Into The Awakened Land:

Attention, Arousal and The Mindful Eye

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"There are these two young fish swimming along, and they happen to meet an older fish swimming the other way, who nods at them and says, "Morning, boys. How's the water?" And the two young fish swim on for a bit, and then eventually one of them looks over at the other and says, "What the hell is water?"[1]

[1] Wallace, D. F., & Kenyon College. (2009). *This is water: Some thoughts, delivered on a significant occasion about living a compassionate life*. New York: Little, Brown.

Summary

Some of the most obvious and important realities are often the hardest to see. Although human beings harbour unprecedented sophistication in relation to their capacity for adaptive environmental negotiation, they also become so easily untethered from the simple act of *being*. The ancients understood the value of this mode, whereby early Buddhist dharma highlights the importance of being *mindful* towards the present moment, from a stance of *wakefulness* and *alertness*. Such capacities likely encompass an *arousing* quality, which may be associated with distinct attentional features directly accessible through a range of neurocognitive scientific methods. However, despite the utility and availability of such techniques, the wakeful and arousing qualities of mindfulness remain largely unexplored.

In the present thesis, my primary aim was to examine mindfulness through the lens of adaptive gain theory (AGT), which positions the locus-coeruleus noradrenaline system (LC-NA) as a central arousal-based modulator of human wakefulness and attention during the adaptive negotiation of environmental information. Specifically, I converged the use of pupillometry – a reliable index of LC-NA activity – with a range of attentional stimuli to examine mindfulness as an AGT-predicted mode of elevated LC-NA arousal and augmented attention.

Across seven experiments harnessing concurrent examinations of attentional processes and pupillary indices of noradrenergic activity, I demonstrated that mindfulness was associated with increased subjective indices of attentiveness and awareness, enhanced capacities for exploratory attention and associated shifts into tonic LC-NA arousal states. However, there were limited mindfulness-induced changes to performance-based assessments of alerting, orienting and executive network efficiency or increased LC-NA activation indicative of elevated arousal. Taken together, these results serve to embellish our current understanding of mindfulness as a capacity for wakefulness, awareness and enhanced attentional negotiation of environmental demands. That is, the “awakening” typically associated with mindfulness and meditation-related capacities may be more than mere metaphor, inviting future endeavour to reveal yet more information about the wakeful properties of the contemplative mind.

"The capital-T Truth…has everything to do with simple awareness; awareness of what is so real and essential, so hidden in plain sight all around us, all the time, that we have to keep reminding ourselves over and over:

This is water.

This is water."[2]

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[2] Wallace, D. F., & Kenyon College. (2009). *This is water: Some thoughts, delivered on a significant occasion about living a compassionate life*. New York: Little, Brown.

Acknowledgments

Firstly, I'd like to thank my supervisor, Travis Proulx, for the ongoing guidance, support and feedback. Your expertise, approachability and - of equal importance - your music recommendations[3] significantly helped me to develop as a confident researcher, and as a loyal fan of Let's Eat Grandma. Thank you for addressing my doubts and concerns along the way. It's been great working with you. My deepest gratitude also to Cardiff University for affording me the time and resources to focus wholly on learning at the highest level. It is greatly appreciated.

Importantly, I would like to dedicate this thesis to my family, most of whom reside quietly in the 'shire, and to others who've long departed (Betty, Brian, Paul, Terry, Robbie. Miss you guys). Thank you for everything. This section just isn't long enough.

To my parents. You've only ever been open, loving and supportive, no matter what shade of life I've inhabited. For that, I am eternally grateful. Thank you for your endless acceptance and encouragement. I hope that somehow, I've made you proud through it all.

To my three beautiful siblings – my best friends – you're all far cleverer than I am. Thanks for accompanying me on this weird and wonderful life journey, never judging, always smirking, as thick as thieves, until the end.

To Grandad, Helen and Eva – how lucky for me to have you all. There's a cosiness and warmth you bring to my life that I'd be very lost without. Thank you for always being there.

To my nephews, Elliott and George, and my niece, Lilybet. You all arrived during a strange and worrying time for our world, but I truly hope you can flourish in a more hopeful era. I look forward to watching you all grow up. Try and do a better job of this than we have.

And to Jess. Thank you for putting up with the trials and tribulations of an old man going back to school. You've exhibited an unparalleled level of warmth, belief, and acceptance that I probably don't deserve. Hey! It's your turn now.

Finally, I would like to dedicate this thesis to my Nan, Audrey Aplin. Your advice, humour and stoicism are sorely missed, but I remain guided by their echo. I know you would've loved to see this little achievement. Rest easy.

[3] Moonlighting as a staff writer for Pitchfork really enhanced our supervisions.

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Chapter 1: General Introduction[4]

Overview

In this chapter, I review literature supporting the conceptualisation of mindfulness as a capacity for enhanced vigilant attention and improved attentional control. Subsequently, I utilise this knowledge to position mindfulness as a unique capacity for *wakefulness,* characterised by an optimal arousal state through the lens of adaptive-gain theory (AGT). Specifically, I propose that dispositional mindfulness and nurtured mindfulness states can be understood as representing distinct patterns of activity within the locus-coeruleus noradrenaline (LC-NA) system, namely an adaptive *tonic* LC-NA mode, which promotes a form of wakefulness, awareness and non-judging acceptance toward internal and external experience. I contend that utilising pupillometry - a readily available method for gauging LC-NA activity - during assessments sustained attention and attentional control can effectively test such proposals, providing the rationale for the present body of research. At the end of the chapter, I provide an overview of seven studies exploring attentional and psychophysiological processes as a function of trait mindfulness, mindfulness-based interventions / inductions and magnitudes of meditation experience / frequency, concluding with a discussion of the potential implications of my research.

[4] Portions of this Chapter inform the basis of a submitted manuscript (Hill, J. R. J., Vanderwert, R., and Proulx, T. 2021)

"There is a moment, a cusp, when the sum of gathered experience is worn down by the details of living. We are never so wise as when we live in the moment."[5]

- Paul Kalinithi

"There is a moment of sheer panic when I discover Paul's apartment overlooks the park and is obviously more expensive than mine."[6]

- Patrick Bateman

"Each of us literally chooses, by his way of attending to things, what sort of universe he shall appear to himself to inhabit"[7]

- William James

Moments. They come and go unnoticed or jolt us into being. They fill our worlds with colour or endow all manner of suffering. They eb, they flow, and for the lifetime we've known them, we still can't quite "seize" one. Or can we? And if so, what defines its capture? The answer may indeed reside in an ability to "see a world in a grain of sand"[8], insofar as being fully attentive and aware of *this right now,* in each moment as it unfolds, without judgment, would appear to occupy a unique attentional space, whereby time itself is suspended by the perceptive spotlight of a vigilant mind. To be *mindful*, it would seem,

[5] 'When Breath Becomes Air' by Paul Kalinithi (2015, p. 103)
[6] Patrick Bateman, from 'American Psycho' by Bret Easton Ellis (1991, p. 416)
[7] The quote was obtained from: Quotepark (n.d.). Retrieved January 1st, 2022 from https://quotepark.com/quotes/
[8] 'Auguries of Innocence' by William Blake (1803), as listed in 'Blake' by Peter Ackroyd (pg. 39).

harbours great influence over existential experience, necessitating a deeper understanding of what characterises this seemingly straightforward, yet altogether more difficult to conceptualise, capability. Accordingly, the backbone of the present research is comprised of efforts to expand upon existing explications of what characterises mindfulness, specifically within the context of attentional and arousal-based mechanisms.

A Spring Day in Massachusetts

In the Spring of 1979, whilst sitting quietly in his room at a Worcester County retreat centre, a young Doctor from New York experienced a vivid and instantaneous 10-second 'vision' that would change the course of his life, and the lives of many others, forever. This brief flash of insight, although still not fully explainable to the now Professor Emeritus (Kabat-Zinn, 2011), represented the inception of a decades-long proliferation of mindfulness-based research and clinical practice across the globe, resulting in a remarkable and ever-burgeoning increase in the number of scientists and practitioners dedicating their time and effort to learning more about what it means to be mindful (Clarke, Barnes, Black et al., 2018). As such, pretty much everything that was contained in those fateful 10 seconds has now come to pass, insofar as new fields of investigation have been initiated, specialised clinics have been established, and meaningful professions have been forged around the world (Kabat-Zinn, 2011).

Naturally, the increased (and increasing) popularity of mindfulness has ignited and maintained a high level of enthusiasm within the academic sphere, spawning ubiquitous PhD studentships and defining careers. As a result, harnessing insights from cognitive, neurobiological and clinical domains, scientific endeavour has made impressive progress in attempting to conceptualise what mindfulness is, how it works and what it means for the human condition. However, the concept of mindfulness remains relatively nebulous, and the forty years of appreciable scientific interest since that spring day in Massachusetts has revealed fruitful empirical lacunas, ripe for new inquiry. Accordingly, converging insights from attentional and neuroanatomical domains, the present thesis examines mindfulness through the lens of the human attentional and noradrenergic systems, in the hope of illuminating two understudied components residing at the heart of emerging conceptualisations of mindfulness: *wakefulness* and *arousal.*

Awakening: More Than Mere Metaphor

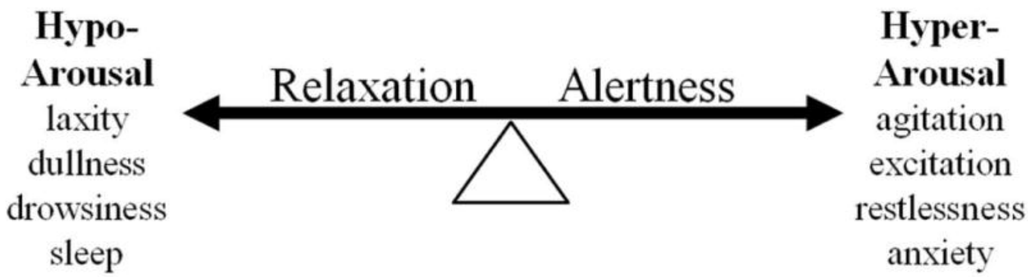
The earliest known origins of our current concept of the term "mindfulness" emerge from the Pali words *sati* and *vipassana* from the ancient Indian Buddhist tradition. *Sati* implies the ability to remain alert, attentive and aware, and *vipassana* implies insight cultivated by meditation, with the overall goal being *bodhi* or *awakening* (Britton, Lindahl, Cahn, Davis and Goldman, 2014; Nisbet, 2017). Although over 2,500 years old, meditative teachings arising from Buddhist philosophy only formally found their way into Western therapeutic science in the early 1980s. This was in the shape of Mindfulness-Based Stress Reduction (MBSR, Kabat-Zinn, 1982), which represented the first tangible manifestation of our young doctor's daydream to convey the clinical benefits of mindfulness to a global audience. Although MBSR was the first established and structured formulation of Buddhist-derived mindfulness teachings within a Western clinical context, it notably harboured no reference to Buddhism itself, instead tailoring its full attentional focus on the utility of mindfulness practice to help alleviate chronic pain and associated psychological distress. Indeed, in the subsequent drive to render mindfulness more agreeable to the Western palate (e.g., by enhancing accessibility for individuals who may be put off by traces of spirituality or dogma), the practice became largely contextualised as a therapeutic intervention to help dampen psychological distress (Hayes, 2004; Kabat-Zinn, 1990; Segal, 2002), and as a self-maintenance tool to augment daily wellbeing (Mani et al., 2015). By extension, a lot more emphasis has been placed on the relaxing / alleviating effects of meditation and much less on the wakefulness-promoting, arousing and vigilant effects (Britton et al., 2014). This has resulted in a plethora of mindfulness-based frameworks that remain decontextualised from their Buddhist roots. Considering that much of the Buddhist dharma emphasises the necessity of alertness and wakefulness in ongoing meditative practice - components which are theorised to give rise to an awareness of experience that nurtures insight into potentially maladaptive habitual patterns (Britton et al., 2014; Vago and Silbersweig, 2012) - the promotion of *sati* for an *awakened mind* would appear to warrant deeper consideration.

The founding father of mindfulness-based therapeutic practice in the West has characterised mindfulness as “the awareness that arises from paying attention, on purpose, in the present moment and non-judgmentally” (Kabat-Zinn, 1990) and as “being awake” (Kabat-Zinn, 1982), essentially positioning a wakeful mode of attentiveness, awareness and non-judging acceptance as central to any conceptualisation of mindfulness. Indeed, these dimensions occupy primary roles in many contemporary definitions and models of mindfulness (Bishop, Lau, Shapiro, et al., 2004; Kabat-Zinn, 2003; Lutz, Slagter, Dunne and Davidson, 2008; Shapiro, Carlson, Astin and Freedman, 2006), prompting an abundance of experimental inquiry into the neurocognitive mechanisms giving rise to these wakefulness-related elements and how they interact with different attentional and cognitive demands. In a comprehensive review of Buddhist texts and scientific articles, Britton et al. (2014) concluded that mindfulness-based meditation indeed nurtures attentionally stable, wakefulness-promoting effects by guarding against the extremes of hypoarousal (relaxation and non-alertness) and hyperarousal (restlessness and anxiety) (Figure 1), thus emphasising a distinct quality of "relaxed alertness" in the conceptualisation of meditative practice. It is possible that this stable form of alertness, which promotes an active, non-judgmental awareness and acceptance of present moment experience (Britton et al., 2014), regardless of whether the experience is positive or negative (e.g., *decentering;* Bishop, et al., 2004), is linked to elevations in *arousal,* specifically to the activity of the locus-coeruleus noradrenaline (LC-NA) system. This proposal offers a tantalising opportunity to contribute to a more comprehensive understanding of what it means to be mindful, in both disposition and practice, by examining central dimensions of mindfulness through the lens of the "Awakened Mind" (Britton et al., 2014).

However, despite the availability of novel and accessible methods to directly converge subjective assessments of specific mindfulness dimensions, behavioural tests of sustained / executive attention and "online" psychophysiological assessments of arousal in relation to the LC-NA system, such endeavour remains neglected within the mindfulness literature. Accordingly, the broader aim of the present thesis is to examine mindfulness as a distinct mode of psychophysiological arousal giving rise to increased vigilance and attentional control, with the general expectation that the "awakening" originally promoted by Buddhist dharma is more than mere metaphor. Naturally, when embarking on such a task, it is necessary to review current understandings of the human attention system and how attentional and neurobiological systems have been shown to interact with mindful traits and states.

Figure 1.

Mindfulness as Relaxed Alertness



Note. Figure reproduced with permission from Britton, Lindahl, Cahn, Davis and Goldman (2014).

The Attention System of the Human Brain

Human attention cannot be treated as a singular entity, but rather a variegated set of processes that constitute the brain's attentional system. Generally, attention can be conceptualised as three distinct neurocognitive networks, each of which are subserved by three independent, yet interconnected, neural systems; the alerting, orienting and executive networks (for reviews, see Posner and Petersen, 1990 and Petersen and Posner, 2012). The alerting network modulates arousal for the ability to remain vigilant and prepared over time for the detection of incoming stimuli (Josefsson and Broberg, 2011; Malinowski, 2013, Petersen and Posner, 2012). Alerting consists of both tonic effects (tonic alertness – also called intrinsic alertness / vigilant attention; this refers to a sustained level of vigilance that facilitates the ongoing monitoring and detection of environmental stimuli) and phasic effects (phasic alertness; this refers to increased response readiness briefly following task-related warning signals for optimal performance and response-locked evaluation of performance reflecting cognitive load), both of which are required for ongoing attentional engagement throughout a task (Britton et al., 2014; Sorensen, Osnes, Visted et al., 2018; Tang, Holzel and

Posner, 2015). Specifically, tonic effects are believed to provide the cognitive tone for performing more complex functions, such as attentional / executive control, thus representing a foundational precondition for other forms of attention (Britton et al., 2014).

The second network is the orienting network, which concerns the ability to prioritise sensory input based on modality or location (e.g., by orienting towards the spatial location of incoming stimuli), thus representing *selective* attention (Petersen and Posner, 2012). The orienting system consists of both exogenous (reflexive and automatic responses to warning stimuli) and endogenous processes (allocation of attentional resources towards a predetermined location) (Mayer, Dorflinger, Rao and Seidenberg, 2004) and is related to several frontal and posterior cortical areas (Petersen and Posner, 2012).

The executive network was originally characterised as a capacity for efficient target detection (Posner and Petersen, 1990), whereby the moment of detection captures awareness in a very specific way through increased interference across the attentional system (Petersen and Posner, 2012). Due to the limited capacity of attentiveness and awareness, target detection requires focal attention - a doorway to the conscious state - which necessarily facilitates the monitoring and suppression of salient but irrelevant stimuli in favour of task-relevant information (Sorensen et al., 2018). This process recruits greater activity within the medial frontal cortex and the anterior cingulate cortex (ACC) in response to conflicting relative to non-conflicting information, thus facilitating top-down regulation of task-related processes and goals (e.g., executive control) (Petersen and Posner, 2012). As such, the ACC, specifically the dorsal portion, appears to play an important role in the monitoring and resolution of executive conflict (Carter and Krug, 2012). Similarly, the ACC is activated in response to an array of inconsistent / expectancy-violating stimuli that are not linked to specific tasks (Sleegers and Proulx, 2015), such as incongruous word pairings (Randles, Proulx and Heine, 2011), anomalous playing cards (Sleegers, Proulx and van Beest, 2015) and uncanny / threatening pictorial human faces (Proulx, Sleegers and Tritt, 2017).

As such, the human attention system allows for a dynamic interaction with the environment through efficient detection, selection and adaptive negotiation of a diverse range of expected and salient stimuli. More specifically, the efficiency of, and interactions between, each of these attentional networks represents an overall ability to remain vigilant and wakeful throughout a task for the purposes of prioritising stimuli, monitoring task-related conflict / incongruence and responding optimally to task-related information. Experimentally, a range of attention tasks and signal detection methods have been developed to behaviourally assess these capabilities, allowing for robust, objective assessments of vigilance and attentional control.

For example, the Attention Networks Task (ANT) has been utilised extensively to examine the functioning of each network. Specifically, the ANT converges assessments of alerting, orienting and executive control (Posner and Petersen, 1990) as a function of cognitive subtractions between cue and target stimuli (Fan et al., 2002. See Chapter 4, studies 4 and 5 for calculations). Improved efficiency of the alerting network implies an enhanced ability to sustain attention, alertness and vigilance in preparation for incoming task-related objects / stimuli. Enhanced efficiency of the orienting network suggests an enhanced ability to *selectively* attend to spatially relevant incoming stimuli (e.g., facilitating attentional redirection). Improved functioning of the executive network implies enhanced ability to detect novel / conflicting elements and to manage resources accordingly for conflict resolution (e.g., detecting distractor salience / incongruence and managing cognitive resources for efficient responding) (Arora et al., 2020; Posner, 2008). Other tasks utilised to assess executive performance in the face of incongruent information include the Stroop task (Stroop, 1935), which assesses the ability to exert attentional control over the habitual process of word reading in favour of attending to and responding to a less typical task – colour identification.

Several tasks have also been designed to assess sustained attention and alertness / vigilance using continuous performance target-detection paradigms, such as the Sustained Attention to Response Task (SART) and the Continuous Performance Test (CPT). These tasks require participants to press a key in response to frequently presented non-targets (numbers (SART) or letters (CPT)) and to withhold their responses to infrequent targets (specific number or letter) (see Chapters 4 and 5). The central idea behind the paradigm is that continuous performance over many trials encourages automatic responses to non-target 'go' trials and that sustained attention, vigilance and active controlled processing is required to detect the infrequent 'no-go' trials and to withhold the prepotent automatic response to these trials (inhibitory control) (Peebles & Bothell, 2001; Roca et al., 2011; Roebuck et al., 2017). Therefore, these tasks are defined as measuring the ability to sustain attention and vigilance to repetitive, non-arousing stimuli in a mindful, conscious way, and to detect infrequent targets during a task that would otherwise lead to habituation, distraction and mind wandering (Robertson et al, 1997). The ability to constantly monitor and detect infrequent stimuli is conceptualised as a capacity for sustained vigilance / tonic alertness (Rosenberg et al., 2013; Warm et al., 2008), which by extension provides the 'cognitive tone' for performing more involved executive functions (Posner, 2008), such as aiding the efficiency of the executive management of prepotent responses to guide appropriate performance-based engagement. Capacities for sustained vigilance vary widely between individuals and is related to personality differences, brain structure, neurological health and other cognitive capabilities (Kanai et al., 2011; Robertson et al., 1997; Rosenberg et al., 2013).

Such attentional capacities also appear to be modulated by arousal-based mechanisms (Geva, Zivan, Warsha and Olchik, 2013; Petersen and Posner, 2012; Smallwood, Brown, Tipper et al., 2011). For example, the alerting system is strongly related to arousal, specifically to the neurotransmitter noradrenaline (NA), which is released in both a tonic (spontaneous, vigilance-promoting increases) and phasic manner (task/response-locked bursts) under the governance of a tiny brainstem structure known as the locus coeruleus (LC). Importantly, adaptive gain theory (AGT) (Aston-Jones and Cohen, 2005) proposes that the phasic mode of NA release is characterised by intermediate tonic activity and allows for *top-down exploitation* of task-specific rewards for optimal performance. Conversely, the tonic mode of NA release represents a marked elevation in LC-NA activity and reduced phasic responses, typically initiated by undemanding tasks or in initial responses to inconsistent / unexpected information, which is conducive to *bottom-up exploration* of internal and external experience, which may also promote intentional and unguided internal trains of thought (Aston-Jones and Cohen, 2005; Bruya and Tang, 2018; Smallwood and Andrews-Hanna, 2013)[9].

