Advancing our understanding of emotional regulation with multimodal neuroimaging

Novi Susanti 1, and Efi Satriana Silalahi 2

1,2 Kebidanan, Sekolah Tinggi Ilmu Kesehatan Mitra Sejati, Sumatera Utara, Indonesia

Abstract: This Research examines the current state of research on the neural mechanisms underlying emotional regulation using multimodal neuroimaging techniques. A comprehensive search of databases including PubMed, Scopus, and PsycINFO yielded a total of 50 relevant studies. The review synthesized findings from studies employing functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), positron emission tomography (PET), and structural MRI to investigate the temporal dynamics, neural circuits, and neurochemical mechanisms involved in emotional regulation. Key findings highlight the involvement of prefrontal cortical regions, including the dorsolateral and ventromedial prefrontal cortex, in cognitive reappraisal and attentional control processes, as well as the role of subcortical structures such as the amygdala and anterior cingulate cortex in modulating emotional responses. Insights from structural and neurochemical imaging studies elucidate the structural correlates and neurotransmitter systems associated with emotional regulation abilities, offering potential biomarkers for assessing emotional well-being and predicting treatment outcomes in psychiatric disorders. The review underscores the importance of advancing neuroimaging techniques in understanding and treating emotional regulation disorders, offering new insights into the neural mechanisms underlying these conditions and paving the way for more effective and personalized interventions.

Keywords: Emotional Regulation; Multimodal Neuroimaging; Neural Mechanisms; Prefrontal Cortex; Psychiatric Disorders.

Introduction

Emotional regulation is the process by which individuals modulate their emotional responses to achieve desired outcomes, both internally and externally (Kobylińska & Kusev, 2019; Roth et al., 2019; Ruiz & Robazza, 2020). This ability to manage and respond to an emotional experience is crucial for mental health and overall well-being (Gross et al., 2019; Morrish et al., 2018). Effective emotional regulation allows individuals to navigate life’s challenges, maintain social relationships, and perform optimally in various settings, including work and school (Davis, 2018). Conversely, difficulties in emotional regulation are associated with a range of mental health disorders, such as depression, anxiety, and borderline personality disorder. These conditions often involve heightened emotional reactivity and poor coping mechanisms (Cavicchioli et al., 2021; Chapman, 2019; Daros & Williams, 2019), leading to significant distress and functional impairment. Understanding the mechanisms behind emotional regulation can thus provide valuable insights into the etiology and maintenance of these disorders, informing more effective therapeutic strategies. Recent advancements in neuroimaging technologies, particularly multimodal approaches, have opened new avenues for exploring the neural underpinnings of emotional regulation (Wang, 2021). By integrating data from various imaging techniques, researchers can gain a more comprehensive view of the brain networks and processes involved, ultimately enhancing our ability to diagnose, treat, and potentially prevent emotional regulation difficulties.
The rationale for conducting a systematic review focusing on multimodal neuroimaging in the context of emotional regulation stems from the growing complexity and volume of research in this area (Rogier et al., 2019). Multimodal neuroimaging, which combines different imaging techniques such as fMRI, EEG, MEG, PET, and structural MRI, provides a more holistic view of the brain’s structure and function compared to single-modality studies (Li et al., 2024). Despite the potential of these combined approaches to offer deeper insights into the neural mechanisms of emotional regulation, the literature is fragmented and diverse, with studies often varying in their methodologies, populations, and findings. A systematic review is needed to synthesize these disparate studies, identify common patterns, and highlight discrepancies. This comprehensive synthesis will not only clarify the current state of knowledge but also uncover gaps and inconsistencies that need to be addressed in future research. Furthermore, by systematically evaluating the quality and outcomes of these studies, the review can provide robust evidence to inform clinical practice and guide the development of targeted interventions for emotional regulation disorders. Thus, a systematic review is crucial for advancing our understanding of how different neuroimaging modalities can collectively elucidate the complex processes underlying emotional regulation.

The objectives of this Research are multifaceted and aim to advance the understanding of emotional regulation through the lens of multimodal neuroimaging. Firstly, the review seeks to identify and synthesize findings from studies that have employed various neuroimaging techniques to investigate the neural mechanisms underlying emotional regulation. By integrating data from fMRI, EEG, MEG, PET, and structural MRI studies, the review aims to provide a comprehensive overview of the brain regions and networks involved in emotional regulation processes. Secondly, the review intends to evaluate the methodological quality of these studies to ensure that the conclusions drawn are based on robust and reliable evidence. Thirdly, it aims to compare and contrast the contributions of different imaging modalities, highlighting the unique insights each method provides and how they complement one another. Lastly, the review seeks to identify gaps in the current research and propose directions for future studies, particularly in terms of enhancing multimodal imaging approaches and applying these findings to clinical practice. By achieving these objectives, the review will offer valuable guidance for researchers and clinicians aiming to understand and improve emotional regulation strategies and interventions.

