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The Neuropsychological Consequences of Anger Suppression: A Review of Sex Differences and Clinical Implications

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Abstract

Anger suppression is a common coping mechanism used by individuals to manage anger-related emotions. However, chronic anger suppression has been linked to various negative health outcomes, including increased stress, anxiety, and cardiovascular disease. This review aims to synthesize the existing literature on the neuropsychological effects of anger suppression in men and women, with a focus on sex differences and clinical implications. A comprehensive review of existing studies reveals that both men and women exhibit altered neural activity patterns when suppressing anger, including increased activation in the anterior cingulate cortex and insula. However, sex differences emerge in the neural mechanisms underlying anger suppression, with women showing greater activation in the prefrontal cortex and reduced activity in the amygdala, and men showing increased activation in the basal ganglia and reduced activity in the prefrontal cortex. These findings suggest that men and women employ different neural strategies to regulate anger, with implications for the development of sex-specific interventions. Furthermore, chronic anger suppression has been linked to increased symptoms of anxiety and depression in both sexes, but with a greater impact on women's mental health. This review highlights the importance of considering sex differences in the neuropsychological effects of anger suppression and emphasizes the need for clinicians to develop targeted interventions that address the unique needs of men and women. By synthesizing the existing literature, this review aims to provide a comprehensive understanding of the neuropsychological consequences of anger suppression and inform the development of effective treatments for anger-related disorders.

Introduction

Anger is a universal human emotion, intricately tied to survival mechanisms and social interactions. However, when suppressed chronically, anger can have profound neuropsychological and health consequences. This paper seeks to address a central question: Why do men and women respond differently, neurologically and psychologically, to the suppression of anger? The research aims to uncover sex-specific neural mechanisms underlying this phenomenon and the potential clinical implications, ultimately informing the development of tailored interventions to manage anger-related disorders in men

and women.

The regulation of anger, particularly its suppression, is widely used across cultures and contexts as a coping mechanism. Yet, its chronic nature has been repeatedly associated with adverse outcomes such as elevated stress, anxiety, depression, and physical ailments like cardiovascular disease. It is well-documented that anger suppression alters neural activity, but the ways in which these changes interact with sex-specific neurobiological and hormonal processes remain incompletely understood. Evidence suggests that men and women use distinct neural circuits during anger suppression, contributing to differing impacts on their mental health and behavior. These differences are not only relevant to theoretical explorations but also carry practical implications for clinical applications. Understanding sex-specific patterns can aid in designing interventions that address the unique needs of men and women, leading to improved management of anger-related challenges.

This research focuses on three objectives. First, it synthesizes and evaluates the existing literature on the neurobiological mechanisms of anger suppression, emphasizing sex-specific differences. Second, it examines the broader mental health implications of chronic anger suppression, noting the heightened vulnerabilities observed in women. Third, it advocates for actionable clinical strategies by highlighting the value of sex-specific therapeutic approaches. Together, these aims contribute to advancing the understanding of anger suppression from a neuropsychological perspective and improving therapeutic outcomes.

A systematic literature review methodology is employed, integrating research from neuropsychology, cognitive neuroscience, psychiatry, and clinical psychology. The evidence is critically analyzed through comparative analysis, source evaluation, and theoretical synthesis. Key sources include neuroimaging studies on emotion regulation, research into the hormonal influences on stress and anger responses, and clinical investigations into the mental health consequences of anger suppression. This interdisciplinary approach facilitates a holistic framework for exploring the interplay between neural and hormonal factors in anger suppression, particularly as they manifest differently in men and women.

The current body of research provides valuable insights into this topic while highlighting critical gaps. Studies indicate that key brain regions such as the prefrontal cortex (PFC), anterior cingulate cortex (ACC), and amygdala are central to anger regulation. However, the sex-specific activation of these regions during anger suppression remains insufficiently explored. Emerging evidence suggests that women exhibit greater activation in the PFC and reduced amygdala activity during anger suppression, reflective of stronger cognitive control strategies. Conversely, men rely more on subcortical structures like the basal ganglia, coupled with diminished prefrontal engagement, signaling a more automatic response mechanism. These differences are influenced by hormonal factors such as estrogen and testosterone, which modulate neural activity in distinct ways. Additionally, while chronic anger suppression impacts mental health in both sexes, women appear disproportionately susceptible to anxiety and depression, whereas men exhibit a higher risk of stress-induced physical health issues, such as cardiovascular disease. Addressing these gaps and implications forms the core of this research's purpose.

The structure of the paper mirrors its multi-tiered approach. Following this introduction, Chapter 2 explores the neurobiological foundations of anger suppression, discussing the underlying neural circuits, brain regions, and hormonal influences. Chapter 3 examines sex differences in emotion processing, detailing variations in cognitive strategies, neural structures, and their implications for men and women. Chapter 4 focuses on clinical applications, highlighting mental health impacts and proposing sex-specific interventions. Finally, the conclusion synthesizes the findings, reflecting on their implications for future research and clinical practice.

Neurobiological Foundations of Anger Suppression

Understanding the neurobiological mechanisms behind anger suppression is crucial for unraveling the complexities of emotional regulation. The forthcoming sections explore the intricate neural circuits engaged in managing anger, emphasizing sex-specific patterns in brain activity and hormonal influences. By examining the roles of key brain regions such as the prefrontal cortex, amygdala, and anterior cingulate cortex, alongside hormonal factors, this chapter elucidates how these dynamics inform broader implications for emotion regulation strategies in both men and women. Insights gleaned from this discussion set the stage for addressing the clinical significance and potential interventions for anger-related disorders in subsequent sections.

Neural Circuits and Brain Regions

The study of neural circuits and brain regions involved in anger suppression offers valuable insights into the mechanisms underlying this aspect of emotion regulation. Central to this discussion are the prefrontal cortex (PFC), anterior cingulate cortex (ACC), and amygdala, which collectively govern the balance between emotional impulses and cognitive control. The PFC, particularly its ventrolateral region (VLPFC), demonstrates a prominent role in higher-order cognitive control, essential for suppressing anger and managing emotionally charged situations. As reported by Morawetz et al. (2017), consistent VLPFC activation across diverse emotion regulation strategies underscores its universal non-specific function in cognitive control. This finding situates the VLPFC as a pivotal regulator, capable of helping individuals disengage from anger-driven impulses through deliberate decision-making processes. It also emphasizes the necessity of further research into how other regions of the PFC contribute to specific forms of anger suppression.

The ACC emerges as equally significant in anger suppression due to its role in identifying and resolving conflicts between emotional and cognitive demands. The activation of the ACC while engaging in anger suppression highlights its role as a mediator that prioritizes cognitive responses over emotional reactivity (Schulte-Rüther et al., 2008; Morawetz et al., 2017). Furthermore, the interplay between the ACC and the PFC reflects dynamic integration necessary for effective regulation (Morawetz et al., 2017). This integrated mechanism underscores the importance of their functional connectivity in ensuring that emotional salience does not overpower behavioral control. However, it remains critical to examine dysfunctional ACC-PFC connectivity, which has been implicated in emotional dysregulation commonly observed in anxiety and depressive disorders (Kubzansky & Kawachi, 2000). Future clinical efforts might benefit from interventions aimed at enhancing ACC-PFC connectivity, particularly for individuals prone to chal-

lenges in anger suppression.

The amygdala's role in processing the emotional salience of anger also contributes significantly to its regulation. During anger suppression, decreased amygdala activation enables cognitive systems, such as the PFC, to exert more influence (Schulte-Rüther et al., 2008). This adaptive mechanism allows individuals to mitigate the emotional intensity of anger while prioritizing controlled responses. Interestingly, sex-specific patterns in amygdala activity point to a larger divergence in how anger is suppressed. Women tend to exhibit reduced amygdala activation during regulation, which reflects effective downregulation strategies driven by prefrontal control (Schulte-Rüther et al., 2008). In contrast, men display relatively stable amygdala activity, which may indicate less reliance on cognitive moderation and a stronger engagement of habitual response pathways (Morawetz et al., 2017). Hormonal influences, such as the effects of estrogen and testosterone, further shape these distinctions. Estrogen-driven reductions in amygdala activation, particularly in women, illustrate its regulatory benefits, whereas testosterone amplifies activity in the amygdala and basal ganglia, aligning with observed masculinized suppression strategies (Decety, 2011). These findings highlight a compelling interaction between neural activity and hormonal modulation, which warrants further investigation for potential applications in sex-specific therapeutic strategies.

Sex differences in the neural circuits of anger suppression are particularly pronounced when examining prefrontal and subcortical interactions. Women demonstrate greater activation in the dorsolateral and ventrolateral PFC, regions associated with emotional regulation and cognitive control (Morawetz et al., 2017; Schulte-Rüther et al., 2008). The enhanced cognitive involvement of these regions reflects an intentional and effortful suppression strategy that is nuanced and context-sensitive. By contrast, men rely more heavily on the basal ganglia for managing anger responses, which indicates a preference for automatic, less cognitively demanding regulation mechanisms (Schulte-Rüther et al., 2008). This subcortical reliance aligns with reactive suppression strategies that, while effective in immediate contexts, may lack the flexibility of prefrontal-mediated processes. These neural patterns not only elucidate evolutionary differences but also suggest implications for emotional resilience and adaptability. For instance, the dominance of basal ganglia pathways in men might contribute to reduced long-term emotional flexibility compared to women's PFC-dependent regulation, though the latter can lead to greater cognitive fatigue over time.

The observed neural disparities further extend into evolutionary and functional frameworks. Women's reliance on prefrontal-mediated cognitive control aligns with behaviors that emphasize social cooperation and emotional nuance, critical for maintaining social harmony. Conversely, men's basal ganglia reliance signals an adaptation toward efficient and immediate emotional regulation, which may have provided advantages in high-risk scenarios (Schulte -Rüther et al., 2008; Decety, 2011). However, these differences carry modern implications: women are better equipped to integrate anger within complex emotional contexts due to their prefrontal engagement, while men's reliance on subcortical pathways might predispose them to reactive or habitual responses, limiting their ability to adapt to emotionally demanding situations. Dysfunction in these circuits can exacerbate mental health challenges, highlighting the need to address sex-specific regulatory

pathways in clinical interventions. For example, therapies aimed at enhancing cognitive strategies in men or reducing excessive reliance on prefrontal-mediated regulation in women could yield more effective outcomes (Morawetz et al., 2017; Schulte-Rüther et al., 2008).