As such, any thorough experimental examination of mindfulness as a distinct attentional and wakeful capacity necessitates the recruitment of a diverse range of methodologies, encompassing self-report measures (for the collection of internal cognitive states), performance-based tests of attention (for objective assessments of attentional efficiency), inconsistency inductions (for assessments of attentional salience responses) and temporally sensitive techniques to gauge fluctuations in arousal during these processes. However, despite such methods being readily available and relatively straightforward to coalesce, empirical endeavour in this respect remains sparse.

Accordingly, I review the current landscape relating to behavioural and neuroanatomical conceptualisations of mindfulness as an enhanced capacity for alertness and

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[9] Such characteristics are elaborated upon throughout this introductory chapter in relation to mindfulness, cognitive content and psychophysiological assessment (e.g., ‘Adaptive Gain Theory (AGT) and The Dark Blue Place’).

wakefulness, utilising insights obtained from attention tasks, self-report methods and neuroscience to present the case for examining mindfulness across a range of specific attentional paradigms / techniques (for example, inconsistency inductions, self-reported cognition, objective tests of attention). Crucially, I then highlight the necessity of harnessing these techniques in tandem with assessments of *arousal*, specifically by using an underutilised assessment of locus coeruleus activity; pupillometry.

Mindfulness as Augmented Attention

The way in which we utilise alerting, orienting and executive strategies to attend to internal and external events can have a vast impact on our perceptions, thoughts and behaviours, and by extension, our psychological wellbeing and sense of personal identity (Sood and Jones, 2013). As such, the ability to cultivate stable attentional states and to filter out irrelevant or unhelpful stimuli harbours potentially profound implications for many aspects of daily existence. However, steadying the spotlight of attention is difficult, and individuals commonly find that sustaining their attention on a task or an object can be effortful, irritating and even stressful (Zanesco et al., 2013). Therefore, distinct capacities for attentional processing are likely reflected in differential levels of efficiency of the alerting, orienting and executive systems. Specifically, considering what we know about attention, distinct individual differences and nurtured states most conducive to wakeful modes of awareness and associated enhancements to sustained attention and attentional control are likely to influence and interact with behavioural, neuroanatomical and psychophysiological components of the human attention system. As such, when embarking on an examination of mindfulness as a capacity for wakefulness and arousal, it is necessary to understand how both trait and induced states of core dimensional qualities of mindfulness have been demonstrated to relate to broader attentional indices of alertness / vigilance, executive function, cognitive content and responses to inconsistent stimuli.

Dispositional Mindfulness. Although the flexible nature of personality renders the systematic investigation of dispositional mindfulness complicated (Tang et al., 2016), extant research has harnessed a range of self-report measures to gauge trait levels of specific dimensional qualities. Two of the most widely used[10], which are also employed throughout the present thesis, are the Mindful Attention and Awareness Scale (MAAS, Brown and Ryan, 2003) and the Five Facet Mindfulness Scale-15 (Baer et al., 2008).

The MAAS assesses the tendency to be fully attentive and aware in the present moment, without distraction, thus effectively gauging the attentiveness and awareness dimensions of mindfulness (Brown and Ryan, 2003). In terms of behavioural assessments of attentional vigilance, the MAAS has been associated with improved accuracy-based performance during two sustained attention tasks[11] reliably shown to reflect capacities for ongoing vigilance and alertness, namely the Continuous Performance Test (CPT, Conners, 2000; Schmertz, Anderson and Robins, 2009) and the Sustained Attention to Response Task (SART, Robertson et al., 1997; Cheyne, Carriere and Smilek, 2006), displaying moderate to large correlation coefficients: -.31 to -.51.

The FFMQ assesses five distinct facets of mindfulness, namely capacities for observing, describing, awareness, non-judging and non-reactivity toward internal and / or external experience (Baer et al., 2008). As such, the FFMQ can assess the attentiveness and awareness dimensions of mindfulness (e.g., Observing, Describing, Awareness) and the non-judgmental accepting dimension (e.g., Non-Judging).

[10] See Appendix 0i for operational description of these measures.

Behaviourally, beneficial associations have been observed between total FFMQ / FFMQ-Describing scores and i), improved accuracy-inferred sustained attention and vigilance outcomes during the SART (reduced errors) and ii), improved accuracy to incongruent stimuli during the Stroop task (reduced interference effects) (Stroop, 1935; Josefsson and Broberg, 2011), with standardised coefficients ranging from -.22 to -.25. Moreover, FFMQ-Describing and FFMQ-Non-Judging have been associated with improved orienting function during the Attention Network Task (standardised coefficient: -.44) (ANT, Fan et al., 2002; Sorensen et al., 2018)[12]. Similarly, heightened FFMQ-Awareness has been associated with reduced flanker interference effects in the form of improved accuracy to incongruent targets (Lin et al., 2019), displaying a moderate correlation of -.35.

It should be noted that the majority of these studies did not control for lifestyle-related factors, such as diet, exercise, sleep habits, alcohol / drug use or work-related stress, each of which can reasonably be assumed to represent important potential confounds when assessing relationships between trait mindfulness and attention outcomes. Although the study conducted by Cheyne and colleagues (2006) did assess and control for sleep-related habits, this variable was not shown to be associated with trait mindfulness or SART outcomes. Most studies consistently controlled for age and gender in analyses.

Taken together, these findings imply that higher levels of attentiveness, awareness and non-judging acceptance, as assessed by the MAAS and specific sub-facets of the FFMQ (see also, Appendix 0i), likely facilitate the ability to remain alert for the detection of incoming stimuli, whilst also harbouring a receptive “executive” attention for the open detection of novel and / or conflicting information (Tang et al., 2015). Moreover, they suggest that specific FFMQ facets associated with awareness and non-judging facilitate enhanced detection of, and diminished conscious reactivity to, incongruency in conflict awareness tasks, implying a non-judgmental acceptance of - and subsequent disengagement from - conflict once it has been detected (Teper and Inzlicht, 2013). Such insights serve to illustrate that dispositional mindfulness can be viewed as an individual difference variable conducive to enhanced vigilance and attentional control, prompting further endeavour to explore coincident assessments of psychophysiological mechanisms potentially underlying these capabilities.

Mindfulness Training. In addition to examining associations between dispositional mindfulness and attentional capabilities indicative of ongoing alertness and attentional control, task-based attentional performance and core dimensions of mindfulness are also actively nurtured during mindfulness practice / training. Buddhist traditions have long acknowledged the fluctuating nature of attention and have utilised distinct mental training techniques to stabilise attention for the facilitation of behavioural and emotional regulation (Zanesco, King, MacLean and Saron, 2013). Indeed, by its very definition, meditation is a self-regulatory attentional activity, the essence of which is often referred to as attention control and awareness training (Claxton, 1987; Walsh and Shapiro, 2006), widely considered as central components of meditative practice (Bishop et al., 2004; Kabat-Zinn, 2003; Lutz et al., 2006; Tang et al., 2015).

Specifically, the attentiveness, awareness and non-judgemental acceptance arising from meditative engagement correspond to two experiential techniques inherent to most mindfulness-based practices. The first type of practice is designed to nurture sustained attentional focus and awareness on an external object (focused attention; FA). Eventually, repeated FA practice develops into a more ‘open’ non-judgmental awareness and acceptance of all internal and external phenomena, facilitating an experiential ‘stepping back’ from thoughts, emotions and sensory events and viewing them simply as transitory phenomena (open monitoring; OM) (Britton et al., 2018; Lutz et al., 2008). Indeed, supporting the linkage between FA and OM meditative techniques and core mindfulness dimensions, structured mindfulness-based interventions / training programmes and longer-term meditation practice have been shown to enhance attentiveness, awareness and non-judgmental acceptance across a range of self-report measures, including the FFMQ (Frostadottir and Dorjee, 2019; Schance, Vollestad, Visted, et al., 2020; Zhu, Wang, Chen, et al., 2021) and the MAAS (McGarrigle and Walsh, 2011; Vinchurkar, Singh and Viseweswaraiah, 2014). These findings suggest that meditative practice reliably augments subjectively assessed indices of awareness and acceptance, which as discussed, are associated with improvements in sustained attention and executive function and likely reflect the relaxed alertness associated with mindfulness practice. Moreover, discussed findings prompt examinations of moderative effects of awareness / acceptance on relationships between mindfulness training and attentional outcomes (Zhu et al., 2021).

FA and OM practices would also appear to map neatly onto the attentional requirements of many tasks assessing sustained attention / vigilance and executive function. Specifically, FA and OM techniques are theorised to enhance three attentional processes and their underlying neural networks: (i), the ability to sustain attentional focus on an object (e.g., the breath / task goals) whilst remaining aware and vigilant to internal / external phenomena (e.g., mind-wandering / external distractors), (ii), the capacity to detect such distracting information and disengage from it, and (iii), the ability to return attention to the object in the presence of competing information (Lutz et al., 2008). Respectively, these processes pertain to alertness, which governs sustained attention and vigilance towards task-related objects (e.g., awareness), executive control, which assesses distractor salience / incongruence without attachment (e.g., non-judging acceptance), and orienting, which facilitates attentional redirection in the presence of distractors / task conflict (Lutz et al., 2008; Malinowski, 2013; Posner, 2008). These attentional capabilities can be reliably assessed through the utilisation of a range of performance-based tests of attention, such as the CPT, SART, ANT, Stroop and other comparable tests of sustained attention / vigilance and executive function (Conners et al., 2000; Fan et al., 2002; Robertson et al., 1997; Stroop, 1935). Moreover, enhanced abilities to detect internal / external distractors and repeatedly orient attention back to an attentional object would appear well-suited for the continual identification of ongoing cognitive processes, which can also be assessed during attention tasks via thought probing (e.g., task-related / task-unrelated thoughts, Unsworth & Robison, 2016) as a function of mindfulness-based practice.

Indeed, extant research illustrates the utility of mindfulness-based practices, whether in the form of clinical interventions, retreats or brief inductions, at enhancing behaviourally assessed indices of sustained attention / vigilance (e.g., increased accuracy to infrequent targets) during the SART / CPT (Andreu et al., 2019; Badart, McDowall and Prime, 2018; Mrazek, Smallwood and Schooler, 2012; Yakobi, Smilek and Danckert, 2021), alerting and attentional orientation during the ANT (Lao, Kissane and Meadows, 2016; Yakobi et al., 2021), executive response inhibition during SART-like tasks and the Stroop (Casedas, Vadillo and Lupianez, 2020; Chan and Woolacott, 2007; Gallant, 2016; Moore and Malinowski, 2009) and executive function during the ANT (Jha, Krompinger and Baime, 2007; Norris, Creem, Hendler and Kober, 2018; Yakobi et al., 2021). These results suggest that, from a behavioural perspective, the FA and OM techniques practiced during mindfulness training facilitate increased alertness, awareness and acceptance during performance-based tests of attention for i), the early detection of infrequent / inconsistent stimuli, ii), the utilisation of task-related warning signals for optimal performance, and iii), the efficient disengagement from distracting / inconsistent / incongruent information. Considering that such capacities rely on dynamic interactions between the tonic and phasic effects of the human attention system (Britton et al., 2014; Sorensen et al., 2018; Tang et al., 2015), assessing mindfulness through the lens of the psychophysiological mechanisms underlying alerting, orienting and executive attention processes will likely provide much-needed insight into the role of arousal in mindfulness-induced attentional change. Specifically, I propose that the *awareness* nurtured by FA practice and the *acceptance* fostered by OM techniques are, respectively, comparable to bottom-up 'outward' and 'inward' exploratory characteristics of a *tonic* attentional mode[13], insofar as each construct implies a broadening of the attentional field to detect and respond non-judgmentally to unfolding / unexpected events, rather than relying on a phasic filtering of experience. Moreover, I propose that the attentional benefits of mindfulness are likely mirrored by *subjectively* assessed enhancements in sustained attention (e.g., cognitive content), which may also be related to distinct arousal-based signatures.

Mindfulness and Cognition

The human capacity to explore vast and complex inner psychological landscapes has allowed the species to flourish, thanks to an ability to manifest insights from experience and project future scenarios based on what has been done in the past (Baird, Smallwood and Schooler, 2011). Indeed, the finest examples of human ingenuity, creativity and complex problem-solving rely on the fact that the spotlight of our attention spends an inordinate amount of time directed *within* the mind, whereby it's typically focused on the future

[13] These modes are inextricably linked to AGT-predicted tonic and phasic LC-NA activity, as outlined in 'Adaptive Gain Theory (AGT) and The Dark Blue Place'.

(Ottaviani and Couyoumdjian, 2013; Smallwood, Nind and O'Connor, 2009) and oriented toward personal goal resolution (Baird et al., 2011). Importantly, this tendency to drift into temporally defined internal worlds consumes roughly 50% of our waking lives (Brewer, Worhunsky, Gray, et al., 2011; Smallwood, Ruby and Singer, 2013) and represents a mental untethering from the present moment and from any consistent train of thought required for the successful negotiation of task-related stimuli. Such cognitive decoupling has been termed "mind wandering", which is characterised by 'inward', internally-generated and self-referential thought processes, which are wholly independent from task-related attentional requirements, especially when these requirements demand little of one's cognitive resources (Smallwood and Schooler, 2016).

As much as the human condition is defined and augmented by intricate internal dialogues, such introspection can, depending on the context, also have a detrimental impact on many aspects of daily existence, whereby ruminating about the past or worrying about the future can serve to initiate and / or maintain depressive and anxious symptoms (Hoffman, Banzhaf, Kanske, et al., 2016; Seli, Beaty, Marty-Dugas and Smilek, 2019; Sood and Jones, 2013). As such, there is a need for a deeper evaluation of the dispositional, attentional and neurobiological characteristics that may underlie, and interact with, this distinctly human tendency.

Naturally, self-generated 'offline' thought processes are not independent of the context in which they occur (Smallwood and Andrews-Hanna, 2013), which is crucial to consider when examining such processes in relation to specific attentional capacities and in the selection of appropriate cognitive methods to assess these capabilities. Gauging levels of mind wandering has garnered multiple approaches within the literature, ranging from retrospectively employed scale-based measures (e.g., the Daydreaming Frequency Scale (DDFS, Linares Gutierrez et al., 2019) to experience-sampling methods administered *during* task completion (Unsworth and Robison, 2016). Probe sampling has been demonstrated as a reliable method that does not interfere with sustained attentional performance or response inhibition requirements. Moreover, emerging recommendations identify optimal probe-sampling techniques, namely by: (i) providing at least three possible responses for participants to choose from to prevent automatic responding, (ii) ensuring that mind wandering can be differentiated from other species of off-task thought (e.g., non-alertness, eternal distraction), and iii) probe presentation frequency are appropriate for the task (e.g., approximately one minute apart for the widely used SART and CPT tasks) (Robison, Miller and Unsworth, 2019).

Utilising these methods, mind wandering has been shown to be associated with diminished performance during tasks assessing sustained attention / vigilance (e.g., SART and CPT) (Bastian and Sakur, 2013; Schooler at al., 2014; Smallwood and Schooler, 2006; Stawarczyk et al., 2014), thus supporting conceptualisations of mind wandering as a task-unrelated thought process, especially within the context of relatively undemanding attention tasks such as the SART and CPT. Indeed, "task-unrelated" entirely depends on the task. It is important to note that the 'inward' nature of mind wandering represents a task in and of itself, whereby internal mental life is insulated from external distraction. This intentional and unguided internal pursuit of *personal* goals is at the expense of relatively undemanding *external* goals (Seli, Beaty, Marty-Dugas and Smilek, 2017), thus explaining the discussed literature. In other words, the *adaptive* features of mind wandering favour the exploratory pursuit of *meaningful* tasks related to personal goals, such as exploring trains of thought for the detection of new ideas / rewards. Such features are often observed during tasks which lack compelling inputs relative to more complex tasks that demand more cognitive resources (Baird et al., 2011; Smallwood and Andrews-Hanna, 2013), rendering performance-based tests of attention useful methods for timebound non-clinical explorations into the nature of the untethered mind.

Observed contrasts between mindfulness and mind wandering in relation to performance during undemanding tasks that require *external* attention has prompted some researchers to position mindfulness at the "antithetical edge of the attentional continuum" to mind wandering (Linares Gutierrez, Kubel, Giersch et al., 2019, p. 194). Such performance-based contrasts invite expectations that subjective reports of mind wandering will be attenuated by mindful traits and states. Indeed, this has been shown to be the case, insofar as dispositional mindfulness is reliably inversely related to mind wandering (Schooler, 2014) and mindfulness training has consistently resulted in reduced instances of mind wandering (Giannandrea et al., 2019; Greenberg et al., 2019; Morrison et al., 2013; Rahl et al., 2017). These findings suggest that increased trait dimensions of mindfulness and participation in mindfulness-based training interventions facilitate the prompt detection of, and disengagement from, the wandering mind, thus redirecting attention back to the present moment. Such contentions would appear to position mindfulness and mind wandering as opposing constructs. However, viewed through the lens of aforementioned tonic effects of the human attention system, the two constructs may in fact be more conceptually aligned. For example, internally directed self-referential thought processes likely emerge from similar bottom-up tonic explorations of 'inward' representations (Smallwood et al., 2011, Smallwood et al., 2013) as those associated with the introspective awareness of mental representation and sensory experience facilitated by mindfulness (Britton et al., 2004; Lutz et al., 2008). This proposal raises interesting questions about the comparable and contrasting characteristics of mindfulness and mind wandering in relation to tonic and phasic attentional effects and the neurobiological / psychophysiological mechanisms that underlie these capacities. Exploring such questions will likely provide further insight into mindfulness as an enhanced capacity for wakefulness and arousal.

Taken together, it appears that trait indices and inductions of mindfulness can be understood as enhanced self-reported capacities for attentiveness, awareness and non-judging acceptance. Moreover, mindfulness appears to exert augmentative effects on subjective (e.g., reduced mind wandering) and behavioural (e.g., enhanced performance) indices of sustained attention / vigilance and executive efficiency, which can conceivably be viewed as an increased capacity for wakefulness among higher-trait mindfulness individuals and those participating in meditative practice (Britton et al., 2014). However, there is by no means consensus that dispositional mindfulness is consistently and robustly associated with these outcomes (Goilean, Gracia and Tomas, 2021; Lykins, Baer and Gottlob, 2012; Quickel, Johnson and David, 2014) or that mindfulness-based interventions enhance self-reported mindfulness (Visted, Vollestad, Nielsen and Nielsen, 2015) and attentional performance during the SART, CPT, Stroop and ANT (Im et al., 2021; Lao et al., 2016). This necessitates the inclusion of such measures in any scientific excursion into the wakeful / arousal-based qualities of mindfulness. Moreover, although substantial empirical inquiry has been afforded to the role of mindfulness in task-based assessments of sustained attentional performance and attentional control, explicit investigations into the impact of mindfulness on immediate and downstream responses to broader information that violates prior expectations is absent from the literature. Such endeavour is important, as not all environmental stimuli will conform to our expectations, thus offering unique opportunities to examine how distinct attentional capabilities can modulate human responses to perceptual conflict. Specifically, attentional and arousal-based capacities to remain alert and aware for the adaptive negotiation of perceptual inconsistency likely correspond to differential activation of aforementioned tonic and phasic attentional and psychophysiological systems. As such, examining such processes may provide a fuller picture of the wakefulness / arousal-promoting qualities of mindfulness. Accordingly, prior to reviewing neuroscientific evidence contributing to conceptualisations of mindfulness as an alert / wakeful capacity, it is useful to consider the potential role of mindfulness in human attentional responses to inconsistent stimuli.

Mindfulness and Inconsistency

Observed improvements in executive performance as a function of trait mindfulness and meditative engagement typically manifest as more efficient behavioural responses to perceptually incongruent stimuli (Josefsson and Broberg, 2011; Lin et al., 2018). This is likely because the awareness and non-judging acceptance dimensions of mindfulness are conducive to the monitoring of, and subsequent disengagement from, inconsistent information, thus reducing the negative influence of incongruency on performance (Slutsky, Rahl, Lindsay and Creswell, 2017; Teper and Inzlicht, 2013). Considering that awareness and non-judging acceptance are likely indicative of increased capacities for bottom-up internal / external exploration associated with tonic alertness (Aston-Jones and Cohen, 2005), examining the role of mindfulness in behavioural and psychophysiological responses to a range of isolated inconsistency inductions may further illuminate the arousal-based qualities underlying mindful traits and states.

