Meditation, CBT, and Neural Plasticity: A Comparative Investigation of Non-Pharmacological ADHD Interventions

Abstract

This study investigates the impact of mindfulness meditation as an adjunctive treatment for adults with Attention-Deficit/Hyperactivity Disorder (ADHD). By integrating neuroimaging, behavioural assessments, and self-reports, the research explores the effects of an eight-week mindfulness intervention on cognitive flexibility, emotional regulation, and neural activity in the default mode network (DMN). Participants were divided into three groups: ADHD medication combined with mindfulness meditation, and a medication-only control group, with limited inclusion of a cognitive-behavioural therapy (CBT) group for comparison. Functional Magnetic Resonance Imaging (fMRI) was used to assess changes in DMN activity and connectivity with cognitive control regions, while behavioural tasks such as the Wisconsin Card Sorting Test (WCST) evaluated cognitive adaptability. Emotional regulation was measured using the Difficulties in Emotion Regulation Scale (DERS).

The study hypothesises that mindfulness meditation, in combination with medication, will significantly reduce DMN activity, enhance cognitive control, and improve emotional regulation compared to medication alone. Mindfulness meditation is expected to demonstrate unique benefits, including heightened attentional focus, improved present-moment awareness, and reduced impulsivity. Findings aim to provide a deeper understanding of neuroplasticity in ADHD and inform the development of accessible, tailored interventions. This research contributes to the growing body of evidence supporting non-pharmacological approaches, with a strong emphasis on mindfulness meditation as a key component of multimodal ADHD management frameworks.

Introduction

This project explores the impact of meditation on enhancing cognitive flexibility and emotional regulation, specifically focusing on individuals with attention deficit hyperactivity disorder (ADHD). ADHD is a neurodevelopmental disorder characterized by persistent patterns of inattention, hyperactivity, and impulsivity that interfere with functioning or development (Norman et al., 2024a). It is associated with executive dysfunction, which affects the brain's ability to manage emotions, thoughts, and actions (Willcutt et al., 2005). Executive function refers to a set of cognitive processes managed by the prefrontal cortex of the brain that help individuals plan, organize, initiate, monitor, and regulate their behaviour. These abilities are crucial for goal-directed activities, problem-solving, and adapting to changing circumstances. It is likely that ADHD arises from maldevelopment in brain regions such as the prefrontal cortex, basal ganglia, and anterior cingulate cortex, which regulate executive functions necessary for human self-regulation (Norman et al., 2024b).

ADHD is commonly associated with deficits in attention, emotional regulation, and cognitive flexibility, which are linked to habitual patterns within the brain's default mode network (DMN) (Fateh et al., 2023). These habitual pathways often reinforce impulsive behaviours and emotional dysregulation, posing challenges for individuals with ADHD in terms of self-regulation and cognitive control (Marques et al., 2024). NICE guidelines highlight the importance of a multimodal approach to ADHD treatment, combining pharmacological and non-pharmacological strategies to comprehensively address these challenges. Among non-pharmacological interventions, mindfulness meditation has emerged as a promising tool for modulating DMN activity, reducing habitual self-referential thought patterns, and enhancing cognitive and emotional regulation.

Neurological Conditions and Treatment

In ADHD, irregular communication within attention networks and self-control areas disrupts focus and impulse regulation (Castellanos et al., 2009). While stimulants effectively manage core symptoms, NICE guidelines advocate for complementary behavioural strategies to provide sustainable benefits. Meditation can reduce activity in brain regions linked to mind-wandering, enhancing focus and emotional regulation (Cairncross & Miller, 2020). Cognitive-behavioural therapy (CBT) reshapes thought patterns through a top-down approach, engaging the prefrontal cortex to strengthen executive function pathways (Goldin et al., 2012). By challenging negative thoughts, CBT fosters neuroplasticity, improving emotional regulation over time (Beck, 2011; Tang et al., 2015a). Transcranial magnetic stimulation (TMS), using magnetic fields to directly stimulate neural activity in areas like the dorsolateral prefrontal cortex, provides immediate effects, enhancing connectivity and modulating neurotransmitters (Lefaucheur et al., 2014). While CBT works gradually through behavioural changes, TMS offers faster, targeted neural effects, with both leveraging the brain's adaptability (Tang et al., 2015a). Together, they exemplify complementary methods for influencing brain function.

Literature Review

Emerging research suggests that meditation (Cairncross & Miller, 2020; Keng et al., 2011; Tang et al., 2015b), particularly mindfulness-based practices, can positively influence brain structure and function, fostering neuroplasticity—the brain's ability to adapt and form new neural connections (Hölzel et al., 2011a; Wielgosz et al., 2018). Meditation has been shown to alter the brain’s default mode network (DMN), which is associated with habitual and self-referential thought patterns. The DMN, a network that includes areas such as the medial prefrontal cortex, posterior cingulate cortex, and parts of the parietal lobe, is typically active when the brain is at rest or engaged in self-referential and internally directed thoughts (Smith

et al., 2018). In individuals with ADHD, these habitual patterns are linked to impulsivity, distractibility, and difficulty with sustained attention (Sonuga-Barke & Castellanos, 2007). By examining meditation's potential to disrupt these patterns and improve cognitive flexibility, this study could reveal a promising, non-pharmacological approach to managing ADHD symptoms (Hölzel et al., 2011b).

The existing research on meditation show that Meditation, particularly mindfulness-based practices, has been shown to foster neuroplasticity, improve emotional regulation, and enhance cognitive flexibility. These effects are primarily achieved through modulation of the brain's default mode network (DMN), which governs self-referential and habitual thought patterns (Hölzel et al., 2011; Wielgosz et al., 2018). In general populations, mindfulness practices reduce DMN activity, leading to improved focus, reduced impulsivity, and better emotional control (Tang et al., 2015; Cairncross & Miller, 2020). Studies have also shown structural brain changes in regions like the medial prefrontal cortex and posterior cingulate cortex, which are crucial for attention and self-regulation (Hölzel et al., 2011; Smith et al., 2018).

While existing research demonstrates meditation's impact on brain structure, the durability of these changes requires further investigation, particularly in ADHD populations. There has been a notable lack of long-term studies examining meditation's sustained effects on ADHD. Most research has focused on shorter intervention periods (typically 8-12 weeks) with limited or no follow-up data. One paper, (Mitchell et al., 2017) conducted a 6-month follow-up after an 8-week mindfulness program, finding some maintenance of attention improvements, but the sample size was small (n=24) and lacked a control group.

