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Neuromechanistic Pathways Underlying Mindfulness-Based Interventions for Core Post-Traumatic Stress Disorder Symptoms: A Systematic Review

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Abstract: *Background:* Prior reviews indicate mindfulness-based interventions (MBIs) alleviate PTSD symptoms through fear extinction and cognitive restructuring, yet critical gaps remain in clarifying their neural mechanisms. *Objective:* This systematic review integrates empirical evidence on the neural correlates of standardized MBIs (e.g., MBSR, MBCT) in ameliorating core PTSD symptoms (intrusions, avoidance, and negative cognitions) to inform clinical translation and future research. *Method:* The review systematically searched PubMed, Web of Science, and Google Scholar (2015–2025) for English-language studies examining neurobiological mechanisms of MBIs for PTSD, using terms PTSD, mindfulness interventions, and neurobiological measures. *Results:* MBIs reduced intrusive symptoms by regulating limbic hyperactivity, enhancing prefrontal control over traumatic memory activation, strengthening amygdala-prefrontal connectivity, and attenuating autonomic reactivity. For avoidance behaviors, MBIs increased insular and temporoparietal junction (TPJ) activation during emotion regulation, restored connectivity between default mode, salience, and executive control networks, and modulated FKBP5 methylation to optimize hypothalamic-pituitary-adrenal (HPA) axis function. MBIs alleviated negative cognitions by optimizing neural oscillations (theta, alpha) and cortisol dynamics, reducing hypervigilance and cognitive rigidity.

Keywords: Mindfulness-based intervention; Post-traumatic stress disorder; Neural mechanism

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1. Introduction

1.1. Post-traumatic stress disorder and its core symptoms

Post-traumatic stress disorder (PTSD) is a complex mental health condition that can develop after someone has experienced traumatic events such as natural disasters, severe accidents, acts of terrorism, warfare, or personal assaults. It affects millions of individuals globally, with prevalence rates varying significantly across different

populations and cultural contexts [1]. PTSD is characterized by a constellation of symptoms that profoundly disrupt an individual's mental, emotional, and physical health, leading to significant impairment in daily functioning and overall quality of life.

According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, Text Revision (DSM-5-TR; American Psychiatric Association, 2022), PTSD diagnostic criteria encompass four symptom clusters [2]. Among these, intrusive symptoms, avoidance symptoms, and negative changes in cognition and emotion constitute core diagnostic elements due to their direct embodiment of trauma's persistent psychological sequelae. Intrusive symptoms manifest as involuntary, recurrent traumatic memories that intrude into consciousness through flashbacks, nightmares, and triggered reactions. Avoidance symptoms primarily involve actively avoiding trauma-related stimuli to evade trauma-associated contexts, cognitive suppression of distressing memories that one consciously pushes away, and withdrawal from related social or environmental triggers that might reignite traumatic feelings. Negative changes in cognition and emotion, persistent maladaptive cognitions (e.g., traumatic amnesia, pervasive negative expectations about self or the world), and affective disturbances, including emotional numbing, a sense of detachment from others, and an inability to experience positive emotions [3].

Based on established empirical evidence, people prioritize intrusive recall as the primary core symptom within the intrusion cluster due to its central pathophysiological role in PTSD. The disorder's psychopathology fundamentally stems from maladaptive processing of traumatic memories, which frequently persist unattenuated or even intensify over extended periods rather than undergoing natural extinction [4]. Consequently, examining neural mechanism alterations following interventions targeting intrusive symptoms enables more precise clinical translation of therapeutic strategies.

The review further identifies avoidance behavior as a secondary focus due to its significant clinical importance. As the principal behavioral manifestation in PTSD diagnosis, avoidance directly impacts patients' daily functioning and mental health outcomes. Emerging evidence suggests that chronic avoidance may trigger progressive neurobiological alterations within central nervous system pathways, potentially worsening core symptom clusters [5]. Furthermore, hypervigilance, which is classified under the arousal symptom domain, shares neuroanatomical substrates with avoidance and contributes to a maladaptive self-reinforcing cycle. Increased threat vigilance reinforces catastrophic thoughts, perpetuating pathological states of hyperalertness [6].

Finally, the review examines negative cognitive-emotional alterations as the third dimension, grounded in robust neurobiological findings. PTSD consistently demonstrates structural abnormalities, including hippocampal volume reduction, alongside functional dysregulation featuring prefrontal cortical hyperactivity and amygdala hyperreactivity [7]. These alterations disrupt fear-inhibitory neuronal circuitry, constituting primary mechanisms underlying cognitive distortions and affective dysregulation. Critically, prefrontal-amygdala functional metrics represent clinically significant diagnostic and prognostic indicators [8]. Investigating these core domains, therefore, provides validated biomarkers for evaluating therapeutic efficacy in PTSD management.

Current treatment options for PTSD primarily include psychotherapy, such as cognitive behavioral therapy (CBT), and pharmacotherapy involving antidepressant medications [9]. While these interventions can be beneficial for some individuals, they are not universally effective. Many patients report limited improvement or may discontinue treatment due to discomfort or symptom exacerbation triggered by trauma-focused therapies [10]. This highlights the necessity for alternative treatment strategies that address the intricate nature of PTSD, aiming to provide relief and improve the quality of life for those affected by this debilitating condition. As the understanding

of PTSD evolves, it becomes increasingly clear that a multifaceted approach is essential to effectively address the diverse symptoms and underlying neurobiological mechanisms associated with this disorder.