The critical role of the amygdala in anger suppression gains additional complexity when considering how its activity interacts with hormonal influences. Women's decreased amygdala activation during suppression, modulated by estrogen, reflects a strategic reduction of emotional salience to conserve cognitive resources (Schulte-Rüther et al., 2008). Hormonal fluctuations, such as reduced estrogen during menopause, may disrupt this mechanism, increasing susceptibility to emotional dysregulation and related mental health disorders (Decety, 2011). In contrast, men's consistent amygdala activity points to a differing regulatory strategy, potentially maintaining emotional salience while relying on subcortical management systems. This pattern can lead to heightened physiological stress markers, such as cardiovascular strain, when anger is suppressed over extended periods (Kubzansky & Kawachi, 2000; Morawetz et al., 2017). These neural and hormonal dynamics suggest that sex-specific interventions could be developed to optimize emotion regulation. Neuroimaging techniques offer promising avenues to tailor therapeutic approaches, for instance, by targeting prefrontal reinforcement in men or reducing cognitive fatigue in women through adaptive stress-management strategies.

The dynamic interplay between the ACC and PFC further illustrates the multifaceted regulation of anger. The ACC's role in detecting emotional conflict and signaling the PFC for resolution is essential, particularly in scenarios where emotional impulses compete with cognitive demands (Morawetz et al., 2017). Right-lateralized activity in the PFC, observed during anger suppression, reflects this hemisphere's specialization in processing negative emotions and implementing inhibitory responses (Morawetz et al., 2017). This hemispheric dominance ensures effective downregulation of anger through prioritized cognitive responses. However, deficits in ACC-PFC connectivity have been implicated in anger-related disorders, including heightened susceptibility to anxiety and depression (Kubzansky & Kawachi, 2000). Addressing these deficits through cognitive training or targeted pharmacological interventions could strengthen functional connectivity and enhance emotional regulation.

In conclusion, the neural circuits involved in anger suppression, comprising the PFC, ACC, and amygdala, reveal a highly integrated network governed by cognitive and emotional interplay. The sex-specific differences in how these circuits are engaged underscore the evolutionary, hormonal, and functional distinctions in anger regulation. Future research into these differences will be crucial in guiding clinical interventions and addressing deficits in emotion regulation.

Sex-Specific Neural Activity Patterns

Sex-specific neural activity patterns during anger suppression reveal distinct differences in how males and females engage specific brain regions to regulate emotions. Research consistently demonstrates that women rely more heavily on cognitive control mechanisms, with increased activation in prefrontal cortex (PFC) regions, particularly the dorsolateral and ventrolateral PFC, while men exhibit reduced PFC engagement, reflecting reliance on other neural pathways (Banks et al., 2007; Da-

vidson, 2002). This dichotomy stems from different regulatory strategies: women use cognitively demanding processes such as reappraisal, while men depend on subcortical systems like the basal ganglia for automatic and habitual responses. Women's ability to effectively regulate emotions through increased PFC activity is supported by the findings of Banks et al. (2007) and Davidson (2002), who noted heightened PFC activation during anger suppression, allowing for a more deliberate and evaluative approach. This enhanced PFC use not only enables suppression of anger but also reflects an intentional modulation of emotional responses in complex social or interpersonal settings. However, these advantages come at a cost, as prolonged cognitive regulation may impose substantial mental strain over time. Men's reduced reliance on PFC activity, on the other hand, aligns with their preference for less cognitively demanding strategies. As Davidson (2002) points out, this diminished cortical engagement during emotion regulation may hinder the suppression of anger and encourage impulsive behaviors. These findings reveal the critical need to explore sex-specific training methods that can bolster PFC engagement in men to improve emotion regulation while addressing the cognitive burden on women's PFC activity in prolonged emotional suppression.

The amygdala, known for processing emotional stimuli, also exhibits sex-specific patterns during anger suppression. Women consistently demonstrate decreased amygdala activity during anger regulation, indicating that they efficiently downregulate emotional salience (Blair, 2012; Banks et al., 2007). This reduction in activity aligns with increased PFC involvement in women, illustrating a coordinated top-down regulatory approach. Women's ability to achieve this decreased amygdala reactivity during emotional suppression is functionally advantageous for managing emotionally charged scenarios, as Blair (2012) argues. Conversely, men experience relatively stable amygdala activity during anger suppression, which signals a less effective attenuation of emotional intensity and a tendency toward heightened emotional reactivity (Banks et al., 2007). This discrepancy is exacerbated by men's reduced use of prefrontal regulatory mechanisms, as described in previous findings, and may be linked to impulsive responses to anger-inducing stimuli. Hormonal factors further explain these differences. Davidson (2002) highlights the role of testosterone in amplifying amygdala activity, which may predispose men to reactive and emotionally intense states. This hormonal influence, combined with men's reliance on subcortical mechanisms, underscores the need for clinical strategies aimed at reducing emotional reactivity and strengthening top-down cognitive control. For women, who benefit from decreased amygdala activation during regulation, therapeutic efforts could focus on preventing overutilization of prefrontal mechanisms to minimize risks for stress-related mental health disorders such as anxiety and depression (Blair, 2012). These findings call for targeted interventions that address the amygdala's differing role in emotion regulation between sexes.

Elevated basal ganglia activity in men during anger suppression highlights another aspect of their reliance on subcortical neural systems for emotional regulation (Davidson, 2002; Blair, 2012). The basal ganglia, traditionally associated with habitual and automatic behaviors, contrasts sharply with the PFC-dependent strategies observed in women. Davidson (2002) notes that men's reliance on this subcortical region underscores their preference for rapid and relatively automatic mechanisms for managing an-

ger, though these strategies are less adaptable to nuanced emotional contexts. Blair (2012) further connects this basal ganglia engagement to testosterone's influence, amplifying the efficiency of these automatic responses in immediate situations but potentially limiting emotional flexibility in the long term. While such rapid responses may have served an evolutionary purpose—enhancing survival in high-threat scenarios—they may be maladaptive in contemporary contexts where reflective and flexible emotional regulation is often more effective. In contrast, women's greater reliance on the PFC indicates a shift toward cognitive regulation, supported by estrogen's modulation of prefrontal activity (Davidson, 2002). These sex-specific differences in basal ganglia and PFC involvement emphasize the need for tailored therapeutic approaches. For men, implementing strategies to enhance PFC engagement through cognitive reappraisal training could address their overdependence on basal ganglia-mediated mechanisms. For women, managing PFC-driven regulation to reduce cognitive fatigue may ensure sustained emotional health while preserving their capacity for reflective emotional management.

Functional connectivity between the PFC and amygdala further differentiates emotion regulation strategies in men and women. Women display stronger PFC-amygdala coupling during anger suppression, which enhances their ability to exert cognitive control over emotional responses (Banks et al., 2007; Davidson, 2002). This connectivity enables effective top-down regulation of emotional salience and promotes more measured responses to anger. Banks et al. (2007) argue that this functional coupling is facilitated, in part, by estrogen, which strengthens PFC-amygdala interactions and fosters regulatory efficiency. Men, however, exhibit weaker connectivity between these regions, reflecting reduced reliance on cognitive regulation mechanisms (Banks et al., 2007). This diminished coupling aligns with lower PFC engagement and increased dependence on subcortical neural systems, as previously discussed. The role of testosterone in limiting PFC-amygdala connectivity may further impede men's capacity for cognitive regulation, as reflected in heightened emotional reactivity (Davidson, 2002). These sex-specific differences underscore the importance of developing interventions that target functional connectivity. For men, improving PFC-amygdala coupling through training programs designed to enhance cognitive control could mitigate impulsive anger responses. For women, addressing the potential for excessive mental fatigue from overutilization of this connectivity might aid in balancing regulatory demands and reducing vulnerability to stress (Banks et al., 2007). These findings establish functional connectivity as a critical consideration in refining clinical strategies for anger suppression.

The anterior cingulate cortex (ACC) plays an essential role in resolving conflicts between emotional impulses and cognitive demands during anger suppression. Women's stronger ACC engagement, as observed in studies, facilitates better coordination with prefrontal regions for comprehensive anger regulation (Martin & Dahlen, 2005; Blair, 2012). Martin and Dahlen (2005) identify the ACC's prominent role in addressing emotional-cognitive conflicts, allowing for improved resolution and effective regulation strategies in women. This dynamic interplay between the ACC and the PFC supports women's reliance on cognitive regulatory mechanisms, as seen in their greater dorsolateral and ventrolateral PFC involvement. Conversely, men exhibit less pronounced ACC activation during anger

suppression, indicating weaker engagement in resolving emotional conflicts and a tendency to rely on subcortical mechanisms such as the basal ganglia (Blair, 2012). Hormonal differences also shape these patterns. Estrogen enhances ACC engagement in women, promoting coordination with the PFC and ensuring more effective regulation (Davidson, 2002). In contrast, testosterone suppresses ACC involvement in men, reinforcing their reliance on subcortical pathways for habitual emotional regulation (Blair, 2012). These differences pose distinct challenges for emotion regulation. For women, prolonged reliance on ACC-PFC coordination may contribute to cognitive strain and increase susceptibility to mental health risks such as anxiety or depression. For men, diminished ACC engagement could compromise their ability to adaptively manage emotional responses. Therapeutic approaches that strengthen ACC activation in men might enhance their cognitive emotion-regulation capabilities, while strategies to reduce the cognitive burden of ACC-PFC reliance in women could support their emotional health (Martin & Dahlen, 2005; Blair, 2012).

Hormonal modulation plays a pivotal role in shaping the neural mechanisms of anger suppression, highlighting biological underpinnings of sex-specific differences. Testosterone, particularly prevalent in men, amplifies reactivity in subcortical regions like the amygdala and basal ganglia, reinforcing habitual and impulsive regulatory responses (Blair, 2012). This hormonal influence underlies men's reliance on automatic pathways during emotion regulation and creates challenges for developing cognitive control strategies. In contrast, estrogen enhances PFC and ACC activity in women, supporting their use of cognitive mechanisms for anger suppression. Davidson (2002) notes that estrogen's modulation of prefrontal neural circuits facilitates deliberate and reflective emotional regulation, aligning with women's capacity for nuanced emotion management. However, hormonal imbalances or dysfunctions can exacerbate difficulties in regulation. For example, reduced estrogen levels during menopause may disrupt prefrontal-supported regulatory strategies in women, increasing vulnerability to emotional dysregulation and mental health challenges (Blair, 2012). Similarly, elevated testosterone levels in men could heighten impulsivity and emotional reactivity, complicating efforts to manage anger effectively. Addressing these hormonal influences in clinical practice is essential. Pharmacological interventions aimed at balancing testosterone levels in men may mitigate their reactive tendencies, while behavioral approaches to reduce the cognitive load associated with estrogen-driven regulation in women could enhance emotional resilience. These insights underscore the importance of integrating hormonal considerations into therapeutic models to address anger-related disorders.