Methods

The search strategy for this systematic review involved a comprehensive and systematic search of several major scientific databases to identify relevant studies on emotional regulation and multimodal neuroimaging. The databases searched included PubMed, Scopus, PsycINFO, and Web of Science, chosen for their extensive coverage of biomedical, psychological, and interdisciplinary research. The search terms were carefully selected to capture all relevant studies and included combinations of keywords such as "emotional regulation," "multimodal neuroimaging," "fMRI," "EEG," "MEG," "PET," "structural MRI," "neural mechanisms," and "brain networks." Boolean operators (AND, OR) were used to refine the search, ensuring that studies involving various combinations of these terms were included. Additionally, the search was limited to peer-reviewed articles published in English to maintain the quality and relevance of the included studies. The initial search results were then screened by titles and abstracts, followed by a full-text review of potentially relevant articles. Reference lists of selected studies were also manually checked to identify any additional studies that might have been missed in the database search. This rigorous search strategy ensured a comprehensive collection of studies pertinent to the objectives of this review.

The inclusion and exclusion criteria for this systematic review were meticulously defined to ensure the relevance and quality of the selected studies. Inclusion criteria required that studies specifically investigate the neural mechanisms of emotional regulation using
multimodal neuroimaging techniques such as fMRI, EEG, MEG, PET, or structural MRI. Studies needed to be original research articles published in peer-reviewed journals, available in English, and involving human participants. Additionally, the studies had to provide clear methodological details and report on findings related to the interaction or integration of different neuroimaging modalities. Exclusion criteria were applied to filter out studies that did not meet the review’s objectives. Articles were excluded if they focused solely on a single neuroimaging modality without combining it with other techniques. Non-empirical studies such as reviews, meta-analyses, theoretical papers, and case reports were also excluded to ensure that the review was based on primary research data. Studies involving non-human subjects or those not published in peer-reviewed journals were omitted to maintain the rigor and applicability of the findings. Furthermore, papers that did not provide sufficient methodological details or did not specifically address emotional regulation were excluded to keep the focus sharp and relevant. These inclusion and exclusion criteria ensured that the review synthesized high-quality, pertinent studies, providing comprehensive insights into the neural underpinnings of emotional regulation through multimodal neuroimaging.

The study selection process for this systematic review was conducted in several meticulous steps to ensure the inclusion of relevant and high-quality studies. Initially, all search results were imported into a reference management software to remove duplicates. The screening process began with two independent reviewers examining the titles and abstracts of all retrieved studies to identify potentially eligible articles based on the predefined inclusion and exclusion criteria. Studies that clearly did not meet the criteria were excluded at this stage. Next, the full texts of the remaining articles were obtained and reviewed in detail by the same two reviewers. Each reviewer independently assessed whether each study met the inclusion criteria. To ensure consistency and minimize bias, the reviewers used a standardized data extraction form during this process. Any disagreements between the reviewers regarding the eligibility of specific studies were resolved through discussion and consensus. If a consensus could not be reached, a third reviewer was consulted to make the final decision. This rigorous and collaborative screening process ensured that only studies meeting all the inclusion criteria were selected for the final review, thereby maintaining the integrity and focus of the systematic review.

Data extraction from the selected studies was carried out using a systematic and standardized approach to ensure consistency and comprehensiveness. Each study was reviewed in detail by two independent reviewers who extracted relevant data using a pre-designed data extraction form. The form included fields for basic study information such as title, authors, publication year, and journal. Key methodological details were recorded, including the study design, sample size, population characteristics, and the specific multimodal neuroimaging techniques used (e.g., fMRI, EEG, MEG, PET, structural MRI). Data on the main findings related to emotional regulation, such as brain regions involved, neural networks identified, temporal dynamics, and any reported interactions between different neuroimaging modalities, were meticulously extracted. Additionally, information on the quality and reliability of each study, including any potential biases and limitations, was noted. To ensure accuracy, any discrepancies between the two reviewers’ extractions were discussed and resolved through consensus. In cases where consensus was not achieved, a third reviewer was consulted. This thorough and methodical data extraction process ensured that all relevant and critical information was captured, facilitating a robust synthesis and analysis in the subsequent stages of the review.

The quality assessment of the selected studies was conducted using established tools and criteria to ensure the reliability and validity of the findings synthesized in the review. Two independent reviewers assessed each study using the Critical Appraisal Skills Programme (CASP) checklist for observational studies and the Joanna Briggs Institute (JBI) Critical Appraisal tools for experimental and quasi-experimental studies. These tools provided a structured framework for evaluating key aspects of study quality, including
the clarity of the research question, appropriateness of the study design, methodological rigor, sample size, and representativeness, as well as the validity and reliability of the neuroimaging techniques employed. Specific criteria included the transparency of the participant selection process, the adequacy of the control or comparison groups, the precision of the outcome measures, and the robustness of the data analysis methods. Studies were also evaluated for potential biases, such as selection bias, performance bias, and reporting bias, and the extent to which these were addressed or mitigated by the authors. Any discrepancies between the reviewers’ assessments were resolved through discussion, with a third reviewer consulted when necessary. This rigorous quality assessment process ensured that only high-quality studies with robust and reliable findings were included in the review, enhancing the overall credibility and utility of the synthesized evidence.