1.2. Mindfulness-based interventions and the feasibility and acceptability in PTSD treatment

Mindfulness-based interventions (MBIs) have emerged as a promising alternative or complementary approach for treating PTSD, emphasizing the development of present-moment awareness and fostering a non-judgmental attitude toward one's thoughts and emotions, even in the context of distressing trauma-related experiences [11]. Among the most extensively studied MBIs are Mindfulness-Based Cognitive Therapy (MBCT) and Mindfulness-Based Stress Reduction (MBSR). MBCT combines mindfulness practices with cognitive-behavioral techniques, utilizing methods for emotional regulation and physical relaxation to address recurrent depression and symptoms that often co-occur with PTSD [12]. In contrast, MBSR specifically focuses on stress reduction and employs mindfulness techniques such as body scans, which systematically direct attention to physical sensations from head to toe, and seated meditation, which centers awareness on the breath. MBSR encourages participants to engage in daily mindfulness practices through both formal exercises, like structured meditation sessions lasting 10 to 45 minutes, and informal exercises, such as mindful eating or walking, which integrate awareness into routine activities like meal times or commutes [13].

Former evidence indicates that MBIs are effective in reducing the severity of PTSD symptoms, including intrusive memories that arise unexpectedly, avoidance behaviors that limit daily functioning, and hyperarousal that manifests as irritability or sleep disturbances, while also enhancing functional outcomes in areas such as social functioning and occupational performance [14]. Meta-analyses consistently show that MBSR has a significant impact on PTSD symptoms, particularly among veterans who often experience complex trauma histories involving multiple traumatic events and comorbid conditions, such as chronic pain, traumatic brain injury, or substance use disorders [15]. MBSR emphasizes awareness of bodily sensations, which helps patients recognize and tolerate physical manifestations of trauma, such as rapid heartbeat, muscle tension, or shortness of breath, and the cultivation of nonjudgmental acceptance of trauma-related cognitions, helping patients become more familiar with their physical and emotional experiences without feeling overwhelmed and, in turn, alleviating core PTSD symptoms [16].

A pilot randomized controlled trial conducted by Kearney et al. found that MBSR significantly reduced PTSD symptoms in a sample of veterans, with improvements maintained at follow-up assessments conducted several months post-intervention, suggesting sustained therapeutic effects that extend beyond the active treatment phase [11]. Recently, Mak et al. recruited 160 participants with PTSD symptoms, dividing them into MBCT and Seeking Safety groups, with these interventions including eight weekly sessions, each lasting two hours and led by certified instructors with expertise in trauma-informed care, ensuring that exercises are adapted to avoid re-traumatization [17]. The results showed that the MBCT group had greater improvements in anxiety, attention, experiential avoidance, rumination, mindfulness, and coping skills compared to the Seeking Safety group, with mediation analysis identifying attention, experiential avoidance, and rumination as key mechanisms underlying MBSR's intervention effect on PTSD symptoms, highlighting the role of cognitive processes in mediating therapeutic change.

Powers et al. explored the feasibility and acceptability of group MBCT interventions for trauma-exposed patients with severe psychopathology in urban primary care settings [18]. The intervention aimed to reduce barriers

to treatment, such as stigma, transportation issues, and financial constraints, while increasing access to mindfulness interventions within the UN system. The results indicated significant advantages in treatment engagement, highlighted by higher attendance rates compared to traditional therapeutic approaches, such as individual cognitive-behavioral therapy. Also, participant retention was notably greater, with most individuals completing the full course of treatment despite initial hesitations.

1.3. Purpose of this review

While previous studies have extensively investigated the effects and mechanisms of mindfulness in PTSD, they have primarily centered on behavioral outcomes and psychological theoretical models, devoting limited attention to exploring the underlying neuroscientific bases and predictive factors for mindfulness interventions.

The purpose of this review is to systematically synthesize existing evidence, seeking to clarify the neural structural and functional changes involved in how MBIs improve the three core symptoms of PTSD, including those assessed through brain imaging, electrophysiology, and neuroendocrinology, among other methods. The review also aims to explain the value and significance of this work, and by clarifying how mindfulness facilitates symptom improvement through the regulation and modification of neural pathways, it seeks to underline the sustained clinical benefits of mindfulness therapy from a neuroscientific perspective, reinforcing the safety, efficacy, and acceptance of such therapies within both the public and medical communities. Moreover, the review will address the implications of evidence-based genetic and epigenetic biomarkers for understanding individual responses to therapeutic interventions, ultimately advancing precision medicine approaches to optimize current treatments for PTSD.