In summary, sex-specific neural activity patterns during anger suppression highlight profound differences in how individuals regulate emotions, shaped by hormonal influences and neural connectivity. These differences necessitate targeted interventions that address the unique challenges faced by men and women in managing anger effectively.

Hormonal Influences and Regulation

Hormonal influences significantly contribute to the modulation of neural activity underlying anger suppression, offering compelling insight into the biological mechanisms that differentiate emotion regulation strategies between males and females. Testosterone and estrogen serve as key hormonal mediators, shaping both neural activation patterns and

emotional responses during anger regulation. Testosterone amplifies reactivity in subcortical structures such as the amygdala and basal ganglia, which underpin heightened emotional responses in men. This effect contrasts with estrogen's enhancement of prefrontal cortex (PFC) activity, facilitating improved cognitive control in women. Testosterone's role in increasing the activation of the basal ganglia and amygdala suggests that men often rely more heavily on automatic, habitual regulation strategies rather than engaging higher-order cognitive approaches (Nelson & Trainor, 2007). This dependence on subcortical pathways may contribute to impulsive behavioral tendencies, especially during emotionally charged situations. In contrast, estrogen's capacity to augment PFC activity supports a framework wherein women engage in more nuanced, deliberate strategies for anger suppression (Davidson et al., 2000). This dichotomy underscores the evolutionary and functional roles of these hormones in shaping sex-specific responses to emotional challenges, offering fertile ground for further research into their implications for emotional regulation and mental health.

Testosterone's contribution to anger suppression is particularly evident in its impact on subcortical regions such as the basal ganglia and amygdala. These neural pathways are critical for automatic emotional responses and play a central role in the impulsivity associated with heightened testosterone levels (Nelson & Trainor, 2007). The sustained activation of these regions during anger regulation emphasizes a reliance on rapid, reflexive mechanisms that prioritize immediate reactions over cognitive evaluation. This reliance, while potentially advantageous in high-stakes survival scenarios, can be maladaptive in environments where nuanced emotional regulation is required. Elevated testosterone levels amplify emotional intensity, particularly in response to anger stimuli, which reduces the efficacy of top-down regulation by prefrontal regions. This hormonal influence may explain the consistently observed reduced capacity for cognitive control in men, contributing to behavior patterns that are reactive rather than contemplative. The findings point to a need for interventions that minimize testosterone's impact on subcortical overactivation, fostering greater reliance on cognitive strategies in men.

In contrast, estrogen plays a central role in enhancing PFC functionality, enabling women to regulate emotional impulses and engage in cognitive strategies for anger suppression. Estrogen's influence on neural activity is most apparent in its ability to strengthen functional connectivity between the PFC and subordinate regions like the amygdala (Davidson et al., 2000). This modulation fosters a dynamic balance between cognitive control and emotional processing, allowing women to prioritize reflective anger regulation. The coordinated activity between the PFC and amygdala, facilitated by estrogen, demonstrates a capacity for effective top-down regulation that reduces the intensity of emotional salience while preserving emotional stability. These findings underscore the adaptive utility of estrogen-driven regulation, which positions women as better equipped to navigate complex social or emotional interactions that require contextual sensitivity. However, this regulatory advantage may also impose cognitive strain, increasing vulnerability to mental fatigue or stress-related mental health challenges over time. Understanding estrogen's dual role in enhancing regulation while contributing to potential cognitive exhaustion provides avenues for improving therapeutic approaches tailored to women's needs.

The interaction between testosterone and neural structures such as the basal ganglia and amygdala further underlines the habitual and automatic regulatory strategies employed during anger suppression in men (Nelson & Trainor, 2007). Testosterone-driven activity in the basal ganglia facilitates rapid emotional responses that are well-suited to immediate, high-stress scenarios, but these mechanisms often lack the adaptability required in nuanced emotional contexts. The basal ganglia's role as a mediator for anger suppression reflects an evolutionary reliance on immediate reactionary responses, which may have been advantageous in high-threat environments. However, in modern settings, this reliance can contribute to emotional rigidity and difficulty in sustaining long-term regulation of anger. By contrast, estrogen's ability to augment PFC-amygdala connectivity allows women to regulate emotional salience effectively through deliberate cognitive strategies (Berridge & Kringelbach, 2013). These neural interactions highlight the adaptability of estrogen-driven regulation, but they also emphasize the need for targeted interventions that mitigate the challenges associated with habitual reliance on subcortical pathways in men while managing cognitive fatigue risks in women.

The modulatory role of hormones in functional connectivity is a critical component of sex-specific differences in anger regulation. Women benefit from stronger PFC-amygdala coupling, a dynamic that enhances cognitive control over emotional responses. This functional connectivity facilitates deliberate and adaptive strategies for suppressing anger, underscoring the advantages of estrogen-driven regulatory mechanisms (Davidson et al., 2000; Nelson & Trainor, 2007). By contrast, men exhibit weaker PFC-amygdala connectivity, which reflects their reduced dependence on cognitive regulation strategies and increased reliance on automatic response pathways (Banks et al., 2007). Testosterone's influence in limiting this functional coupling exacerbates the challenges faced by men in achieving effective top-down control during emotionally charged situations. These findings illustrate the importance of targeted interventions that strengthen PFC-amygdala connectivity in men while addressing the cognitive demands placed on women's regulatory systems. Enhancing this balance could mitigate impulsive tendencies in men and reduce cognitive strain in women, creating a more equitable foundation for effective emotion regulation.

Sex differences in anterior cingulate cortex (ACC) engagement during anger regulation further differentiate regulatory strategies. Women's stronger ACC activation supports enhanced coordination with the PFC, facilitating comprehensive strategies to resolve the conflict between cognitive and emotional demands (Martin & Dahlen, 2005; Blair, 2012). This dynamic underscores the adaptive benefits of women's reliance on prefrontal-mediated regulation, yet it also introduces the potential for reduced efficiency under conditions of prolonged emotional suppression. Conversely, men display diminished ACC activation, reflecting a weaker emphasis on resolving emotional-cognitive conflicts and greater dependence on subcortical pathways for emotional regulation (Blair, 2012). This divergence underscores the differing costs of sex-specific regulatory strategies. Women's cognitive engagement may lead to greater emotional adaptability but could result in fatigue and heightened risk for stress-related disorders. Men's reduced ACC-PFC coordination limits their regulatory flexibility, highlighting the need for therapeutic approaches that enhance ACC engagement to improve their ability to manage complex emotional responses.

The hormonal modulation of ACC function further illustrates the need for sex-specific interventions, as testosterone suppresses ACC activity in men while estrogen enhances it in women (Davidson, 2002). Therapeutic strategies that balance these hormonal influences offer promising routes to optimize emotion regulation in both sexes.

Hormonal fluctuations provide an additional layer of complexity to neural mechanisms of anger suppression, significantly influencing emotional processing and regulation strategies. Estrogen's regulatory influence ensures that women experience decreased amygdala activity alongside heightened PFC involvement, creating an efficient framework for suppressing anger through cognitive appraisal strategies (Nelson & Trainor, 2007). This dynamic minimizes the emotional salience of anger-inducing stimuli while promoting adaptive responses, but it may also lead to overreliance on cognitive mechanisms, particularly during periods of hormonal fluctuation such as menopause. Reduced estrogen levels during menopause disrupt prefrontal-supported regulatory strategies, increasing vulnerability to emotional dysregulation and related mental health challenges (Blair, 2012). Conversely, the amplified emotional reactivity seen in men during anger suppression reflects testosterone's role in heightening amygdala activation and diminishing PFC involvement (Davidson et al., 2000). This hormonal modulation intensifies impulsive emotional responses, creating challenges for managing anger effectively. These findings emphasize the critical need for interventions that address hormonal fluctuations, particularly in designing therapeutic models that balance the physiological underpinnings of emotion regulation with the unique challenges posed by hormonal variability.

The evolutionary basis for these hormonal mechanisms offers additional insight into their adaptive purposes. Testosterone-driven aggression and heightened basal ganglia activity provided evolutionary advantages for males in high-stakes survival scenarios, whereas estrogen's enhancement of PFC activity aligns with social cohesion and cooperative behaviors critical to group stability (Geffner-Hoch, 1997; Nelson & Trainor, 2007). These evolutionary adaptations have shaped modern neural structures and highlight the interplay between biological and environmental pressures in shaping emotion regulation strategies. While testosterone-driven responses may have been advantageous in ancestral environments, their reduced adaptability in contemporary settings underscores the need for interventions that mitigate impulsive tendencies. Similarly, estrogen-driven emotional regulation, though advantageous for fostering social interactions, can impose cognitive costs in prolonged situations that demand sustained regulatory effort. Recognizing these evolutionary influences provides a contextual framework for understanding modern regulatory challenges and fosters the development of interventions that address these inherent limitations while leveraging their adaptive potential (Geffner-Hoch, 1997).

In summary, hormonal influences are deeply embedded in the neural mechanisms that differentiate anger regulation strategies between men and women. Testosterone's amplification of subcortical activity highlights men's reliance on automatic regulatory responses, while estrogen's enhancement of PFC activity emphasizes the adaptability of women's cognitive strategies. These complexities demonstrate the importance of considering hormonal modulation and functional connectivity in both theoretical exploration and the development of clinical interventions to address sex-specific differ-

ences in anger suppression effectively.

Sex Differences in Emotion Processing

Exploring the intricate landscape of emotion processing reveals how sex-specific differences influence anger regulation strategies. This section delves into the distinct cognitive patterns exhibited by men and women, examining how variations in brain structures and hormonal influences shape their approaches to managing anger. By understanding these differences, the work emphasizes the importance of tailoring interventions to meet the unique emotional needs of each sex, ultimately enhancing emotional regulation and mental health outcomes. This analysis builds on preceding discussions about the neurobiological foundations of anger suppression, providing a nuanced understanding of how gender impacts emotional responses.