Another paper, (Zylowska et al., 2008) tracked participants for one year after mindfulness training but suffered from high dropout rates (>40%) making conclusions about durability difficult. The complex nature of ADHD as a neurodevelopmental disorder necessitates

longer-term, controlled studies to determine the sustainability of meditation's benefits for symptom management. Current research limitations largely stem from studies focused on neurotypical populations rather than ADHD-specific samples. Given that ADHD brains exhibit distinct neural connectivity patterns, findings from general population studies may not directly translate, highlighting the need for targeted research with ADHD populations (Norman et al., 2024b)

As mindfulness studies often lack adequate controls for placebo effects, there's potential for expectancy biases, where participants believe in benefits simply because they are engaging in an intervention (Van Dam et al., 2018). This could lead to an overestimation of meditation's true impact on ADHD symptoms without robust controls (Lopes et al., 2024). Several studies examining meditation's effects on ADHD have faced criticism for methodological limitations in their control conditions. (Bueno et al., 2015) studied mindfulness for ADHD but used a waitlist control group, which doesn't account for non-specific effects like participant expectations and time spent in structured activity. (Nardi et al., 2020) compared meditation to "treatment as usual" without matching for time, attention, or participant expectations. The positive results couldn't separate meditation's specific effects from general benefits of regular group meetings and instructor attention. A 2022 paper (Lee et al., 2022) reported significant improvements in ADHD symptoms after meditation training, but their control group received no intervention, making it impossible to determine if benefits came from meditation specifically or from receiving any form of structured support.

Furthermore, ADHD is not a one-size-fits-all diagnosis—impulsivity, hyperactivity, and inattention manifest differently in each individual (Chaulagain et al., 2023a). Research should consider how different meditation practices might target specific symptom clusters rather than suggesting universal efficacy. ADHD is often marked by difficulty maintaining focus

rather than a reliance on habitual thought patterns (Knouse et al., 2019). While DMN modulation could reduce some impulsive and self-referential thinking, a broader approach addressing both attention enhancement and emotional regulation might be more effective. Lastly, mindfulness practices require a degree of self-regulation, which can be challenging for individuals with ADHD, especially without initial guidance or adaptation (Nicastro et al., 2021). More research on how to make mindfulness more accessible for ADHD populations, potentially through shorter or modified practices, could increase its applicability

Current ADHD treatments show limitations in addressing both cognitive and emotional regulation challenges, creating an urgent need to explore complementary approaches given the disorder's global prevalence (Faraone et al., 2021a). While meditation demonstrates positive effects on brain plasticity and default mode network (DMN) function in general populations, we lack understanding of its specific benefits for individuals with ADHD, who exhibit atypical neural connectivity patterns. This study addresses this knowledge gap by investigating meditation's potential as a non-pharmacological intervention for ADHD, while considering crucial factors such as placebo effects, symptom heterogeneity, and the necessity for ADHD-adapted mindfulness practices.

Study Objectives

This study examines the effects of mindfulness meditation on ADHD, addressing a critical research gap. While mindfulness benefits various mental health conditions, its impact on ADHD-specific neural activity and symptoms is underexplored. Using a pre-post experimental design with fMRI and behavioural testing, the study evaluates the efficacy of mindfulness meditation as an adjunctive treatment to ADHD medication. The research focuses on changes in neural activity and cognitive performance to assess the potential of mindfulness meditation to improve attention, emotional regulation, and impulse control in

individuals with ADHD. The study hypothesizes that mindfulness meditation combined with medication will provide superior short-term improvements in attention, emotional regulation, and impulse control compared to medication alone. Furthermore, it predicts sustained benefits in cognitive flexibility, stress resilience, and quality of life, highlighting mindfulness as a promising intervention for long-term ADHD management. By identifying the unique contributions of mindfulness meditation, this research aims to inform the development of accessible and effective strategies for enhancing well-being and functional outcomes in ADHD populations.

Research Question

1.Does mindfulness meditation, in combination with ADHD medication, effectively increases connectivity in the DMN associated with ADHD?

2.Does the intervention lead to measurable improvements in cognitive flexibility, attention, and emotional regulation?

3.What specific improvements in cognitive flexibility can be observed following each intervention? Can these be quantified with objective measures, such as response inhibition tasks, or brain imaging that highlights shifts in network connectivity?

Methods

fMRI

This study employs functional Magnetic Resonance Imaging (fMRI) to measure changes in default mode network (DMN) activity. Pre- and post-intervention fMRI scans will track neural changes in participants across three groups: mindfulness meditation, CBT, and medication-only control, over an eight-week intervention period. The primary focus will be

on DMN activity patterns, with an emphasis on detecting reductions indicative of improved attentional control. Functional connectivity analyses will explore integration between the DMN and attention-related regions, assessing whether mindfulness meditation or CBT enhances network connections associated with attention and impulse regulation. Imaging data will be processed using, with results compared across groups using Anova.

Participants will complete the Difficulties in Emotion Regulation Scale (DERS) to evaluate changes in emotional regulation pre- and post-intervention. The DERS measures six dimensions of emotional regulation, including non-acceptance of emotional responses, impulse control difficulties, and emotional clarity. Changes in DERS scores over time will indicate whether mindfulness meditation or CBT enhances participants' capacity to manage emotional responses.

Cognitive flexibility will be assessed using the Wisconsin Card Scoring Test (WCST), a task designed to evaluate participants' ability to adapt cognitive strategies in response to changing task demands. Performance on the WCST will provide an objective measure of cognitive adaptability.

The study integrates neuroimaging, behavioural tasks, and self-report tools to capture both objective and subjective outcomes. While neuroimaging data quantifies changes in brain activity and connectivity, self-report measures assess participants' perceived improvements in emotional and cognitive regulation. This multi-modal approach will provide a comprehensive understanding of how mindfulness meditation and CBT, in combination with medication, influence ADHD management.

Design

This study employs a randomized controlled pre-post design with a 6-month follow-up, comparing three groups (n=25 each): Medication+ Mindfulness Meditation (MM), Medication+ CBT, and Medication-only control. Assessments will be conducted at three timepoints: baseline (T0) one week before intervention, post-intervention (T1) within one week of completion, and follow-up (T2) at 6 months after intervention completion.

At each timepoint, participants will undergo fMRI scanning during rest and attention tasks, complete the DERS for emotional regulation assessment and the WCST for cognitive flexibility evaluation. Clinical ADHD symptom assessments will also be conducted. All assessments will be administered by trained researchers blind to group allocation, with fMRI sessions following standardized protocols that include identical sequences of rest periods and cognitive tasks at each timepoint. Self-report measures will be administered in a fixed order with standardized instructions.