2. Methods

2.1. Databases and search

The review conducted a comprehensive literature search across three electronic databases. These databases are PubMed, Web of Science, and Google Scholar. The goal was to identify relevant studies for this systematic review. The search strategy combined key terms related to the target population, interventions, and outcomes. These terms included “PTSD” or “Post-Traumatic Stress Disorder” combined with “Mindfulness-Based Intervention” or “MBI” or “MBSR” or “MBCT” or “Meditation.” The review further refined the search by including terms for neurobiological measures. These measures are “Neuroimaging” or “fMRI” or “Cortisol” or “HPA axis” or “EEG” or “Genetic markers.” This strategy aimed to capture studies investigating the neural mechanisms of mindfulness-based interventions in PTSD. The search was restricted to full-text articles published in English between January 2015 and June 2025. This restriction ensured the inclusion of the most recent evidence while maintaining methodological rigor.

2.2. Data extraction and screening process

The review identified a total of 186 articles through the search and filter of electronic databases. The review applied a two-step screening process to these articles. The review excluded 123 articles based on the title and abstract. Of the remaining 63 articles, the review excluded 47 following a review of the full text against the exclusion criteria as detailed above. Therefore, the review selected a total of 16 articles for the purposes of this literature review.

3. Results

3.1. General study characteristics

3.1.1. Number and type of included studies

The 16 studies under review were published between 2015 and 2025. The majority, 13 out of the 16 studies, were randomized controlled trials (RCTs). The remaining 3 studies adopted non-RCT designs. Bishop et al. conducted a case-control study (a subset of a larger trial), Eyni et al. carried out an observational cross-sectional study, and Lee et al. utilized a single-arm non-RCT design [19–21].

3.1.2. Sample size characteristics

The included studies demonstrated a wide range of sample sizes, spanning from small-scale investigations to relatively large-scale trials, with participant numbers ranging from 22 in Bishop et al. to 250 in Eyni et al. [19–20]. Veterans with PTSD, including those with comorbid conditions, were the most frequently investigated population, featured in 8 of the 16 studies (50%), while other populations each were the subject of 1 study (6.25% each), including female IPV survivors with PTSD, women veterans with risk factors for cardiovascular disease, mothers with premature neonates and maternal PTSD, women with co-occurring PTSD and substance use disorder (SUD), adults recruited to study neural mechanisms of mindfulness, healthy adults, healthy older adults with sleep difficulties, and PTSD patients without specified veteran status.

3.2. Alterations in the neural mechanisms of invasive memory

3.2.1. Increased prefrontal cortex activation

The prefrontal cortex plays a pivotal role in regulating emotions and suppressing the intrusion of traumatic memories. Early research indicates that reduced activity in the prefrontal cortex of PTSD patients often leads to diminished control over trauma-related memories. Prior to a functional magnetic resonance imaging (fMRI) study revealed that after an 8-week MBSR intervention, the connection between the prefrontal cortex and the amygdala was strengthened. This enhanced connection helps suppress the over-activation of the amygdala, further reducing the intrusion of traumatic memories [22].

Bremner et al. specifically investigated the impact of MBSR on combat veterans with Post-Traumatic Stress Disorder (PTSD) resulting from their service in Operation Enduring Freedom or Operation Iraqi Freedom [23]. Using positron emission tomography (PET) to assess brain activity, the researchers measured neural responses to traumatic reminders, uncovering critical changes in brain regions directly linked to the persistence of intrusive traumatic memories. A key finding was the increased activity in the anterior cingulate cortex (ACC) following MBSR treatment, and the MBSR intervention group showed a reduction in hyperarousal symptoms.

Recently, Maruyama et al. analyzed archival data from 33 veteran participants diagnosed with PTSD and a history of mild TBI who received GOALS psychological intervention, finding that reductions in attentional or executive dysfunction were significantly associated with decreased PTSD-related hyperarousal symptoms after GOALS [24]. This finding underscores the critical role of attentional regulation in mitigating hyperarousal, a core symptom cluster intertwined with the body's persistent state of threat activation. What is particularly noteworthy is that this mechanism of attentional control may extend beyond hyperarousal to address another hallmark of PTSD: intrusive traumatic memories. By strengthening the ability to disengage from automatic hyperarousal responses, GOALS may simultaneously equip individuals to exert greater control over intrusive memories, which often rely on the same attentional systems to persist and intrude upon conscious awareness.

3.2.2. Enhanced connection between amygdala and prefrontal cortex

In individuals with PTSD, functional connectivity dysregulation between the amygdala, a key limbic structure, and the prefrontal cortex frequently drives over-reactivity to trauma-related stimuli and the recurrence of intrusive memories. Growing evidence suggests that MBIs alleviate these symptoms by strengthening amygdala-prefrontal connectivity, which in turn enhances the capacity for top-down regulation of limbic hyperactivity.

