	19

Note. SAD - Social Anxiety Disorder, PTSD - Posttraumatic Stress Disorder, GAD - General Anxiety Disorder, BP - Blood Phobia, PD - Panic Disorder, PDA - Panic Disorder and Agarophobia; LSAS - Liebowitz Social Anxiety Scale , PCL-5 - Posttraumatic Stress Disorder Checklist for DSM-5, MASQ - Mood and Anxiety Symptom Questionnaire, MQ - Mutilation Questionnaire, CAPS - Clinician-Administered PTSD Scale, F 1/12 rule - the first and 12th criteria of the DSM-5 for diagnosing PTSD.

Table 5

Neural oscillations across various frequency bands in PTSD studies

Authors	Diagnosis	EEG/ MEG	Task	oscillations reported
Popescu et al., 2023	PTSD	MEG	a cued rule-switching task	θ, α, β, γ
Shim et al., 2022	PTSD	EEG	auditory oddball paradigm	θ, α, low β, high β
Reuveni et al., 2022	PTSD	MEG	trauma and neutral script, and imagery	γ, β, α, θ, δ
De La Rose et al., 2019	PTSD	EEG	implicit visual threat semantic memory recognition	θ
Waldhauser et al., 2018	PTSD	MEG	a think/no-think task	γ
Khanna et al., 2017	PTSD	MEG	Emotional Stroop Task	θ
Mc Dermott et al., 2016	PTSD	MEG	working memory task	α
Cohen et al., 2013	PTSD	EEG	emotion-provoking pictures	θ, β

Note. θ- theta, α- alpha, β- beta, δ- delta, γ- gamma.

Table 6

Neural oscillations across various frequency bands in anxiety disorders studies

Authors	Diagnosis	EEG/ MEG	Task	oscillations reported
Gan & Li, 2023	SAD	EEG	angry, neutral faces, voices	θ
Cavanagh et al., 2017	GAD	EEG	flanker task	θ
Menella et al., 2017	BP	EEG	emotional go/no-go task	α, θ, δ
Silva et al., 2017	PD	EEG	visual oddball paradigm	γ
Gerez et al., 2016	GAD	EEG	oddball paradigm	δ, β
de Carvalho et al., 2015	PDA	EEG	computer simulation of anxiety situations	β
Gordeev, 2008	PDA	EEG	oddball paradigm	β, α, θ

Note. SAD - Social Anxiety Disorder, GAD - General Anxiety Disorder, BP - Blood Phobia, PD - Panic Disorder, PDA - Panic Disorder, and Agoraphobia. θ- theta, α- alpha, β- beta, δ- delta, γ- gamma.