Human attention is constantly bombarded with large volumes of information. The task for attention is to select preferred inputs for further processing. As such, the more salient the data is, the more likely it is to enjoy deeper consideration. Of greatest salience to the human being is information high in threat, pleasure and / or inconsistency, characteristics which exert the strongest effects on the human attention system (Sood and Jones 2013). In relation to the latter component, inconsistent information represents a mismatch between expectation and experience, insofar as we generally expect our experiences to align with how we expect the world to operate (e.g., the world is just (Lerner, 1980) and the dove is white (Piaget, 1937)). Such mismatches can take many ‘low-level’ or ‘high-level’ forms and exist on a variety of experiential levels, ranging from the profundity of meaning violations (Proulx and Heine, 2010) and existential threats (Sheldon, Greenberg and Pyszczynski, 2015) to the visual incongruency of anomalous playing cards (Sleegers, Proulx and van Beest, 2015) and manipulated pictorial faces (Proulx, Sleegers and Tritt, 2017). As such, in accordance with extant proposals (Proulx, Inzlicht and Harmon-Jones, 2012), inconsistency is a term that can be used to refer to any violation, incongruency or prediction error arising from detected mismatches between expectation and experience. Moreover, as is likely the case with mortality salience primes (Sheldon et al., 2015), combining inconsistent and threatening information (e.g., thinking about one’s mortality is at once unusual and threatening) likely enhances the salience of the information, which is directly testable using novel types of stimuli.

Emerging from the detection of any inconsistency (e.g., ‘low-level’ (red ace of spades, Stroop / flanker incongruence) and ‘high-level’ (mortality salience, meaning threats), is likely a common, biologically based syndrome of aversive arousal (Proulx et al., 2012), indicative of an elevation in LC activity in the face of unexpected environmental changes (Aston-Jones and Cohen, 2005; Yu and Dayan, 2005). Such arousal motivates the initiation of compensatory behaviours in a palliative attempt to reduce the discomfort associated with this arousal (Proulx et al., 2012). Compensatory behaviours have been identified by theorists as falling into four categories: assimilation (reinterpreting experiences to align with expected relationships, such as interpreting a black fox as a dog), accommodation (revising expected relationships to align with experiences - accepting that black foxes exist), affirmation (increasing adherence to alternative expected relationships, which can be related or unrelated to the violated expected relationships, such as taking a firmer stance on criminal punishment following the presentation of anomalous stimuli) and abstraction (enhanced motivation to abstract *new* relationships, which are unrelated to the source of the inconsistency, such as the detection of hidden patterns in environmental ‘noise’), the most studied of which in relation to the inconsistency-compensation processes is affirmation (Proulx et al., 2012).

Assessing arousal and compensatory behaviour in response to a range of low-level and high-level inconsistency inductions has garnered various approaches in the literature. For example, affirmation of unrelated moral beliefs has been demonstrated to follow the presentation of incongruent word pairs (Randles, Proulx and Heine, 2011). Moreover, greater arousal, as assessed by increased pupil diameter, has been shown to follow the presentation of incongruent human faces (Proulx et al., 2017), whereas increased arousal and affirmation / abstraction behaviour have each been tied to the presentation of anomalous playing cards (Sleegers, Proulx and van Beest, 2015) and the initiation of incongruent feedback (Sleegers, Proulx and van Beest, 2021). Studies utilising these methods have generally demonstrated that compensatory responses to inconsistency provide a reliable palliative method to alleviate the arousal induced by this inconsistency, in line with pertinent predictions (Proulx et al., 2012). Consequently, an overarching explanation of the relationship between inconsistency, arousal and compensation has reasonably been proposed as consisting of three stages; i) inconsistency between expectancy and experience, ii) aversive arousal associated with inconsistency, and iii) compensatory efforts to ameliorate this arousal (Proulx, et al., 2012).

Prior observations that mindfulness reliably enhances performance during tasks presenting ‘low-level’ inconsistencies (e.g., Stroop, incongruent flankers) invites predictions that mindfulness will also impact upon general inconsistency-arousal-compensation processes. As discussed, the mindfulness dimensions of awareness and non-judging acceptance, which are theorised to emerge from an enhanced capacity for alertness and wakefulness (Britton et al., 2014), likely facilitate the vigilant detection of novel, distracting and / or incongruous task-based information and the subsequent distancing and disengagement from any cognitive / psychophysiological reactivity to this information (Lutz et al., 2008; Malinowski, 2013). These 'awakened' capabilities to detect, monitor and efficiently process inconsistent stimuli and to accept internal experiences arising from such stimuli (e.g., through FA and OM techniques) represent natural parallels to the mindfulness-related capacity to monitor conscious experience, refocus to the present moment upon the detection of environmental distractors / mind wandering, and to non-judgmentally accept cognitive / emotional representation.

As such, mindfulness essentially promotes conflict-monitoring by opening the doors of perception and facilitating enhanced *awareness* for the detection of early sensory signals. In turn, greater awareness of inconsistency and threat results in increased arousal responses (Teper and Inzlicht, 2013), which, thanks to an enhanced *acceptance* and disengagement from this arousal, does not translate into greater palliative affirmatory efforts to alleviate the arousal. As such, awareness and acceptance are naturally beneficial for the instigation of executive control via a distancing from inconsistency reactivity (Slutsky et al., 2017; Teper and Inzlicht, 2013). Intuitively, therefore, it could be reasoned that mindful traits and states likely *enhance* inconsistency-induced arousal through awareness and *diminish* compensatory responses to this arousal through acceptance. Accordingly, the present thesis complements the implementation of performance-based tests of attention and experience sampling methods with a series of inconsistency-inductions designed to augment our understanding of mindfulness as an alert and wakeful capacity.

To examine whether the proposed wakeful qualities of mindfulness exert any impact on attentional performance, cognition and inconsistency-arousal-compensation processes, a broader review of the neuroscientific findings linking mindfulness, attention and proposed arousal states is necessary.

Neuroanatomical Correlates of Mindfulness, Mind Wandering and Inconsistency Detection

Augmented Attention. Neuroscientific support for the conceptualisation of mindful traits and states as enhanced capacities for vigilance and wakefulness has continued to demonstrate marked structural and functional changes in areas of the brain associated with a tonic mode of alertness (for reviews, see Britton et al., 2014 and Tang et al., 2015). For example, in relation to dispositional mindfulness, magnetic resonance imaging (MRI) has revealed reliable associations between MAAS scores and increased volume / activation in areas of the brain associated with tonic alertness, awareness and executive control, including increased grey matter volume of the right precuneus[14] (Zhuang, Bi, Li, et al., 2017) and in the bilateral anterior cingulate cortex (ACC) (Lu, Song, Xu et al., 2014), as well as greater activation of the temporoparietal junction (TPJ), dorsolateral prefrontal cortex (dlPFC) and superior parietal lobe (SPL) (Dickenson et al,. 2012). Moreover, mindfulness-based interventions (MBIs) have been shown to increase cortical activity within the ACC, TPJ, dlPFC, insula and orbitofrontal cortex (OFC), as well as enhancing white matter density connecting the ACC to other brain structures and grey matter density in the insula (Fox et al., 2016; Gotnik et al., 2016; Young et al., 2018). Considering the respective roles of these brain regions associated with tonic alertness, awareness, orienting and attentional control (Fox et al., 2014; Totah et al., 2009; Wu et al., 2017), reasonable conclusions can be made for a general neuroscientific consensus that

[14] See glossary of terms in Appendices.

mindfulness promotes sustained vigilance and wakefulness, and that previously discussed behavioural outcomes are likely modulated by enhanced activity / connectivity in one or more of these regions (Tang et al., 2015). Moreover, such changes may be associated with distinct activation of the tonic LC-NA system, which is directly testable by combining attention tasks and measures of physiology.

Cognition. Further support for mindfulness as enhanced vigilance and improved attentional performance emerges from extensive analyses of a network of the brain associated with mind wandering - the default mode network (DMN) – a name which implies that activity within this network represents a neural baseline from which more task-focused attentional states deviate (Smallwood, Bernhardt, Leech et al., 2021). DMN activity is typically assessed utilising functional MRI (fMRI) blood-oxygen-level dependent (BOLD) contrast, a method which utilises the fact that blood releases oxygen to active neurons at a greater rate than to inactive neurons, thus coupling observable blood oxygenation with neuronal activity. Specifically, BOLD signals reflect the change in haemodynamics within a macro-scale (1-27mm^3) cortical area in order to reliably map neural activation in specific brain regions, such as the DMN (Parker and Razlighi, 2019). Utilising such methods, the DMN has been demonstrated to be functionally and spatially distant from primary motor and sensory networks, evidencing a unique cortical division, whereby DMN-related neuronal activity encompasses a selection of widely distributed brain regions in the parietal, temporal and frontal cortex. Specifically, increased activity in these areas has been observed during self-generated 'off-task' thought processes, whereas decreased neural activity in these areas is exhibited during tasks requiring sustained attention / attentional control. Such 'task deactivations' are most prominent within the PMC and mPFC, which also exhibit anticorrelations with 'task-positive' brain regions (e.g., dlPFC, ACC) (Smallwood, Bernhardt, Leech et al., 2021). Increased activation within the DMN is associated with greater periods of internally driven cognitive processes, namely mind wandering, and with diminished sustained attentional performance (Garrison, Zeffiro, Scheinost et al., 2015; Smallwood, Bernhardt, Leech et al., 2021; Unsworth and Robison, 2017). Meditative engagement has been shown to reliably exert decreased activation in the two primary nodes of the DMN - the posteriormedial cortex (PMC) and the medial PFC (mPFC) (Smallwood et al., 2021) - whilst enhancing activity in task-positive brain regions (namely the ACC and dlPFC) and reducing self-reported mind wandering during continued attentional performance and at rest (Devaney, Levin, Higgins et al., 2021; Brewer et al., 2011; Garrison et al., 2015). Mindfulness has also been associated with reduced DMN connectivity during the Stroop task, indicating less disruption / distraction during the processing of incongruent / inconsistent stimuli (Kozasa, Sato, Russell et al., 2017). These findings provide further neuroscientific support for the conceptualisation of mindfulness as promoting vigilance throughout attentional performance, insofar as correlates and anticorrelates of sustained attention / task focus appear to manifest at both behavioural and neurobiological levels. However, as discussed previously, anticorrelations between mind wandering and sustained attentional performance are heavily context-dependent, insofar as the mind typically wanders during relatively undemanding tasks for the augmentation of sustained attention in other areas (Smallwood and Andrews-Hanna, 2013). As such, conceptualising DMN activation - a reliable associate of mind wandering - as a harbinger for reduced attentional performance relative to mindfulness-related brain activation is constrained by the cognitive tools administered. Indeed, the ‘inward’ nature of mind wandering often represents a task in and of itself, whereby DMN activation ensures that internal mental life is insulated from external distraction (Smallwood et al., 2021). This intentional and unguided internal pursuit of *personal* goals is at the expense of relatively undemanding *external* goals (Seli, et al., 2017), thus rendering qualitative attentional distinctions between mindfulness and mind wandering primarily confined to an *outward* present-moment capacity. Examining the *inward* comparability between the two constructs may therefore reveal similar mechanisms of action, which has implications for conceptualising mindfulness as a distinct capacity for sustained and wakeful attention.

Inconsistency Detection. In relation to the neurobiological underpinnings of the human response to inconsistency, the salience network of the brain (SN), which primarily consists of the anterior insula and the dACC, is responsible for the detection and further processing of inconsistent stimuli. As discussed, such detection initiates a common, biologically based syndrome of aversive arousal (Proulx et al., 2012). Indeed, neurocognitive brain structures, namely the ACC and OFC, have been identified as playing a pertinent role in the detection of - and psychophysiological response to - environmental inconsistency (Tritt and Inzlicht, 2012). The ACC, commonly viewed as the "cortical alarm bell" for unexpected events and errors (Gray and McNaughton, 2000; Petersen, 2012), expresses increased activation in response to environmental inconsistency, in turn signalling *noradrenergic* systems to initiate heightened arousal states (Beckman, Johansen-Berg and Rushworth, 2009). Indeed, evidence for the existence of an inconsistency-induced arousal response emerges from studies employing a range of physiological measures demonstrating, for example, enhanced pupillary responses as a result of anomalous playing card presentation (Sleegers, et al., 2015), and increased cardiovascular activity following expectancy violations (Mendes, Blascovich and Lickel, 2002) and unexpected social rejection (Moor, Crone & Van der Molen, 2010).

Mindfulness has been associated with enhanced activity in areas of the brain associated with the vigilant detection and early psychophysiological response to inconsistency and with reduced brain resource allocation representing conscious reactivity to this information (e.g., indicative of reduced conscious mental capture by distractors) (Slagter et al., 2007; Teper and Inzlicht, 2013). As such, mindfulness likely exerts an impact on inconsistency-arousal-compensation processes, insofar as remaining *aware* facilitates increased psychophysiological activity in the face of inconsistency detection, whereas nurturing *acceptance* reduces conscious reactivity to this arousal. Indeed, the reviewed neurocognitive findings are congruent with this characterisation, which is compatible with mindfulness theory and self-report (Baer et al., 2008; Lutz et al., 2008). However, reliable links between mindfulness, inconsistency-induced arousal and compensatory efforts are largely absent from the literature (Sleegers et al., 2021), thus representing a worthwhile opportunity for further investigation.

In summary, the reviewed literature provides convincing evidence that mindfulness and its dimensions, at both trait and state levels, are associated with enhanced capacities for sustained attention, vigilance and executive function in relation to novel and inconsistent / incongruent stimuli. Moreover, the literature highlights that mindfulness interacts with cognition, insofar as internally-generated distractions are diminished. Such capabilities likely emerge from an enhanced capacity to maintain an ongoing awareness of emerging events in the experiential field and to consciously disengage from any conflicting / irrelevant properties of these events. I propose that it is the enhanced awareness and acceptance of internal and external worlds that underlies these attentional capabilities, which can plausibly be understood to characterise mindfulness / meditative engagement as an alert and wakeful capacity (Britton et al., 2014). Specifically, I contend that such capabilities are indicative of enhanced *tonic* alertness, which promotes i) an active, bottom-up *outward* exploration of sensory experience at the level of attentional deployment (e.g., consistent with FA techniques), and ii) an active, bottom-up *inward* exploration of experience / mental representation and subsequent disengagement from internal states to aid non-reactivity (e.g., consistent with OM techniques) (Lutz et al., 2008; Teper and Inzlicht, 2013). Crucially, I propose that these capacities are mirrored by distinct arousal-based signatures.

Despite the necessity of exploring the role of real-time fluctuations in arousal for a deeper understanding of such processes, direct discussion of an important modulating system of cortical arousal – the locus coeruleus noradrenaline system (LC-NA) - is essentially absent from the neuroscientific mindfulness literature. This is not surprising, considering the notorious difficulty in identifying and studying such a small brainstem structure (Maki-Marttunen and Espeseth, 2021). However, although indirect, a relatively cost-effective, flexible and straightforward method of examining LC-NA activity exists in the form of pupillometry, which enables coincident assessments of attentional performance and inferred fluctuations in cortical arousal states. This method therefore provides an enticing opportunity to examine mindfulness in relation to the very neurotransmitter that gives rise to what it means to be *wakeful*.

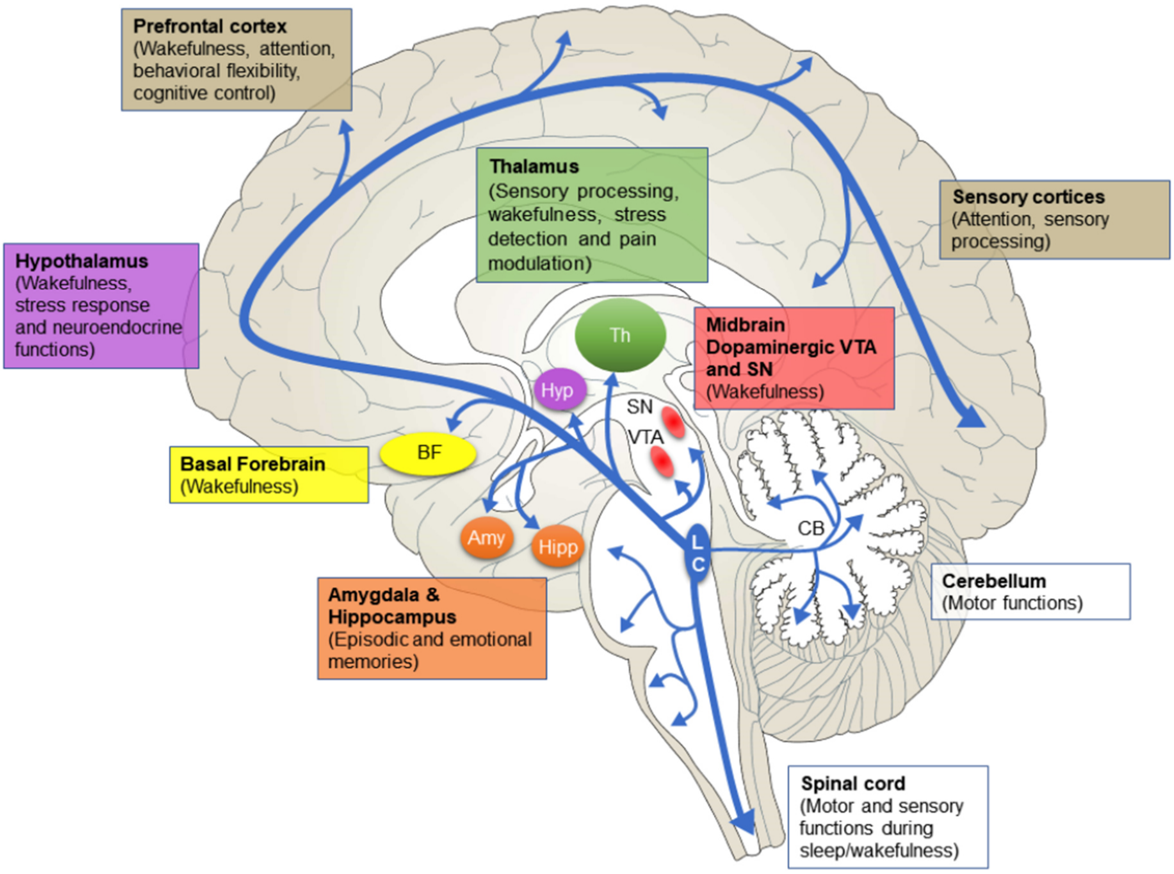
Accordingly, I utilise pupillary methods to examine mindfulness and its central dimensions of awareness and acceptance as inward and outward exploratory attentional modes that are distinctly associated with tonic LC-NA activation (Aston-Jones and Cohen, 2005). Such 'online' assessments of arousal during tasks requiring ongoing awareness and vigilance and the detection of inconsistent stimuli may provide important insights into the role of tonic LC-NA activity in the characterisation of mindfulness as wakefulness. Research in this respect would also address the distinct paucity of mindfulness-related literature combining the use of subjective measures of cognition, performance-based tests of attention and coincident measures of arousal.

Adaptive Gain Theory and the Dark Blue Place.

Deep within the brain, situated in the posterior area of the rostral pons in the brainstem, resides a neuromodulatory nucleus known as the locus coeruleus (LC), Latin for "dark blue place" (Lewis and Short, 1879), thanks to the blueish pigment of melanin within each LC neuron. Remarkably, the LC consists of just 0.00004% of neurons in the human brain but is responsible for virtually all the synthesis of cortical noradrenaline (NA), which is projected widely to a diverse array of anatomical regions associated with vigilance and executive attention (Figure 2). Moreover, strong afferent inputs to the LC originate from several structures associated with sustained attention, including the ACC and OFC, which are implicated in the assessment of rewards and costs and in the detection of inconsistent information (Figure 3). As such, the LC-NA system is positioned as an optimal arousal-based modulator for a range of attentional demands requiring vigilance and cognitive effort (Bari, Chokshi and Schmidt, 2020; Uematsu, Tan and Johansen, 2015). Indeed, almost 20 years ago, an influential and pervasive account of LC-NA function – the Adaptive Gain Theory (Aston-Jones and Cohen, 2005) – contextualised the role of the LC in specific neurocognitive processes, which helped shape our current understanding of the LC-NA system in relation to distinct attentional and cognitive dynamics.

Figure 2.

Widespread Efferent Projections of the LC Throughout the Human Brain

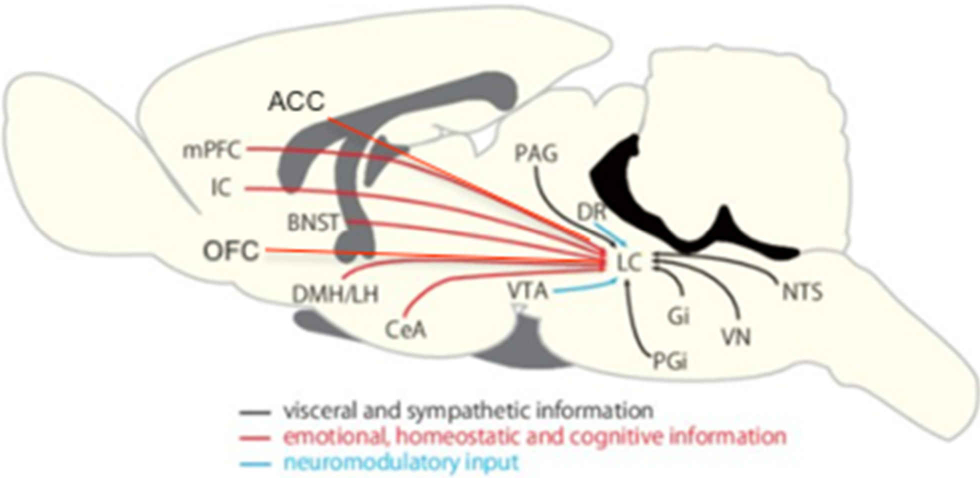


Note. LC = locus coeruleus. Ascending, cerebellar and descending efferent pathways displayed as blue arrows. Pictured here are projections to broader brain regions, but the ascending pathways encompass the ACC, dPFC, OFC, and insula. The cerebellar and descending pathways encompass the PCC and precuneus (adapted from Bari, Chokshi and Schmidt, 2020).