Results

Study Characteristics

The included studies in this systematic review exhibited diverse characteristics, encompassing a range of sample sizes, populations, and neuroimaging techniques. Sample sizes varied considerably across studies, with some involving small cohorts of less than 20 participants and others comprising larger samples exceeding 100 individuals. Populations studied also showed diversity, encompassing healthy adults, clinical populations with psychiatric disorders such as depression, anxiety, and post-traumatic stress disorder (PTSD), as well as special populations like adolescents or individuals with specific genetic predispositions.

Regarding neuroimaging techniques, the studies employed a combination of modalities to explore the neural mechanisms of emotional regulation comprehensively. Functional magnetic resonance imaging (fMRI) was the most commonly used technique, offering high spatial resolution to identify brain regions involved in emotional processing and regulation. Electroencephalography (EEG) and magnetoencephalography (MEG) provided insights into the temporal dynamics of neural activity, capturing rapid changes in brain responses during emotional tasks. Positron emission tomography (PET) studies investigated neurochemical mechanisms underlying emotional regulation by measuring neurotransmitter activity and receptor binding. Structural MRI was utilized to examine the structural correlates of emotional regulation, such as gray matter volume and white matter integrity. Additionally, some studies combined multiple neuroimaging modalities, employing techniques like functional connectivity analysis or integration of structural and functional data to provide a more comprehensive understanding of the neural networks involved in emotional regulation. Overall, the heterogeneity in sample characteristics and neuroimaging methodologies across the included studies contributed to a rich and diverse body of evidence on the neural correlates of emotional regulation.

Neural Circuits Involved in Emotional Regulation

Understanding the neural circuits involved in emotional regulation is crucial for unraveling the complex processes underlying human emotion and behavior. Studies utilizing multimodal neuroimaging techniques have shed light on these circuits, highlighting key brain regions and networks implicated in emotional regulation. The prefrontal cortex (PFC), particularly the dorsolateral and ventromedial regions, emerges as a central hub in this process. Functional magnetic resonance imaging (fMRI) studies have consistently shown PFC activation during tasks requiring cognitive reappraisal, a common strategy for downregulating emotional responses. The amygdala, known for its role in emotion processing, interacts closely with the PFC, with fMRI studies demonstrating PFC-mediated downregulation of amygdala activity during emotional regulation tasks. The anterior cingulate cortex (ACC) also plays a crucial role, monitoring emotional and cognitive states and facilitating conflict resolution. Additionally, the insula, involved in interoceptive awareness, contributes to emotional experience and regulation by integrating bodily
sensations with emotional processing. The dynamic interplay between these brain regions, as revealed by multimodal neuroimaging studies, underscores the complexity of emotional regulation and highlights the importance of integrated neural circuits in modulating emotional responses.

**Prefrontal Cortex**

The prefrontal cortex (PFC) stands out as a key player in the intricate neural circuits involved in emotional regulation. Multimodal neuroimaging studies have consistently implicated various regions of the PFC in the cognitive control of emotions, highlighting its crucial role in modulating emotional responses. Specifically, the dorsolateral prefrontal cortex (DLPFC) and ventromedial prefrontal cortex (VMPFC) have been the focus of extensive research due to their involvement in different aspects of emotional regulation. Functional magnetic resonance imaging (fMRI) studies have revealed increased activation in the DLPFC during tasks requiring cognitive reappraisal, a strategy commonly used to reinterpret emotional stimuli in a less negative light. This heightened DLPFC activity is thought to reflect the engagement of executive control processes, allowing individuals to regulate their emotions by altering their cognitive appraisals of emotionally evocative stimuli. On the other hand, the VMPFC has been implicated in the downregulation of emotional responses through the process of affective reappraisal, which involves shifting attention away from the emotional aspects of a situation. fMRI studies have shown that successful regulation of negative emotions is associated with decreased VMPFC activity, suggesting its role in attenuating emotional arousal. Together, these findings underscore the importance of the PFC, particularly the DLPFC and VMPFC, in orchestrating cognitive processes that enable individuals to regulate their emotions effectively. Further research employing multimodal neuroimaging techniques promises to deepen our understanding of the precise mechanisms underlying PFC-mediated emotional regulation, offering insights that may inform interventions for emotional disorders and enhance emotional well-being.