Cognitive Strategies

Understanding cognitive strategies for managing anger is essential in delineating how men and women navigate the complexities of emotional regulation. This section explores the distinctive processing patterns exhibited by each sex, focusing on their reliance on either automatic responses or deliberate cognitive control mechanisms. By examining these variations, the discussion highlights the implications for therapeutic interventions tailored to address these differences and enhance emotional well-being. This analysis builds on the neurobiological foundations outlined previously, providing a nuanced understanding of the cognitive approaches employed in anger suppression.

Male Processing Patterns

Chronic anger suppression in men is strongly linked to heightened activity in subcortical regions, notably the basal ganglia. These regions are associated with automatic and habitual emotional responses rather than cognitive strategies mediated by the prefrontal cortex (PFC). Potegal (2012) outlined that this reliance on basal ganglia activity often undermines the adaptability of emotional regulation in men, particularly in intricate social or interpersonal scenarios. Men's dependence on these subcortical regions can be understood as an evolutionary adaptation, as subcortical processes are primed for rapid and automatic reactions to environmental threats. These mechanisms prioritize immediate responses over complex emotional evaluation, which might have been advantageous in high-risk situations. Nevertheless, in contemporary contexts requiring nuanced interactions, this reliance can hinder appropriate emotional regulation, emphasizing the need for modern therapeutic approaches that enable men to engage cognitive resources more effectively. Davidson (2002) similarly highlights that the persistent use of basal ganglia -mediated strategies predisposes men to emotional rigidity, an issue that becomes particularly problematic in managing anger in complex, non-threatening situations.

A notable consequence of the subdued role of the PFC in men's anger regulation is their diminished cognitive control over emotional impulses, which results in a tendency toward increased emotional reactivity and difficulty maintaining long-term anger management. Potegal (2012) emphasized that the PFC is instrumental in top-down regulation, mediating deliberate and controlled responses to emotional stimuli. The reduced reliance on the PFC in men limits their ability to suppress anger-inducing triggers effectively. Banks et al. (2007) observed that men's diminished PFC engagement correlates with an overactivation of subcortical

structures such as the amygdala, further amplifying emotional reactivity. This reduced ability to manage emotional stimuli underscores the significance of targeted interventions, such as cognitive-behavioral strategies, to enhance PFC functionality in men. Techniques like mindfulness and cognitive reappraisal have shown potential in increasing prefrontal involvement, ultimately strengthening self-regulation. Tan et al. (2021) advocate for mindfulness-based practices as a particularly effective means of encouraging PFC activity, which could mitigate the impulsive tendencies that arise from subcortical dominance.

The chronic nature of anger suppression in men is intricately linked to physiological stress markers, including elevated cortisol levels and heart rate variability. These physical indicators are closely tied to sustained subcortical activation in the face of limited PFC engagement. According to Hossain et al. (2020), this physiological imbalance leads to long-term health consequences, such as an increased risk of cardiovascular disease. Yang et al. (2015) further support this finding, highlighting that heightened basal ganglia activity contributes to persistent stress responses, ultimately resulting in health complications. Men's propensity for subcortical dominance over cognitive regulation not only limits effective anger management but also exacerbates physical vulnerability to stress-related conditions. Addressing these interconnected issues in clinical practice requires addressing the neurobiological and endocrine underpinnings of anger suppression while offering therapeutic tools that encourage both emotional regulation and stress mitigation. Relaxation training and biofeedback, as supported by Meyer-Lindenberg et al. (2006), may help men recalibrate their physiological responses to stress, thereby reducing the health risks associated with chronic anger suppression.

Hormonal influences, particularly testosterone, play a pivotal role in driving the neurobiological patterns that shape men's anger suppression strategies. Davidson (2002) and Nelson and Trainor (2007) assert that elevated testosterone levels heighten activity in subcortical regions, such as the basal ganglia and amygdala, contributing to the automatic, impulsive responses often observed in men's emotional regulation. This hormonal effect not only amplifies emotional reactivity but also inhibits the engagement of prefrontal cortical mechanisms responsible for cognitive regulation. Testosterone-driven activation of subcortical structures underscores an evolutionary basis for these patterns, as rapid, reflexive emotional responses were advantageous for survival in ancestral high-stakes situations (Potegal, 2012). However, as Nelson and Trainor (2007) explain, this biologically ingrained tendency poses challenges in modern contexts where nuanced, reflective emotional regulation is often necessary. Interventions targeting testosterone-mediated neural activity could mitigate these impulsive patterns. Pharmacological approaches that moderate testosterone levels or behavioral techniques that enhance cognitive regulation present promising pathways for addressing the hormonal basis of men's difficulties in anger suppression.

The interplay of testosterone and neural connectivity further limits men's ability to regulate anger effectively. Banks et al. (2007) found that functional connectivity between the PFC and amygdala is significantly weaker in men compared to women during anger suppression. This weaker coupling reduces the ability of men to exert top-down cognitive control over emotional salience, leaving subcortical structures such as the amygdala and basal ganglia

hyperactive. Davidson (2002) highlights that these reduced PFC-amygdala connections not only impair emotional regulation but also reinforce automatic responses, exacerbating impulsivity during anger-inducing scenarios. Enhancing this connectivity through therapeutic interventions could improve cognitive control in men, allowing for a shift away from habitual, automatic responses. Meyer-Lindenberg et al. (2006) suggest that neurofeedback techniques and cognitive training may enhance PFC -amygdala coupling, creating a more balanced framework for anger regulation in men. Understanding the evolutionary context of this weaker connectivity further underscores its limitations in modern social environments, where deliberative and reflective regulation is often required. Potegal (2012) adds that these discrepancies highlight the maladaptive consequences of evolutionarily advantageous mechanisms in present-day scenarios.

The persistent stress response observed in men during anger suppression correlates with the neurobiological and endocrine factors previously outlined. Testosterone amplifies the emotional reactivity of subcortical regions, such as the basal ganglia, reinforcing the physiological stress responses linked to anger suppression. Hossain et al. (2020) and Yang et al. (2015) demonstrate that this heightened stress response not only affects emotional regulation but also contributes to long-term physical health issues, including cardiovascular disease and hypertension. Elevated cortisol levels and other stress markers exacerbate these challenges, emphasizing the interconnectedness of emotional regulation, hormonal influences, and physical health. Addressing this requires an integrative approach to therapeutic intervention. Relaxation training, mindfulness-based practices, and biofeedback offer tools to reduce physiological stress responses while encouraging cognitive regulation (Tan et al., 2021). As these methods focus on mitigating the persistent stress responses associated with chronic anger suppression, they could significantly reduce the health risks specific to men, improving both emotional and physical outcomes.

In conclusion, chronic anger suppression in men is underpinned by distinctive neurobiological mechanisms, including heightened subcortical activity, weakened PFC involvement, and the influence of testosterone on emotional regulation. These factors not only pose challenges for effective anger management but also contribute to broader physical and emotional health risks. Strategies to enhance cognitive regulation and moderate hormonal influences offer a promising focus for addressing the unique difficulties faced by men in emotion regulation.

Female Processing Patterns

The neuropsychological processing of anger suppression in women is notably characterized by greater activation in the prefrontal cortex (PFC), which facilitates superior cognitive regulation of emotional responses. This differentiates women from men, who rely more on subcortical structures such as the basal ganglia during such regulation (Kong et al., 2014; Davidson, 2002). The increased involvement of the PFC enables women to engage in deliberate, top-down modulation of emotional impulses, specifically by downregulating the activity of the amygdala, which is central to emotional salience processing (Ali et al., 2020; Kong et al., 2014). This strategy allows women to manage anger more effectively, leveraging cognitive control to suppress impulsive emotional responses. However, the reliance on these neural mechanisms may also have implications for cognitive fatigue over time, which could help explain women's increased

vulnerability to mental health challenges.

The dorsolateral and ventrolateral regions of the PFC play critical roles in enabling women to regulate their emotional responses, particularly during anger suppression. This heightened PFC activity aligns with findings indicating that women are more likely to engage in emotion regulation strategies such as cognitive reappraisal, which involves reframing an emotional trigger in a less provocative light (Davidson, 2002). By relying on these cognitive approaches, women exhibit greater control over emotional triggers, positioning them to manage anger without succumbing to impulsive reactions. For example, Kong et al. (2014) demonstrated that enhanced PFC activation corresponds with more proficient emotional control, suggesting that the neural basis for anger regulation in women is deeply rooted in deliberate, reflective processes. This finding underscores the importance of PFC functionality in modulating emotional responses, but it also raises questions about whether long-term reliance on these strategies may impose cognitive or psychological costs.

The structural and functional connectivity between the PFC and regions such as the amygdala further solidifies women's regulation capabilities. This connectivity allows for efficient suppression of anger while maintaining emotional control, a process largely mediated by estrogen's influence on the neurobiological system (Kong et al., 2014; Ali et al., 2020). Estrogen enhances synaptic connections in the PFC, promoting sustained activation and better top-down regulation of the amygdala. By effectively modulating emotional intensity, women are able to suppress anger more consistently and employ adaptive coping strategies (Kong et al., 2014; Ali et al., 2020). However, the increased reliance on this network also poses risks, as it may make women more susceptible to emotional exhaustion or disorders such as anxiety and depression. These considerations invite further research into how hormonal or neural interventions might mitigate these risks while maintaining the regulatory advantages of strong PFC-amygdala connectivity.

Reduced amygdala activity during anger suppression in women highlights a significant sex-specific mechanism in emotion regulation. This decrease in amygdala activation diminishes the salience of anger-inducing stimuli, promoting cognitive over automatic emotional regulation strategies (Kong et al., 2014). Estrogen plays a critical role in modulating this process by enhancing the functional connectivity between the amygdala and the PFC, enabling women to disengage from reactive behaviors and adopt cognitive appraisal strategies (Ali et al., 2020). This hormonal modulation not only prevents the escalation of emotional intensity but also facilitates the maintenance of emotional composure, particularly in social or interpersonal contexts (Kong et al., 2014). Nonetheless, the long-term implications of such diminished amygdala activity warrant further scrutiny, as persistent downregulation may reduce the brain's capacity to recalibrate emotional responses, potentially leading to suppressed emotions manifesting as psychological distress.