Integral to the adaptive negotiation of a complex and constantly changing world is the ability to either narrow one's attentional focus to the task at hand or to broaden one's attention and awareness to encompass a wider range of stimuli. Adaptively balancing these modes of attention enables strategic responses to multifarious environmental stimuli in a way that promotes maximal reward. In order to meet this challenge, organisms harbour decision-making processes reflective of a synergistic interplay between *exploiting* known sources of reward (a *top-down* reaction to stimuli, based on task-related expectations) and *exploring* the environment for potentially more fruitful sources (an active *bottom-up* search-and-detect strategy).

Figure 3.

Afferent Inputs to the LC from Specific Brain Areas



Note. LC = locus coeruleus. Afferent inputs to the LC from forebrain (red), neuromodulatory (blue), midbrain and brainstem (black) regions. ACC and OFC depicted, which provide information to the LC in relation to rewards, costs and stimuli inconsistency. Also pictured: CeA = central nucleus of the amygdala, BNST = bed nucleus of the stria, terminalis, DMH/LH = dorsomedial and lateral hypothalamus, DR = dorsal raphe, Gi nucleus gigantocellularis, IC = insula, mPFC = medial prefrontal cortex, NTS = nucleus tractus solitarius, PAG = periaqueductal gray, PGi = nucleus paragigantocellularis, VN = vestibular nucleus, VTA = ventral tegmental area (adapted from Uematsu, Tan and Johansen, 2015).

Adaptive gain theory (AGT) posits that the LC-NA system arbitrates the trade-off between these exploitative and exploratory behaviours through adaptive adjustments in noradrenergic firing, which mediate attentional states characterised by two modes of cortical arousal. The first is the *phasic* alertness mode, which fires reactive bursts of NA for an increased short-term readiness to respond to task-related warning signals in order to exploit known reward avenues. Exploitation tasks are tasks that we are well-accustomed to, such as driving to work. When engaged in these tasks, expectations of what might occur during their completion are applied (e.g., stopping at a red light) and of what rewards should be obtained (e.g., arriving to work on time). The phasic firing filters out irrelevant information (e.g., the colours of other cars) and *narrows* attention to the most relevant task elements (e.g., traffic light signals). However, not all task-related expectations will be met, which may represent a form of *expected* uncertainty inherent to task completion (e.g., broken traffic light) or *unexpected* uncertainty (e.g., a skydiver landing at the crossing). This form of uncertainty initiates a *tonic* alertness mode, characterised by an increased overall activation of arousal and reduced phasic reactions. This promotes an attentional mode of vigilance and endogenous mental preparedness in order to be able to detect and respond to novel environmental stimuli in an *exploratory* attentional state for the acquisition of new expectancy-based signals (Aston-Jones and Cohen, 2005; Bruya and Tang, 2018). As discussed, this form of tonic attention manifests as an *outward* exploration of environmental / sensory events to eliminate habitual responding or an *inward* exploration of mental representation and affective experience. Inward exploratory attention can be understood to encompass the detection / unbiased labelling of internal experience emerging from capacities for awareness and non-judging acceptance (Lutz et a., 2008; Teper and Inzlicht, 2013), or it can be characterised by the intentional and unguided 'offline' probing of mental models and temporal space associated with mind wandering (Seli et al., 2017; Smallwood et al., 2011).

As such, the tonic LC-NA mode promotes a range of active, bottom-up exploratory processes, whereas the phasic LC-NA mode facilitates a reactive, top-down focus conducive to habitual task engagement.

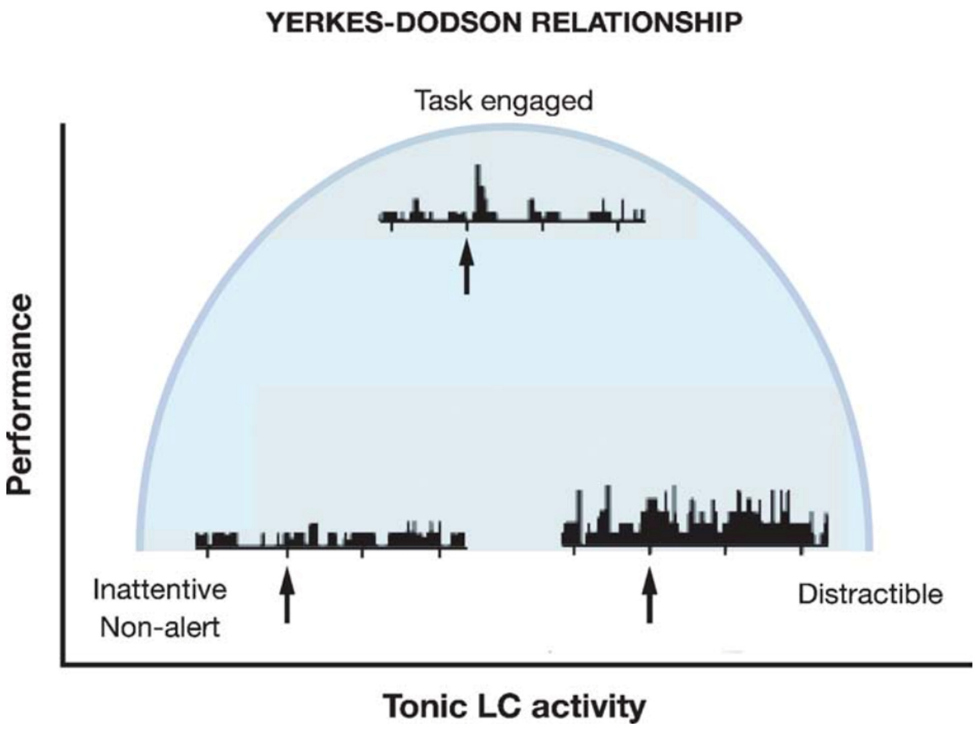
Considering the presented reciprocal connections between the LC and brain regions associated with salience detection, sustained attention and executive function (Figures 2 and 3), these modes of cortical noradrenaline release are therefore likely to be critical for the modulation of neural processing in different brain networks, both altering and amplifying the function of these systems in response to task-based expectations about stimuli properties and ongoing reward contingencies (e.g., as conveyed by ACC and OFC computations). Specifically, by enhancing signal-to-noise ratios in target neurons, intermediate LC-NA activity increases neuronal gain, allowing the system to respond to task-relevant information in a top-down, *phasic* manner and to ignore task-irrelevant information (Aston-Jones and Cohen, 2005; Unsworth and Robison, 2017). Therefore, the LC-NA is crucial in the regulation of attentional states, whereby fluctuations in attention closely correspond to fluctuations in LC-NA activity.

LC-NA Activity and Task Performance

The relationship between LC-NA neuronal activity, attentional performance and exploitative / exploratory behavioural functions can broadly be mapped onto the classic Yerkes-Dodson (YD) inverted ‘U’ curve of arousal and performance (Dodson, 1915) (Figure 4), whereby a low tonic range indicates inattentiveness and non-alertness, an intermediate tonic range promotes stimuli-induced phasic LC firing and optimal top-down task performance (consistent with intra-task exploitation) and higher levels of tonic activity reflect distractibility (e.g., mind wandering), restlessness and task disengagement (indicative of bottom-up exploratory attentional states) (Aston-Jones, Rajkowski and Cohen, 1999; Hanoch and Vitouch, 2004). Naturally, this relationship has implications for the role of the LC in ongoing performance during the most widely used tasks of sustained and executive attention. In fact, it has been suggested that attentional control failures during these tasks are due to a dysregulation of phasic firing and a variegated ability of cortical structures to control attention in a goal-directed manner (Unsworth and Robison, 2017). In other words, when tonic LC-NA is too low or too high, structures associated with sustained and regulated attention are no longer adequately modulated by the LC, which can result in reduced activity in frontal and parietal structures that require optimal levels of LC-NA activity. Moreover, physiological indices of the tonic LC-NA mode, typically initiated in response to inconsistency to prompt learning (Gilzenrat et al., 2010; Proulx et al., 2012) and during repetitive and relatively undemanding tasks promoting mind wandering (Smallwood et al., 2011; Unsworth and Robison, 2017), have been consistently related to off-task thought reports and performance-inferred attentional lapse / disengagement, components reliably associated with DMN activation (Smallwood et al., 2021). As such, it would appear that the tonic LC-NA mode harbours limited utility in relation to ongoing task performance.

Figure 4.

Yerkes-Dodson Relationship Between Tonic LC-NA Arousal and Performance



Note. Inverted-U relationship between tonic LC activity and sustained attentional performance. Performance is poor at low levels of tonic discharge (drowsiness, non-alertness) and at higher levels (no phasic responses, distractibility) but optimal at intermediate levels (optimal phasic LC activation toward task-relevant stimuli) (from Aston-Jones and Cohen, 2005).

However, the dawn of human culture was not solely contingent on phasic task engagement. Human beings must also know when to disengage from habitual tasks in order to explore environments for new sources of expectancy / reward and to protect internally directed cognition from external distraction for the purposes of adaptive problem solving and future planning. It is this capacity that gave rise to abstract and symbolic thought, advanced creative projection of personal worlds and intricate expressions of self-awareness (Puccio, 2017). As such, the validity of characterising mind wandering / 'offline' thought and associated changes in DMN or tonic LC-NA activation as indices of 'attentional lapse' is, as discussed, wholly dependent on the type of tasks that are utilised to propose such characterisations. Indeed, although clearly maladaptive for the purposes of exploitative performance, elevated tonic LC-NA arousal has been demonstrated to enhance a host of adaptive functions associated with exploratory task disengagement. Animal studies have shown that tonic LC stimulation facilitates earlier exploration for better opportunities during waning patch-foraging tasks (Kane, Vazey, Wilson, et al., 2017), whereas insights from pharmacology have demonstrated that the administration of NA reuptake inhibitors, such as atomoxetine, reboxetine and desipramine, which mimic the effects of tonic LC-NA activity, promote cognitive flexibility and reversal learning in rats and monkeys (Lapiz, Bondi and Morilak, 2007; Seu, Lang, Rivera and Jentsch, 2009). Enhanced social flexibility in humans during stranger-dyadic social interactions has also been observed as a result of similar pharmacological interventions (Delgado, Phelps and Robbins, 2011; Tse and Bond, 2003). Moreover, indirect measures of human tonic LC-NA activity have revealed that a hallmark aspect of attentional control - the ability to switch attention between environmental classes or 'sets' - is associated with a greater magnitude of tonic LC-NA arousal (Pajkossy, Szollosi, Demeter et al., 2017; Pajkossy, Szollosi, Demeter et al., 2018). Clearly, there is adaptive value in the tonic LC-NA mode and associated attentional states, which serve to optimise performance on a broader scale (Aston-Jones and Cohen, 2005; Hanoch and Vitouch, 2004) and may contribute to the flexible exploratory capacity to 'decouple' attention from external perception when tasks require limited attentional engagement. Such adaptiveness may also be related to similar yet functionally different capacities for exploration, namely mindfulness.

Considering the discussed attentional and neuroanatomical processes associated with tonic and phasic modes of LC-NA activity, it stands to reason that any inherent capacity / learned skill (e.g., mindfulness) or cognitive tendency (e.g., mind wandering) related to these processes may also be implicated in distinct patterns of LC-NA arousal, specifically in relation to performance-based tests of attention and inconsistency responses. The present research aims to explore such proposals by examining mindfulness as an adaptive capacity for tonic alertness through the lens of AGT-predicted LC-NA activity.

Mindfulness and the LC-NA System

Considering the nature of the attentional training techniques afforded by mindfulness-based meditative practice (e.g., FA and OM), as well as discussed associations between mindfulness and behavioural / neurobiological indices of sustained attention, alertness and executive control (Britton et al., 2014; Tang et al., 2015), mindfulness represents a pertinent candidate to examine through the lens of AGT-predicted LC-NA function. That is, the increased attentiveness, awareness and acceptance associated with mindful traits and states may well emerge from a form of wakefulness defined by tonic LC-NA activity.

At first glance, the YD inverted-U shape of arousal (e.g., AGT-predicted LC-NA activity) and performance (e.g., tasks requiring optimal vigilant attention and attentional control) would appear to map congruently onto recent conceptualisations of mindfulness as a form of "relaxed alertness" (Britton et al., 2014, Figure 1), which guards against the effects of hypoarousal (e.g., low tonic activity / non-alertness) and hyperarousal (e.g., tonic LC-NA activity, distractibility) in favour of an assumed phasic, task-locked attentional state characterised by intermediate levels of tonic activity. However, as previously discussed, the YD relationship ignores the utility of the upper end of the curve (e.g., the tonic LC-NA mode), which likely harbours adaptive value for many tasks requiring exploratory attention, heightened awareness and sensitivity to unfolding experience for the detection of new signals. By extension, capacities proposed as representing increased bottom-up inward / outward exploratory vigilance and awareness (e.g., mindfulness) are essentially positioned by YD-based predictions as representing 'maladaptive' states of arousal. However, enhanced attentional performance in tasks requiring ongoing vigilance and increased activity in areas of the brain indicative of sustained elevations in arousal are reliably associated with mindful traits and states, which implies that the utility of mindfulness for improved performance in such tasks may not reside in an increased ability to apply top-down, phasic responses to task-related signals (e.g., centre of YD curve / phasic LC-NA activity) but rather in an enhanced capacity to remain aware of *all* environmental stimuli and internal experience without judgment or reactivity (e.g., tonic LC-NA activity without distraction, as nurtured through FA and OM). As such, I propose that capacities for mindful attentiveness, awareness and acceptance are associated with AGT-predicted *tonic* LC-NA activation, manifesting as enhanced vigilance and awareness of the experiential field (Lutz et al., 2008), without the distraction typically associated with elevated arousal states (Aston-Jones and Cohen, 2005). I contend that it is this tonic LC-NA mode that characterises recent conceptualisations of mindfulness as a capacity for *wakefulness* (Britton et al., 2014).

Curiously, examining mindfulness through the lens of the LC-NA system remains absent from the literature (e.g., Table 1, Tang et al., 2015), necessarily prompting a unique line of inquiry utilising coincident assessments of LC-NA activity during performance-based tests of sustained / executive attention and in response to the administration of specific types of inconsistent / incongruent stimuli. Accordingly, the presented research employs established behavioural methods with a novel, accessible and underutilised proxy of LC-NA activity: pupil dilation.

A Window to the Wakeful Mind

Pupillary dilation in response to task demands has long been known to represent a valid psychophysiological marker of cognitive effort (Kahneman, 1973). These task-evoked pupillary responses (TEPR) are also sensitive to attentional control demands, such as those elicited by Stroop incongruency (Laeng, Orbo, Holmlund and Miozzo, 2011) and incongruent ANT flankers (Geva, Zivan, Warsha and Olchik, 2013), suggesting that stimuli inducing the most cognitive conflict require increased attentional control and elicit greater levels of response-locked TEPR indicative of cognitive effort (Geva et al., 2013; Laeng et al., 2011). These TEPR are indicative of an inhibition of distracting incongruent stimuli and reflect attempts to control prepotent responses in the presence of such stimuli in addition to response evaluation (van Steenbergen and Band, 2013). This is consistent with prior work demonstrating specific psychophysiological responses to task conflict, such as greater N2 event-related potentials (ERPs) occurring 200ms-300ms after incongruent target onset during the ANT (Norris, Creem, Hendler and Kober, 2018) and increased N2 and Pe ERPs (components related to conflict monitoring and executive response inhibition, respectively) during No-Go CPT performance (Schoenberg, Hepark, Kan et al., 2014). Importantly, task-locked TEPR have been reliably demonstrated as providing an indirect assessment of LC-NA activity, insofar as phasic spikes in LC activity in response to task demands are consistently followed by pupillary dilation (~300ms after LC spikes) (Aston-Jones and Cohen, 2005; Joshi, Li, Kalwani and Gold, 2016). This is because task-based attentional demands processed by centres in the brain governing responses to task difficulty / effort (e.g., ACC and OFC) are projected to the LC for NA-related phasic resource allocation (Figure 3), which is reflected in greater TEPR activity tied to task engagement / behavioural responses.

In relation to task-based inconsistency, *response-locked* TEPR to inconsistent /

incongruent stimuli is reflective of LC-NA phasic activity indicative of task engagement, conscious reactivity and phasic bursts of arousal facilitating decision-making to ensure optimal completion of the task (Geva et al., 2013; Zarzeczna, von Hecker, Proulx and Haddock, 2020). Such LC-NA firing also manifests as *pre-response* TEPR in response task-related warning signals / cues conducive to task performance (Geva et al., 2013). TEPR can also reflect temporally sustained elevations in LC-NA activity associated with the initial perception of inconsistent information when no response is required, in line with research showing early physiological responses associated with unconscious perceptual discernment of inconsistent stimuli (Proulx et al., 2017; Sleegers et al., 2015; Zarzeczna et al., 2020). As such, depending on the context, TEPR activation can occur in a cue-locked, target-locked, response-locked and inconsistency-induced manner. As such, inconsistency-induced TEPR signifies increased vigilance emerging from the cognitive conflict / sympathetic arousal associated with inductions of inconsistency, incongruency and threat (Geva et al., 2013; Proulx et al., 2012; Sleegers et al., 2015; Zarzeczna et al., 2020), whereas cue-locked and response-locked TEPR reflects phasic responses to warning signals / motor commission in relation to task-related preparation and cognitive effort for ongoing performance. Indeed, pre-response and post-response TEPR have been demonstrated to exhibit attentional network specificity during the ANT, insofar as pre-response TEPR is generally elevated following alerting and orienting cues (indicative of enhanced preparatory alertness / arousal) and incongruent targets (indicative of increased cognitive conflict), whereas post-response TEPR is elevated in response to motor commission during incongruent target trials (indicative of increased cognitive effort following a response that required inhibition of distractors) (Geva et al., 2013).

Baseline pupillary diameter (bPD) also exhibits remarkably congruent activity with fluctuations in LC-NA arousal, specifically in relation to baseline LC firing (Figure

5, Aston-Jones and Cohen, based on Rajkowski, Kubiak, & Aston-Jones, 1993; Joshi et al., 2016). Moreover, as predicted by AGT, elevated bPD in humans reliably predicts task disengagement typically associated with distractibility and exploratory attention manifesting at the higher end of the LC-NA curve (Figure 4) (Gilzenrat, Nieuwenhuis and Cohen, 2010). Finally, bPD has been shown to be predictive of task performance, whereby very large or very small magnitudes of bPD (and reduced phasic TEPR) are associated with poor performance, but intermediate magnitudes of bPD (and increased phasic TEPR) are related to optimal performance (Murphy, Robertson, Balsters and O'Connell, 2011). This inverted-U relationship between bPD and performance bears marked resemblance to the Yerkes-Dodson arousal-performance curve and promotes bPD as a reliable index of the entire tonic LC-NA spectrum.

Taken together, these findings demonstrate that pupil diameter indirectly, yet reliably, reflects LC-NA function, insofar as a hypoactive / non-alert mode of LC-NA arousal is associated with smaller bPD and the absence of TEPR, a task-focused phasic mode of LC-NA arousal is associated with intermediate bPD and optimal stimuli/response-locked TEPR, and a vigilant / distractible exploratory tonic mode of LC-NA arousal is associated with larger bPD and enduring elevations in TEPR (Gilzenrat et al., 2010; Unsworth and Robison, 2016). As such, by utilising this proxy of LC-NA activity, it may be possible to identify distinct patterns of LC-NA arousal underlying mindful capacities and 'mindless' states, specifically in relation to tasks assessing vigilance, attentional control and inconsistency responses. However, it is important to note that the proposed functional relationship between pupil diameter and LC-NA activity in humans is largely based on indirect evidence (e.g., from studies employing pharmacological, MRI and electrocephalogram (EEG) methods) and that PD may reflect processes other than LC-NA arousal. For example, there is evidence to suggest that associations between neural activity and PD are not unique to the LC but can also be found in several other brain regions (Joshi et al, 2016), implying that activity throughout many cortical and subcortical structures may also be associated with fluctuations in pupil diameter. As such, despite the observed close relationships between LC activity and PD (Gilzenrat et al., 2010; Jepma and Nieuwenhuis, 2011), (a) the precise mechanisms underlying these observations are not fully understood, and (b) there may be further processes contributing to PD change other than LC-NA arousal, implying that PD is not under direct control of the LC but is instead closely correlated with its activity, representing a "reporter" proxy of LC function (Joshi et al., 2016). These are important points to remember when interpreting the findings of the present thesis, and indeed any study utilising PD to infer LC-NA processes.