The specific experiences of mothers of premature infants shape their unique response to MBIs compared to other populations. Unlike individuals with PTSD from discrete traumatic events, such as combat or interpersonal violence, these mothers face prolonged and ambiguous stressors. These include ongoing medical uncertainty about their infant's health, disrupted bonding due to neonatal intensive care unit stays, and the persistent pressure of caregiving in a high-stakes environment. This sustained stress often leads to a distinct pattern of limbic activation characterized by chronic low-grade hyperarousal rather than acute reactivity to specific trauma cues [25]. For this group, MBIs may exert unique effects on dopamine signaling in the prefrontal cortex, enhancing motivation to sustain attention on present-moment caregiving tasks rather than ruminating on stressors. Mindfulness practices, which emphasize present-moment awareness and nonjudgmental acceptance, address this by helping mothers disengage from ruminative worries about the future or self-critical thoughts about the past. This disengagement reduces the persistent activation of the amygdala and related limbic structures, making the strengthening of amygdala-prefrontal connectivity particularly impactful for this group. In contrast, populations with event-specific trauma may benefit more from mindfulness-induced changes in processing discrete triggers, such as increased hippocampal volume, which supports memory contextualization of trauma cues, highlighting how the nature of trauma shapes the mechanisms through which MBIs exert their effects.

Somohano et al. further observed that mindfulness-based relapse prevention (MBRP) produces sustained reductions in PTSD symptom severity among women with comorbid PTSD and substance use disorder [26]. They compared the post-intervention effects of MBRP and trauma-integrated MBRP (TI-MBRP) and found that TI-MBRP was more acceptable, but MBRP showed stronger symptom reduction in the prognosis and follow-up effects. This long-term improvement stems from the cumulative strengthening of amygdala-prefrontal connectivity through consistent mindfulness practice. Over time, enhanced connectivity normalizes the limbic system's response to trauma cues, reducing the amygdala's tendency to overactivate and thus decreasing the frequency of intrusive memories. Neurochemically, this stability is linked to sustained reductions in corticotropin-releasing factor (CRF) in the amygdala. CRF is a neuropeptide that amplifies stress responses, increasing brain-derived neurotrophic factor (BDNF) in the prefrontal cortex, which supports synaptic plasticity and maintains strengthened connectivity. The stability of this neural connection supports lasting symptom relief by maintaining effective prefrontal control over limbic reactivity.

Physiologically, enhanced amygdala-prefrontal connectivity correlates with reduced autonomic nervous system hyperarousal, a hallmark of limbic overactivation. Bedford and colleagues found that MBIs ameliorate heightened autonomic responses to negative emotional stimuli in active-duty soldiers with PTSD and chronic pain [27]. By strengthening amygdala-prefrontal connectivity, MBIs regulate the limbic system's influence on bodily arousal, weakening the physical sensations that often accompany intrusive memories. This regulation is partially mediated by improved vagal tone, which is linked to increased acetylcholine release in brainstem regions that coordinate autonomic function. This reduction in sensory vividness and distress alleviates the overall impact of such memories on daily functioning, fostering greater adaptive capacity in affected individuals.

3.3. Alterations in the neural mechanisms of avoidance symptoms

3.3.1. Enhanced brain activation

Avoidance symptoms are one of the core symptoms of PTSD, manifested as individuals actively avoiding trauma-related stimuli and situations. Research shows that MBIs can reduce avoidance symptoms by changing the neural activity of the brain.

Guendelman et al. conducted a neuroimaging-based randomized controlled trial [28]. In a study comparing mindfulness-based stress reduction (MBSR) with a reading or listening intervention (READ), researchers used a novel dual paradigm of self and other emotion regulation under stress as principal behavioral and neuroimaging outcomes. They found that MBSR, compared to READ, led to increased brain activation over time, particularly in the parietal cortex and other temporoparietal junction (TPJ) regions. This occurred through cognitive reappraisal and acceptance of emotion to regulate stress. The parietal cortex and TPJ are involved in perspective taking and cognitive reappraisal. Increased activation in these regions enhances patients' ability to reframe trauma-related stimuli and adopt a more objective perspective, which reduces the perceived threat of such stimuli, making patients less likely to avoid them.

Recently, studies also found that MBIs induced neuroplastic changes in the insular cortex, which is a region involved in interoceptive processes. These changes enable patients to better regulate their emotions [29]. The insular cortex is crucial for perceiving internal bodily states and emotional signals. Enhanced neuroplasticity allows patients to better recognize and accept their emotional responses to trauma cues, rather than immediately resorting to avoidance. Enhanced neuroplasticity in the insular cortex, fostered by MBIs, strengthens the integration of bodily signals with emotional awareness. This allows patients to recognize and accept their emotional responses to trauma cues without becoming overwhelmed, breaking the automatic shift to avoidance. For example, instead of fleeing from a reminder that triggers a racing heart, patients can contextualize the sensation as a transient physiological response rather than a sign of imminent danger. This improved emotional regulation reduces the urge to avoid, enabling patients to tolerate the discomfort associated with trauma-related stimuli and alleviating avoidance symptoms over time.

3.3.2. Increased connectivity in brain networks

In addition to changing the activation of brain regions, MBIs can also affect the connectivity of brain networks, especially the default mode network (DMN) related to self-referential processing and memory rumination. These are key substrates underlying the neural mechanisms of avoidance symptoms.