The 8-week intervention period commences immediately following baseline assessment. The MM group will engage in daily guided meditation sessions lasting 20 minutes, five days per week, while the CBT group will attend weekly 90-minute therapy sessions. Both intervention groups will participate in weekly group support meetings. The control group will maintain their regular medication schedule throughout the study period.

To ensure consistency and control for circadian effects, all data collection will occur at consistent times of day across all timepoints. Participants will maintain their usual medication dosage throughout the study duration, with any changes being carefully documented. This structured approach allows for comprehensive evaluation of both immediate and long-term effects of the interventions while controlling for potential confounding variables.

Participants

The study will recruit 75 adults diagnosed with ADHD, aged 18–40, drawn from clinical settings, ADHD support groups, and online forums. Participants will be carefully screened to ensure they meet DSM-5 diagnostic criteria for ADHD and are currently on stable ADHD medication regimens. The age range of 18–40 years focuses on adults with ADHD in early to middle adulthood, minimizing variability and avoiding confounding factors like age-related cognitive decline or comorbid conditions. This group is more likely to have stable medication regimens and aligns with recruitment methods targeting support groups and online forums. The range ensures a controlled sample relevant to the study's goals while addressing ADHD-specific challenges in this demographic. Exclusion criteria will include any history of consistent meditation practice, previous engagement with mindfulness-based interventions or CBT, or current use of alternative therapies that could influence baseline neurocognitive measures.

Participants will be randomly assigned to one of three groups:

ADHD medication + Mindfulness Meditation (MM) group

ADHD medication + Cognitive Behavioural Therapy (CBT) group

ADHD medication only (control group)

To minimize bias, all groups will be informed that the study aims to observe the effects of different adjunctive therapies on cognitive and emotional function in ADHD when combined with medication. The control group will be told they are part of a "treatment as usual" condition to assess the long-term effects of their current medication regimen.

Intervention

The intervention for this study will involve two eight-week programs: a mindfulness meditation program and a Cognitive Behavioural Therapy (CBT) program, both specifically designed to target attention control, emotional regulation, and cognitive flexibility in individuals with ADHD. All participants will continue their prescribed ADHD medication throughout the study.

ADHD medication + Mindfulness Meditation (MM) group:

Participants will engage in 20-minute guided meditation sessions five days a week, focusing on breath awareness, attention control, and non-judgmental observation of thoughts. They will use breathing as an anchor to practice sustained focus, gently redirecting attention when their minds wander. Non-judgmental observation will encourage noticing thoughts and reactions without attachment, aiming to reduce reactivity and improve emotional regulation.

ADHD medication + Cognitive Behavioural Therapy (CBT) group:

Participants will attend weekly 90-minute individual CBT sessions with trained therapists. These sessions will focus on identifying and challenging negative thought patterns, developing coping strategies, and improving time management and organizational skills. Participants will be given daily homework assignments to practice CBT techniques learned during the sessions.

Both groups will have weekly group meetings to support consistency and adherence, provide additional guidance, and encourage participants. These group sessions will address common challenges that individuals with ADHD might face during their respective interventions, such as difficulty managing distractions or maintaining motivation to practice. The group sessions will also provide a platform for participants to share experiences, reinforcing their commitment to the routine.

Additionally, participants in both groups will receive supplemental materials, including audio guides and written resources, to reinforce the techniques learned and support independent practice.

ADHD medication only (control) group:

This group will continue with their regular medication routines without engaging in any structured mindfulness or CBT activities, serving as a baseline against which to measure the effects of the MM and CBT programs.

Through this structured approach, the interventions aim to foster skills in cognitive flexibility, emotional regulation, and attention control, with the ultimate goal of assessing the impact of mindfulness meditation and CBT on ADHD symptoms beyond pharmacological treatment alone. The study will compare the efficacy of these two approaches in combination with ADHD medication to determine which intervention provides more significant improvements in ADHD symptom management and overall well-being.

Ethical considerations

Ethical considerations are essential in studying meditation's impact on neural firing patterns and cognitive flexibility in individuals with ADHD. Ensuring participant safety, well-being, and informed consent is paramount when working with a clinical population. Informed consent requires participants to be fully informed about the study's purpose, procedures, risks, and benefit (*UK Policy Framework for Health and Social Care Research - Health Research Authority*, n.d.) Information must be presented in clear, accessible language, accounting for ADHD-related attentional challenges. Participants must understand their involvement is voluntary and can be withdrawn at any time without penalty, as outlined in the

British Psychological Society (BPS) Code of Human Research Ethics (2021). This respect for autonomy fosters trust and ensures informed participation.

Minimizing psychological and physical risks is equally important. Meditation may evoke challenging emotions or thoughts, particularly during self-awareness practices. Participants should be informed of this possibility, with mental health resources readily available. For fMRI scans, screening for contraindications like claustrophobia or metal implants is necessary, along with providing clear instructions and emotional support to reduce anxiety. Accommodations for ADHD-specific symptoms, such as attention difficulties and restlessness, should include flexible scheduling, breaks, and straightforward instructions. Researchers should monitor adverse reactions and adjust protocols or provide additional guidance as needed.

Ethical considerations also extend to the use of a control group. Control participants may not receive active intervention, which could affect expectations. Researchers must clearly explain the rationale for group assignments and offer control participants the option to join the meditation program after the study, ensuring equitable access to potential benefits. Transparency about the study's exploratory nature is critical, managing participant expectations by clarifying that meditation may not lead to significant improvements in ADHD symptoms.

Post-study debriefing and support are vital to ethical research. Participants should have the opportunity to discuss their experiences, receive further resources for independent meditation practice, and be informed of the study findings, particularly if positive effects on ADHD symptoms are observed. This transparency fosters respect and supports participants' interest in the research's implications for ADHD management.

Analysis & Reporting

This study's analysis will use a multi-faceted approach, including neuroimaging, behavioural testing, and self-report measures, to evaluate the effects of mindfulness meditation on ADHD symptoms. Overactivity in the DMN is associated with increased mind-wandering and distractibility in ADHD (Posner et al., 2014). By examining DMN connectivity with cognitive control regions, the study seeks to identify neural changes linked to reduced DMN activity and improved attentional stability. Functional and structural connectivity analyses will further explore shifts in brain network dynamics, potentially revealing strengthened connections between the DMN and attention networks, indicating enhanced focus and cognitive control.