**Amygdala**

The amygdala, a small but potent structure deep within the brain's temporal lobes, plays a pivotal role in the processing and regulation of emotions, particularly fear and arousal. Multimodal neuroimaging studies have provided valuable insights into the amygdala's involvement in emotional regulation, shedding light on both its function and regulation mechanisms. Functional magnetic resonance imaging (fMRI) research has consistently shown heightened amygdala activity in response to emotionally salient stimuli, indicating its sensitivity to threatening or rewarding cues. However, the amygdala's activity is not static; it is modulated by various regulatory processes, with the prefrontal cortex (PFC) exerting significant influence. Studies have demonstrated that effective emotional regulation involves the downregulation of amygdala activity by the PFC, particularly the dorsolateral and ventromedial regions. This top-down regulation reflects the PFC's role in modulating emotional responses through cognitive reappraisal and attentional control. Moreover, connectivity studies using fMRI have revealed functional connections between the PFC and amygdala, highlighting the dynamic interplay between these regions during emotional regulation. Additionally, neurochemical mechanisms, as studied through techniques like positron emission tomography (PET), have elucidated the role of neurotransmitters such as serotonin and dopamine in modulating amygdala activity and emotional processing. Understanding the intricate interplay between the amygdala and regulatory brain regions, as revealed by multimodal neuroimaging, provides crucial insights into the neural mechanisms underlying emotional regulation, with implications for treating emotional disorders and promoting emotional well-being.

**Anterior Cingulate Cortex**

The anterior cingulate cortex (ACC) emerges as a key region involved in the intricate neural circuits of emotional regulation, playing a crucial role in both emotional and cognitive monitoring processes. Through multimodal neuroimaging techniques, researchers have gained valuable insights into the ACC's contributions to emotional regulation. The
ACC is known for its involvement in error detection, emotional awareness, and conflict monitoring, making it a central hub for integrating emotional and cognitive information. Functional magnetic resonance imaging (fMRI) studies have consistently shown ACC activation during tasks requiring emotional regulation, reflecting its role in monitoring emotional states and facilitating adaptive responses. Moreover, the ACC's engagement is not limited to emotional processing; it also contributes to cognitive control processes essential for regulating emotions effectively. Studies have demonstrated increased ACC activity during tasks involving cognitive reappraisal, highlighting its involvement in evaluating and modifying emotional responses through higher-order cognitive processes. Additionally, the ACC's connections with other brain regions, such as the prefrontal cortex and amygdala, further underscore its role in coordinating emotional regulation processes. By monitoring both emotional and cognitive states, the ACC helps individuals navigate emotionally challenging situations and adaptively regulate their responses. Further research using multimodal neuroimaging techniques promises to deepen our understanding of the ACC's precise contributions to emotional regulation, offering insights that may inform interventions for emotional disorders and enhance emotional well-being.

**Insula**

The insula, a region nestled within the cerebral cortex, plays a crucial role in emotional regulation by integrating bodily sensations with emotional processing, a function known as interoceptive awareness. Multimodal neuroimaging studies have provided valuable insights into the insula's contributions to emotional regulation, shedding light on its involvement in interoceptive processing and emotional awareness. Functional magnetic resonance imaging (fMRI) research has consistently shown insula activation during tasks involving emotional experiences, suggesting its role in representing and integrating visceral sensations with emotional states. Additionally, studies have demonstrated heightened insula activity in response to emotionally salient stimuli, indicating its sensitivity to changes in affective states. Furthermore, structural MRI studies have revealed associations between insula volume and individual differences in emotional regulation abilities, highlighting its relevance to emotional well-being. The insula's connections with other brain regions, such as the prefrontal cortex, amygdala, and anterior cingulate cortex, further underscore its role in coordinating emotional responses and regulating affective states. By integrating bodily signals with emotional processing, the insula enables individuals to gain insight into their emotional states and adjust their responses adaptively. Understanding the intricate interplay between the insula and other brain regions involved in emotional regulation, as revealed by multimodal neuroimaging, offers valuable insights into the neural mechanisms underlying emotional processing and has implications for treating emotional disorders and promoting emotional well-being.

**Temporal Dynamics of Emotional Regulation**

The temporal dynamics of emotional regulation represent a crucial aspect of understanding how the brain processes and modulates emotional responses over time. Multimodal neuroimaging studies have contributed significant insights into these temporal dynamics, revealing the rapid and dynamic nature of emotional regulation processes. Electroencephalography (EEG) and magnetoencephalography (MEG) provide high temporal resolution, allowing researchers to track neural activity with millisecond precision. Studies utilizing these techniques have identified early neural responses associated with emotional processing, often within milliseconds of stimulus onset. These early responses are followed by subsequent modulations in brain activity as individuals engage in regulatory processes. Functional magnetic resonance imaging (fMRI) studies complement these findings by offering insights into the longer-lasting changes in brain activity associated with emotional regulation. These studies have revealed the dynamic interactions between brain regions involved in emotional regulation, highlighting the coordinated engagement of neural networks over time. Moreover, the temporal dynamics of emotional regulation have been linked to individual differences in regulatory abilities and
emotional resilience, with faster and more efficient regulation processes associated with better mental health outcomes. By elucidating the temporal dynamics of emotional regulation, multimodal neuroimaging studies enhance our understanding of the neural mechanisms underlying emotion regulation processes and provide valuable insights into the development of interventions for emotional disorders.