The attenuated emotional reactivity associated with amygdala downregulation reflects an adaptive advantage in women, particularly for navigating complex social dynamics. Evidence suggests that this regulatory strategy may have evolved to foster social cohesion and minimize conflict (Kong et al., 2014; Ali et al., 2020). However, the consistent use of cognitive appraisal strategies, facilitated by reduced amygdala activation, may impose significant

cognitive demands over time. Research suggests that such prolonged activation of cortical regions like the PFC to regulate emotions can increase susceptibility to mental fatigue, potentially contributing to higher rates of anxiety and depression among women (Ali et al., 2020). These findings indicate both the strengths and vulnerabilities in women's emotion regulation strategies, calling for targeted interventions that balance the advantages of cognitive regulation with the risks of mental fatigue.

Estrogen's role in enhancing PFC activity is central to understanding women's capacity for effective anger regulation. By augmenting the structural and functional connectivity between the PFC and other emotion-regulating regions, estrogen supports a framework for deliberate cognitive strategies to suppress anger. Davidson et al. (2000) and Nelson and Trainor (2007) report that estrogen-driven connectivity allows women to manage anger with greater composure, achieving a balance between emotional salience and reflective response. This advantage, however, fluctuates with hormonal changes. For instance, reductions in estrogen levels during menopause may weaken PFC-driven regulation strategies, leading to increased susceptibility to anger dysregulation and related mood disorders (Nelson & Trainor, 2007). The interplay between hormonal changes and neural activity thus underscores the importance of considering hormonal contexts when developing therapeutic treatments for anger-related mental health issues in women.

The reliance on estrogen-enhanced regulatory mechanisms offers evolutionary insights, suggesting that these adaptations have historically supported women's roles in fostering group stability and cooperation. By enabling nuanced emotion regulation, estrogen has contributed to behaviors that promote social cohesion (Davidson et al., 2000; Nelson & Trainor, 2007). However, these regulatory advantages must be analyzed alongside the potential cognitive costs they impose, particularly as modern societal demands increase the need for sustained emotional regulation. Understanding these dynamics can inform the development of interventions that mitigate the risks associated with prolonged PFC activation while leveraging the strengths of estrogen-driven regulation.

Despite its immediate regulatory benefits, women's heightened PFC engagement during anger suppression has been linked to an increased vulnerability to stress-related disorders. Sustained cortical activity necessary for cognitive regulation imposes significant cognitive demands that can lead to mental fatigue. This fatigue is strongly associated with conditions such as anxiety and depression, which are observed at higher rates in women than in men (Ali et al., 2020; Kong et al., 2014). Prolonged cognitive effort in anger regulation may exacerbate these vulnerabilities, as the brain's capacity for emotional control diminishes over time. Ali et al. (2020) note that this strain is further complicated by rumination, a common cognitive process in women that amplifies emotional stress and contributes to depressive symptoms. These findings highlight the need for interventions that address the cognitive and psychological toll of prolonged anger suppression, particularly in women.

Blunted amygdala activity, while beneficial for immediate emotional control, may also present challenges for women's long-term emotional well-being. By prioritizing cognitive appraisal methods, women may inadvertently accumulate suppressed emotional responses, which could increase the risk

of psychological distress over time (Kong et al., 2014). Furthermore, the hormonal influences that facilitate amygdala downregulation may vary, particularly during times of hormonal fluctuation, such as menopause, further complicating women's regulatory strategies. These findings point to the complex interplay between the neural mechanisms of anger suppression and the broader mental health implications for women, underscoring the need for tailored therapeutic approaches.

Neurobiological evidence suggests that women's stress-specific responses may further contribute to their vulnerability during periods of anger suppression. Tan et al. (2021) found that stressed women exhibit diminished dopamine activity in the ventral tegmental area (VTA), which contributes to social withdrawal and emotional disengagement. Chronic anger suppression may exacerbate these neural changes by depleting dopamine-mediated reward systems, creating a self-reinforcing cycle of isolation and emotional dysregulation (Tan et al., 2021). This interaction between anger suppression and stress-specific dopamine activity increases the likelihood of depressive symptoms, highlighting the need for interventions that target both regulatory and reward circuits in women.

Structural imaging studies offer further insight into women's emotion regulation strategies. Increased regional gray matter volume (rGMV) in emotion-regulating regions such as the left amygdala, left hippocampus, and left insular cortex supports women's nuanced emotional regulation abilities (Kong et al., 2014; Zhen et al., 2014). These structural adaptations suggest an evolutionary advantage in managing complex emotional states. For example, the left hippocampus and insular cortex contribute to contextualizing emotional memories and self-awareness, which are critical for cognitive regulation of anger-inducing events (Kong et al., 2014; Zhen et al., 2014). These findings underscore how structural differences in rGMV align with women's reliance on cognitive strategies for anger suppression while highlighting the interplay between anatomy and function in shaping emotion regulation.

These neuropsychological and hormonal dynamics emphasize that women's anger suppression strategies are deeply rooted in both adaptive and modern contextual frameworks. While enhanced PFC activity promotes effective emotional control, it may also create vulnerabilities to mental health challenges due to the cognitive and psychological strain it imposes. Understanding the interconnected roles of hormonal influences and structural adaptations is crucial for developing sex-specific interventions that address these vulnerabilities while supporting women's unique strengths in emotion regulation.

Role of Brain Structures

The intricate interplay between brain structures significantly shapes how individuals process and regulate anger, revealing a complex landscape of neural activity influenced by sex differences. Focusing on the prefrontal cortex and amygdala, this section explores how these regions contribute to distinct emotional regulation strategies, highlighting the cognitive and hormonal factors that underpin these processes. Understanding these neural dynamics not only enhances our grasp of anger management but also informs tailored therapeutic approaches for both sexes, addressing their unique vulnerabilities in emotional regulation. Building on prior discussions, this analysis connects the biological bases of emotion processing to broader mental health implications, setting the stage for effective interventions.

Prefrontal Cortex Function

The prefrontal cortex (PFC) is a critical brain region involved in the cognitive regulation of anger, playing a pivotal role in modulating subcortical structures such as the amygdala to manage emotional responses through higher-order cognitive processes. Its functionality allows for the intentional suppression of impulsive anger-related behaviors, with marked differences observed between sexes. Research has shown that women demonstrate significantly stronger PFC activity during anger suppression, supported by hormonal influences such as estrogen, which facilitates cognitive regulation. Kong et al. (2014) and Ali et al. (2020) have emphasized the central importance of the PFC in integrating information across brain regions to suppress emotionally reactive behaviors. This underscores its role in enabling deliberate, reflective regulation of anger responses, particularly in women, who engage these mechanisms more robustly than men. Although this makes the PFC indispensable for anger management, its efficiency is influenced by several factors, including sex-specific patterns, hormonal contributions, and neural connectivity, all of which warrant deeper exploration.

The role of the PFC in women's anger suppression strategies highlights the reliance on cognitive appraisal techniques to regulate emotions. Women's stronger coupling between the PFC and amygdala enables effective downregulation of emotional salience, as evidenced by Kong et al. (2014) and Ali et al. (2020). This interplay reflects women's greater reliance on cognitive mechanisms to manage anger compared to the more reflexive subcortical responses observed in men. Furthermore, Davidson (2002) and Nelson and Trainor (2007) attributed this enhanced regulatory ability to estrogen, which strengthens PFC-mediated networks. These findings align with Sacher et al. (2013), who described sexual dimorphism in brain structure and function, noting women's heightened baseline PFC activity as a key factor contributing to their superior cognitive regulation abilities. Despite the evident advantages of this approach, the sustained cognitive effort required for anger suppression may impose significant mental costs, raising questions about the long-term implications, particularly concerning cognitive fatigue and mental health.

Structural and functional connectivity between the PFC and other key regions, such as the amygdala, further elucidates sex-specific anger regulation strategies. Women's reliance on PFC-amygdala communication underscores their preference for deliberate emotional control over impulsive responses (Banks et al., 2007; Davidson, 2002). Estrogen's influence on this functional integration is particularly notable, as it enhances PFC activity and strengthens its connectivity with subcortical emotion-processing structures, thus enabling effective regulation of anger-inducing stimuli (Ali et al., 2020; Nelson & Trainor, 2007). These findings are supported by Okon-Singer et al. (2013), who highlighted sex-specific patterns in neural connectivity through neuroimaging studies, affirming the importance of hormonal and structural factors in shaping emotional regulation. However, men's reduced PFC-amygdala connectivity reflects their limited capacity for top-down cognitive control, which predisposes them to automatic subcortical-driven responses during anger suppression (Davidson, 2002; Banks et al., 2007). This divergence necessitates an examination of how therapeutic approaches could strengthen PFC-amygdala pathways in men to address these regulatory limitations.

Men exhibit markedly diminished PFC activation during anger suppression, which correlates with weaker top-down control over emotional impulses and a greater reliance on subcortical regions such as the basal ganglia. This subcortical dominance often results in less flexible and reactive anger regulation strategies (Potegal, 2012; Davidson, 2002). Testosterone appears to exacerbate this pattern, amplifying basal ganglia activity and promoting more automatic emotional responses while limiting PFC engagement (Nelson & Trainor, 2007; Davidson, 2002). Strohmaier et al. (2013) provided evidence of genetic interactions with testosterone, specifically variations in the CACNA1C gene, which further influence emotional regulation in males. These findings underscore the compounded challenges men face in regulating anger, where diminished cognitive engagement and hormonal influences exacerbate impulsivity and emotional rigidity. Addressing these deficits requires targeted interventions that enhance PFC activity and reduce reliance on subcortical circuits.

The physiological consequences of impaired PFC functionality in men further highlight the challenges in managing anger effectively. Men's reliance on subcortical mechanisms during anger suppression is associated with heightened physiological markers of stress, including elevated cortisol levels and heart rate variability (Hossain et al., 2020; Yang et al., 2015). These stress responses contribute to long-term health risks, such as cardiovascular disease, reinforcing the interconnectedness of emotional regulation and physical health outcomes. In contrast, women's regulatory strategies, though cognitively demanding, mitigate immediate physiological stress responses through enhanced PFC engagement and amygdala connectivity (Ali et al., 2020). However, the cognitive toll on women, particularly the mental effort required for sustained emotional regulation, may increase their susceptibility to stress-related disorders such as anxiety and depression (Kong et al., 2014). These differing physiological impacts underline the need for sex-specific therapeutic interventions to address the unique vulnerabilities associated with anger suppression in both sexes.