The findings are anticipated to align with the forest plot below, extracted from a 2022 meta-analysis conducted by Angela Fabio et al (Angela Fabio et al., 2022). This analysis, which synthesized data from seven studies, revealed a combined effect size (g) of 0.77 for mindfulness-based interventions targeting ADHD symptoms (95% CI: 0.22–1.33, Z = 2.72, p = 0.006). These results indicate that mindfulness-based interventions have a statistically significant impact on reducing ADHD symptoms and suggests a robust impact, demonstrating that mindfulness-based interventions can effectively reduce ADHD symptoms.

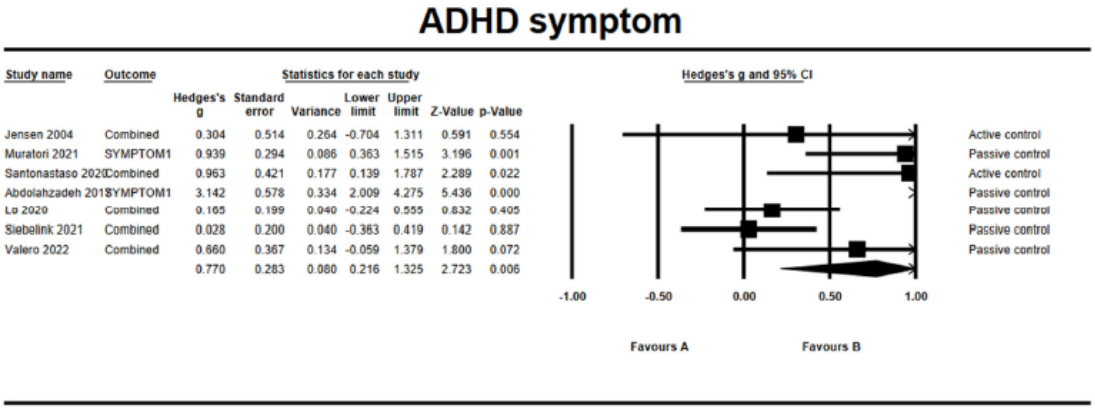

Figure 2. Forest plots of effect size for ADHD symptoms [28,31–33,36,38,39].

Behavioural data from cognitive tests will be analysed using repeated measures Analysis of Variance (ANOVA) to compare performance on cognitive flexibility and attention control tasks before and after the intervention in both meditation and control groups. The Wisconsin Card Sorting Test (WCST) will assess cognitive flexibility (Luiselli et al., 2013). Repeated measures ANOVA will identify significant improvements in the meditation group's cognitive abilities compared to the control group, providing evidence of mindfulness practice's effects on ADHD-related cognitive functions.

As can be seen from the figure below from a similar study, (Basso et al., 2019) the meditation group demonstrated an increase in accuracy from 97.23% (± 0.76) to 98.55% (± 0.36), showing a near-significant improvement ($t(20) = -2.024$, $p = 0.057$). In contrast, the control group showed a slight decrease in accuracy from 98.08% (± 0.48) to 97.41% (± 0.65), which was not statistically significant ($t(19) = 1.218$, $p = 0.238$). The results from Basso et al. (2019) show that the meditation group's accuracy improved slightly, increasing from 97.23% to 98.55%. This change was close to being statistically significant. In comparison, the control group's accuracy decreased slightly, from 98.08% to 97.41%, but this change was not significant, suggesting it could have been due to random variation.

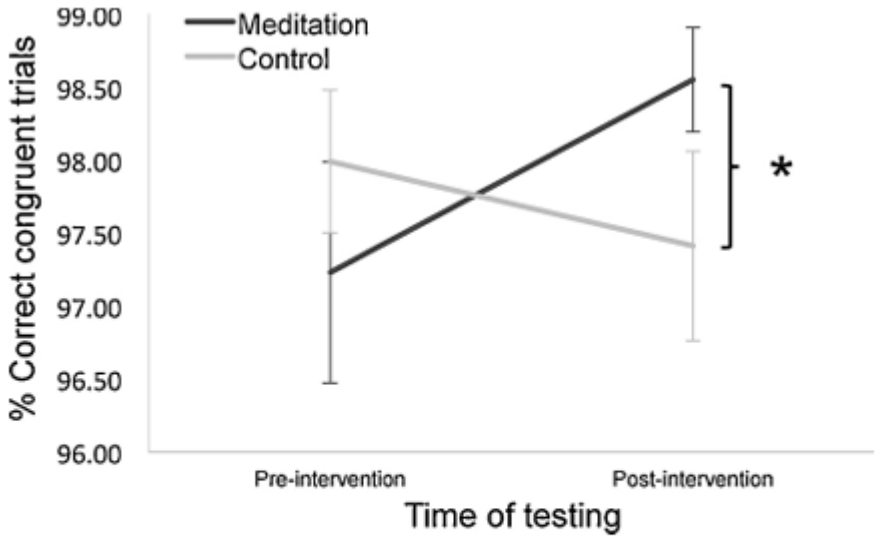

Fig. 3. Data are presented as averages (± SEM) for the meditation and control groups both before and after the intervention. Eight weeks of meditation significantly enhanced attention as assessed by accuracy (percent correct) on congruent trials of the Stroop Color and Word Task (* represents a significant time x group interaction, $F(1,39) = 5.449$, $p = 0.025$, partial $\eta^2 = 0.123$).

To examine the relationship between neural and behavioural changes, Pearson's correlation analysis will explore associations between neuroimaging findings and behavioural outcomes (Penny et al., 2007). This will determine whether reductions in DMN activity or enhanced connectivity with cognitive control regions correlate with improvements in cognitive flexibility, attention, or emotional regulation, as assessed by behavioural tests and self-report measures. Correlations will help establish whether neuroplasticity—evidenced by changes in brain connectivity—translates into practical benefits for individuals with ADHD.

The below table from a paper published in 2022 (Bremer et al., 2022), demonstrate that one month of mindfulness meditation practice leads to the functional reorganization of large-scale brain networks. The table demonstrates that one month of mindfulness meditation leads to significant reorganisation of large-scale brain networks, including the default mode network (DMN), dorsal salience network, and insular salience network. Notable changes were observed in regions such as the middle temporal gyrus, superior frontal gyrus, and posterior

cingulate cortex, with highly significant p-values and strong peak activations. These findings suggest that mindfulness fosters neuroplasticity, improving functional connectivity in networks responsible for attention, emotional regulation, and self-referential thinking.