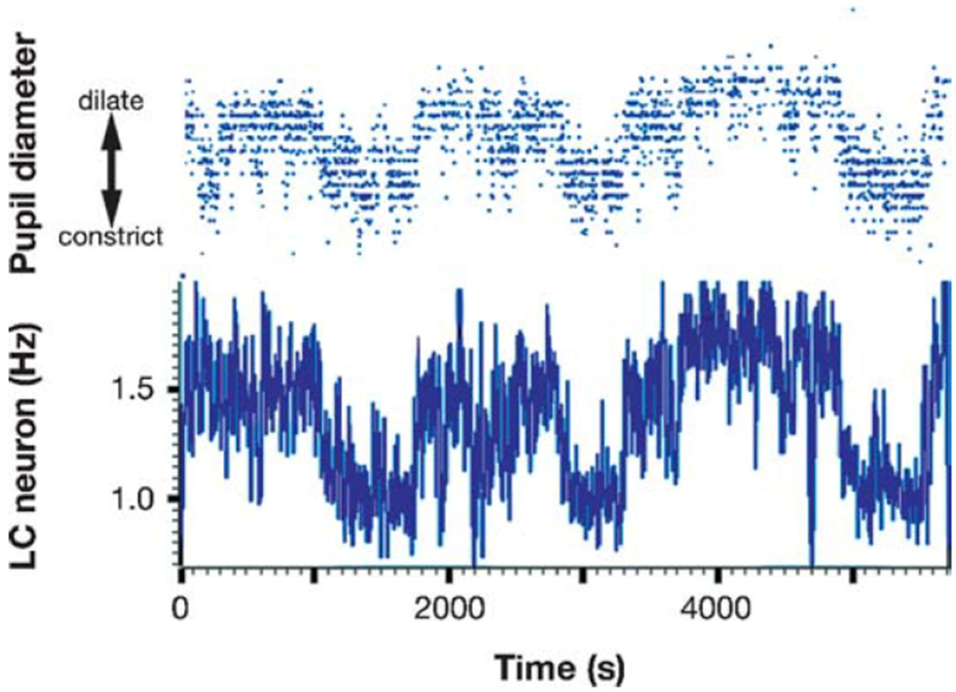
The Mindful Eye

If, as proposed, mindfulness can be conceptualised as a capacity for enhanced wakefulness / alertness (Britton et al., 2014) conducive to an increased awareness and acceptance associated with the bottom-up exploratory characteristics of a *tonic* attentional mode (Aston-Jones and Cohen, 2005; Petersen and Posner, 2012), then one would expect such capacities to be associated with fluctuations in arousal that are accessible through pupillary assessments of tonic and phasic LC-NA activity.

Specifically, mindfulness-based capacities and practices associated with FA and OM likely reflect 'inward' and 'outward' elements of the same tonic coin, insofar as the outward exploration of sensory experience (e.g., awareness) (FA) and the inward exploration of mental representation (e.g., non-judging acceptance) (OM) are each associated with exploratory attentional capacities, thus serving to augment expectancies that mindfulness will be associated with increased tonic LC-NA activity. As such, it is possible that mindfulness is related to larger bPD during attention tasks, reflecting sustained tonic LC-NA arousal conducive to an active, bottom-up scanning of the environment favouring vigilant and efficient detection of internal and external experiential events.

Figure 5.

Relationship Between Tonic Pupil Diameter and Baseline Firing Rate of LC Neuron in Monkey



Note. Baseline pupil diameter and concurrent LC firing rate during pretrial fixation period (from Aston-Jones and Cohen, 2005).

Additionally, research proposing that mindfulness enhances attentional control through an ability to *disengage* (e.g., through non-judging acceptance) from the cognitive reactivity typically induced by incongruent / inconsistent information illustrates that mindfulness may diminish the need for neurocognitive resources recruited for the ongoing control / inhibition of prepotent responses to this information. As such, one would expect mindfulness to be related to *reduced* cortical resource allocation following motor responses to incongruent / conflicting targets, manifesting as diminished magnitudes of *post-response* TEPR. As such, although tonic LC-NA activity may be higher in mindful individuals / states, phasic responses to manage cognitively-taxing stimuli / distractors are expected to be utilised to a lesser extent whilst retaining comparable levels of performance. In this sense, through the lens of AGT, the mindful pupil is expected to be larger and less reactive.

AGT also predicts that tonic LC-NA activity is initiated by information that violates our expectations of how the world should operate (e.g., prediction errors arising from diminishing task rewards, inconsistent facial features, anomalous playing cards, etc). That is, any information that is inconsistent with our expectations initiates greater LC-NA arousal, which can be reliably assessed through increased bPD across inter-trial epochs (Gilzenrat et al., 2010) and through greater magnitudes of TEPR during within-trial epochs immediately following inconsistent information (Proulx et al., 2017). These pupillary indices represent shifts into exploratory attentional states for the acquisition of new signals crucial for learning (Aston-Jones and Cohen, 2005), but also for the avoidance of aversion associated with elevated arousal states (Proulx et al., 2012). Considering that enhanced awareness and receptiveness toward environmental stimuli likely facilitates early detection of inconsistent information, the magnitude of LC-NA arousal in response to this information is likely to be greater among mindful individuals (Teper and Inzlicht, 2013). This can be reliably tested with concurrent examinations of bPD and TEPR in various tasks inducing different forms of inconsistency. Moreover, thanks to an enhanced *acceptance* of internal experience, mindfulness likely facilitates disengagement from psychophysiological activation, rendering mindful individuals less likely to be impacted by this arousal and negating the need for palliative affirmatory efforts. This should be reflected in concurrent examinations of compensatory behaviour.

Additional context for the expected pupillary correlates of mindful traits and states emerges from prior work demonstrating distinct psychophysiological associations with mind wandering. As discussed, active ‘decoupling’ from *outward* tonic attention for the cultivation of an ‘offline’ *inward* mode of tonic exploration is conducive to the bottom-up navigation and maintenance of internally generated thoughts (Linares et al., 2019; Smallwood and Schooler 2014., Smallwood, 2013). Such decoupling is reliably related to increased pupillary activation, insofar as greater bPD has been observed during periods of ‘offline’ thought relative to periods of top-down task focus, suggesting that this ‘inward’ mode of exploratory attention and offline cognition is associated with elevated LC-NA activity (Smallwood, Brown, Tipper et al., 2011). As such, although mind wandering may not be conducive to ‘online’ task completion, it represents a correlate of the broader adaptive utility of AGT-predicted tonic LC-NA activation, which facilitates exploratory attention for adaptive learning and is reliably accessible through bPD examination. In relation to mindfulness, the ‘decoupled’ exploratory stance associated with mind wandering is directly comparable to the bottom-up attentional state nurtured by OM practice, whereby an active, non-judging exploration and labelling of internal mental representation is likely facilitated by similar elevations in LC-NA arousal, and by extension, comparable assessments of bPD. This invites pupillary assessment of both mindfulness and mind wandering during similar tasks to obtain a richer insight into what it means to be wakeful.

To summarise, the “relaxed alertness” proposed to characterise mindful traits and states, specifically in relation to capacities for awareness and non-judging acceptance (Britton et al., 2014), may emerge from an enhanced tonic LC-NA mode of alertness conducive to an active bottom-up exploration of sensory / psychological experience, whereby the threshold to enter a tonic mode is lower for mindful individuals / states. This enhanced capacity for tonic LC-NA activation may harbour adaptive utility in terms of occupying a state of readiness for the early detection of incoming stimuli, especially in the service of environmental exploration and the learning of novel demands. Such capacities can be assessed using pupillometry, whereby the mindful pupil is expected to be larger (e.g., bPD and inconsistency induced TEPR) and less reactive (e.g., post-response TEPR indicating cognitive effort). Moreover, these indices of LC-NA activity can be utilised in tests of ongoing vigilance (e.g., alerting, orienting and vigilance portions of the ANT / sustained attentional components of the SART and CPT), executive control (e.g., incongruent stimuli during the Stroop / executive portion of the ANT) and novel inductions of inconsistency (e.g., unusual stimuli / AGT-predicted capacities for tonic LC-NA activation during waning task utility), whereby greater bPD and elevated inconsistency-induced TEPR should be evidently enhanced among mindful individuals and as a result of mindfulness training, and also predictive of performance in tasks requiring vigilant attention. Considering that tonic LC-NA activation is also essential for DMN activation, it would also be expected that bPD would be greater during periods of self-generated thought than during periods of on-task thought.

Thanks to recent technological advances in the domains of cognitive science and psychophysiology, the windows into the awakened land have never been more accessible, insofar as mindfulness can be examined conjointly through the lens of distinct neurocognitive and attentional processes in relation to prominent theory pertaining to LC-NA function. As such, the combined use of novel inconsistency inductions, established sustained attention tasks, robust experience sampling methods and ongoing pupillary assessments would appear to offer a rich and multifaceted insight into the characterisation of mindfulness as a wakeful state, whereby the 'outward eye' is aware and the 'inward eye' accepts.

Overview of Studies

In order to test the general assumptions outlined in the present Chapter, outcomes employed throughout this thesis are grouped into three broad categories in relation to study-specific hypotheses; self-report, attentional and pupillary outcomes, with the general expectation that mindful traits and training programmes would be related to greater magnitudes of core mindfulness dimensions (e.g., attentiveness, awareness, non-judging acceptance), improved sustained and executive attentional performance (e.g., during ANT, SART, CPT tasks), enhanced indices of tonic LC-NA arousal (e.g., greater bPD and inconsistency-induced TEPR) and diminished phasic LC-NA arousal associated with cognitive effort (e.g., reduced TEPR reactivity following motor responses to conflicting information). To test these predictions, I conducted a series of experiments employing a range of established and novel performance-based tests of attention as well as unique inductions of inconsistency in order to examine the impact of trait and induced mindfulness on these neurocognitive processes, specifically in relation to AGT-predicted fluctuations in LC-NA activity. Each empirical chapter is accompanied by a more detailed overview of each Study from the outset.

In Chapter 2, I present two studies aimed at examining the impact of dispositional mindfulness on inconsistency-arousal-compensation processes. Study 1 explored behavioural inconsistency-compensation processes utilising the Stroop task. Study 2 utilised inconsistency-induced TEPR to infer distinct elevations in LC-NA activity in response to novel violations of expectation.

Subsequently, in Chapter 3, I present a follow-up study (Study 3) designed to explore the potential moderative role of trait mindfulness in relation to novel compensatory responses to inconsistency-induced arousal, explicitly within the context of AGT-predicted, pupillary-inferred shifts between phasic and tonic modes of LC-NA activity and exploratory attention.

In Chapter 4, I present two studies (Studies 4 and 5) examining the effects of two unique mindfulness-based interventions (MBIs) on a selection of performance-based tests of attention through the lens of AGT. Specifically, Study 4 explores the impact of a four-week mindfulness-based intervention (Acceptance and Commitment Therapy (ACT)) on attention network efficiency and on capacities for sustained attention in relation to performance (response latencies, accuracy) and arousal (pupillary-inferred correlates of tonic and phasic LC-NA activity). Similarly, for Study 5, I developed and delivered a novel four-week mindfulness-based training programme (Mindfulness-Based Cognitive Attention Training (MBCAT[15])) to examine its effect on performance and pupillary activity during a unique task combining assessments of attention network function and ongoing tonic alertness and vigilance. This task has not yet been administered in mindfulness research. In each of these studies, self-reported mindfulness was assessed as a function of ACT / MBCAT participation and as a potential mediatory mechanism for the impact of MBIs on neurocognitive outcomes. The impact of MBCAT training on psychological wellbeing was also examined.

Subsequently, in Chapter 5, I present an online study[16] (Study 6) exploring the behavioural effects of meditation practice on two performance-based tests of attention. Specifically, I examined the impact of Vipassana meditation - in terms of both historical experience and current practice frequency - on attention network function and sustained attention / vigilance. I also harnessed the opportunity to examine the effects of meditation on self-reported mindfulness and psychological wellbeing within the context of the COVID-19

[15] *Note.* The significant amount of time and resources dedicated to developing this intervention was in anticipation of being able to flexibly deliver repeated waves of MBCAT, both as replications of this study and as new eye-tracking experiments (e.g., delivering to meditating populations, utilising alternative attention tasks, applying intervention to inconsistency-compensation processes). This work was naturally rendered temporarily void due to the pandemic but does provide a solid foundation for future application (see COVID-19 impact statement).

[16] Originally intended as a laboratory-based eye-tracking experiment (see COVID-19 impact statement).

pandemic.

In Chapter 6 - my final empirical chapter - I explored the impact of a brief online MBCAT induction on identical indices of attention and on similar COVID-related outcomes as those examined in Study 6[17].

Finally, in my concluding chapter (Chapter 7), I integrate findings across all studies, discuss implications and future directions, and provide an overall conclusion to my thesis.

[17] As above.

Overview of Analytical Strategy

General linear models (GLM) and paired *t*-tests were utilised to examine the impact of inconsistency induction and self-reported mindfulness on arousal in Study 2.

I utilised linear mixed models (LMM) and generalised LMMs (GLMM) in Studies 3, 4, 5, 6 and 7 using the *lme4* and *afex* packages for *R* to account for random effects of study-specific variables (see also Appendix 0iii) when examining outcomes relating to attention and arousal (e.g., response latencies, accuracy, probe responses and pupillary variables). For ANT network analyses, *t*-tests were implemented to ensure network scores were significantly different from zero, thus validating the existence of each network prior to mindfulness-related analyses.

Multivariate Analysis of Covariance (MANCOVA) and follow-up ANCOVAs were also utilised to explore effects of meditation and mindfulness induction on self-reported mindfulness and psychological distress, and on attention network scores (studies 6 and 7).

Multiple comparison analyses, control for Familywise Error Rates (FWER), were administered on resultant significant models only ($p < .05$), utilising Tukey criterion through the *emmeans* package for *R*.

For studies preceded by a priori sample size calculations, criteria were set to .80 power with a significance level of < .05 using G*Power (Faul et al., 2009) for small-moderate effect sizes observed in research utilising comparable methods and outcomes measures.

All data preparation techniques in relation to response latencies, accuracy and pupillary variables are outlined in Appendix 0ii.

Throughout this thesis, effect sizes for all pertinent comparisons relating to my primary hypotheses are reported as Cohen's *d.*

Implications

To summarise, the current thesis presents a series of experiments designed to obtain a deeper understanding of what it means to be mindful, both in terms of dispositional personality and practiced states. Although established theoretical conceptualisations of mindfulness and substantial empirical endeavour have served to highlight mindfulness as an increased ability to remain alert and vigilant, a core mechanism conceivably positioned to underlie these factors - arousal - has been neglected in the mindfulness literature. I believe that converging mindfulness-related insights from behavioural and neurobiological domains with knowledge of the arousal modulating system of the human brain may provide important and much-needed clarity around mindfulness as a wakeful capacity. That is, exploring fluctuations of the brain's noradrenergic system via pupillometry in tandem with behavioural indices of attentional performance may reveal an important arousal-based mechanism underlying some of the cognitive benefits of mindfulness. By extension, such insights may harbour profound implications for the tailoring of mindfulness-based interventions for the targeting of specific mental difficulties associated with LC-NA dysregulation and / or attentional and cognitive biases.

Chapter 2: Inconsistency-Compensation, Arousal and Dispositional Mindfulness (Studies 1-2)

Overview

As outlined in Chapter 1, examining mindfulness through the lens of inconsistency-induced arousal may offer valuable insights into the wakeful qualities of awareness and acceptance and their role in inconsistency-compensation processes. Moreover, specific proposals arising from recent studies exploring inconsistency-arousal-compensation processes offer novel and potentially fruitful opportunities to explore several understudied research directions in the literature.

Current knowledge about the impact of distinct personality variables on inconsistency-compensation processes and associated arousal responses is very limited. There is also a paucity of research evidencing direct links between inconsistency-induced arousal and specific compensatory behaviours. Accordingly, in the current Chapter, I present two studies that were designed to test whether dispositional mindfulness - a proposed capacity for enhanced vigilance, attentional control and tonic LC-NA activity - influences the potency of arousal and compensatory responses to inconsistent / incongruent information. In Study 1, I focus on inconsistency, mindfulness and compensatory action. In Study 2, I augment these aims through concurrent examination of arousal in the form of pupillary dilation (task-evoked pupillary responses; TEPR) as a proxy for LC-NA activity. As such, across studies, I explored the role of trait mindfulness in moderating relationships between inconsistency, arousal and compensation through the lens of AGT-predicted attentional and psychophysiological processes. In both studies, participants were exposed to conceptually inconsistent stimuli (incongruent Stroop pairs in Study 1, expectancy-violating faces in Study 2), followed by measures of compensatory affirmation of moral beliefs in the form of bond severity and adherence to sensitive political / moral stances. Dispositional mindfulness in both tasks was assessed using the Five Facet Mindfulness Questionnaire (FFMQ), whereby individual facets (e.g., awareness and non-judging acceptance) and total scores were entered as moderators of relationships between inconsistency, arousal (Study 2 only) and compensatory behaviour. It was hoped that such endeavour would provide much-needed insight into the impact of personality variables on inconsistency-compensation processes and contribute to emerging conceptualisations of mindfulness as a distinct capacity for enhanced attentional awareness and associated increases in arousal in the presence of expectancy-violating / inconsistent information.

Study 1 revealed no evidence of Stroop-induced inconsistency on compensatory affirmation behaviour or a role for mindfulness in this relationship. Study 2 did illustrate a clear bias for the early preferential processing of inconsistent / expectancy-violating stimuli over threatening stimuli, which was reliably associated with distinct patterns of arousal. Moreover, there was tentative evidence that the addition of threatening information to inconsistent stimuli enhanced early arousal effects when compared to lower-level inconsistency. General levels of stimuli-induced arousal were also associated with subsequent compensatory affirmation, thus positioning present research at the inception of demonstrating such links. However, a theorised moderating role of mindfulness on compensatory behaviour and arousal through increased awareness and acceptance was largely not supported. Implications of these findings in relation to central expectations are discussed in Chapter 7.

Study 1: Stroop Incongruence Exerts no Influence on Compensatory Affirmation, No Moderative Role for Mindfulness

Stimuli that are inconsistent with our expectations and / or represent two incongruous representations simultaneously are afforded salience in the human attention system. This prompts an attentional orienting response toward stimuli features, which in turn initiates an arousal-based reaction and subsequent palliative attempts to reduce this arousal through compensatory efforts (Proulx, Inzlicht & Harmon-Jones, 2012). Recent experimental examinations of proposed links between inconsistency, arousal and subsequent compensatory action have utilised a diverse range of tools to infer such processes. For example, increased compensatory affirmation – proposed by the meaning-maintenance model (MMM) as an attempt to address a perceived inconsistency / violation of one meaning framework by affirming an unrelated, intact meaning framework (Randle, Heine and Santos, 2013) - has been reliably demonstrated to succeed a wide range of expectancy violating / inconsistent stimuli, such as incongruous word pairs (Randles, Proulx and Heine, 2011), absurdist literature (Proulx, Heine and Vohs, 2010), unexpected correct answers (Sleegers, Proulx and van Beest, 2021), the surreptitious switching of experimenters (Proulx and Heine, 2009) and anomalous playing cards (Sleegers, Proulx and van Beest, 2015). As such, affirming intact meaning frameworks serves to ameliorate discomfort - a form of arousal typically outside of the awareness of the perceiver - caused by the inconsistency / meaning violation. Such compensatory affirmation has been shown to encompass behaviour affirming structure and personal control in relation to factors unrelated to the source of inconsistency (Proulx et al., 2010) and, notably, to include behaviour affirming unrelated schemas and moral beliefs (Proulx and Heine, 2009; Randles et al., 2011). For example, participants who read a hypothetical arrest report about a prostitute were informed that they could choose how much bail to set for the release of the prostitute (between $0 and $999) (Randles et al., 2011), thus providing experimenters the opportunity to assess potency (e.g., greater bond severity) of belief affirmation that prostitution is wrong (e.g., prostitution / sex for money is incongruent with commonly held views about relationships and is unlawful). Crucially, following subliminal presentation of meaningless words (e.g., meaning threat), bond severity was shown to increase, implying greater compensatory affirmation following inconsistency / threat (Randles et al., 2011). Indeed, this identical measure has been administered in several inconsistency induction experiments as a reliable way to evaluate degrees of compensatory affirmation (Proulx and Heine, 2008; Proulx et al., 2010). Additional measures of compensatory affirmation involve assessing strength of moral beliefs using Likert-type scale questioning covering a range of culturally sensitive topics (e.g., individuals are more likely to adhere to stronger moral beliefs about abortion after being presented with a threat).

As such, experimental inductions of inconsistency and subsequent assessments of compensatory affirmation can be operationalised across a diverse range of paradigms and need not be meaningfully or conceptually related to one another to initiate compensation.