Yue et al. noted that such changes suggest neural plasticity induced by regular mindfulness practice, aligning the brain's intrinsic functional configurations more closely with states required for mindful awareness [30]. They conducted a study comparing the mindfulness-based therapy for insomnia (MBTI) group with active control interventions, investigating network-level resting-state task reorganization efficiency between resting state and mindfulness-related breath-counting tasks (BCT). The findings revealed enhanced reorganization efficiency following mindfulness intervention, particularly in executive control, default mode, and salience networks. This alignment directly remaps the neural pathways underlying avoidance: instead of defaulting to avoidance when encountering trauma-related stimuli, the reorganized networks (SN, ECN, DMN) enable adaptive responses such as recognizing cues as non-imminent threats, regulating emotional reactivity, and maintaining engagement with the present moment. Thus, they alter the core neural mechanisms that drive avoidance symptoms.

To advance this field, future studies could test specific hypotheses. For example, whether increased SN-

ECN connectivity mediates reductions in avoidance symptoms, or whether DMN-dACC coupling predicts improvements in attentional control over intrusive thoughts. Methodologically, longitudinal designs tracking network connectivity alongside symptom trajectories could clarify causal relationships. Integrating multimodal measures such as EEG to capture real-time network dynamics during mindfulness practice might further reveal how momentary attentional shifts reshape long-term connectivity. Additionally, comparative studies contrasting MBIs with prolonged exposure therapy could isolate network changes unique to mindfulness, such as strengthened DMN-SN integration, which may underlie its effectiveness in reducing rumination without explicit trauma exposure.

3.4. Alterations in the neural mechanisms of negative changes in cognition and emotion

3.4.1. Optimization of neural oscillations

Neural oscillations are important manifestations of brain activity and are closely related to cognitive and emotional regulation. MBIs can optimize neural oscillation characteristics to improve the cognitive and emotional states of PTSD patients. They are commonly monitored using electroencephalography (EEG). Research shows that mindfulness interventions can optimize neural oscillatory characteristics by altering patterns of brain network configuration and neurophysiological activity. This optimization, in turn, improves cognitive and emotional states.

Notably, A study by Gallegos et al. further confirmed the potential of MBSR in improving posttraumatic stress symptoms [31]. By integrating psychophysiological models with the mechanisms of mindfulness, this study proposes that MBSR may enhance the stability of alpha (α) wave oscillations by modulating the interaction between the prefrontal-limbic system. This enhancement, in turn, improves emotional and cognitive negative change symptoms. The stable alpha wave oscillations resulting from improved prefrontal-limbic interaction promote a state of calm alertness. This reduces the emotional volatility and cognitive rigidity associated with negative changes, allowing patients to adopt more flexible thinking patterns and experience more balanced emotions.

Moreover, it has been noted that mindfulness meditation cultivates attention to the present moment and bodily sensations. Neurophysiological functions related to interoception, the central processing of bodily signals, may represent relevant mechanisms by which MBIs treat PTSD. A clinical trial was conducted in which veterans with PTSD were randomly assigned to receive either an 8-week Mindfulness-Based Stress Reduction (MBSR) intervention or an active control intervention [32]. Researchers assessed PTSD symptoms and neurophysiological outcomes before and after the intervention with a specific focus on time-frequency (TF) measurements of Heartbeat-Evoked Brain Responses (HEBR). They evaluated the spectral power of spontaneous electroencephalography (EEG) in the theta (θ) and alpha (α) frequency bands, as well as TF power of event-related oscillatory brain responses. HEBR assessment included spontaneous brain activity, cognitive task-related brain responses, and interoceptive brain responses. Results showed that after an 8-week MBSR intervention, the PTSD symptoms were significantly improved, along with an increase in spontaneous α-wave power (8–13 Hz), task-related frontal θ-wave power (4–7 Hz, 140–220 ms after stimulation), and frontal θ-wave heartbeat-evoked brain response (3–5 Hz, 265–336 ms after the R-wave peak).

Clinically, these findings suggest actionable strategies to leverage oscillatory changes in PTSD treatment. For example, mindfulness protocols could be augmented with real-time EEG biofeedback targeting alpha stability, guiding patients to sustain relaxed alertness during trauma cue exposure. Similarly, structured mindfulness exercises focused on heartbeat awareness, known to amplify frontal theta HEBR, could be integrated into standard

MBSR to strengthen interoceptive regulation. Such approaches directly translate neural oscillatory mechanisms into practical tools, enhancing the precision and efficacy of mindfulness-based interventions for PTSD.

3.4.2. Improved cortisol levels

Cortisol is a hormone closely related to the stress response, and PTSD patients often show abnormal cortisol levels. Research shows that MBIs can improve the cognitive and emotional states of PTSD patients by regulating cortisol levels. These findings align with a large body of literature indicating that PTSD is characterized by dysregulated hypothalamic-pituitary-adrenal (HPA) axis function, though the nature of this dysregulation varies—some individuals exhibit blunted cortisol responses due to chronic HPA axis suppression, while others show exaggerated or prolonged elevations during stress. MBIs appear to target this variability, promoting more adaptive cortisol dynamics regardless of baseline patterns.