Seed region	Cluster region		p_{FDR}	$p_{uncorrected}$	k_E	T_{max}	Peak MNI-coordinates		
							x	*y*	*z*
spDMN	R	Middle temporal gyrus	0.002	< 0.001	104	5.18	56	− 12	− 16
dSN	L	Superior frontal gyrus	0.019	< 0.001	72	5.45	− 20	18	60
	L	Posterior cingulate cortex	0.045	0.001	53	4.43	− 10	− 36	46
	L	Inferior temporal gyrus	0.019	< 0.001	68	4.30	− 52	− 50	− 20
	L	Inferior parietal lobule	0.016	< 0.001	85	4.13	− 46	− 36	58
insSN	L	Middle frontal gyrus	0.243	0.006	36	4.90	− 28	38	48
	L	Posterior cingulate cortex	0.198	0.003	46	4.22	− 2	− 38	50

Table 3. ANOVA results and peak activations of clusters with associated anatomic regions. k_E Number of voxels in cluster, T_{max} Maximum value of T-statistic in cluster, *spDMN* superior posterior default mode network, *dSN* dorsal salience network, *insSN* insular salience network, *R* Right hemispheric, *L* Left hemispheric.

Self-report measures, including the DERS, will capture participants' perceived changes in emotional regulation and mindfulness. These self-reported changes will be compared with neuroimaging and behavioural data to provide a more comprehensive understanding of meditation's impact on ADHD outcomes. This multi-dimensional analysis, integrating neuroimaging, behavioural assessments, and self-report data, aims to comprehensively evaluate mindfulness meditation's effects on neural firing patterns and cognitive functions in ADHD. The findings may reveal the potential of mindfulness as a complementary intervention to improve cognitive control, emotional regulation, and attention capacity in individuals with ADHD, highlighting both its neurological and practical benefits.

It is important to recognise, however, that self-reporting may lead participants to attribute unrelated factors to the perceived efficacy of the treatment, which should be considered when interpreting the results.

The figure below illustrates the anticipated data distribution, which deviates from normality, as is often observed in research involving ADHD populations or meditation interventions.

This non-normal distribution highlights a critical consideration for statistical analysis, the application of methods, such as Analysis of Variance (ANOVA), which inherently assume normality of the data. ANOVA is a statistical method designed to evaluate differences between group means, operating under the assumption that the underlying data follows a normal distribution. When this assumption is violated, as is often the case with non-normal distributions, the validity of the test results may be compromised. It is therefore important to acknowledge the limitations of this method and interpret the findings with caution, recognizing that alternative approaches may better suit non-normal data.

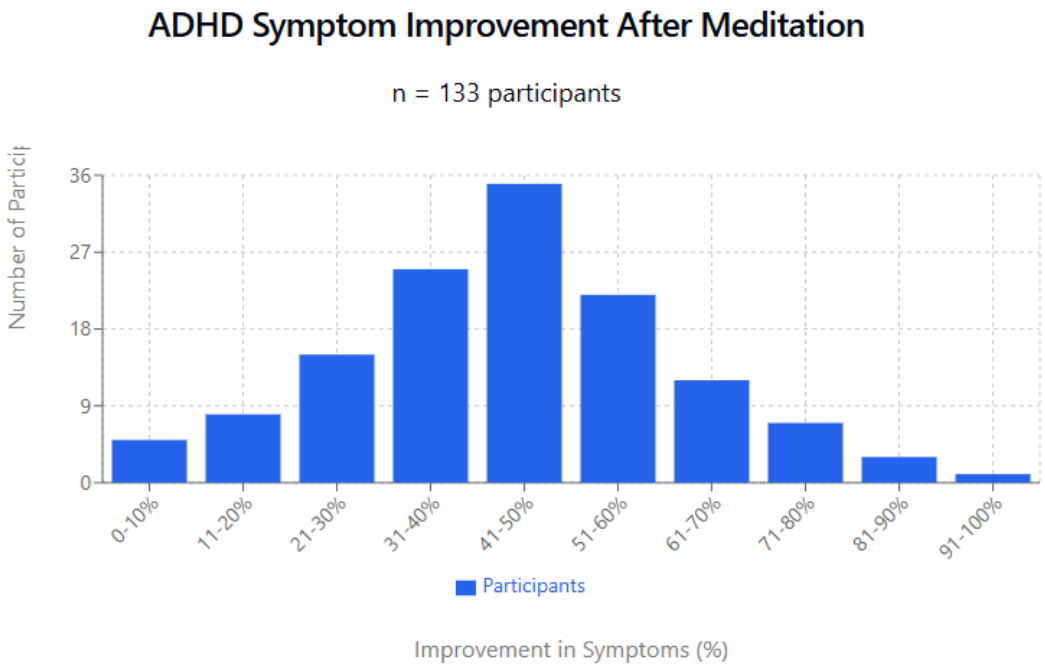

Figure 1: Right-skewed distribution showing varied individual responses to meditation intervention

Although the General Linear Model (GLM) offers advantages for handling non-normal distributions and missing data, this study will use Analysis of Variance (ANOVA) to align with previous research and enable direct comparisons with similar studies on meditation and ADHD. While ANOVA assumes normality and complete datasets, its use ensures

consistency. Limitations will be addressed with caution, and additional validation methods will be applied to ensure robust conclusions.

Discussion

This research explores mindfulness meditation and CBT as complementary treatments to ADHD medication, addressing a critical gap in understanding their combined effects. While medication remains the primary treatment, the potential synergistic benefits of these interventions with medication are understudied. The decision to exclude a meditation-only control group reflects ethical considerations about withholding standard care. Through a multi-modal approach combining neuroimaging, behavioural testing, and self-reporting, this study will evaluate how meditation and CBT may enhance medication-based ADHD treatment.

Interpretation of Neuroimaging Results

The study hypothesizes that mindfulness meditation, combined with ADHD medication, will disrupt patterns in the default mode network (DMN) associated with ADHD. Mindfulness is expected to reduce DMN overactivity during rest, decreasing self-referential thinking and mind-wandering—key contributors to ADHD symptoms. This reduction likely stems from enhanced present-moment awareness and attentional focus. Additionally, mindfulness meditation may strengthen connectivity between the DMN and cognitive control networks, supporting better attentional regulation. Neuroimaging will assess whether these changes reflect a shift from maladaptive DMN activity to task-oriented focus. Compared to the medication-only group, the mindfulness group is anticipated to show greater reductions in DMN activity and stronger DMN-cognitive control connectivity, highlighting the combined benefits of mindfulness and medication.