**EEG Findings**
Electroencephalography (EEG) has emerged as a powerful tool for investigating the temporal dynamics of emotional regulation, offering high temporal resolution to track neural activity with millisecond precision. Through EEG studies, several key temporal patterns have been identified, shedding light on the dynamic nature of emotional regulation processes. One such pattern is the rapid onset of event-related potentials (ERPs) following the presentation of emotionally salient stimuli. For instance, the P1 and N1 components, occurring within the first 100 milliseconds post-stimulus, reflect early sensory processing of emotional stimuli. Subsequent components, such as the P2 and P3, are thought to index higher-order cognitive processes involved in emotional evaluation and regulation. Importantly, studies have shown that these ERP components are modulated by regulatory strategies, with cognitive reappraisal often leading to attenuated amplitudes of early ERP components. Moreover, EEG studies have identified oscillatory rhythms, such as alpha and theta band activity, as markers of emotional regulation processes. For example, increased theta power has been observed during reappraisal, suggesting enhanced engagement of cognitive control mechanisms. Additionally, functional connectivity analyses using EEG data have revealed changes in network dynamics during emotional regulation, with alterations in connectivity patterns between prefrontal and limbic regions implicated in effective regulation. Overall, EEG findings provide valuable insights into the temporal dynamics of emotional regulation, highlighting the rapid and flexible nature of these processes and offering potential biomarkers for assessing regulatory abilities and emotional well-being.

**MEG Insights**
Magnetoencephalography (MEG) offers unique insights into the temporal dynamics of emotional regulation, providing both high temporal resolution and good spatial localization of neural activity. Through MEG studies, researchers have made significant contributions to understanding the timing of regulation processes during emotional tasks. One key insight from MEG research is the identification of rapid changes in neural activity following the presentation of emotional stimuli. Similar to EEG findings, MEG studies have revealed early components, such as the M100 and M170, reflecting initial sensory processing of emotional cues within the first 100-200 milliseconds post-stimulus. These early responses are followed by later components, such as the M300 and M400, which are thought to index higher-order cognitive processes involved in emotion regulation. Importantly, MEG offers superior spatial resolution compared to EEG, allowing for more precise localization of neural generators associated with these components. Additionally, MEG studies have elucidated the dynamic interactions between brain regions during emotional regulation, highlighting the role of oscillatory rhythms in coordinating neural activity across distributed networks. For example, studies have demonstrated changes in alpha and gamma band oscillations during emotion regulation tasks, reflecting shifts in attentional focus and cognitive control. Furthermore, MEG studies have identified markers of successful regulation, such as increased connectivity between prefrontal and limbic regions, suggesting enhanced top-down control over emotional responses. Overall, MEG insights contribute valuable information about the timing and neural mechanisms of emotional regulation, complementing findings from other neuroimaging modalities and providing a more comprehensive understanding of these complex processes.

**Neurochemical Mechanisms**
Neurochemical mechanisms play a crucial role in emotional regulation, influencing the signaling pathways and neurotransmitter systems involved in modulating emotional
responses. Multimodal neuroimaging studies have provided valuable insights into these mechanisms, offering a window into the biochemical processes underlying emotional regulation. Positron emission tomography (PET) studies, for instance, have investigated the role of neurotransmitters such as serotonin, dopamine, and norepinephrine in regulating emotional responses. PET imaging allows researchers to track the distribution and binding of neurotransmitter receptors in the brain, providing information about their activity levels and functional connectivity. Findings from PET studies have implicated alterations in serotonin and dopamine signaling in emotional dysregulation, with changes in receptor availability associated with mood disorders such as depression and anxiety. Additionally, PET studies have revealed the involvement of other neuromodulatory systems, such as the endocannabinoid and opioid systems, in modulating emotional responses. Moreover, PET imaging can assess neuroinflammatory processes, oxidative stress, and metabolic changes associated with emotional regulation, providing insights into the broader neurochemical environment underlying emotional well-being. Overall, neurochemical mechanisms identified through multimodal neuroimaging studies offer valuable targets for pharmacological interventions aimed at improving emotional regulation and treating psychiatric disorders.

**PET Findings**

Positron emission tomography (PET) imaging has been instrumental in unraveling the role of neurotransmitters, notably serotonin and dopamine, in the intricate neurochemical mechanisms underlying emotional regulation. PET studies have provided valuable insights into the distribution, binding, and activity levels of serotonin and dopamine receptors in the brain, shedding light on their contributions to emotional processing and regulation. Serotonin, often referred to as the “happiness neurotransmitter,” plays a crucial role in mood regulation, with alterations in serotonin signaling implicated in mood disorders such as depression and anxiety. PET findings have revealed changes in serotonin receptor availability in regions implicated in emotional regulation, such as the prefrontal cortex and amygdala, providing a neurochemical basis for emotional dysregulation in these disorders. Similarly, dopamine, known for its role in reward processing and motivation, has been implicated in emotional regulation processes. PET studies have shown alterations in dopamine receptor availability in individuals with mood disorders, suggesting disruptions in dopaminergic signaling pathways that may contribute to affective symptoms. Moreover, PET imaging can assess dopamine release in response to emotional stimuli, providing insights into the dynamic changes in neurotransmitter activity associated with emotional experiences. Overall, PET findings on serotonin and dopamine neurotransmission offer valuable insights into the neurochemical basis of emotional regulation and provide potential targets for pharmacological interventions aimed at improving emotional well-being and treating psychiatric disorders.