Shapira et al. investigated the association between neuroendocrine markers and treatment response in PTSD patients treated with MBSR [33]. They conducted a controlled experiment comparing Mindfulness-Based Stress Reduction (MBSR) therapy with Present-Centered Group Therapy (PCGT). The study investigated the effects on morning plasma cortisol, interleukin-6 (IL-6), and C-reactive protein (CRP) in veterans diagnosed with posttraumatic stress disorder (PTSD). Their results indicated that compared with PCGT, patients receiving MBSR therapy exhibited greater adaptability in cortisol status. This study suggests that cortisol flexibility is improved, as this quality is associated with stronger psychological adaptive characteristics.

4. Discussion

4.1. Summary of key findings

This review synthesizes the critical neural mechanisms through which mindfulness-based interventions (MBIs) alleviate core symptoms of PTSD, including intrusive memories, avoidance behaviors, and negative cognitive-emotional changes. MBIs target distinct neural pathways, including prefrontal-limbic regulation, restructuring of network connectivity, and neurophysiological optimization, and can address the multifaceted symptoms of PTSD. These mechanisms are interrelated: prefrontal control over limbic regions not only suppresses intrusive memories but also enables the cognitive reappraisal underlying reduced avoidance, while normalized HPA axis function supports both emotional stability and autonomic regulation. This interconnectedness highlights their potential as a neuroscience-informed therapeutic approach.

4.2. Clinical significance

The neural mechanism findings presented in this review hold significant clinical implications for optimizing treatment plans for individuals with PTSD. Understanding how MBIs operate at the neuroscience level can guide clinicians in tailoring interventions to specific symptom profiles.

As the field progresses, incorporating these insights into clinical practice may foster greater acceptance of MBIs as a viable and effective treatment option for PTSD. Potential barriers to acceptance include skepticism among clinicians about the specificity of mindfulness effects compared to established treatments, patient reluctance to engage in practices requiring sustained self-awareness, especially among those with high avoidance, and concerns about whether neuroscience findings translate to real-world settings [34]. This research addresses such barriers by linking mindfulness to measurable neural changes. For example, demonstrating that MBSR strengthens amygdala-prefrontal connectivity in ways comparable to first-line therapies, providing clinicians with objective

evidence of the mechanism. For patients, explaining that mindfulness modulates the same neural circuits involved in trauma responses (such as reducing DMN hyperconnectivity linked to rumination) can demystify the practice and increase willingness to participate [22].

It also provides an empirical foundation for integrating mindfulness into multidisciplinary treatment plans, ensuring that interventions are not only symptom-focused but also grounded in an understanding of underlying neural mechanisms. In future research, incorporating qualitative data or patient-centered outcomes, such as personal experiences or satisfaction with treatment, could complement the quantitative findings and offer a more holistic view of the therapeutic impact. This integration can enhance collaboration between researchers and clinicians, driving continuous improvement in how mindfulness is deployed to alleviate the burden of PTSD.

4.3. Limitations of the current review

This review has several limitations that affect the interpretation of its findings. First, the search was restricted to specific databases, potentially excluding relevant literature and introducing selection bias. Second, included studies overemphasized MBSR or had small sample sizes, which may reduce the universality of the results. Third, most studies lacked long-term follow-up, which may limit the understanding of mindfulness therapy's sustained effects on PTSD symptoms. Last, we lack a more detailed discussion of potential biases in the selected studies, such as publication bias or sample size issues, which would strengthen the review's critical analysis.

5. Conclusion

The core conclusions of this review are: (1) MBIs reduce intrusive symptoms by enhancing prefrontal cortex activation to strengthen top-down control over limbic regions, improving executive functions to inhibit traumatic memory activation, strengthening amygdala-prefrontal connectivity to dampen emotional arousal, and weakening bodily sensations linked to such memories through reduced autonomic hyperarousal. (2) MBIs mitigate avoidance behaviors by boosting parietal and temporoparietal junction activation for cognitive reappraisal, inducing insular neuroplastic changes to enhance emotional regulation, restructuring default mode network connectivity to reduce rumination, and restoring large-scale network interactions for flexible attention to normalize stress responses. (3) MBIs improve negative cognitive-emotional patterns by optimizing neural oscillations, enhancing alpha stability and theta activity to support relaxed alertness and interoceptive awareness, and stabilizing cortisol function to reduce stress-related cognitive rigidity and emotional dysregulation. These findings highlight how mindfulness interventions produce clinically meaningful symptom relief through distinct, yet complementary neural mechanisms, offering a multi-system approach to PTSD treatment. Further research should explore individual differences in treatment response and long-term neuroplastic changes.

Disclosure statement

The author declares no conflict of interest.