Behavioural Outcomes in Cognitive Flexibility

Cognitive performance will be evaluated using the Wisconsin Card Sorting Test (WCST) for cognitive flexibility. These assessments will be administered pre- and post-intervention across all groups (medication + mindfulness, medication + CBT, and medication-only control). Based on the interventions' distinct mechanisms, we anticipate different patterns of improvement. The mindfulness group may show stronger gains in sustained attention and response inhibition through enhanced present-moment awareness. The CBT group might excel in cognitive flexibility due to improved problem-solving and cognitive restructuring skills. While both intervention groups are expected to outperform the medication-only control, their pathways to improvement may differ. These behavioural measures will complement neuroimaging data, demonstrating how mindfulness and CBT enhance cognitive adaptability beyond medication alone. The comparative analysis will reveal which cognitive domains respond best to each intervention, enabling more targeted treatment recommendations based on individual cognitive profiles.

Emotional Regulation and Mindfulness

Mindfulness meditation, combined with ADHD medication, is expected to improve cognitive flexibility, attention, and emotional regulation. Cognitive flexibility will be assessed with the Wisconsin Card Sorting Test (WCST), while self-report measures like the Difficulties in Emotion Regulation Scale (DERS) will evaluate emotional regulation and attentional focus. Mindfulness is hypothesized to enhance sustained attention and impulse control by fostering present-moment awareness and reducing reactive behaviours. These improvements are expected to exceed those in the medication-only control group, highlighting mindfulness’s added benefits for ADHD management.

Correlations Between Neural and Behavioural Changes

If Pearson's correlation analysis reveals significant associations between reductions in DMN activity, increased connectivity in cognitive control regions, and improvements in cognitive and emotional regulation, it would suggest that neural changes are directly linked to observable improvements in ADHD symptoms. Such correlations would support the idea that neuroplasticity induced by meditation has functional significance for behaviour, reinforcing the potential of mindfulness meditation as a tool for managing ADHD.

Limitations

Several key limitations should be considered when interpreting this study's results. Self-report measures, while valuable for understanding subjective experiences, may be influenced by participant bias and social desirability (Kim & Kim, 2016). The eight-week intervention period may also be insufficient to observe substantial neural changes, as deeper structural adaptations typically require longer periods of practice. Furthermore, ADHD's heterogeneous presentation necessitates more targeted intervention approaches, and mindfulness practices may prove challenging for individuals with ADHD without proper adaptation (Chaulagain et al., 2023b; Mitchell et al., 2015).

The study addresses critical gaps in understanding meditation's neural effects on ADHD, particularly focusing on DMN-prefrontal cortex connectivity and its relationship to cognitive control. While this multi-modal approach combining neuroimaging, behavioural assessments, and self-reports provides comprehensive insights, future research directions should be considered. Studies implementing longer follow-up periods would better capture sustained effects, while exploration of varied mindfulness approaches could better address different

ADHD symptom clusters. Additionally, developing ADHD-specific meditation adaptations would make these interventions more accessible and effective (Fitzpatrick et al., 2018).

Research should also expand beyond the current focus to address both attention enhancement and emotional regulation, considering individual differences in ADHD presentation when designing interventions (Faraone et al., 2021b). This foundation will help develop more accessible, personalized ADHD management strategies that effectively complement existing treatments. The ultimate goal is to better understand how mindfulness practices affect brain function while exploring interventions that can improve daily functioning among adults diagnosed with ADHD, offering new avenues for effective management strategies tailored specifically towards enhancing quality of life among those affected by this condition

Conclusion

This research will aim to propose that combining medication with mindfulness meditation may enhance ADHD treatment outcomes by improving cognitive flexibility and emotional regulation. Neural changes in DMN activity and connectivity with cognitive control regions will indicate intervention-induced neuroplasticity linked to better cognitive and emotional functioning. Mindfulness meditation will show promise as a non-pharmacological adjunct to medication, offering a holistic approach to managing ADHD by addressing both neural and behavioural aspects. Notably, the study will identify a pronounced impact of mindfulness meditation on reducing DMN activity during rest and improving present-moment awareness. This will suggest that meditation may be particularly effective in helping individuals with ADHD disengage from self-referential thoughts and maintain focus on current tasks.

Both the mindfulness group and the medication-only control group will demonstrate improvements in emotional regulation, as measured by the Difficulties in Emotion Regulation Scale (DERS). However, the mindfulness group will likely show more pronounced

improvements, highlighting the potential added value of integrating mindfulness into ADHD management. The medication-only control group will show some improvements due to continued pharmacological treatment, but these changes will likely be less pronounced than in the mindfulness group. This will underscore the potential value of combining medication with non-pharmacological interventions for more comprehensive ADHD management. NICE guidelines [NG87] will reinforce the importance of multimodal approaches to ADHD treatment, recommending the integration of behavioural therapies alongside medication to achieve optimal outcomes. Furthermore, NICE's emphasis on individualised care will support the exploration of tailored non-pharmacological interventions, such as mindfulness, to address the diverse symptom profiles and needs of individuals with ADHD.

Future research should continue to explore the long-term effects of mindfulness meditation on ADHD, potentially expanding this approach to a broader range of age groups and ADHD subtypes to confirm its applicability and effectiveness across diverse populations. Additionally, investigating ways to optimise mindfulness practices specifically for ADHD populations could enhance their accessibility and impact.

If further validated, mindfulness meditation could become an integral part of ADHD treatment protocols, offering clinicians and patients a valuable option to complement medication. This would allow for more personalised treatment approaches, helping individuals develop greater self-regulation, emotional resilience, and adaptability based on their specific needs and preferences. In conclusion, this study will highlight the potential of integrating non-pharmacological interventions with standard medication treatment for ADHD. By demonstrating the neural and behavioural benefits of mindfulness meditation, it will pave the way for more comprehensive, multi-modal approaches to ADHD management that address the complex nature of the disorder and improve overall quality of life for those affected.