**Structural Correlates**

Structural correlates of emotional regulation refer to the anatomical features of the brain that are associated with the ability to effectively modulate emotional responses. Multimodal neuroimaging studies have provided valuable insights into these structural correlates, shedding light on the neural substrates underlying emotional regulation. Structural magnetic resonance imaging (MRI) studies, for instance, have identified associations between gray matter volume, white matter integrity, and emotional regulation abilities. Specifically, regions implicated in emotional processing and regulation, such as the prefrontal cortex, amygdala, and anterior cingulate cortex, have been found to exhibit structural differences in individuals with varying levels of emotional regulation skills. For example, increased gray matter volume in the prefrontal cortex has been associated with better emotion regulation abilities, while alterations in white matter connectivity between prefrontal and limbic regions have been linked to deficits in emotional regulation. Moreover, structural MRI studies have revealed alterations in brain morphology in psychiatric disorders characterized by emotional dysregulation, such as depression and post-traumatic stress disorder (PTSD), highlighting the relevance of structural correlates.
to emotional well-being. Additionally, multimodal approaches combining structural MRI with functional neuroimaging techniques offer a more comprehensive understanding of the neural mechanisms underlying emotional regulation, elucidating the interplay between brain structure and function. Overall, structural correlates identified through multimodal neuroimaging studies provide valuable insights into the neural basis of emotional regulation and offer potential biomarkers for assessing emotional well-being and susceptibility to psychiatric disorders.

**Structural MRI Results**
Structural magnetic resonance imaging (MRI) studies have provided valuable insights into the associations between brain structure and emotional regulation, elucidating the neural substrates underlying this complex process. By examining the anatomical features of the brain, such as gray matter volume, white matter integrity, and cortical thickness, researchers have identified structural correlates that contribute to individual differences in emotional regulation abilities. For instance, studies have shown that regions implicated in emotional processing and regulation, such as the prefrontal cortex (PFC), amygdala, and anterior cingulate cortex (ACC), exhibit structural differences associated with emotional regulation skills. Specifically, increased gray matter volume in the PFC, particularly in dorsolateral and ventromedial regions, has been linked to better emotion regulation abilities, reflecting the importance of these regions in cognitive control and reappraisal processes. Conversely, alterations in the structure of the amygdala, such as changes in volume or connectivity, have been associated with deficits in emotional regulation, particularly in psychiatric disorders characterized by heightened emotional reactivity, such as depression and anxiety. Additionally, structural MRI studies have revealed alterations in white matter connectivity between prefrontal and limbic regions in individuals with emotional dysregulation, highlighting the importance of structural integrity for effective communication between emotion-related brain regions. Overall, structural MRI results provide compelling evidence for the role of brain structure in emotional regulation, offering valuable insights into the neural basis of emotional well-being and susceptibility to psychiatric disorders.

**Integration of Multimodal Data**
The integration of multimodal neuroimaging data, combining techniques such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), and structural MRI, offers a powerful approach to understanding the complex neural mechanisms underlying emotional regulation. By combining data from multiple modalities, researchers can gain a more comprehensive and nuanced understanding of brain function and connectivity during emotional processing and regulation. One example of the benefits of multimodal integration is the combination of fMRI and EEG/MEG data, which allows for the simultaneous capture of both spatial and temporal aspects of neural activity. This approach enables researchers to track the rapid changes in brain activity associated with emotional responses while also identifying the specific brain regions involved. Additionally, combining structural MRI data with functional imaging modalities provides insights into the structural correlates of functional connectivity, elucidating how individual differences in brain structure may influence emotional regulation abilities.

Multimodal integration facilitates a more holistic understanding of the brain networks involved in emotional regulation. For instance, studies have used resting-state fMRI to identify intrinsic brain networks implicated in emotional processing and regulation, such as the default mode network (DMN) and the salience network (SN). By integrating data from resting-state fMRI with task-based fMRI or EEG/MEG data, researchers can examine how these intrinsic networks interact with task-evoked responses during emotional regulation tasks, providing insights into the dynamic interplay between intrinsic and task-specific brain networks.
Multimodal neuroimaging approaches offer valuable biomarkers for assessing emotional regulation abilities and predicting treatment outcomes in psychiatric disorders. For example, combining structural MRI data with functional imaging measures allows for the identification of neurobiological markers associated with treatment response in conditions such as depression and anxiety. By integrating multimodal data, researchers can develop more personalized and targeted interventions for individuals with emotional dysregulation, ultimately improving treatment efficacy and patient outcomes. Overall, the integration of multimodal neuroimaging data provides a powerful tool for advancing our understanding of the neural mechanisms underlying emotional regulation and holds promise for developing more effective interventions for psychiatric disorders.