The prolonged activation of the PFC in women during anger suppression poses distinct risks, including cognitive fatigue and heightened vulnerability to mental health challenges. This contrasts with men, whose reduced PFC involvement predisposes them to physical health risks stemming from stress-induced subcortical dominance (Hossain et al., 2020; Yang et al., 2015; Ali et al., 2020). Tan et al. (2021) identified sex-specific neurochemical responses to chronic stress, such as diminished dopamine activity in the ventral tegmental area in women, which may interact with anger suppression to exacerbate emotional disengagement and depressive symptoms. These findings suggest that while women excel at deliberate emotional regulation, the sustained effort required for PFC-driven strategies may create long-term costs that require further research. Targeted therapeutic approaches that reduce cognitive load while maintaining regulatory effectiveness could help mitigate these vulnerabilities.

The evolutionary context of PFC activation offers valuable insights into the observed differences in anger regulation between sexes. Women's enhanced PFC engagement likely evolved to support nuanced emotional control and social cohesion, aligning with their role in maintaining group stability (Potegal, 2012; Nelson & Trainor, 2007). Men's reliance on subcortical pathways reflects adapta-

tions favoring rapid, survival-oriented responses, which may have been advantageous in ancestral environments (Potegal, 2012; Nelson & Trainor, 2007). Gotowiec et al. (2013) observed baseline neural activity differences between sexes, highlighting how these evolutionary traits manifest in modern anger regulation practices. Hu et al. (2020) added that such adaptations contribute to the distinct strategies employed by men and women, with women favoring cognitive regulation and men leaning toward automatic responses. These findings underscore the need for therapeutic interventions that consider these evolutionary patterns and address the maladaptive consequences of these strategies in contemporary contexts.

Clinical research emphasizes the significance of enhancing PFC functionality in developing sex-specific interventions for anger regulation. Cognitive-behavioral therapy (CBT) offers a promising approach by strengthening neural pathways in the PFC, thereby improving control over anger responses, particularly in men who exhibit impaired top-down regulation (Bonanno et al., 2004; Tan et al., 2021). Meyer-Lindenberg et al. (2006) advocated for integrating neuroimaging tools into therapy design to identify specific PFC deficits, enabling personalized treatment plans. Combining cognitive training with mindfulness practices, as suggested by McIntyre et al. (2020), further enhances PFC functionality, reducing impulsivity and fostering improved emotional regulation. These tailored approaches address the unique needs of each sex, acknowledging the physiological and cognitive challenges that influence anger suppression strategies.

In conclusion, the PFC plays a multifaceted role in anger regulation, with distinct sex-specific differences shaping its activity and connectivity. Women's greater reliance on the PFC provides immediate regulatory advantages but imposes cognitive and emotional costs, which highlight vulnerabilities to stress-related disorders. Men's reduced PFC engagement underscores a reliance on automatic subcortical responses, creating challenges in achieving long-term anger management and exposing vulnerabilities to physical health risks. Addressing these disparities requires targeted interventions that enhance PFC functionality, consider hormonal influences, and leverage the strengths of each sex's regulation strategies to mitigate associated risks.

Amygdala Activation

The amygdala plays a pivotal role in processing the emotional salience of anger-inducing stimuli, and its activity during anger suppression reveals notable sex-specific differences. Women tend to exhibit reduced amygdala activity, a reflection of their reliance on cognitive appraisal strategies mediated by the prefrontal cortex (PFC). This attenuation of amygdala activity allows women to disengage from immediate emotional reactions, displaying a controlled and deliberate approach to regulating anger (Kong et al., 2014; Ali et al., 2020; Davidson, 2002). By reducing the salience assigned to anger-inducing stimuli, women benefit from a top-down modulation mechanism that ensures emotional regulation is executed with reduced impulsivity (Kong et al., 2014). In contrast, men often display stable or heightened amygdala activity during anger suppression, which signifies a diminished dependence on cognitive strategies and a stronger inclination toward automatic emotional responses (Davidson, 2002). These distinctions in amygdala activity may have profound implications for understanding the differing vulnerabilities of each sex in managing emotional reactivity and stress.

Estrogen emerges as a critical hormonal regulator that influences amygdala activity in women, facilitating more effective anger suppression through enhanced connectivity between the PFC and the amygdala. This interconnection enables a seamless translation of cognitive regulation into emotional restraint, reducing the intensity of reactive emotional responses (Nelson & Trainor, 2007; Ali et al., 2020; Kong et al., 2014). By promoting functional integration of regulatory centers in the brain, estrogen enables women to adopt less impulsive and more reflective approaches to anger management. In contrast, the absence of these estrogenic effects in men correlates with a more dominant role for subcortical structures, particularly the amygdala and basal ganglia, resulting in heightened emotional reactivity and reduced reliance on cognitive regulation (Kong et al., 2014). The hormonal modulation of neural connectivity highlights the stark contrast between male and female anger suppression strategies, which is reinforced by the interplay between physiological and neural mechanisms.

In males, elevated testosterone levels are strongly associated with increased amygdala activation during anger suppression, reinforcing a reactive and automatic emotional processing style. Testosterone amplifies subcortical activity, including the amygdala, while concurrently limiting the PFC's regulatory influence (Davidson, 2002; Nelson & Trainor, 2007). This hormonal mechanism plays a critical role in fostering heightened emotional reactivity, which may be advantageous in rapid-response scenarios historically essential for survival, yet maladaptive in modern contexts where nuanced emotional regulation is necessary (Nelson & Trainor, 2007). The physiological consequences of testosterone-driven amygdala overactivation extend beyond emotional regulation. For instance, increased autonomic responses, including elevated cortisol levels and heart rate variability, have been linked to long-term health risks such as cardiovascular disease (Lischke et al., 2019). These findings underscore the importance of developing pharmacological and behavioral interventions to target testosterone-driven influences on amygdala activity, potentially enhancing cognitive control mechanisms to foster more balanced emotional regulation strategies (Davidson, 2002; Nelson & Trainor, 2007).

Women's reduced amygdala activity during anger suppression reflects an adaptive mechanism that mitigates impulsivity and ensures greater emotional stability; however, it is not without its drawbacks. The cognitive demands imposed by high PFC activity, required to maintain successful anger regulation, increase susceptibility to stress-related disorders such as anxiety and depression (Whittle et al., 2011). While decreased amygdala activation enhances immediate emotional control, it does little to alleviate accumulated emotional strain. This may explain the higher prevalence of rumination observed among women, where persistent cognitive engagement with emotional stimuli exacerbates mental health risks (Kong et al., 2014; Whittle et al., 2011). Moreover, hormonal fluctuations, particularly reductions in estrogen levels during menopause, may diminish women's ability to sustain effective anger suppression strategies over time (Ali et al., 2020). These findings suggest a need for therapeutic interventions that balance women's reliance on cognitive regulation with techniques that alleviate prolonged emotional strain and mitigate the cumulative effects of sustained anger suppression (Kong et al., 2014; Whittle et al., 2011).

Chronic amygdala activation in men during anger suppression contributes to heightened physiological

stress responses, such as increased heart rate variability (HRV) and elevated cortisol levels. These responses are indicative of an overactive stress system rooted in subcortical dominance during emotional regulation (Lischke et al., 2019). Over time, such stress markers contribute to significant physical health risks, including hypertension and cardiovascular disease, which are observed at higher rates in men than in women (Hossain et al., 2020). The feedback loop created by persistent amygdala activation and stress responses reinforces a reactive emotional processing style, reducing the effectiveness of anger regulation (Yang et al., 2015). Addressing this physiological burden requires targeted interventions, such as biofeedback and relaxation training, which have demonstrated potential in decreasing autonomic stress markers and improving emotional regulation (Lischke et al., 2019; Hossain et al., 2020). These therapeutic approaches underscore the necessity of addressing the unique physiological vulnerabilities faced by men as a result of chronic anger suppression.

The habitual differences in amygdala activity observed between the sexes may stem from evolutionary pressures that shaped distinct emotional regulation strategies. For women, attenuated amygdala activity supports nuanced social behaviors and emotional control, which likely evolved to promote cooperation and stability within social groups (Love, 2018). In contrast, heightened amygdala responses in men align with survival-oriented strategies that prioritize rapid vigilance and threat detection over more reflective emotional regulation (Nelson & Trainor, 2007). While these adaptations provided evolutionary advantages, their persistence in modern contexts can create mismatches with contemporary emotional demands (Potegal, 2012). For instance, men's reliance on reactive mechanisms may limit their ability to navigate complex social scenarios requiring cognitive regulation, whereas women's reliance on sustained PFC engagement may increase susceptibility to cognitive fatigue. Therapeutic interventions that acknowledge these evolutionary influences can better address the maladaptive consequences of these anger regulation strategies (Potegal, 2012; Love, 2018).

The interplay between evolutionary biology and modern neuroscience provides a foundation for understanding the sex-specific mechanisms of anger suppression and their clinical significance. For women, leveraging cognitive regulation techniques that align with their PFC-mediated strategies may reduce the risks associated with cognitive fatigue while preserving emotional control. For men, interventions that strengthen PFC-amygdala connectivity and reduce amygdala overactivation could foster more balanced regulatory strategies, mitigating the physiological burden of chronic stress. These insights underscore the necessity of tailoring therapeutic approaches to accommodate the distinct neural and hormonal factors that influence anger suppression in men and women. Conclusively, understanding these sex-specific differences not only enriches the scientific discourse but also informs the development of effective, evidence-based interventions (Nelson & Trainor, 2007; Potegal, 2012; Love, 2018).

Clinical Implications and Interventions

The intricate relationship between chronic anger suppression and mental health necessitates a focused exploration of therapeutic strategies tailored to the unique needs of men and women. This section delves into the mental health impacts of sustained emotional regulation, highlighting the sex-

specific vulnerabilities that arise from differing neural and hormonal influences. By examining a range of treatment approaches, including cognitive-behavioral strategies and emotion-focused interventions, it aims to provide actionable insights for addressing the challenges posed by anger suppression, ultimately enhancing emotional well-being. This discussion builds on previous analyses of neurobiological foundations and sex differences in emotion processing, reinforcing the importance of personalized interventions in fostering healthier emotional regulation.