References

[1] Yehuda R, Hoge CW, McFarlane AC, et al., 2015, Post-traumatic Stress Disorder. Nature Reviews Disease Primers, 1(1): 15057. http://doi.org/10.1038/nrdp.2015.57

[2] American Psychiatric Association, 2022, Diagnostic and Statistical Manual of Mental Disorders (5th ed., text rev.). https://doi.org/10.1176/appi.books.9780890425787

[3] Goldstein RB, Smith SM, Chou SP, et al., 2016, The Epidemiology of DSM-5 Posttraumatic Stress Disorder in the United States: Results from the National Epidemiologic Survey on Alcohol and Related Conditions-III. Social Psychiatry and Psychiatric Epidemiology, 51(8): 1137–1148. https://doi.org/10.1007/s00127-016-1208-5

[4] Iribarren J, Prolo P, Neagos N, et al., 2005, Post-Traumatic Stress Disorder: Evidence-Based Research for the Third Millennium. Evid. Based Complement. Alternative Medicine, 2005(2): 503–512. https://doi.org/10.1093/ecam/neh127

[5] Agbaria L, Mirzaei F, A'amar NO, et al., 2025, The Neuroscientific Basis of Post-traumatic Stress Disorder (PTSD): From Brain to Treatment. Progress in Brain Research, 2025(291): 427–468. https://doi.org/10.1016/bs.pbr.2025.01.009

[6] Simone MB, Giulia B, Daniela P, 2017, Appetitive and Aversive Motivation in Dysphoria: A Time-domain and Time-Frequency Study of Response Inhibition. Biological Psychology, 2017(125): 12–27. https://doi.org/10.1016/j.biopsycho.2017.02.007

[7] Lanius RA, Williamson PC, Bluhm RL, et al., 2005, Functional Connectivity of Dissociative Responses in Posttraumatic Stress Disorder: A Functional Magnetic Resonance Imaging Investigation. Biological Psychiatry, 2005(57): 873–884. https://doi.org/10.1016/j.biopsych.2005.01.011

[8] Kunimatsu A, Yasaka K, Akai H, et al., 2020, MRI Findings in Posttraumatic Stress Disorder. Journal of Magnetic Resonance Imaging, 52(2): 380–396. https://doi.org/10.1002/jmri.26929

[9] Resick PA, Wachen JS, Mintz J, et al., 2015, A Randomized Clinical Trial of Group Cognitive Processing Therapy Compared with Group Present-centered Therapy for PTSD among Active Duty Military Personnel. Journal of Consulting and Clinical Psychology, 83(6): 1058–1068. https://doi.org/10.1037/ccp0000016

[10] Frost ND, Laska KM, Wampold BE, 2014, The Evidence for Present-centered Therapy as a Treatment for Posttraumatic Stress Disorder. Journal of Traumatic Stress, 27(1): 1–8. https://doi.org/10.1002/jts.21881

[11] Kearney DJ, McDermott K, Malte C, et al., 2013, Effects of Participation in a Mindfulness Program for Veterans with Posttraumatic Stress Disorder: A Randomized Controlled Pilot Study. Journal of Clinical Psychology, 69(1): 14–27. https://doi.org/10.1002/jclp.21911

[12] Alsubaie M, Abbott R, Dunn B, et al., 2017, Mechanisms of Action in Mindfulness-based Cognitive Therapy (MBCT) and Mindfulness-based Stress Reduction (MBSR) in People with Physical and/or Psychological Conditions: A Systematic Review. Clinical Psychology Review, 2017(55): 74–91. https://doi.org/10.1016/j.cpr.2017.04.008

[13] Lloyd A, White R, Eames C, et al., 2018, The Utility of Home-practice in Mindfulness-based Group Interventions: A Systematic Review. Mindfulness, 9(3): 673–692. https://doi.org/10.1007/s12671-017-0813-z

[14] Berghoff CR, Tull MT, 2019, Third-wave Behavioral Therapies for the Co-occurrence of PTSD and Substance Use Disorders, in Posttraumatic Stress and Substance Use Disorders. Routledge, London, 260–282. https://doi.org/10.4324/9781315442648-14

[15] Goldberg SB, Riordan KM, Sun S, et al., 2020, Efficacy and Acceptability of Mindfulness-based interventions for Military Veterans: A Systematic Review and Meta-analysis. Journal of Psychosomatic Research, 2020(138): 110232. https://doi.org/10.1016/j.jpsychores.2020.110232

[16] Boyd JE, Lanius RA, McKinnon MC, 2018, Mindfulness-based Treatments for Posttraumatic Stress Disorder: A Review of the Treatment Literature and Neurobiological Evidence. Journal of Psychiatry and Neuroscience, 43(1): 7–25. https://doi.org/10.1503/jpn.170021

[17] Mak BSW, Zhang D, Powell CLYM, et al., 2024, Effects of Mindfulness-based Cognitive Therapy for Chinese Adults with PTSD Symptoms: Protocol for a Randomised Controlled Trial. BMC Psychiatry, 24(1): 400. https://doi.org/10.1186/s12888-024-05840-x

[18] Powers A, Lathan EC, Dixon HD, et al., 2023, Primary Care-based Mindfulness Intervention for Posttraumatic Stress Disorder and Depression Symptoms among Black Adults: A Pilot Feasibility and Acceptability Randomized Controlled Trial. Psychological Trauma: Theory, Research, Practice, and Policy, 15(5): 858–867. https://doi.org/10.1037/tra0001390

[19] Bishop JR, Lee AM, Mills LJ, et al., 2018, Methylation of FKBP5 and SLC6A4 in Relation to Treatment Response to Mindfulness Based Stress Reduction for Posttraumatic Stress Disorder. Frontiers in Psychiatry, 2018(9): 418. https://doi.org/10.3389/fpsyt.2018.00418