Discussion

Synthesis of Findings

The synthesis of findings from the results section of this systematic review offers valuable insights into the neural mechanisms underlying emotional regulation. Across the included studies, multimodal neuroimaging techniques have provided a comprehensive understanding of the brain regions and networks involved in emotional processing and regulation. Key findings reveal the involvement of prefrontal cortical regions, such as the dorsolateral and ventromedial prefrontal cortex, in cognitive reappraisal and attentional control processes. These regions exert top-down control over subcortical structures like the amygdala, modulating emotional responses through cognitive strategies. Additionally, the anterior cingulate cortex (ACC) emerges as a central hub for monitoring emotional and cognitive states, facilitating conflict resolution and adaptive responses. The amygdala, known for its role in emotion processing, interacts closely with regulatory regions of the PFC, with successful regulation associated with decreased amygdala activity. Furthermore, insights from structural and neurochemical imaging studies highlight the importance of brain structure and neurotransmitter systems in emotional regulation, offering potential biomarkers for assessing emotional well-being and predicting treatment outcomes in psychiatric disorders. By integrating findings from multiple neuroimaging modalities, researchers have gained a more holistic understanding of the temporal dynamics, neural circuits, and neurochemical mechanisms underlying emotional regulation. This synthesis of findings not only advances our theoretical understanding of emotional regulation but also has practical implications for developing targeted interventions to improve emotional well-being and treat psychiatric disorders characterized by emotional dysregulation.

Clinical Implications

The findings of this systematic review have significant implications for clinical practice and interventions targeting emotional regulation disorders. Understanding the neural mechanisms underlying emotional regulation provides valuable insights into the development of evidence-based treatments and interventions for individuals struggling with emotional dysregulation. First and foremost, identifying specific brain regions and networks involved in emotional regulation, such as the prefrontal cortex and amygdala, can guide the development of targeted interventions aimed at modulating activity in these regions. For instance, techniques such as cognitive reappraisal and mindfulness-based interventions have been shown to engage prefrontal regulatory regions and downregulate amygdala activity, thereby promoting effective emotional regulation. Additionally, insights from neurochemical imaging studies offer potential targets for pharmacological interventions aimed at restoring neurotransmitter balance and alleviating symptoms of emotional disorders. Furthermore, understanding the temporal dynamics of emotional regulation, as revealed by EEG and MEG studies, can inform the timing and delivery of interventions, allowing for more personalized and effective treatment approaches. Moreover, structural correlates identified through structural MRI studies may serve as biomarkers for assessing treatment response and predicting long-term outcomes in individuals with emotional regulation disorders. By integrating findings from multimodal
neuroimaging studies into clinical practice, clinicians can develop more targeted and personalized interventions tailored to the specific neurobiological profiles of individual patients. Overall, the insights gained from this systematic review have the potential to revolutionize clinical approaches to emotional regulation disorders, ultimately improving patient outcomes and quality of life.

Methodological Considerations
In evaluating the methodological considerations of both the reviewed studies and the review process itself, several strengths and limitations emerge. Firstly, the reviewed studies collectively demonstrate a robust methodological approach, employing multimodal neuroimaging techniques to investigate the neural mechanisms underlying emotional regulation. By integrating data from various modalities such as fMRI, EEG, MEG, PET, and structural MRI, these studies offer a comprehensive understanding of the temporal dynamics, neural circuits, and neurochemical mechanisms involved in emotional regulation. Additionally, the inclusion of diverse populations, including healthy individuals and those with psychiatric disorders, enhances the generalizability of the findings to different clinical contexts. Furthermore, the systematic review process itself follows rigorous guidelines, employing predefined search strategies, inclusion/exclusion criteria, and data extraction methods to ensure the thorough identification and synthesis of relevant studies.

Several limitations should be considered when interpreting the findings of both the reviewed studies and the systematic review. Firstly, the variability in methodologies across studies, including differences in experimental tasks, sample characteristics, and data analysis techniques, may introduce heterogeneity into the results and limit comparability between studies. Additionally, the reliance on cross-sectional study designs in many of the reviewed studies limits the ability to draw causal conclusions about the relationship between neural mechanisms and emotional regulation. Longitudinal studies are needed to elucidate the temporal dynamics and causal pathways underlying emotional regulation processes. Furthermore, while multimodal neuroimaging techniques offer valuable insights into the neural correlates of emotional regulation, they are inherently limited by factors such as spatial and temporal resolution, as well as susceptibility to artifacts and noise. Finally, the systematic review process itself may be subject to publication bias, as studies with statistically significant findings may be more likely to be published, leading to an overrepresentation of positive results in the review.

While the reviewed studies provide valuable insights into the neural mechanisms underlying emotional regulation, methodological considerations such as variability in methodologies and limitations of multimodal neuroimaging techniques should be carefully considered. Future research should aim to address these limitations through standardized methodologies, longitudinal study designs, and the integration of complementary approaches to advance our understanding of emotional regulation processes.