Executive Conflict and Inconsistency. Stimuli that is not merely novel or inconsistent with prior experiences, but also concurrently inducive of inherently incongruous experiences may render the effects of inconsistency-induced conflict particularly acute (Proulx, et al., 2017). For example, widely used and consistently validated performance-based tests of attention often incorporate conceptually inconsistent / incongruent stimuli to induce cognitive conflict in order to assess capacities for executive control. Specifically, incongruent target-flanker conditions during the Attentional Network Task (ANT; Fan et al., 2002) and incongruent colour-word pair conditions during the Stroop task (Stroop, 1935) likely serve to induce a level of inconsistency / conflict comparable to that induced by similar incongruous visual stimuli (e.g., nonsense word pairs, Randles et al., 2011). Indeed, the presentation of ANT / Stroop incongruence has been demonstrated to elicit enhanced *post-response* arousal responses indicative of greater allocation of neural resources to aid conflict resolution (Damen et al., 2021; Geva et al., 2013; Laeng et al., 2011) (see also ANT outcomes in studies 4 and 5). Moreover, elevated arousal responses to these stimuli are evident *prior* to motor commission, which bear marked magnitudinous similarities to those initiated by salient inductions of inconsistency (e.g., expectancy / meaning violations, Proulx et al., 2017; Sleegers et al., 2015). This indicates that comparable aversive arousal states likely succeed various manifestations of inconsistency prior to any required response (Proulx et al., 2012), positioning such tasks as reliable and effective experimental inductions of inconsistency and offering unique opportunities to extend existing knowledge about the role of specific individual difference moderators in these processes.

Affirmation of Beliefs as a Compensatory Response.[18] Several meaning-threat studies have demonstrated enhanced affirmation of moral beliefs following inconsistency inductions in the form of aforementioned social judgements and adherence to strongly held views around political and moral issues (Proulx and Heine, 2009; Proulx, Heine and Vohs, 2010; Randles, Proulx and Heine, 2011). The present research explores these outcomes as a function of Stroop conflict to establish the predicted inconsistency-compensation linkages in terms of affirmation processes.

Mindfulness as Attentional Moderator of Inconsistency-Compensation. There has been limited research examining the impact of moderating factors on inconsistency-compensation processes. Although extant work demonstrates interesting moderating effects of extremism (Sleegers et al., 2015), self-esteem (McGregor and Marigold, 2003) and self-

[18] See 'Materials' section.

regulation (Galliot et al., 2006), the role of trait mindfulness has been largely ignored in the inconsistency-compensation literature. Considering the well-documented benefits of mindfulness on a range of attentional (Josefsson and Broberg, 2011; Moore and Malinowski, 2009) and psychological outcomes (Giannandrea et al., 2019; Solati et al., 2017), and the role of different threat / inconsistency reactions in maintaining adaptive / maladaptive coping mechanisms (Korte et al., 2021), it seems prudent to extend current understanding about the specific moderative qualities of mindfulness on inconsistency-compensation processes. More specifically, positioning mindfulness as a capacity for increased awareness and acceptance of inward and outward experience fosters expectations that this capacity would likely translate into changes in behavioural reactivity to such experiences.

Dispositional mindfulness has been reliably associated with enhanced performance during tests of executive attention, including improved response inhibition (Schmertz et al., 2009), reduced Stroop Interference Effects (Josefsson and Broberg, 2011; Moore and Malinowski, 2009) and diminished incongruent flanker interference (Lin et al., 2018). Such attentional benefits are theorised to emerge from an increased capacity for mindful individuals to exhibit non-judgmental awareness and acceptance towards all internal and external experiences without being caught up in irrelevant / distracting mental phenomena (Britton et al,. 2018). This capability likely manifests as an enhanced capacity to detect distracting / incongruous task-based information and to subsequently disengage from this information (Lutz et al., 2008; Malinowski, 2013), thus improving performance. Such augmented attentional capacities would appear beneficial for the efficient detection of inconsistent stimuli and the subsequent executive management of attentional resources typically required to resolve associated conflicts. Indeed, greater levels of mindfulness have been associated with improved attentional deployment in the form of early behavioural orienting towards inconsistent stimuli (~100ms after stimulus onset) and faster disengagement from these stimuli to aid executive performance (~500-600ms after stimulus onset) (Brown et al., 2013; Jha et al., 2007; Teper and Inzlicht, 2013). This capacity for the early detection of - and subsequent disengagement from - perceptual inconsistency is congruent with conceptualisations of mindfulness as representing a highly attuned awareness of the experiential field and a non-evaluative and accepting attentional stance toward any emotional / aversive states arising from inconsistent / affective stimuli (Brown et al., 2007; Brown et al., 2013; Teper and Inzlicht, 2013).

Taken together, these findings invite conclusions that mindfulness facilitates efficient recruitment of regulatory resources to aid immediate awareness of / engagement with inconsistent stimuli and to promote disengagement from any cognitive / psychophysiological reactivity emerging this inconsistency (Slutsky, et al., 2017). Interestingly, this process has been proposed as a central mechanism underlying improved threat responses for downstream benefits to emotional regulation among high trait mindfulness individuals (Brown et al., 2013; Teper and Inzlicht, 2013; Slutsky et al., 2017). Moreover, extant models highlighting the underlying impact of mindfulness-related improvements in executive attention on emotional regulation invite additional hypothetical consequences of augmented executive control processes (Teper and Inzlicht, 2013). The present chapter frames a proposed mindfulness-related modulation of the inconsistency-arousal-compensation process as a suitable candidate. Specifically, if mindful awareness enhances early attentional deployment towards inconsistent / threatening information, then the psychophysiological impact of these stimuli will be more pronounced, representing tonic elevations in LC-NA activity. However, consistent with mindfulness as a capacity for acceptance of internal sensory experience, mindful individuals will be more likely to disengage from this arousal, and by extension, less likely to engage in palliative compensatory responses to alleviate the arousal. This should be reflected in reduced compensatory affirmation.

In the present online study, behavioural links between inconsistency presentation and compensatory affirmation are established and the potential moderating role of trait mindfulness on these relationships is examined. In Study 2, behavioural processes are augmented with concurrent psychophysiological evaluation, with the expectation that trait mindfulness will modulate specific arousal states consistently demonstrated to follow variegated methodological inductions of inconsistency and influence the compensatory efforts associated with this arousal (Proulx, Inzlicht & Harmon-Jones, 2012; Geva et al., 2013; Laeng et al., 2011; Proulx, Sleegers and Tritt., 2017).

For the present study, general expectations were two-fold: 1), Stroop-induced inconsistency will exert increased compensatory affirmation of unrelated schemas, and 2), dispositional mindfulness will moderate these responses, insofar as greater levels of mindfulness will result in reduced inconsistency-induced compensatory affirmation. It was hoped that findings in this respect would offer novel insights into the role of specific individual difference measures in inconsistency-compensation processes and set the stage for further examinations of these processes in relation to mindfulness and arousal-based outcomes.

Hypotheses

Consistent with extant literature demonstrating enhanced compensatory affirmation following inconsistency induction (Proulx and Heine, 2009; Randles et al., 2011), it was predicted that Stroop conflict would induce increased affirmation of unrelated schemas, specifically in the form of increased bond severity (H1a) and greater affirmation of political and moral beliefs (H1b), thus establishing behavioural inconsistency-compensation processes.

It was also hypothesised that trait mindfulness would be associated with reduced bond severity and diminished affirmation of political and moral beliefs (H2a), consistent with general expectations that dispositional mindfulness would be associated with reduced overall levels of compensatory behaviour.

Finally, drawing from insights demonstrating improved executive function for high trait mindfulness individuals (Josefsson and Broberg, 2011; Moore and Malinowski, 2009; Schmertz, Anderson and Robins, 2009), I address the possibility that mindfulness-related enhancements in executive function may moderate downstream behavioural responses to threatening / inconsistent information (Brown et al., 2013; Slutsky et al., 2017; Teper and Inzlicht, 2013). Specifically, it was hypothesised that dispositional mindfulness would diminish the effects of Stroop conflict on compensatory affirmation, in terms of both bond severity (H2a) and affirmation of political and moral beliefs (H2b).

Method

Participants

A total of 124 participants were recruited through the online recruitment platform Prolific Academic (see https://prolific.co/). Participants received £9.50 as reward for their participation. Twelve participants did not progress beyond the initial instructional stage. Of the remaining 112 participants, four sets of data reflected non-engaged participation and were excluded (e.g., identical responses implying automatic responding, unreasonably fast experiment completion time). Of the remaining 108 participants, three exhibited more than 50% missing responses and were excluded. The final sample consisted of 105 participants (34 males, 71 females; M_{age} = 34.8 [SD = 12.3]). Condition randomisation procedures resulted in 34 participants being allocated to the Control Stroop condition, 32 participants to the Easy Stroop condition and 39 participants to the Hard Stroop condition. The approximate sample size for medium effects was derived from prior studies using comparable methods and analyses to explore the impact of Stroop-induced cognitive conflict on subsequent evaluative behaviour (Damen et al., 2018; 2021) and from sample size and associated power calculations (G*Power; Faul et al., 2009) given an analysis involving three between-subjects levels, a 5% alpha level and .80 statistical power. All questionnaire and experimental data were captured electronically by Qualtrics Online Questionnaires (see https://www.qualtrics.com/uk/). Participants were also asked their age, gender and educational level.

Materials and Procedure[19]

Stroop Task. When attempting to name a word's physical colour, the congruency between the written colour and the actual colour of the word facilitates faster and more accurate responses than if the word-colour pairing is incongruent. The difficulty / conflict experienced when naming an incongruous word (e.g., declaring that a word is blue, when the word reads "green") is known as the Stroop effect (Stroop, 1935), which can be demonstrated by comparing performance on congruent relative to incongruent Stroop trials. Stroop conflict is generally experienced as a negative signal, which can induce the recruitment of neural and motivational resources to aid resolution (Inzlicht et al., 2015). Interestingly, Stroop conflict has also been demonstrated to influence judgement-based responses during successive and unrelated tasks, such as affective perceptions / evaluations of neutral visual stimuli and goal-relevant products (Damen et al., 2018; 2021), thus further justifying use of the Stroop to induce conceptually unrelated compensatory behaviour.

The present research employed a Stroop task containing three distinct Stroop conditions; a Control Stroop condition (participants were required to count the number of letters within each congruent word-colour pair), an Easy Stroop condition (participants were required to declare the colour of words, whereby a low proportion of word-colour pairs were incongruent (< 10%)) and a Hard Stroop condition (all word-colour pairs were incongruent). Comparisons were therefore possible between different levels of Stroop-induced conflict as well as between Stroop and control conditions.

[19] See Appendix 0i: 'Overview of Self-Report Measures' for full details pertaining to the FFMQ.

The 15-Item Five-Facet Mindfulness Questionnaire (FFMQ, Baer et al. 2008): The FFMQ is one of the most widely used measures of trait mindfulness, and assesses sub-components of mindfulness, namely Observing, Describing, Awareness, Non-Judging and Non-Reactivity, as well as Total FFMQ scores. Higher scores represent greater levels of total and subscale-inferred mindfulness. In the present study, alpha coefficients for the sample were good for Observing (α=.78), Describing (α=.82), Awareness (α=.89), Non-Judging (α=.90) and Non-Reactivity (α=.87).

Compensatory Affirmation: Bonds. Employing an assessment of compensatory affirmation utilised in comparable research (Sleegers, Proulx and van Beest, 2015), two counterbalanced scenarios, each outlining a crime (prostitution and viewing pornography in public) were presented subsequently to the Stroop task, whereby participants were asked to choose a bail amount between £0 and £999 for each defendant (*α* = .86). These items were averaged together across scenarios, with higher bonds indicating greater values affirmation. Participants were expected to exert greater bond severity following increased Stroop conflict. The rationale for this expectation was that each scenario represented a situation that is unlawful and morally incongruent with commonly held beliefs about relationships and public decorum. As such, by increasing the penalty, participants were able to affirm pre-existing beliefs about prostitution and public decency.

Compensatory Affirmation: Political and Moral Beliefs. To assess levels of endorsement of political and moral beliefs, a conservatism / liberalism scale was administered asking participants to rate the strength of their agreement on a range of issues, including the death penalty, long prison sentences, gay rights and abortion. Answers were made using a 7-point Likert-type scale, ranging from 0 (*"Strongly Disagree"*) to 3 (*"Neither*

Agree nor Disagree) to 6 (*"Strongly Agree"*). Conservatism-based questions are reverse-scored and answers are summed. As such, higher total scores represent greater liberal affirmation, and lower scores represent greater endorsement of conservatism.

A baseline check for political orientation was administered using a 7-point Likert-type scale (1 = *'conservative'* to 7 = *'liberal'*) and subsequently controlled for in all analyses of post-Stroop bond allocation and moral judgment.

Experimental Procedure

Participants were automatically directed from Prolific Academic to the Qualtrics Online Questionnaires platform to complete the experiment. All demographics (age, gender, highest level of education), questionnaire data and Stroop responses were captured electronically using Qualtrics. Participants completed demographics questions, the FFMQ and baseline political orientation scale prior to the Stroop. Subsequently, participants completed respective Stroop experiments (Control, Easy, Hard) before being presented with the bond and political / moral affirmation measures.

Data Preparation and Analytic Strategy

Outcomes were operationalised as two magnitude-based indices of compensatory affirmation following Stroop engagement; bond severity and political / moral beliefs.

A Multivariate Analysis of Variance (MANOVA) and correlational analyses were implemented to ensure baseline equivalence between Stroop conditions in relation to mindfulness and political orientation, and to examine associations between age and pertinent self-report measures.

Next, Analysis of Covariance (ANCOVA) was utilised to explore Stroop effects on bond severity and affirmation of political beliefs, controlling for age and baseline political orientation. Finally, associations between mindfulness and bond severity / beliefs were examined, followed by interaction effects between Stroop and mindfulness on each outcome.

Results

Demographics Analyses. There were no significant differences in age between genders (t[103] = .47, p = .64) or Stroop conditions (F(2,102) = .04, p = .96), and no gender differences between Stroop conditions ($\chi 2$(2, N = 105) = 1.82, p = .40). Correlation matrices examining associations between age and all facets of mindfulness, adjusting for multiple tests, revealed no significant associations (*all ps* > .64). Age was also not significantly related to personal projects (r[97] = 0.01, p = .88) or bond severity (r[103] = 0.10, p = .30).

Age was significantly negatively related to baseline conservative / liberal orientation (r[103] = -0.22, p = .03), whereby lower scores represent more conservative orientation. This suggests that older participants were more conservative in their political orientation than younger participants. However, age was not related to post-Stroop conservative / liberal views around specific political topics (r[103] = -0.10, p = .33).

Due to observed relationships between age and baseline conservative / liberal orientation, age was controlled for in all analyses exploring Stroop effects on compensatory affirmation outcomes.

Equivalence Tests. MANOVA confirmed baseline equivalence between Stroop conditions in all facets of self-reported mindfulness (V = .09, F(10, 198) = .91, p = .52). There were no significant differences in baseline conservative / liberal orientation between Stroop conditions F(2, 102) = .07, p = .93).

Baseline Political Orientation and Outcome Measures. Baseline conservative / liberal orientation was significantly negatively associated with bond severity (r[103] = -0.22, p = .02), indicating those who viewed themselves as more conservative were more likely to set a higher prostitute bond. As one would expect, baseline conservative / liberal orientation was strongly positively associated with conservative / liberal views around moral issues ($r[103] = .50$, $p < .0001$), with higher scores indicating stronger liberal orientation and views. Accordingly, baseline conservative / liberal orientation was controlled for in all analyses.

Stroop Effects. Contrary to expectations (H1a/b), ANCOVA did not reveal an effect of Stroop condition on bond severity ($F(2, 100) = .75$, $p = .47$, Figure 1), suggesting that Stroop difficulty had no impact on the amount of money elected for the release of a sex worker / public indecency defendant. There was also no effect of Stroop condition on endorsement of liberal / conservative beliefs ($F(2, 100) = .44$, $p = .64$, Figure 2), implying that Stroop difficulty did not influence affirmation of unrelated moral perspectives on a variety of salient cultural and societal issues.

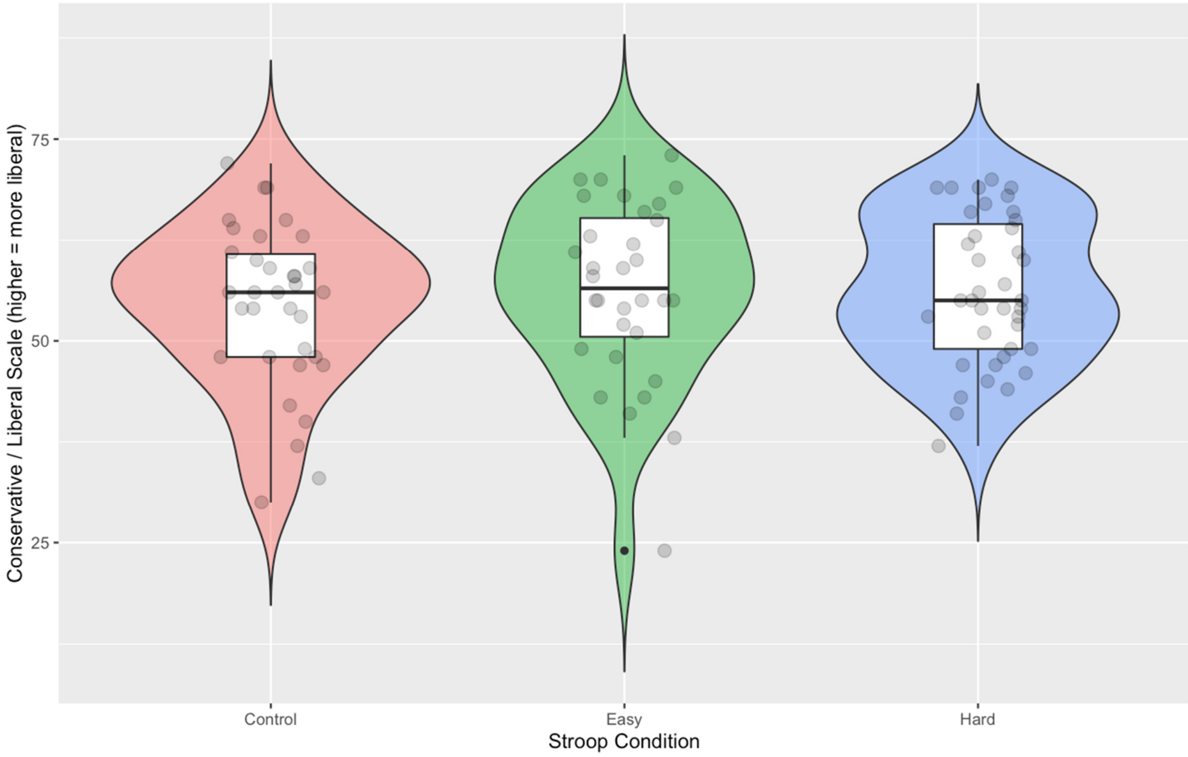
Figure 1.

Stroop Conditions and Bond Severity

Note. Comparisons between Stroop conditions in relation to prostitute bonds, controlling for age and baseline conservative / liberal orientation. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Figure 2.

Stroop Conditions and Endorsement of Political / Moral Beliefs



Note. Comparisons between Stroop conditions in relation to affirmation of political / moral beliefs (conservative / liberal views. Higher scores = more liberal), controlling for age and baseline conservative / liberal orientation. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

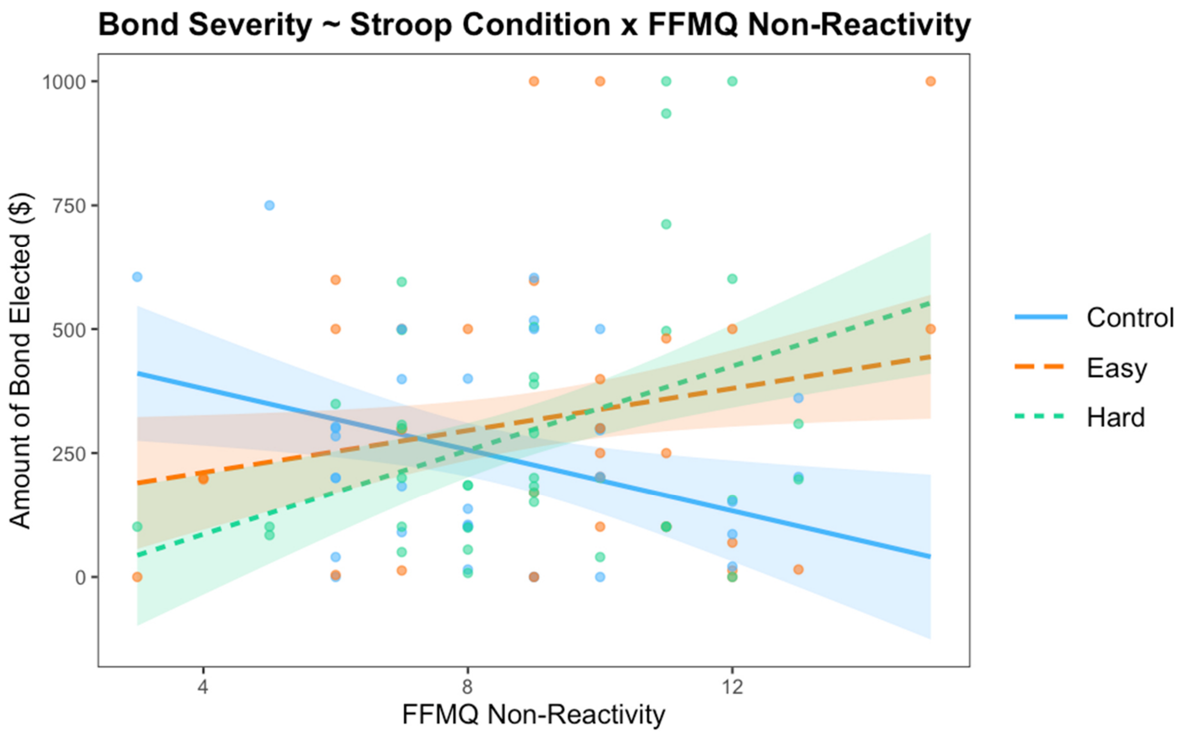
Mindfulness and Affirmation Outcomes. Exploring associations between mindfulness facets / total FFMQ scores and conservative / liberal orientation, adjusting for multiple tests, revealed a significant positive relationship between Observing and political orientation scores ($r[103] = .30$, $p = .03$), suggesting that those harbouring higher capacities for observation generally viewed themselves as more liberal. All other FFMQ facets and total scores were not related to political orientation (all *ps* > .44).