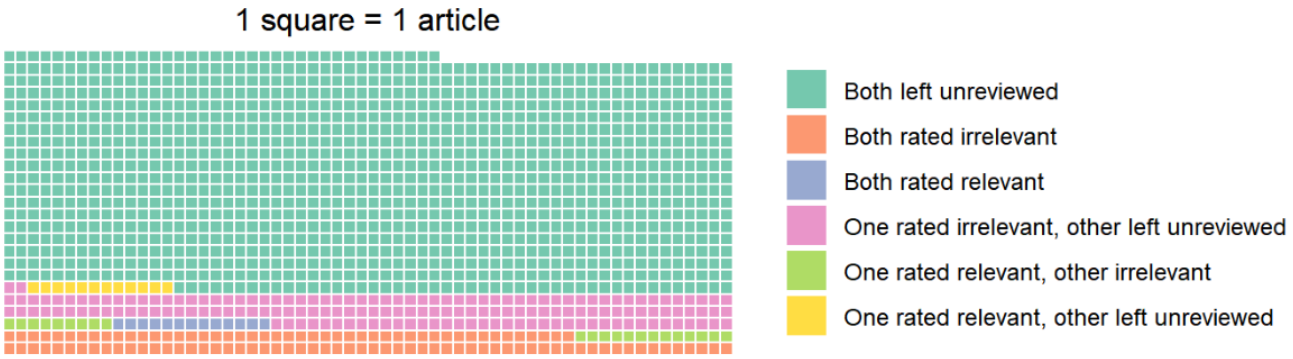

Figure 1

Inter-rater reliability during phase 2

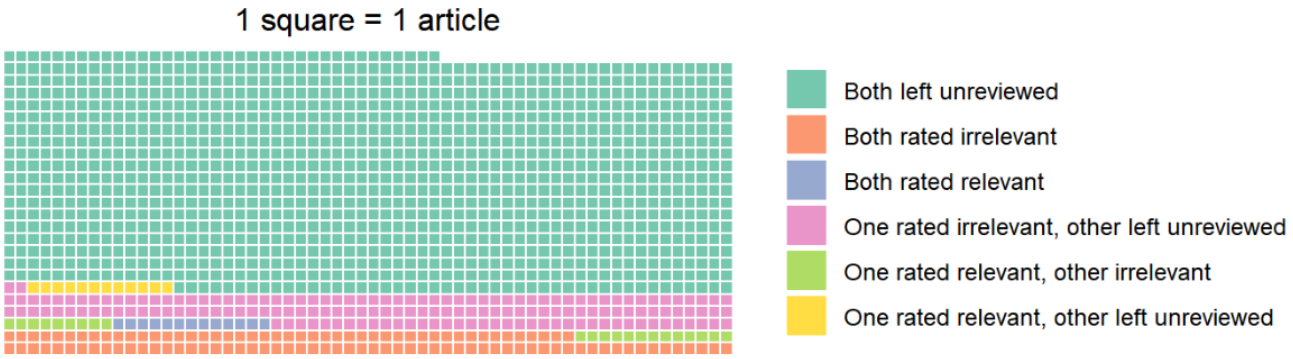

Figure 2

Inter-rater reliability during phase 3

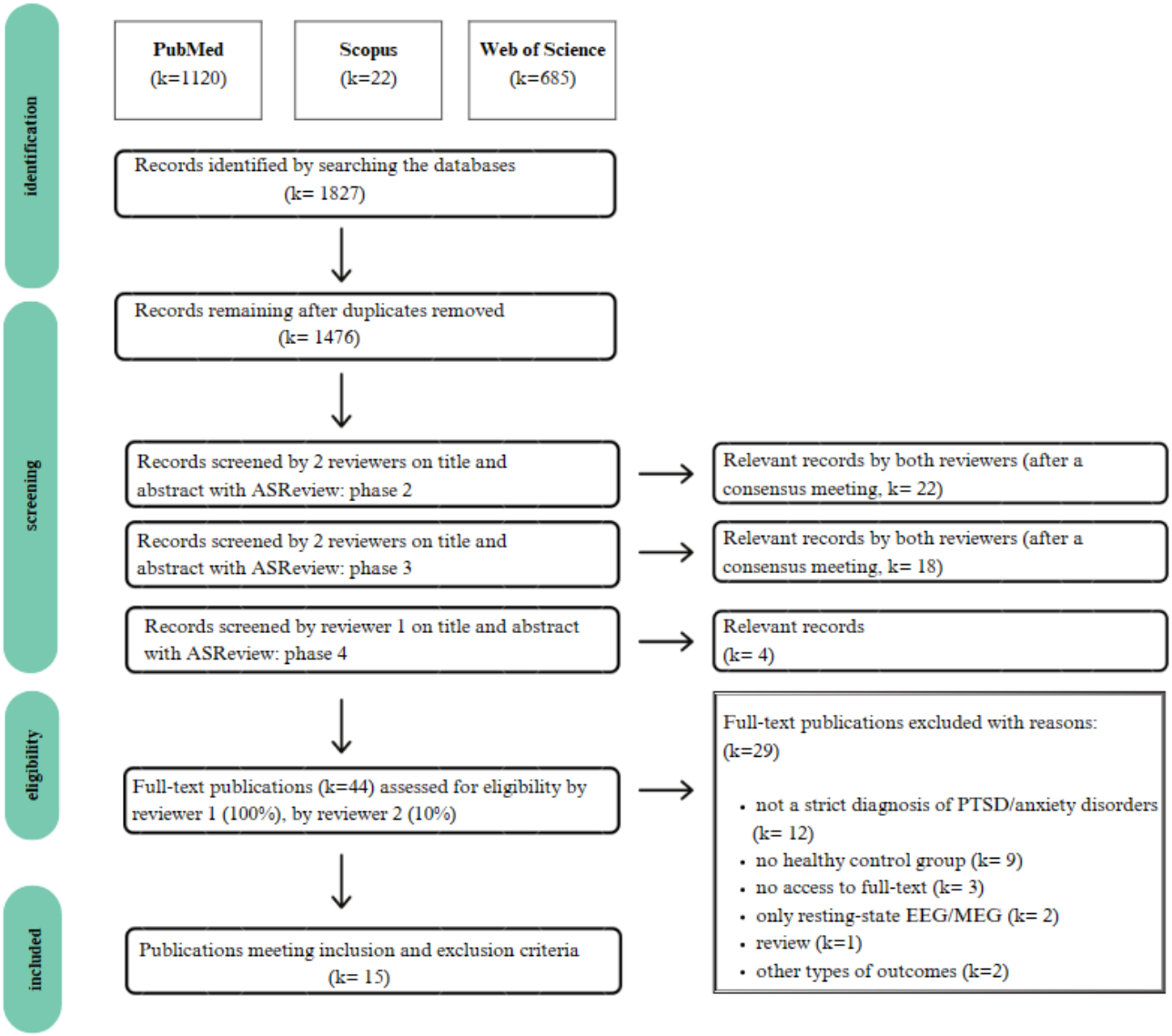

Figure 3

Flowchart of the study selection process