Angela Fabio, R., Lee, Y.-C., Chen, C.-R., & Lin, K.-C. (2022). *Effects of Mindfulness-Based Interventions in Children and Adolescents with ADHD: A Systematic Review and Meta-Analysis of Randomized Controlled Trials*. https://doi.org/10.3390/ijerph192215198

Basso, J. C., McHale, A., Ende, V., Oberlin, D. J., & Suzuki, W. A. (2019). Brief, daily meditation enhances attention, memory, mood, and emotional regulation in non-experienced meditators. *Behavioural Brain Research*, *356*, 208–220. https://doi.org/10.1016/J.BBR.2018.08.023

Bremer, B., Wu, Q., Mora Álvarez, M. G., Hölzel, B. K., Wilhelm, M., Hell, E., Tavacioglu, E. E., Torske, A., & Koch, K. (2022). Mindfulness meditation increases default mode, salience, and central executive network connectivity. *Scientific Reports*, *12*(1). https://doi.org/10.1038/S41598-022-17325-6

Bueno, V. F., Kozasa, E. H., Da Silva, M. A., Alves, T. M., Louzã, M. R., & Pompeiá, S. (2015). Mindfulness Meditation Improves Mood, Quality of Life, and Attention in Adults with Attention Deficit Hyperactivity Disorder. *BioMed Research International*, *2015*. https://doi.org/10.1155/2015/962857

Cairncross, M., & Miller, C. J. (2020). The Effectiveness of Mindfulness-Based Therapies for ADHD: A Meta-Analytic Review. *Journal of Attention Disorders*, *24*(5), 627–643. https://doi.org/10.1177/1087054715625301/ASSET/IMAGES/LARGE/10.1177_1087054715625301-FIG10.JPEG

Castellanos, F. X., Kelly, C., & Milham, M. P. (2009). The restless brain: attention-deficit hyperactivity disorder, resting-state functional connectivity, and intrasubject variability. *Canadian Journal of Psychiatry. Revue Canadienne de Psychiatrie*, *54*(10), 665–672. https://doi.org/10.1177/070674370905401003

Chaulagain, A., Lyhmann, I., Halmøy, A., Widding-Havneraas, T., Nyttingnes, O., Bjelland, I., & Mykletun, A. (2023a). A systematic meta-review of systematic reviews on attention deficit hyperactivity disorder. *European Psychiatry*, *66*(1), e90. https://doi.org/10.1192/J.EURPSY.2023.2451

Chaulagain, A., Lyhmann, I., Halmøy, A., Widding-Havneraas, T., Nyttingnes, O., Bjelland, I., & Mykletun, A. (2023b). A systematic meta-review of systematic reviews on attention deficit hyperactivity disorder. *European Psychiatry*, *66*(1), e90. https://doi.org/10.1192/J.EURPSY.2023.2451

Faraone, S. V., Banaschewski, T., Coghill, D., Zheng, Y., Biederman, J., Bellgrove, M. A., Newcorn, J. H., Gignac, M., Al Saud, N. M., Manor, I., Rohde, L. A., Yang, L., Cortese, S., Almagor, D., Stein, M. A., Albatti, T. H., Aljoudi, H. F., Alqahtani, M. M. J., Asherson, P., … Wang, Y. (2021a). The World Federation of ADHD International Consensus Statement: 208 Evidence-based conclusions about the disorder. *Neuroscience and Biobehavioral Reviews*, *128*, 789–818. https://doi.org/10.1016/J.NEUBIOREV.2021.01.022

Faraone, S. V., Banaschewski, T., Coghill, D., Zheng, Y., Biederman, J., Bellgrove, M. A., Newcorn, J. H., Gignac, M., Al Saud, N. M., Manor, I., Rohde, L. A., Yang, L., Cortese, S., Almagor, D., Stein, M. A., Albatti, T. H., Aljoudi, H. F., Alqahtani, M. M. J., Asherson, P., … Wang, Y. (2021b). The World Federation of ADHD International Consensus Statement: 208 Evidence-

based conclusions about the disorder. *Neuroscience and Biobehavioral Reviews*, *128*, 789–818. https://doi.org/10.1016/J.NEUBIOREV.2021.01.022

Fateh, A. A., Huang, W., Hassan, M., Zhuang, Y., Lin, J., Luo, Y., Yang, B., & Zeng, H. (2023). Default mode network connectivity and social dysfunction in children with Attention Deficit/Hyperactivity Disorder. *International Journal of Clinical and Health Psychology*, *23*(4). https://doi.org/10.1016/j.ijchp.2023.100393

Fitzpatrick, T., Perrier, L., Shakik, S., Cairncross, Z., Tricco, A. C., Lix, L., Zwarenstein, M., Rosella, L., & Henry, D. (2018). Assessment of Long-term Follow-up of Randomized Trial Participants by Linkage to Routinely Collected Data: A Scoping Review and Analysis. *JAMA Network Open*, *1*(8), e186019. https://doi.org/10.1001/JAMANETWORKOPEN.2018.6019

Goldin, P. R., Ziv, M., Jazaieri, H., Werner, K., Kraemer, H., Heimberg, R. G., & Gross, J. J. (2012). Cognitive reappraisal self-efficacy mediates the effects of individual cognitive-behavioral therapy for social anxiety disorder. *Journal of Consulting and Clinical Psychology*, *80*(6), 1034–1040. https://doi.org/10.1037/A0028555

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011a). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research*, *191*(1), 36–43. https://doi.org/10.1016/J.PSCYCHRESNS.2010.08.006

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011b). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research*, *191*(1), 36–43. https://doi.org/10.1016/J.PSCYCHRESNS.2010.08.006

Keng, S. L., Smoski, M. J., & Robins, C. J. (2011). Effects of mindfulness on psychological health: A review of empirical studies. In *Clinical Psychology Review* (Vol. 31, Issue 6, pp. 1041–1056). https://doi.org/10.1016/j.cpr.2011.04.006

Kim, S. H., & Kim, S. (2016). Social Desirability Bias in Measuring Public Service Motivation. *International Public Management Journal*, *19*(3), 293–319. https://doi.org/10.1080/10967494.2015.1021497

Knouse, L. E., Mitchell, J. T., Kimbrel, N. A., & Anastopoulos, A. D. (2019). Development and Evaluation of the ADHD Cognitions Scale for Adults. *Journal of Attention Disorders*, *23*(10), 1090–1100. https://doi.org/10.1177/1087054717707580

Lee, Y. C., Chen, C. R., & Lin, K. C. (2022). Effects of Mindfulness-Based Interventions in Children and Adolescents with ADHD: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *International Journal of Environmental Research and Public Health*, *19*(22), 15198. https://doi.org/10.3390/IJERPH192215198

Lefaucheur, J. P., André-Obadia, N., Antal, A., Ayache, S. S., Baeken, C., Benninger, D. H., Cantello, R. M., Cincotta, M., de Carvalho, M., De Ridder, D., Devanne, H., Di Lazzaro, V., Filipović, S. R., Hummel, F. C., Jääskeläinen, S. K., Kimiskidis, V. K., Koch, G., Langguth, B., Nyffeler, T., … Garcia-Larrea, L. (2014). Evidence-based guidelines on the therapeutic use of repetitive transcranial magnetic stimulation (rTMS). *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology*, *125*(11), 2150–2206. https://doi.org/10.1016/J.CLINPH.2014.05.021