Contrary to expectations (H2a), when controlling for conservative / liberal orientation, mindfulness was not associated with bond severity (all *ps* > .27), indicating that those higher in dispositional mindfulness were no less likely to elect harsher punishments than those reporting lower levels of mindfulness. Similarly, mindfulness was not associated with affirmation of political / moral beliefs (all *ps* > .32), suggesting that capacities for being mindful across facets was not related to the strength of conservative / liberal opinion around salient societal issues.

Stroop Effects and Mindfulness. Interestingly (H2b), exploring interactive effects between Stroop difficulty and dispositional mindfulness in relation to bond severity revealed a significant interaction between Stroop condition and Non-Reactivity ($F(2, 97) = 4.42$, $p = .01$, Figure 3). Higher capacities for non-reactivity were associated with greater bond severity for those who'd participated in the Easy or Hard Stroop condition but not for those who'd participated in the Control Condition. This finding suggests that individuals harbouring greater capacities for non-reactivity were more likely to endorse harsher bond requirements if they'd been confronted with Stroop-based conflict than if they had not.

Figure 3.

Stroop Effects, FFMQ Non-Judging and Bond Severity

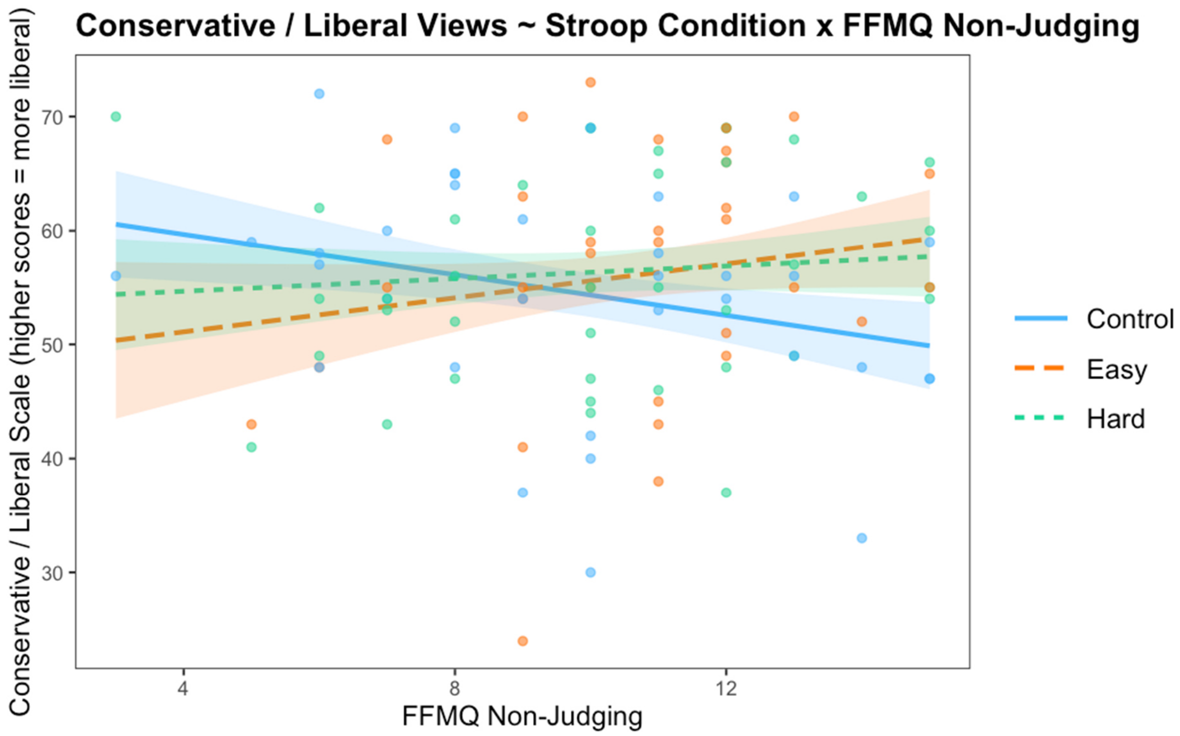


Note. Bond severity as a function of interaction between Stroop condition and FFMQ Non-Reactivity. Higher non-reactivity scores associated with greater bong severity for Easy / Hard Stroop participants but not for Control participants. Shaded areas represent 80% confidence bands.

Exploring interactive effects between Stroop difficulty and dispositional mindfulness on political / moral views (H2b) revealed a trending interaction between Stroop condition and Non-Judging scores (F(2, 97) = 2.44, p = .09, Figure 4), insofar as greater Non-Judging scores were descriptively associated with stronger endorsements of liberal beliefs for those who'd participated in the Easy or Hard Stroop condition, but not for those who'd participated in the Control condition. Remaining interactions were non-significant for each index of compensatory affirmation (all *ps* > .36).

Figure 4.

Stroop Effects, FFMQ Non-Judging and Endorsement of Political / Moral Beliefs



Note. Adherence to political / moral beliefs as a function of interaction between Stroop condition and FFMQ Non-Judging. Higher non-judging scores associated with greater liberalism for Easy / Hard Stroop participants but not for Control participants. Shaded areas represent 80% confidence bands.

Study 1: Summary of Results

Contrary to expectations, increased Stroop difficulty did not amplify the degree of compensatory affirmation in relation to bond severity or endorsement of political / moral beliefs. Moreover, mindfulness was not associated with reduced compensatory affirmation. Despite some interesting interactive effects between Stroop and trait mindfulness on affirmatory outcomes, the overall pattern of results implies that the level of Stroop-induced conflict was not of sufficient strength to induce compensatory affirmation, and that dispositional mindfulness exerted only limited moderative effects. More detailed discussion of these results, including potential implications and future directions located in Chapter 7.

Study 2: Mindfulness Exerts No Influence on Relationships Between Expectancy Violation, Compensatory Affirmation and Arousal

As discussed in Chapter 1, although there exists appreciable literature pertaining to the effects of inconsistency on compensatory behaviour (Proulx et al., 2010; Randles et al., 2011) and arousal (Proulx, Sleegers and Tritt, 2017; Sleegers et al., 2015), less frequently demonstrated are direct links between inconsistency-induced arousal and subsequent compensation (Sleegers et al., 2021). Additionally, building upon prior findings that the convergence of inconsistency and threatening information enhances arousal responses during specific epochs within the same trial (Grupe and Nitsche, 2011; Proulx, Sleegers and Tritt, 2017), there is a need to explore whether this combined arousal response translates into greater compensatory efforts. Finally, the role of dispositional factors in moderating relationships between inconsistency, arousal and compensatory action remains largely unexplored, offering a unique opportunity to examine mindfulness as a wakeful capacity through the lens of inconsistency-compensation processes.

Accordingly, addressing the need to utilise assessments of arousal for a more comprehensive examination of interactions between behavioural and psychophysiological factors governing inconsistency-compensation processes, the present study harnesses pupillometry to assess task-evoked pupillary responses (TEPR) to inconsistent stimuli. Moreover, dispositional mindfulness was explored as a potential moderator of expected associations between inconsistency, arousal and compensation. Finally, in an effort to augment the potency of inconsistency induction, task-based incongruency was replaced with inconsistency manipulations that were operationalised as the presentation of salient / expectancy-violating and threatening pictorial human facial expressions, which have been reliably demonstrated to initiate predicted aversive arousal responses in the form of TEPR-assessed trajectories (Proulx, et al., 2017). It was hoped that employing such methods would allow for a thorough examination of the role of dispositional mindfulness in inconsistency-arousal-compensation processes and address several open questions emerging from recent endeavour.

Pupillary Dilation as LC-NA Arousal Response to Inconsistency. Pupillary dilation (here termed task-evoked pupillary responses (TEPR), whereby the ‘task’ is the observation of inconsistent faces) provides a reliable marker of increased LC-NA activity in response to inconsistency. TEPR has been shown to increase both in response to the initial attentional saliency of stimuli and as a subsequent response to the affective attributes of the stimuli (Aston-Jones and Cohen, 2005). As such, TEPR variability represents differential temporal engagement with task-related attributes, signifying environmentally receptive activation and fluctuation of LC-NA activity. Specifically, elevated pupillary activity in response to the detection of inconsistency manifests as an initial spike in TEPR between 500ms and 1500ms following stimulus onset (period indicative of cognitive conflict processing) and has been demonstrated to succeed a variety of inconsistent / incongruent stimuli, including the Stroop task (Rondeel, van Steenbergen, Holland and van Knippenberg, 2015), pictorial faces (Proulx et al., 2017) and anomalous playing card features (Sleegers et al., 2015). Conversely, TEPR to affective stimuli (e.g., negative / threatening) exhibit sustained and gradual dilation over a longer temporal trajectory beyond 1500ms (period associated with sympathetic nervous system arousal) (Proulx et al., 2017), a response that is exacerbated when inconsistent and affective stimuli are combined (Grupe and Nitschke, 2011). For example, in a novel study, early TEPR peaks (500ms-1500ms) were observed in response to inconsistent / expectancy-violating faces, whereas sustained, gradual increases in TEPR (1500ms+) were observed in response to threatening versions of the same faces

(Proulx et al., 2017), thus reflecting the distinct time course of preferential processing associated with elevated LC-NA activation across stimuli. Moreover, sympathetic nervous system arousal (1500+ms) was amplified when threatening faces were combined with inherently inconsistent stimuli (e.g., Thatcherised features) relative to merely novel faces (e.g., upside-down), suggesting that the presence of incongruity enhances and prolongs sympathetic nervous system arousal (Grupe and Nitschke, 2011; Proulx et al., 2017). This augmentation of the TEPR response when converging inconsistent and threatening stimuli implies that the salience of the information has been bolstered, resulting in a stronger induction of arousal, which may, for example, explain why mortality salience primes (e.g., thinking about one's mortality, which is at once unusual and threatening) have been demonstrated to exert such strong compensatory responses (Sheldon et al., 2015). As such, the distinction between temporal epochs and between singular and combined usages of inconsistency and threat offers unique opportunities to directly compare TEPR across different versions of the same stimuli and between specific time courses for a thorough examination of whether combinations of salient stimuli induce greater magnitudes of LC-NA activation. Importantly, such methods provide a novel opportunity to examine whether compensatory affirmation is uniquely associated with LC-NA arousal during specific time epochs and whether the combination of inconsistent and threatening information results in greater affirmation, which has not yet been tested. Moreover, exploring dispositional variations in relation to these processes, namely the impact of mindfulness on specific temporal indices of elevated LC-NA activity and subsequent compensatory responses may provide important insights into the proposed qualities of wakefulness and alertness underlying mindful capacities and the types of stimuli that such capacities are particularly attuned to.

Human Faces, Inconsistency and Arousal. In order to induce inconsistency in the present study, pictures of human faces were utilised for their flexibility in terms of simultaneously harbouring inconsistent and threatening information in the form of novel orientation, inconsistent / incongruent features and angry features. As such, extending insights from directly comparable prior research evidencing contrasts between two distinct forms of salient stimuli - threatening and expectancy-violating faces (Proulx et al., 2017) - inconsistency was operationalised in a face-valid manner. Three versions of inconsistent faces were utilised, all of which were upside-down, thus representing a novel orientation seldom observed in daily experience. One face type exhibited a neutral expression (upside-down neutral Figure 6), which was expected to initiate the same pattern of TEPR as comparable inconsistent stimuli utilised in prior research (e.g., 500ms - 1500ms peak, Proulx et al., 2017) but without an augmented TEPR during the epoch associated with affective stimuli (1500ms+). Another face type (upside-down Thatcherised**)** included incongruent information in the form of Thatcherised features (oppositely oriented eyes and mouths), which was expected to enhance the 500ms - 1500ms TEPR peak relative to upside-down only faces due to the addition of inherently incongruent information (Proulx et al., 2017). The final inconsistent face type additionally contained threatening information in the form of an angry expression (upside-down angry Thatcherised), allowing for an examination of whether combining negative valence with expectancy-violating stimuli augmented both an early 500ms-1500ms TEPR and a sustained 1500ms+ TEPR. Upright angry faces were also included to ensure that TEPR during periods of cognitive conflict and sympathetic arousal could be compared with non-violating versions of the same stimuli. As such, the general expectation was that stimuli-specific increases in LC-NA activation for inconsistent face types would occur in a stepwise fashion, whereby unusual faces (upside-down) would initiate the least TEPR, inherently incongruous faces (upside-down Thatcherised) would induce greater TEPR and inconsistent threatening faces (upside-down Thatcherised + angry) would initiate the greatest whole-trial increase in TEPR, consistent with the notion that sympathetic arousal is augmented with the addition of inherently incongruent information (Grupe and Nitschke, 2011; Proulx et al., 2017). Moreover, augmented magnitudes of arousal were expected to induce comparable increases in compensatory affirmation behaviour, consistent with inconsistency-arousal-compensation frameworks (Proulx et al., 2012).

Assessment of compensatory affirmation in the present study utilises the same bond severity measure as the that employed in Study 1.

Mindfulness as Attentional Moderator of Inconsistency-Induced Arousal / Compensation. As discussed in Study 1, mindfulness has been shown to be associated with more efficient orienting towards inconsistent information (~100ms after stimulus onset) and faster disengagement from this information (~500-600ms after stimulus onset), behaviours which are accompanied by temporally congruent fluctuations in neural activity in the form of increased early and late event-related potentials (ERP) (Brown et al., 2013; Jha et al., 2007; Teper and Inzlicht, 2013). This is consistent with proposals outlined in Chapter 1 that mindfulness represents enhanced awareness and receptiveness toward environmental stimuli, which likely facilitates early detection of inconsistent / threatening information, resulting in an associated elevation in LC-NA activation. This would likely be reflected in increased TEPR magnitudes during stimulus presentation. Moreover, due to capacities for enhanced acceptance of internal experience and resultant disengagement from these psychophysiological experiences, mindful individuals may be less likely to engage in palliative attempts to ameliorate this arousal. This would be reflected in reduced compensatory affirmation behaviours. Indeed, considering that inconsistency-induced TEPR has previously been demonstrated to be associated with subsequent compensatory action

(Sleegers et al., 2021), mindfulness may also moderate arousal-compensation relationships, insofar as positive associations between TEPR and affirmation indicative of increased palliative reactivity to arousal may only be evident among individuals reporting lower levels of trait mindfulness. As such, the present study aims to build on the paucity of research examining the impact of individual difference moderators on inconsistency-arousal-compensation processes (Sleegers et al., 2015) by exploring how variations in dispositional mindfulness can influence TEPR-inferred shifts into elevated LC-NA activation and associated compensatory efforts to ameliorate this activity.

Accordingly, behavioural and psychophysiological links between inconsistency and compensation are established and the potential moderating role of trait mindfulness on these relationships is examined. There were four overarching expectations of the present study: 1) TEPR-inferred LC-NA arousal will display epoch-specific temporal activation in accordance with the distinct qualitative features of the presented faces (e.g., inconsistent, threatening), 2) greater magnitudes of inconsistency/threat-induced TEPR will exert a greater impact on compensatory affirmation, 3) dispositional mindfulness will be associated with increased TEPR responses to inconsistent / threatening stimuli and 4) reduced inconsistency / threat-induced compensatory affirmation. It was hoped that findings in this respect would offer much-needed insight into the role of arousal in inconsistency-compensation processes and outline the impact of dispositional moderators on such processes.

Hypotheses

Building on prior research evidencing temporal specificity of TEPR responses to different face types (Proulx, et al., 2017), it was hypothesised that faces inducing inconsistency (upside-down, upside-down Thatcherised, upside-down Thatcherised + angry) would initiate greater 500ms-1500ms TEPR than threatening faces containing no inconsistent information (faceup angry), thus evidencing an inconsistency-specific arousal response on both a within-subjects (H1a) and between-subjects level (H1b).

It was also expected that TEPR responses would be greater for inherently incongruent stimuli (upside-down Thatcherised) than for novel stimuli (upside-down neutral), especially during the 500-1500ms period (H2a). Moreover, combining inconsistent and threatening information (upside-down angry Thatcherised) was expected to augment 1500ms+ TEPR responses when compared to the other types of inconsistent faces on both a within-subjects and between-subjects level (H2b). Taken together, such findings would fulfil expectations that magnitude of LC-NA activity would increase in a stepwise fashion according to the level of inconsistency / threat associated with the stimuli.

Consistent with recent work evidencing associations between inconsistency-induced TEPR and subsequent compensatory affirmation responses (Sleegers et al., 2021), it was also predicted that TEPR responses to inconsistent / threatening faces would be positively associated with compensatory bond severity, with greater bond severity associated with greater inductions of TEPR (H3). Findings in this respect would position the present study as the first to demonstrate arousal-compensation relationships utilising different types of expectancy-violating and threatening information.

Exploring the impact of trait mindfulness on inconsistency-induced arousal, it was predicted that mindfulness would moderate the effect of inconsistency on TEPR, insofar as greater mindfulness would be associated with increased TEPR responses to expectancy-violating and threatening stimuli (H4a). Moreover, it was expected that mindfulness would moderate the relationship between arousal and subsequent compensatory affirmation, insofar as greater mindfulness would be related to reduced bond severity relative to lower levels of mindfulness at comparable magnitudes of LC-NA arousal (H4b).

Method

Participants

A total of 91 participants were recruited through the Cardiff University Experimental Management System (EMS), receiving course credit as reward for their participation. Participants were randomly assigned to one of three within-subjects experiments. Data from nine participants could not be used due to there being > 65% of missing pupillary data per subject. The final sample consisted of 82 participants (28 males). All participants were undergraduate students with a mean age of 19.8 (range: 18-24). Power analysis using G*Power (Faul et al., 2007), with an assumed moderate effect size consistent with prior within-subject assessments of PD in response to face-induced cognitive conflict (Proulx, Sleeger and Tritt, 2017) determined a minimum sample of 27 participants per experiment. Random assignment resulted in slightly unequal Ns across conditions.

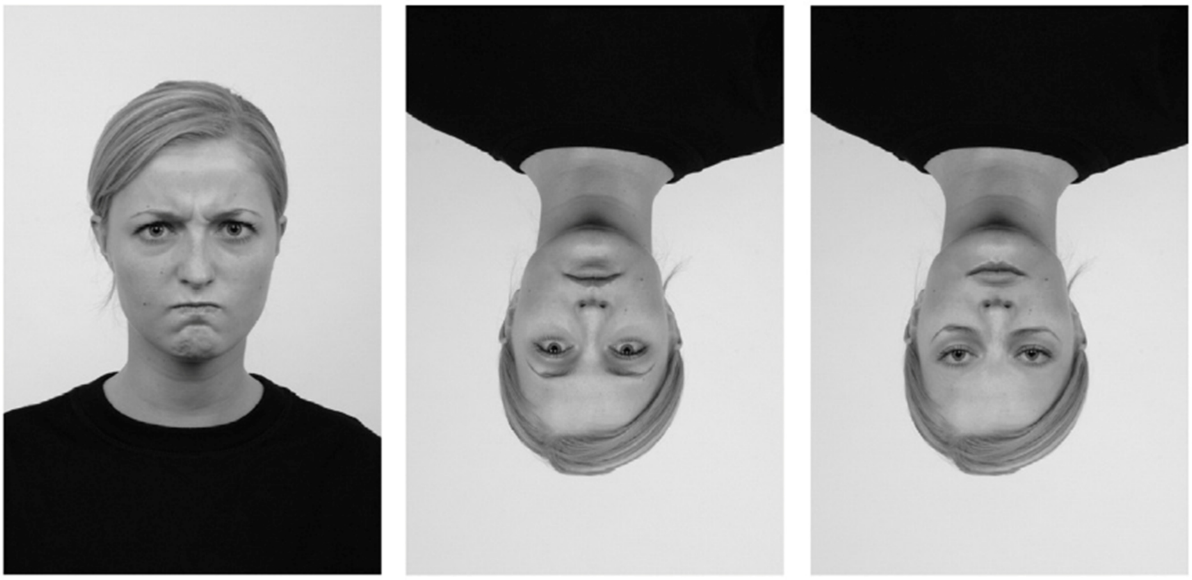
Materials and Procedure

Consistent with comparable research (Proulx, Sleeger and Tritt, 2017), Face stimuli were obtained from the Radboud Faces Database (Langner et al., 2010), which contains pictures of 67 models (Caucasian adults and children, both males and females, and Moroccan Dutch males) displaying eight emotional expressions. Adult Caucasian males and females were used in the present study (see Figure 6 for examples). Upside-down faces were rotated 180° in order to induce expectancy violation. Angry faces were faceup and contained angry emotional expressions. Upside-down Thatcherised faces retained eyes and mouths that were faceup, thus representing enhanced potency of expectancy violation (Proulx, Sleegers and Tritt, 2017).