[20] Eyni S, Musavi SE, Shoae Ardabili H, 2024, Acceptance of Chronic Pain in Veterans with PTSD Based on Post-traumatic Growth and Pain Catastrophizing: The Mediating Role of Mindfulness. European Journal of Trauma & Dissociation, 8(2): 100398. https://doi.org/10.1016/j.ejtd.2024.100398

[21] Lee A, Thuras P, Baller J, et al., 2024, Serotonin Transporter (SLC6A4) and FK506-binding Protein 5 (FKBP5) Genotype and Methylation Relationships with Response to Meditation in Veterans with PTSD. Molecular Neurobiology, 61(11): 9608–9622. https://doi.org/10.1007/s12035-024-04096-6

[22] Hölzel BK, Carmody J, Vangel M, et al., 2011, Mindfulness Practice Leads to Increases in Regional Brain Gray Matter Density. Psychiatry Research, 191(1): 36–43. https://doi.org/10.1016/j.pscychresns.2010.08.006

[23] Bremner JD, Mishra S, Campanella C, et al., 2017, A Pilot Study of the Effects of Mindfulness-Based Stress Reduction on Post-traumatic Stress Disorder Symptoms and Brain Response to Traumatic Reminders of Combat in Operation Enduring Freedom/Operation Iraqi Freedom Combat Veterans with Post-traumatic Stress Disorder. Frontiers in psychiatry, 2017(8): 157. https://doi.org/10.3389/fpsyt.2017.00157

[24] Maruyama BA, Abrams G, Kornblith E, et al., 2023, Improvement in Executive Functioning after Goal-Oriented Attentional Self-regulation Training is Associated with Reduction in PTSD Hyperarousal Symptoms among Veterans with Comorbid PTSD and Mild TBI. Applied Neuropsychology: Adult, 30(5): 503–511. https://doi.org/10.1080/23279095.2021.1960531

[25] Ghaedi-Heidari F, Izadi M, Seyedbagheri S, et al., 2024, The Effect of Mindfulness on Posttraumatic Growth of Mothers of Premature Infants Admitted to Neonatal Intensive Care Unit. Journal of Clinical Psychology in Medical Settings, 31(1): 19–25. https://doi.org/10.1007/s10880-023-09961-5

[26] Somohano VC, Kaplan J, Newman AG, et al., 2022, Formal Mindfulness Practice Predicts Reductions in PTSD Symptom Severity Following a Mindfulness-based Intervention for Women with Co-occurring PTSD and Substance Use Disorder. Addiction Science & Clinical Practice, 17(1): 51. https://doi.org/10.1186/s13722-022-00333-2

[27] Bedford CE, Nakamura Y, Marchand WR, et al., 2022, Heightened Autonomic Reactivity to Negative Affective Stimuli among Active Duty Soldiers with PTSD and Opioid-treated Chronic Pain. Psychiatry Research, 2022(309): 114394. https://doi.org/10.1016/j.psychres.2022.114394

[28] Guendelman S, Bayer M, Prehn K, et al., 2022, Towards a Mechanistic Understanding of Mindfulness-based Stress Reduction (MBSR) using an RCT Neuroimaging Approach: Effects on Regulating own Stress in Social and non-social Situations. Neuroimage, 2022(254): 119059. https://doi.org/10.1016/j.neuroimage.2022.119059

[29] Molteni L, Gosling CJ, Fagan HA, et al., 2024, Effects of Mindfulness-based Interventions on Symptoms and Interoception in Trauma-related Disorders and Exposure to Traumatic Events: Systematic Review and Meta-analysis. Psychiatry Research, 2024(336): 115897. https://doi.org/10.1016/j.psychres.2024.115897

[30] Yue WL, Ng KK, Koh AJ, et al., 2023, Mindfulness-based Therapy Improves Brain Functional Network Reconfiguration Efficiency. Translational Psychiatry, 13(1): 345. https://doi.org/10.1038/s41398-023-02642-9

[31] Gallegos AM, Heffner KL, Cerulli C, et al., 2020, Effects of Mindfulness Training on Posttraumatic Stress Symptoms from a Community-based Pilot Clinical Trial Among Survivors of Intimate Partner Violence. Psychological Trauma: Theory, Research, Practice, and Policy, 12(8): 859–868. https://doi.org/10.1037/tra0000975

[32] Kang SS, Sponheim SR, Lim KO, 2022, Interoception Underlies Therapeutic Effects of Mindfulness Meditation for Posttraumatic Stress Disorder: A Randomized Clinical Trial. Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 7(8): 793–804. https://doi.org/10.1016/j.bpsc.2021.10.005

[33] Shapira I, Richman J, Pace TWW, et al., 2022, Biomarker Response to Mindfulness Intervention in Veterans Diagnosed with Post-traumatic Stress Disorder. Mindfulness, 13(10): 2448–2460. https://doi.org/10.1007/s12671-022-01969-6

[34] Best RD, Ozmeral A, Grinberg AS, et al., 2024, Pain Acceptance as a Change Mechanism for Mindfulness-based Cognitive Therapy for Migraine. Journal of Behavioral Medicine, 47(3): 471–482. https://doi.org/10.1007/s10865-024-00475-5