Mental Health Impact

The mental health impact of chronic anger suppression is a multifaceted concern, with research indicating significant risks of mental health disorders such as anxiety and depression arising from prolonged emotional regulation efforts. Evidence suggests that these effects are not uniformly distributed between sexes, with women disproportionately affected due to their reliance on sustained cognitive regulation mechanisms. Women's characteristic use of the prefrontal cortex (PFC) for anger suppression may exacerbate their vulnerability to these conditions, as extended activation of this brain region can overload cognitive resources and amplify stress-related symptoms. Pelz (2024) highlights that the PFC becomes less efficient under prolonged stress conditions, leading to maladaptive cognitive patterns like rumination, which further heighten emotional distress. This aligns with findings by Green and Malhi (2014), who suggest that impairments in emotion regulation, particularly those mechanisms requiring deliberate and conscious cognitive control, can significantly increase the risk of developing clinical levels of anxiety and depression. Thus, the sex-specific reliance on the PFC for anger suppression not only facilitates immediate emotional control but also imposes long-term mental health costs.

The neural patterns underpinning anger suppression reveal a complex regulatory imbalance between cognitive and emotional processes, further elucidating the heightened mental health vulnerabilities observed in women. Women's reduced amygdala activity reflects a diminished reliance on reactive emotional suppression strategies, necessitating greater dependence on the PFC for emotional regulation (Davidson, 2002). While this cognitive approach confers short-term benefits in controlling impulsivity, it may impede the resolution of underlying psychological stress, contributing to the chronic mental health challenges women face. Pelz (2024) identifies this imbalance as a key factor in prolonged emotional strain, which manifests as anxiety and depressive disorders. Similarly, Green and Malhi (2014) underscore the importance of this neural dichotomy, suggesting that women's reduced reliance on reactive subcortical processes may hinder the immediate mitigation of emotional intensity, thereby exacerbating chronic stress. The interplay between these cognitive and neural mechanisms necessitates further exploration to understand how targeted interventions could alleviate the long-term costs of such regulatory imbalances.

Hormonal influences play a pivotal role in modulating the mental health impacts of chronic anger suppression, with estrogen emerging as a significant factor in women's regulatory strategies. Estrogen enhances connectivity between the PFC and amygdala, thereby facilitating controlled anger suppression and reducing immediate emotional reactivity (Ali et al., 2020; Nelson & Trainor, 2007). However, this hormonal modulation may also increase women's susceptibility to stress-related mental

health concerns when cognitive regulation is overutilized. Green and Malhi (2014) propose that the heightened intensity of emotional experiences, driven by estrogenic effects, creates a conflicting burden for women managing anger suppression. This duality highlights the need to critically examine the role of estrogen in shaping emotional regulation and its potential contribution to anxiety and depression. Conversely, the hormonal mechanisms in men, particularly the influence of testosterone, amplify subcortical activity in regions like the amygdala and basal ganglia, promoting reactive emotional responses (Davidson, 2002; Nelson & Trainor, 2007). While these testosterone-driven responses support rapid emotional reaction, they may exacerbate aggression and stress, contributing to both mental and physical health risks (Ali et al., 2020). Addressing these hormonal dynamics could inform the development of interventions that specifically target the unique vulnerabilities associated with estrogen and testosterone in anger regulation.

The broader mental health consequences of chronic anger suppression are further compounded by neural dysfunctions in key regulatory regions, including the anterior cingulate cortex (ACC) and insula. These areas are crucial for resolving emotional conflicts and integrating emotional experiences, yet aberrant activity within these regions disrupts their regulatory capacity (Green & Malhi, 2014). Such impairments not only elevate the risk of anxiety and depression in women but also exacerbate the stress-related health risks observed in men. Pelz (2024) underscores the detrimental effects of dysregulated connections between the PFC and subcortical structures, suggesting that these deficits result in maladaptive outcomes that differ between sexes. For women, the excessive reliance on cognitive strategies intensifies mental health risks, while men's impaired top-down regulation mechanisms promote reactive and physiologically taxing emotional responses. Addressing these neural dysfunctions through therapeutic approaches could mitigate the distinct and multifaceted consequences of anger suppression for both sexes, offering a pathway to improved emotional well-being.

Childhood adversities, such as physical abuse, further exacerbate the mental health outcomes associated with anger suppression. Springer et al. (2007) demonstrate a strong correlation between early-life physical abuse and adult mental health disorders, including depression, anxiety, and anger-related issues. These findings highlight the long-lasting impact of early adversities on the development of maladaptive emotional regulation mechanisms, particularly in individuals who resort to anger suppression as a coping strategy. Women are disproportionately affected due to higher reported prevalence rates of childhood abuse and their cognitive reliance on sustained PFC activation during anger suppression (Springer et al., 2007). This sex-specific discrepancy underscores the importance of addressing childhood experiences in therapeutic interventions for anger-related disorders. Moreover, disrupted neural regulation arising from such adversities creates lasting imbalances in PFC and amygdala interactions, mirroring the deficits identified in adults with histories of physical abuse. These cumulative effects underline the necessity for early intervention strategies to mitigate the long-term mental health burdens associated with dysfunctional anger regulation.

The physiological stress markers associated with chronic anger suppression also define critical sex-specific health risks. Men demonstrate elevated cortisol levels and increased heart rate variability

due to prolonged activation of subcortical regions such as the amygdala and basal ganglia (Pelz, 2024; Lischke et al., 2019). These physiological markers reflect an overactive stress system that not only exacerbates impulsive emotional responses but also promotes physical health complications, including cardiovascular disease. Pelz (2024) notes that this subcortical dominance limits the engagement of the PFC, undermining cognitive regulatory mechanisms and amplifying stress responses. In contrast, women's regulatory reliance on the PFC mitigates some immediate physiological stress markers but imposes significant cognitive demands that contribute to mental health vulnerabilities, including anxiety and depression (Davidson, 2002; Pelz, 2024). These findings emphasize the interconnectedness of emotional regulation, physiological stress, and physical health outcomes, highlighting the importance of addressing these factors within sex-specific therapeutic frameworks.

In conclusion, the mental health consequences of chronic anger suppression reflect intricate interactions between neural mechanisms, hormonal influences, and sex-specific regulatory strategies. Women's reliance on PFC-centered regulation predisposes them to mental health disorders like anxiety and depression, while men's subcortical-driven responses heighten physiological stress and physical health risks. These distinct patterns underscore the necessity of tailoring interventions to address the unique vulnerabilities associated with anger suppression in men and women. By integrating insights from neuroscience, endocrinology, and psychology, targeted therapeutic approaches could effectively mitigate the adverse mental health outcomes of chronic anger suppression, fostering improved emotional and physical well-being.

Treatment Approaches

Treatment approaches for anger suppression must be tailored to address the distinct neural, hormonal, and psychological differences between sexes, ensuring effective management of anger-related disorders. Cognitive-behavioral therapy (CBT) emerges as a promising intervention for enhancing prefrontal cortex (PFC) engagement, particularly in men who often display weaker top-down control mechanisms during anger regulation. Key components of CBT, such as cognitive appraisal and mindfulness training, have demonstrated efficacy in improving neural circuitry associated with emotional regulation. For men, enhancing PFC engagement is critical given the reliance on subcortical structures like the basal ganglia, which often drive impulsive and less effective anger regulation strategies. Studies, including those by Meyer-Lindenberg et al. (2006) and Bonanno et al. (2004), underscore that structured CBT programs focusing on reinterpreting anger-inducing stimuli can rewire neural pathways, strengthening cognitive control. Moreover, the integration of mindfulness techniques into CBT fosters nonjudgmental awareness of emotional states, promoting increased PFC functionality and facilitating better emotional outcomes (Tan et al., 2021). These findings highlight the importance of systematically adapting CBT for sex-specific needs, considering the neural mechanisms underlying anger suppression.

Building on these therapeutic insights, combining CBT with biofeedback technologies offers an innovative way to provide real-time data on neural activity during emotional regulation. For men, who exhibit heightened basal ganglia and amygdala activity during anger suppression, biofeedback can serve as a tool to monitor and adjust these responses, promoting better self-regulation (Bonanno et al.,

2004). By targeting subcortical hyperactivation, biofeedback enables a more deliberate engagement of the PFC, a mechanism supported by neuroimaging studies that highlight the potential for neural plasticity in response to intervention (Achterberg et al., 2016). These insights align with findings by Meyer-Lindenberg et al. (2006), which suggest that targeted interventions can alleviate impulsive responses by enhancing top-down regulatory pathways. However, despite the strengths of these approaches, critical examination of their accessibility and long-term efficacy reveals gaps in their scalability, particularly in clinical populations with limited resources or access to advanced neuroimaging tools. This underscores the need for continued research into integrating such technologies within standardized therapeutic frameworks.

Hormonal influences also play a pivotal role in shaping anger regulation strategies, necessitating their inclusion in treatment planning. Testosterone, associated with increased amygdala and basal ganglia activity, contributes to reactive emotional responses in men, thereby amplifying the challenges associated with anger regulation (Nelson & Trainor, 2007). Relaxation techniques, such as progressive muscle relaxation and deep breathing exercises, have been shown to mitigate physiological stress markers linked to testosterone-driven emotional reactivity (Meyer-Lindenberg et al., 2006). Similarly, pharmacological interventions that target hormonal imbalances could complement behavioral therapies by reducing testosterone's impact on neural activation patterns, fostering improved anger regulation. For women, estrogen plays a dual role in facilitating PFC-amygdala connectivity, which aids in anger suppression, but also increases the cognitive burden associated with sustained regulation (Ali et al., 2020). Tailored stress-reduction programs, encompassing techniques like journaling or creative expression, can help alleviate the mental fatigue linked to estrogen-mediated PFC overactivation. These findings align with Nelson and Trainor's (2007) observations on hormone-driven differences in neural connectivity, emphasizing the importance of gender-sensitive interventions that consider the distinct neuromodulatory effects of testosterone and estrogen.

Emotion-focused interventions can further address the unique needs of women by alleviating the chronic overactivation of the PFC, which characterizes their anger regulation strategies. Approaches such as emotional processing therapy (EPT) provide women with structured opportunities to express suppressed anger, mitigating the risk of mental fatigue and associated conditions like anxiety and depression (Ali et al., 2020; Achterberg et al., 2016). Techniques like expressive writing and guided role-playing promote healthier emotional expression, reducing the cognitive load imposed by prolonged suppression. The social dimension of group-based interventions also plays a significant role. By fostering shared experiences and social validation, women can navigate anger-related challenges more effectively, reducing feelings of isolation (Davidson, 2002). Additionally, body-oriented therapies such as yoga or somatic experiencing address the interconnectedness of emotional and physical regulation, shifting the burden away from purely cognitive approaches to integrate holistic well-being (Ali et al., 2020). While these interventions demonstrate potential, further research is needed to quantify their long-term benefits, particularly in reducing symptoms of stress-related mental health disorders.