Lopes, A., Sampaio, R., & Tavares, I. (2024). Pain, mindfulness, and placebo: a systematic review. *Frontiers in Integrative Neuroscience*, *18*, 1432270. https://doi.org/10.3389/FNINT.2024.1432270/BIBTEX

Luiselli, J., Happé, F., Hurst, H., Freeman, S., Goldstein, G., Mazefsky, C., Carter, A. S., Kaufman, A. S., Simmons, E. S., Eernisse, E. R., Tsatsanis, K., Fluit, F., Klein-Tasman, B., Feinstein, A., Kahl, A., Poyau, S., Jones, C. R. G., Volkmar, F. R., Wolf, J. M., … Newman, D. B. (2013). Wisconsin Card Sorting Test (WCST). *Encyclopedia of Autism Spectrum Disorders*, 3389–3391. https://doi.org/10.1007/978-1-4419-1698-3_281

Marques, S., Correia-de-Sá, T., Guardiano, M., Sampaio-Maia, B., & Ferreira-Gomes, J. (2024). Emotion dysregulation and depressive symptoms mediate the association between inhibitory control difficulties and aggressive behaviour in children with ADHD. *Frontiers in Psychiatry*, *15*. https://doi.org/10.3389/FPSYT.2024.1329401

Mitchell, J. T., McIntyre, E. M., English, J. S., Dennis, M. F., Beckham, J. C., & Kollins, S. H. (2017). A Pilot Trial of Mindfulness Meditation Training for ADHD in Adulthood: Impact on Core Symptoms, Executive Functioning, and Emotion Dysregulation. *Journal of Attention Disorders*, *21*(13), 1105–1120. https://doi.org/10.1177/1087054713513328

Mitchell, J. T., Zylowska, L., & Kollins, S. H. (2015). Mindfulness Meditation Training for Attention-Deficit/Hyperactivity Disorder in Adulthood: Current Empirical Support, Treatment Overview, and Future Directions. *Cognitive and Behavioral Practice*, *22*(2), 172. https://doi.org/10.1016/J.CBPRA.2014.10.002

Nardi, W. R., Harrison, A., Saadeh, F. B., Webb, J., Wentz, A. E., & Loucks, E. B. (2020). Mindfulness and cardiovascular health: Qualitative findings on mechanisms from the mindfulness-based blood pressure reduction (MB-BP) study. *PLoS ONE*, *15*(9 September). https://doi.org/10.1371/JOURNAL.PONE.0239533

Nicastro, R., Jermann, F., Bluteau Blin, S., Waeber, C., & Perroud, N. (2021). Mindfulness Training for Adults with Attention-Deficit/Hyperactivity Disorder: Implementation of Mindful Awareness Practices in a French-Speaking Attention-Deficit/Hyperactivity Disorder Unit. *Journal of Alternative and Complementary Medicine (New York, N.Y.)*, *27*(2), 179–183. https://doi.org/10.1089/ACM.2020.0216

Norman, L. J., Sudre, G., Price, J., & Shaw, P. (2024a). Subcortico-Cortical Dysconnectivity in ADHD: A Voxel-Wise Mega-Analysis Across Multiple Cohorts. *American Journal of Psychiatry*, *181*(6), 553–562. https://doi.org/10.1176/APPI.AJP.20230026)

Norman, L. J., Sudre, G., Price, J., & Shaw, P. (2024b). Subcortico-Cortical Dysconnectivity in ADHD: A Voxel-Wise Mega-Analysis Across Multiple Cohorts. *The American Journal of Psychiatry*, *181*(6), 553–562. https://doi.org/10.1176/appi.ajp.20230026

Penny, W., Friston, K., Ashburner, J., Kiebel, S., & Nichols, T. (2007). Statistical Parametric Mapping: The Analysis of Functional Brain Images. *Statistical Parametric Mapping: The Analysis of Functional Brain Images*. https://doi.org/10.1016/B978-0-12-372560-8.X5000-1

Posner, J., Park, C., & Wang, Z. (2014). Connecting the dots: a review of resting connectivity MRI studies in attention-deficit/hyperactivity disorder. *Neuropsychology Review*, *24*(1), 3–15. https://doi.org/10.1007/S11065-014-9251-Z

Sonuga-Barke, E. J. S., & Castellanos, F. X. (2007). Spontaneous attentional fluctuations in impaired states and pathological conditions: a neurobiological hypothesis. *Neuroscience and Biobehavioral Reviews*, *31*(7), 977–986. https://doi.org/10.1016/J.NEUBIOREV.2007.02.005

Tang, Y. Y., Hölzel, B. K., & Posner, M. I. (2015a). The neuroscience of mindfulness meditation. *Nature Reviews. Neuroscience*, *16*(4), 213–225. https://doi.org/10.1038/NRN3916

Tang, Y. Y., Hölzel, B. K., & Posner, M. I. (2015b). The neuroscience of mindfulness meditation. *Nature Reviews Neuroscience 2015 16:4*, *16*(4), 213–225. https://doi.org/10.1038/nrn3916

UK Policy Framework for Health and Social Care Research - Health Research Authority. (n.d.). Retrieved November 22, 2024, from https://www.hra.nhs.uk/planning-and-improving-research/policies-standards-legislation/uk-policy-framework-health-social-care-research/

Van Dam, N. T., van Vugt, M. K., Vago, D. R., Schmalzl, L., Saron, C. D., Olendzki, A., Meissner, T., Lazar, S. W., Kerr, C. E., Gorchov, J., Fox, K. C. R., Field, B. A., Britton, W. B., Brefczynski-Lewis, J. A., & Meyer, D. E. (2018). Mind the Hype: A Critical Evaluation and Prescriptive Agenda for Research on Mindfulness and Meditation. *Perspectives on Psychological Science : A Journal of the Association for Psychological Science*, *13*(1), 36–61. https://doi.org/10.1177/1745691617709589

Wielgosz, J., Goldberg, S. B., Kral, T. R. A., Dunne, J. D., & Davidson, R. J. (2018). Mindfulness Meditation and Psychopathology. *Annual Review of Clinical Psychology*, *15*, 285. https://doi.org/10.1146/ANNUREV-CLINPSY-021815-093423

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biological Psychiatry*, *57*(11), 1336–1346. https://doi.org/10.1016/J.BIOPSYCH.2005.02.006

Zylowska, L., Ackerman, D. L., Yang, M. H., Futrell, J. L., Horton, N. L., Hale, T. S., Pataki, C., & Smalley, S. L. (2008). Mindfulness meditation training in adults and adolescents with ADHD: a feasibility study. *Journal of Attention Disorders*, *11*(6), 737–746. https://doi.org/10.1177/1087054707308502