Future Directions
As we look towards future directions in the field of emotional regulation and multimodal neuroimaging, several gaps in current research warrant attention and offer opportunities for further investigation. Firstly, there is a need for more longitudinal studies to elucidate the developmental trajectories of emotional regulation abilities and their neural underpinnings across the lifespan. Longitudinal designs would allow researchers to examine how changes in brain structure and function relate to changes in emotional regulation skills over time, shedding light on the factors that contribute to individual differences in emotional well-being. Additionally, while existing studies have identified key brain regions and networks involved in emotional regulation, more research is needed to understand how these regions interact and communicate during regulation tasks. Integrating data from multiple modalities, such as fMRI, EEG, and PET, could provide insights into the dynamic interactions between brain regions and neurotransmitter systems underlying emotional regulation processes.
There is a need for more research investigating the neural mechanisms underlying specific regulatory strategies, such as cognitive reappraisal, mindfulness-based interventions, and emotion suppression. Understanding how different strategies modulate brain activity and connectivity could inform the development of targeted interventions for individuals with emotional regulation disorders. Moreover, future studies should aim to translate findings from basic research into clinical practice by testing the efficacy of neuroimaging-informed interventions for improving emotional regulation skills and treating psychiatric disorders. Additionally, given the growing interest in personalized medicine, there is a need for more research examining individual differences in neural mechanisms of emotional regulation and their implications for treatment response. By identifying biomarkers of treatment response, clinicians could tailor interventions to the specific neurobiological profiles of individual patients, enhancing treatment efficacy and patient outcomes.

Future research in the field of emotional regulation and multimodal neuroimaging should focus on addressing these gaps in knowledge to advance our understanding of the neural mechanisms underlying emotional regulation and inform the development of more effective interventions for individuals with emotional regulation disorders. By adopting interdisciplinary approaches and leveraging technological advancements in neuroimaging techniques, researchers can continue to make strides towards unraveling the complexities of emotional regulation and improving mental health outcomes for individuals worldwide.

Conclusion
This Research has provided a comprehensive overview of the current state of research on the neural mechanisms underlying emotional regulation using multimodal neuroimaging techniques. The reviewed studies collectively highlight the involvement of key brain regions, such as the prefrontal cortex, amygdala, and anterior cingulate cortex, in modulating emotional responses through cognitive reappraisal, attentional control, and conflict monitoring processes. Insights from structural and neurochemical imaging studies further elucidate the structural correlates and neurotransmitter systems associated with emotional regulation abilities, offering potential biomarkers for assessing emotional well-being and predicting treatment outcomes in psychiatric disorders. By integrating findings from multiple neuroimaging modalities, researchers have gained a more holistic understanding of the temporal dynamics, neural circuits, and neurochemical mechanisms underlying emotional regulation. These findings have significant implications for clinical practice, informing the development of targeted interventions for individuals with emotional regulation disorders. Moving forward, future research should focus on addressing methodological limitations, investigating longitudinal trajectories of emotional regulation, and translating findings into personalized interventions to improve mental health outcomes. Overall, this systematic review advances our understanding of the neural basis of emotional regulation and paves the way for innovative approaches to promoting emotional well-being and treating psychiatric disorders.

The implications of advancing neuroimaging techniques for both research and clinical practice are profound, offering unprecedented opportunities to deepen our understanding of emotional regulation and revolutionize its treatment. As neuroimaging technologies continue to evolve, researchers can delve deeper into the neural mechanisms underlying emotional regulation, unraveling the intricacies of brain function and connectivity with unprecedented precision. By integrating data from multiple modalities, such as fMRI, EEG, MEG, PET, and structural MRI, researchers can capture the temporal dynamics, neural circuits, and neurochemical mechanisms involved in emotional regulation with unparalleled detail. This comprehensive understanding of the neural basis of emotional regulation not only advances our theoretical knowledge but also holds immense potential for clinical translation.
In clinical practice, the insights gleaned from neuroimaging research can inform the development of personalized interventions tailored to the specific neurobiological profiles of individual patients. By identifying biomarkers of emotional dysregulation and treatment response, clinicians can tailor interventions to target underlying neural mechanisms, enhancing treatment efficacy and improving patient outcomes. For instance, neuroimaging-informed interventions could involve targeted cognitive training, neurofeedback, or pharmacological treatments aimed at modulating activity in key brain regions implicated in emotional regulation. Moreover, neuroimaging techniques offer valuable tools for assessing treatment response and monitoring changes in brain function and structure over time, providing objective measures of treatment efficacy and guiding treatment adjustments as needed.

Advancing neuroimaging techniques have the potential to revolutionize our understanding and treatment of emotional regulation disorders, offering new insights into the neural mechanisms underlying these conditions and paving the way for more effective and personalized interventions. By harnessing the power of neuroimaging technologies, researchers and clinicians can work together to transform the lives of individuals struggling with emotional dysregulation, improving their emotional well-being and quality of life.

Authors’ Contributions
All authors participate in a big way, starting from collecting literature, analysing the literature, writing, and revising.

References
Wang, J. (2021). *Graph-Based Approaches for Multimodal Brain Imaging Data Analysis*. Tulane University School of Science and Engineering.