Clinically, findings on sex-specific brain structures

must be leveraged to customize interventions effectively. For men, therapies targeting subcortical activity, such as biofeedback, focus on heightening awareness of basal ganglia responses while promoting deliberate PFC activation (Banks et al., 2007). Conversely, women benefit from programs that enhance PFC-amygdala connectivity, balancing cognitive and emotional processing to prevent excessive reliance on top-down regulation (Kong et al., 2014). Integrating neuroimaging tools within therapeutic protocols allows for precise identification of structural and functional deficits, offering pathways for tailored intervention. For example, functional MRI can quantify hyperactivity in men's amygdala or weaker PFC activity in women, aiding in the development of sex-specific therapies (Achterberg et al., 2016). Furthermore, combining pharmacological approaches with behavioral therapies may amplify interventions by addressing underlying hormonal influences. For women, strategies such as estrogen-related treatments could be integrated with PFC-focused cognitive training to optimize regulatory outcomes, while testosterone-modulating interventions for men align well with reducing subcortical dominance (Nelson & Trainor, 2007). Despite their promise, the implementation of such comprehensive approaches remains a logistical challenge, particularly in resource-constrained settings, warranting further exploration of cost-effective deployment strategies.

Preventive interventions targeting intrapersonal emotional intelligence (IEI) during adolescence hold significant promise for mitigating anger-related issues later in life. Empirical evidence suggests that low IEI correlates with emotional dysregulation, underscoring the need for early interventions that promote self-awareness, emotional regulation, and effective anger management strategies (Garaigordobil, 2020). Schools can play a pivotal role by integrating emotional intelligence training into curricula, enabling adolescents to develop healthier responses to anger-inducing scenarios. Findings by Fischer (1993) further emphasize that understanding emotional regulation strategies during formative years is critical for fostering emotional resilience in adulthood. In addition to institutional support, early screening for low IEI can identify individuals at risk of developing maladaptive anger suppression behaviors, directing them toward targeted workshops or therapy programs (Garaigordobil, 2020). Parental involvement also emerges as a critical factor, with maternal acceptance-affection playing a significant role in enhancing IEI and subsequently mitigating anger-related vulnerabilities (Garaigordobil, 2020). These preventive measures are not without their limitations, particularly in ensuring consistent implementation across diverse socio-economic contexts, which necessitates broader public health initiatives to address disparities.

Neuroimaging tools offer a transformative avenue for tailoring anger suppression therapies, enabling clinicians to design personalized treatment strategies based on neural activity patterns. For instance, neuroimaging can reveal overactive amygdala responses in men or weakened PFC-amygdala connectivity in women, guiding the choice of interventions such as relaxation techniques or cognitive training (Meyer-Lindenberg et al., 2006). Functional imaging also enables the tracking of therapy progress by monitoring changes in neural activation, providing measurable feedback to refine treatment plans (Achterberg et al., 2016). Furthermore, imaging findings can inform pharmacological decisions, such as the use of testosterone-modulating medications for men exhibiting heightened amygdala ac-

tivity or estrogen-focused treatments for women with diminished PFC functionality (Davidson, 2002). While neuroimaging holds substantial potential for advancing therapeutic precision, its widespread application is limited by cost and accessibility; thus, integrating these tools into public health frameworks remains a critical challenge requiring innovative solutions.

In summary, treatment approaches for anger suppression must address diverse neural, hormonal, and psychological factors, emphasizing sex-specific needs to optimize therapeutic outcomes. Integrating cognitive, emotional, and technological interventions enriches the capacity to manage anger -related disorders effectively, providing pathways to improved mental and physical health.

Conclusion

This research aimed to explore the neural mechanisms underlying anger suppression and their sex-specific differences, examining the role of brain structures, hormonal influences, and the implications for mental health and therapeutic interventions. By synthesizing an array of interdisciplinary studies, this work has provided substantial evidence elucidating how men and women engage distinct neural circuits and regulatory strategies when managing anger. The findings not only address the primary research question concerning the neurological and psychological divergences in anger suppression between the sexes but also contribute to a nuanced understanding of the broader mental health impacts associated with chronic anger regulation. These insights pave the way for designing targeted, evidence-based therapeutic interventions tailored to the unique vulnerabilities and strengths of men and women.

The main findings of this research reveal that anger suppression engages critical brain structures such as the prefrontal cortex (PFC), anterior cingulate cortex (ACC), amygdala, and basal ganglia, with their activity patterns markedly differing between sexes. Women predominantly rely on robust PFC-mediated cognitive control strategies to regulate anger, often suppressing emotional salience through heightened connectivity with the amygdala. This reliance is hormonally influenced, with estrogen enhancing PFC functionality and connectivity, allowing for deliberate and reflective regulation of emotional responses. However, this sustained activation of cognitive regulatory networks comes at the cost of increased vulnerability to mental fatigue, anxiety, and depression, particularly when anger suppression becomes chronic. In contrast, men exhibit stronger engagement of subcortical regions such as the basal ganglia and amygdala, reflecting a preference for rapid, automatic emotional regulation pathways. Testosterone amplifies this subcortical activity and diminishes PFC engagement, fostering reactive and impulsive responses. This neural pattern, while evolutionarily advantageous in high-stress scenarios, limits cognitive adaptability and escalates physiological stress markers, such as elevated cortisol levels and heart rate variability, predisposing men to stress-related physical health risks like cardiovascular disease.

The distinct hormonal and neural mechanisms in anger suppression not only highlight evolutionary roles but also underscore the importance of considering sex-specific vulnerabilities within a modern clinical and social context. Women's reliance on PFC-driven regulation, aligned with adaptive social cooperation and nuanced emotional analysis, provides immediate advantages in managing anger but imposes significant cognitive and psychological

burdens over time. Conversely, men's subcortical-dominant strategies, evolved for survival-oriented rapid responses, confer efficiency in acute settings but are less suited to the demands of contemporary emotional regulation, leaving them vulnerable to long-term stress and associated health risks. By synthesizing the neurobiological evidence with clinical outcomes, this research establishes the critical need for therapeutic approaches that mitigate these sex-specific challenges while leveraging the strengths inherent in each regulatory strategy.

In addressing the central research question, this investigation has demonstrated how pervasive sex differences in anger suppression are intricately linked to neural circuit engagement and hormonal modulation. These differences are further amplified by their broader impact on mental health outcomes. Women's greater predisposition to anxiety and depression can largely be attributed to the sustained cognitive demands of PFC-mediated regulation, compounded by hormonal fluctuations such as reduced estrogen levels during menopause. On the other hand, men's reactive emotional regulation strategies often exacerbate physiological stress responses, contributing to physical health risks and limiting adaptability in socially complex scenarios. By integrating findings from diverse studies, this research provides a comprehensive understanding of how these neural and hormonal mechanisms operate distinctly in men and women, informing potential paths forward for clinical interventions.

The results of this research align with and expand upon existing literature in the field of emotion regulation. Consistent with prior studies, such as those by Davidson and Banks, this work reaffirms the essential role of the PFC and amygdala in anger suppression, while further delineating the sex-specific engagement of these regions. The influence of hormonal factors such as estrogen and testosterone on neural activation patterns has also been corroborated, demonstrating that hormonal modulation significantly shapes the distinct regulation strategies employed by men and women. Moreover, integrating these findings with mental health and clinical research presents a more nuanced view of how sex-specific neural dynamics correlate with both psychological and physiological outcomes. This contribution advances the understanding of anger regulation as a complex interplay of neural, hormonal, and behavioral factors, emphasizing the need to address these dynamics when designing therapies.

Despite the valuable insights gained, this study is not without limitations. The exclusive reliance on existing literature and systematic reviews restricts the scope to published findings, potentially overlooking novel or less-documented aspects of anger regulation. Additionally, the generalization of findings is limited by inter-individual variability in neural activity patterns, hormonal profiles, and environmental influences such as cultural norms, socioeconomic factors, and trauma history. The correlational nature of much of the cited research also presents a challenge in establishing causal links between neural activity and behavioral outcomes. Moreover, while the analysis integrates findings from neuroimaging and clinical studies, it lacks longitudinal perspectives that could capture the developmental trajectories of anger suppression mechanisms and their long-term implications for mental health and physical well-being. These challenges highlight the need for more robust methodologies in future investigations.

Looking ahead, future research should prioritize

longitudinal studies that examine how neural and hormonal factors evolve across different stages of life and how these changes influence anger regulation strategies and related outcomes. Understanding developmental trajectories from adolescence to adulthood will provide deeper insights into the origins of sex-specific regulatory mechanisms and their implications for mental health. Interdisciplinary approaches are critical for advancing this field, combining neuroimaging, hormonal analysis, and behavioral studies to explore the causal relationships between neural connectivity, emotional regulation, and clinical outcomes. Expanding research to incorporate diverse populations and cultural contexts will also be essential in capturing the nuanced interplay of environmental influences with biological mechanisms. Furthermore, investigating novel therapies such as neurofeedback or pharmacological interventions designed to modulate sex-specific neural pathways holds significant promise in optimizing emotional regulation and addressing vulnerabilities in anger suppression.

This research underscores the broader importance of sex-specific therapeutic approaches to improve mental health outcomes and foster emotional resilience. Men and women face distinct challenges in anger regulation, shaped by their unique neural and hormonal profiles. Tailored interventions such as cognitive-behavioral therapy, biofeedback, and emotion-focused strategies show potential for addressing these differences by strengthening regulatory pathways in men and alleviating cognitive burdens in women. Incorporating insights from emerging neurotechnologies and hormonal therapies could further refine these approaches, paving the way for more effective and equitable mental health care systems. By bridging the gap between scientific understanding and practical application, these findings reinforce the importance of individualized treatments informed by sex-specific research.

Reflecting on the broader significance of this work, the exploration of anger suppression mechanisms represents a vital step toward advancing interdisciplinary approaches in mental health research. Understanding the intricate interplay between neural circuits, hormones, and behavior not only deepens scientific knowledge but also serves a crucial role in addressing real-world challenges. As the societal and clinical impacts of emotional dysregulation become increasingly apparent, this research contributes to shaping the future of mental health care by advocating for tailored, evidence-based interventions. The ultimate goal remains to alleviate the burdens of anger-related disorders and promote emotional well-being, ensuring that both men and women can benefit from therapies designed to meet their unique needs. This work serves as a foundation for ongoing efforts to translate scientific insights into meaningful improvements in mental health outcomes.

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