Faces task. Face images were 550 x 827 pixels in size and remained on screen for 5000ms. Prior to the presentation of each face, a fixation cross appeared, upon which participants were required to sustain their focus for 1000ms before the trial could progress[20]. Each participant completed 10 practice trials and two experimental blocks of 100 trials each: 39 per face type and 22 probe trials. Each within-subjects condition consisted of two face types.

Figure 6.

Examples of Face Stimuli



Note. Examples of face types: *left panel* = faceup angry, *middle panel* = upside-down neutral, *right panel* = upside-down Thatcherised. Upside-down angry Thatcherised faces (not pictured) were also utilised.

[20] This ensured that participants were paying attention to the screen consistently throughout the task. Moreover, probe trials were interspersed throughout the experiment requiring participants to indicate the valence of the preceding facial expression in order to continue (keypress '1' = negative, '2' = positive), thus augmenting the robustness of attentional checks throughout the task.

The 15-Item Five-Facet Mindfulness Questionnaire (FFMQ, Baer et al. 2008). To assess levels of mindfulness, I utilised the FFMQ[21]. In the present study, alpha coefficients for the sample were good for Observing (α=.80), Describing (α=.85), Awareness (α=.91), Non-Judging (α=.88) and Non-Reactivity (α=.83).

Compensatory Affirmation: Bonds. To examine compensatory affirmation, I utilised identical bond-based assessments as those employed in Study 1 and in comparable prior research (Sleegers, Proulx and van Beest, 2015) (α = .82).

Data Preparation[22]

Task-Evoked Pupillary Responses (TEPR)

Consistent with existing methods exploring task-evoked pupillary responses (TEPR) to visual stimuli (Zarcezna et al., 2019), fluctuations in participants' pupil diameter were analysed across the pupillary time course for each trial (Proulx, Sleeger and Tritt, 2017). Pupil sizes from each eye were averaged together to create a single pupil value. Validity readings, filtering techniques and blink management processes were as outlined in appendices. Baseline differences in pupil size were controlled for by obtaining the average pupil size during a 500ms pre-trial period and subtracting this from subsequent pupil measurements along the pupillary time course.

[21] See Appendix 0i; 'Overview of Self-Report Measures'.
[22] See Appendix 0ii: 'Overview of Procedures and Data Preparation' for full details pertaining to eye-tracker calibration, generalised experimental protocol and behavioural / pupillary pre-processing techniques.

Behavioural outcomes were operationalised as indices of compensatory affirmation following Faces presentation, namely two instances of bond setting.

Experimental Procedure

All demographics (age, gender, highest level of education), questionnaires and Faces stimuli were presented electronically using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). After signing up for the experiment, participants were invited to the Cardiff University Psychology building, whereby behavioural responses and pupillary data were collected over the course of a 45-minute eye-tracking experiment. The study was approved by the University of Cardiff Ethics Committee, and informed consent was obtained prior to entry into the study.

Analytic Strategy

To explore the effects of face type on TEPR, four experimental comparisons were administered, each utilising a 2 (Face Type: faceup angry vs. upside-down neutral, upside-down Thatcherised vs. upside-down neutral, upside-down angry Thatcherised vs. upside-down neutral, upside-down angry Thatcherised vs. upside-down Thatcherised) x 19 (Time: 500 to 5000ms, divided into 250ms bins) repeated-measures GLM analysis and paired *t*-tests. After analysing the entire time window (500 - 5000ms), separate analyses were conducted for the time windows 500 - 1500ms (time period associated with cognitive conflict) and 1500 - 5000ms (time period associated with sympathetic nervous system arousal). Moreover, in order to more robustly compare pupillary responses to expectancy-violating and angry face types, between-subjects face type effects on TEPR were explored in a 2 (Face Type: faceup angry vs. upside-down Thatcherised vs. upside-down angry Thatcherised) x 3 (Epoch: 500-1500ms, 1500-5000ms and whole-trial epochs) GLM analysis.

To investigate potential moderative effects of mindfulness on expectancy-violating arousal responses, linear regression analyses were conducted modelling the effects of face type, total / subscale FFMQ scores (mean-centred), and their respective interaction terms. Additionally, mindfulness was examined as a potential moderator of the relationship between arousal and compensatory affirmation by modelling the effect of whole-trial / epoch-specific TEPR, total / subscale FFMQ scores and their respective interaction terms on bond allocation responses.

Results

Demographics Analyses. No significant differences in age were observed between genders ($t[80] = .72$, $p = .48$) or face type conditions ($F(2,79) = 2.01$, $p = .34$). Age was also not significantly associated with bond severity ($r[80] = -.18$, $p = .23$).

Mindfulness Equivalence. Self-reported mindfulness for all facets of the FFMQ and for total FFMQ scores were similar for each between-subjects face type condition (all *ps* > .54), confirming baseline equivalence for this individual difference measure.

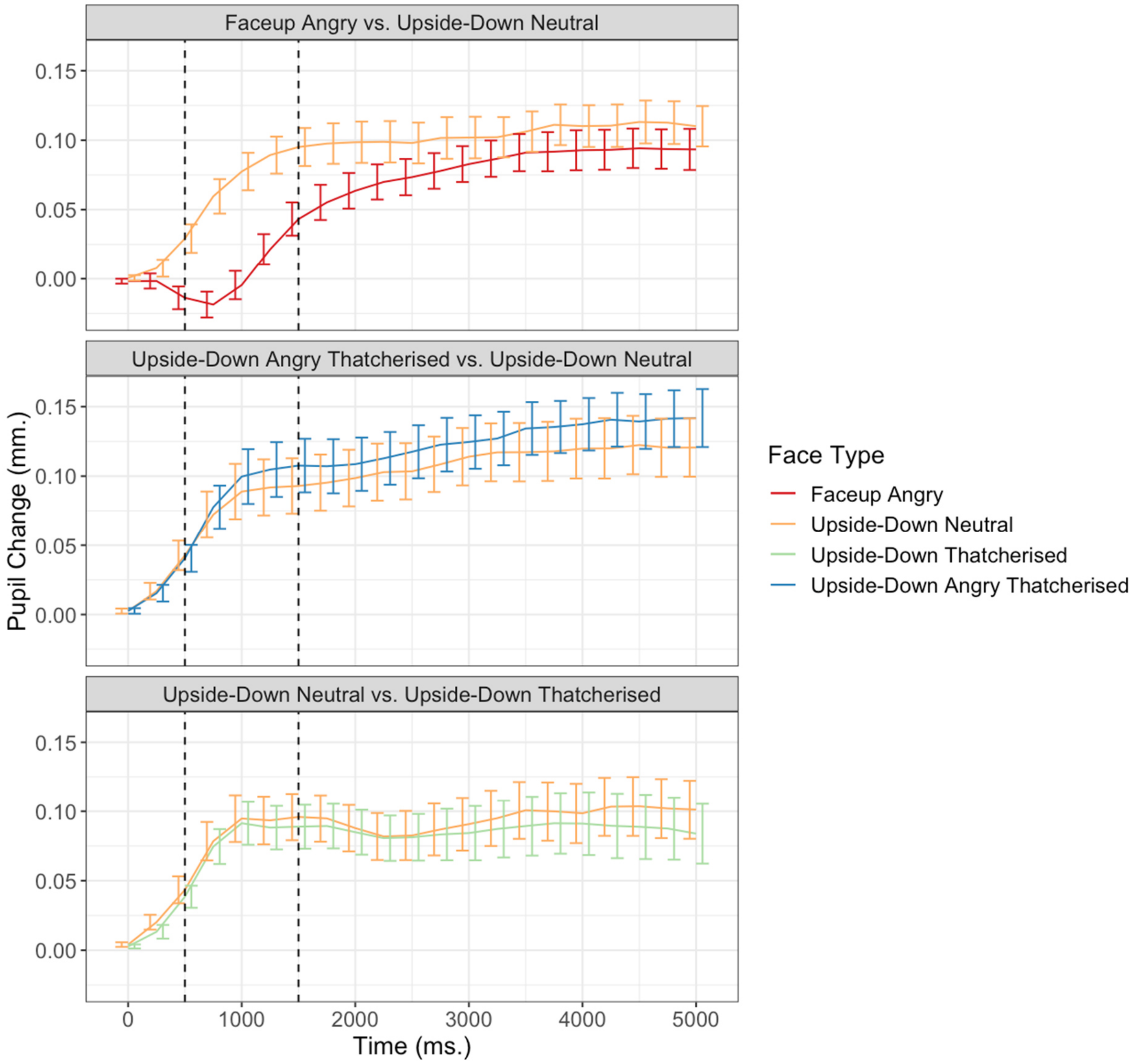
Within-Subjects Face Comparisons

Upside-Down Neutral vs. Faceup Angry Faces. Comparisons of within-subjects face types revealed that upside-down neutral faces elicited greater whole-trial TEPR than angry faces in normal orientation ($F(1, 27) = 8.20$, $p < .01$, $d = .38$). More interestingly, and directly supporting predictions (H1a), there was a significant interaction between face type and time bin ($F(17, 459) = 22.50$, $p < .0001$), insofar as UDN faces elicited significantly greater TEPR than angry faces during the 500-1500ms time window ($p < .0001$, $d = .98$, Figure 7, top panel), confirming the expected augmentative effect of inconsistent stimuli on arousal in the period associated with inconsistency / conflict responses. This effect persisted, albeit marginally, throughout the 1500+ms time period ($p = .08$, $d = .25$).

Upside-Down Neutral vs. Upside-Down Thatcherised Faces. Contrary to expectations (H2a), upside-down Thatcherised faces did not elicit greater whole-trial TEPR than upside-down neutral faces ($F(1, 26) = 2.15$, $p = .15$, $d = .12$, Figure 7, bottom panel). Moreover, there was no face type x time bin interaction for the full trial period ($F(1, 26) = 2.15$, $p = .15$) or within specific epochs (all *ps* > .25). Contrary to prior results (Proulx et al., 2017), these findings contrast with predictions that increased potency of violation (addition of Thatcherised faces) would result in enhanced arousal within cognitive conflict time periods (H2a).

Figure 7.

Baseline-Corrected Task-Evoked Pupillary Responses (TEPR) to Within-Subject Face Types.



Note. Dashed vertical lines mark 500ms and 1500ms time bins. This section of the pupillary trajectory represents the physiological response to inconsistency / cognitive conflict. Post-1500ms trajectories reflect physiological responses to assessments of valence. Error bars for each time bin represent +/- 1 SEM.

Upside-Down Neutral vs. Upside-Down Angry Thatcherised faces. Partly consistent with expectations (H2b), upside-down angry Thatcherised faces elicited marginally greater whole-trial TEPR than upside-down neutral faces ($F(1, 26) = 3.80$, $p = .06$, $d = .20$). However, the interaction between face type and time bin for the whole trial period was non-significant ($F(17, 442) = 1.10$, $p = .36$). Exploring the face type x time bin relationship within the 500ms-1500ms time window revealed a significant interaction ($F(3, 78) = 3.10$, $p = .03$), whereby upside-down angry Thatcherised faces induced greater levels of arousal than upside-down neutral faces in the period associated with cognitive conflict ($p = .02$, $d = .11$, Figure 7, middle panel). No interaction was observed for the 1500+ms time window ($F(13, 338) = 1.30$, $p = .22$**)**. These results suggest that the combined effect of inconsistent / incongruent and threatening information exerted greater inconsistency-arousal than inconsistent information alone. Moreover, the absence of observed differences for the previous face type comparisons (upside-down neutral vs. upside-down Thatcherised faces), indicates that the addition of negative salience was necessary in order to observe significant differences in early arousal responses.

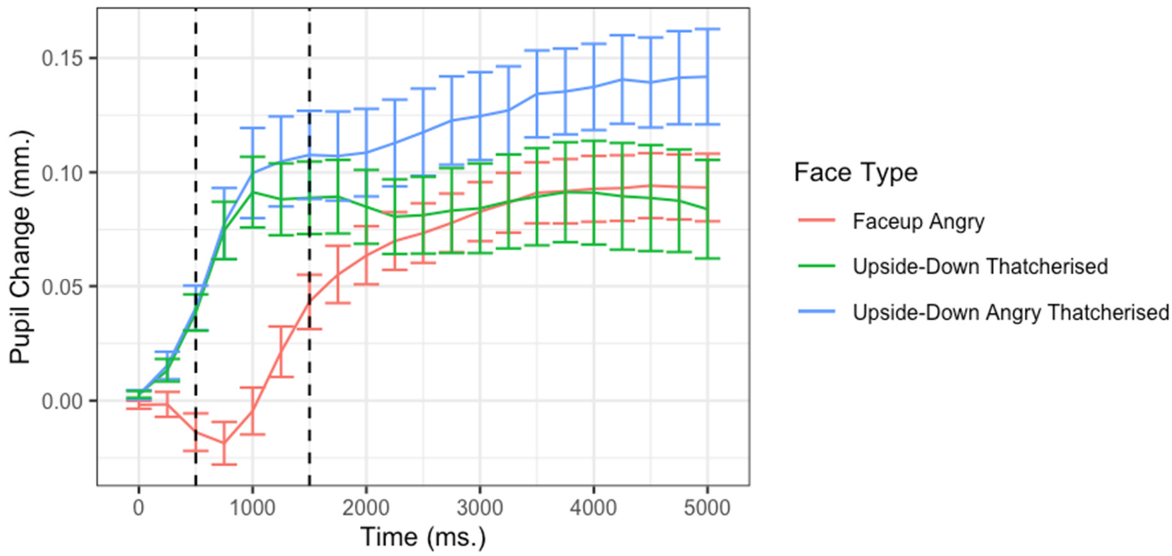
Between-Subjects Face Comparisons

Between-subjects face type comparisons: Upside-down Thatcherised vs upside-down angry Thatcherised vs faceup angry. Comparisons of between-subjects face types revealed a marginally significant main effect of face type for the whole-trial period ($F(2, 79) = 2.90$, $p = .06$). Consistent with predictions (H1b), upside-down angry Thatcherised faces elicited greater whole-trial TEPR than faceup angry faces ($p = .05$, $d = .57$, Figure 8), suggesting that expectancy-violating and threatening information induced greater overall arousal than negative information alone. Exploring differences within the 500-1500ms time window revealed a strong main effect of face type ($F(2, 79) = 10.90$, $p < .0001$), insofar as both upside-down Thatcherised faces ($p < .01$, $d = 1.10$) and upside-down angry Thatcherised faces ($p < .001$, $d = 1.00$) exerted larger TEPR than faceup angry faces, consistent with predictions that expectancy-violating information would induce greater magnitudes of TEPR in the time period associated with cognitive conflict (H1b).

Arousal and compensatory affirmation. Partly supporting predictions (H3a/b), there were significant positive associations between whole-trial / epoch-specific TEPR and bond allocation (Table 1), suggesting that greater levels of arousal were associated with increased compensatory affirmation in response to this arousal. However, General Linear Models (GLM) revealed no main effect of between-subjects face type on bond allocation ($F(2, 79) = .84$, $p = .44$). There were also no significant interactions between whole-trial / epoch-specific TEPR components and face type (all *ps* > .76), suggesting that face type did not moderate the relationship between arousal and subsequent compensatory efforts. Nonetheless, these findings extend limited endeavour with respect to evidencing associations between arousal and compensation more generally.

Figure 8.

Baseline-Corrected Task-Evoked Pupillary Responses (TEPR) to Between-Subject Face Types.



Note. Dashed vertical lines mark 500ms and 1500ms time bins. This section of the pupillary trajectory represents the physiological response to cognitive conflict. The 1500+ms epoch is associated with sympathetic nervous system arousal. Error bars for each time bin represent +/- 1 SEM.

Mindfulness, expectancy violation and arousal. Exploring whether mindfulness moderated the impact of expectancy-violating information on arousal, interactions were examined between FFMQ scores and face type on whole-trial and epoch-specific TEPR. Against expectations (H4a), there were largely no moderative effects of FFMQ subscales / total FFMQ scores were observed for whole-trial or epoch-specific TEPR (all *ps* > .34). There was a trending interaction between FFMQ-Observing scores and between-subject face type for TEPR during the 500-1500ms time window ($F(2, 76) = 2.51$, $p = .08$), which did not warrant further consideration. These results suggest that increased capacities for mindfulness did not result in moderative effects on relationships between expectancy violating information and arousal.

Table 1.

Associations Between TEPR and Compensatory Bond Allocation

Variable	*M*	*SD*	1	2	3
1. Whole-trial TEPR	0.10	0.09			
2. 500ms-1500ms TEPR	0.07	0.08	.88** [.84, .91]		
3. 1500+ms TEPR	0.10	0.09	.99** [.99, .99]	.81** [.75, .86]	
4. Bond Allocation	711.05	426.43	.16* [.01, .31]	.16* [.00, .30]	.16* [.01, .30]

Note. Bond allocation is displayed in American dollars, representing the magnitude of payment participants elected to set for defendant bail release (maximum $1,000), based on the antisocial behaviour they'd just read about. As such, greater bond allocation represents greater compensatory affirmation (see Study 1). Three correlations between bonds and TEPR are displayed; 1 = bond/whole-trail TEPR, 2 = bond/500-1500ms TEPR, 3 = bond/1500ms+ TEPR.
Note. M and *SD* are used to represent means and standard deviations, respectively. Correlation coefficients displayed. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

Mindfulness, arousal and compensatory affirmation. Examining whether dispositional mindfulness influenced associations between arousal and compensatory affirmation responses revealed no significant interactions (all *ps* > .13).

Summary of Results

In a series of bias comparisons, TEPR measurements were utilised to test predictions that inconsistent / expectancy-violating faces induce greater arousal in periods associated with cognitive conflict than other attentionally salient - but non-violating - versions of the same stimuli. Moreover, comparisons were designed to explore whether different *degrees* of inconsistency and the inclusion of threatening information resulted in greater activation of LC-NA. Associations between inconsistency/threat-induced arousal and subsequent compensatory affirmation were also examined, as were potential moderative qualities of trait mindfulness on these processes. There was a clear bias for the early preferential processing of inconsistent stimuli over threatening-only stimuli, as reliably inferred through observations of distinct patterns of arousal. Moreover, combining inconsistent and threatening information served to augment arousal responses, pointing to the possibility that LC-NA activity is activated most strongly across temporal epochs when distinct flavours of salience are combined. Additionally, present results are among the first to explicitly link inconsistency/threat-induced arousal with compensatory behaviour, although this was not moderated by the type of stimuli presented. Mindfulness was not associated with elevated arousal or revealed as an effective moderator of arousal-compensation processes, implying that trait mindfulness did not interact with the level of LC-NA activation induced by inconsistency or the compensatory palliative efforts to ameliorate this arousal. Present results invite future convergence between similarly validated inductions of inconsistency and alternative measures of mindfulness and compensatory behaviour. A more detailed discussion of present findings and their implications are explored in Chapter 7.

Chapter 3: Inconsistency-Induced Arousal Associated with Enhanced Implicit Pattern Abstraction, Moderated by Mindfulness (Study 3)

Overview

The studies presented in Chapter 2 aimed to examine mindfulness as a capacity for awareness and acceptance in relation to the detection of, and receptiveness to, a range of inconsistent stimuli. Moreover, I assessed arousal states proposed to be associated with these capacities through an analysis of TEPR-inferred elevations in LC-NA activity. Behavioural reactivity to inconsistency-induced arousal was explored through an assessment of affirmatory responses. As such, the studies in Chapter 2 aimed to address distinct gaps within the inconsistency-compensation literature, namely the paucity of knowledge around the impact of dispositional variables on inconsistency-compensation processes and explicit links between inconsistency-induced arousal, mindfulness and compensatory behaviour. The current Chapter builds on the recommendations emerging from these studies by presenting a novel experiment utilising a task explicitly designed by AGT theorists to concurrently examine reward-based inconsistency, tonic LC-NA activation and exploratory behaviour. Specifically, the task was operationalised to induce demonstrable inter-trial shifts into the tonic LC-NA mode as a result of gradual reductions in task utility. In Study 3, I employed this task to examine relationships between inconsistency-induced tonic arousal and subsequent behaviour potentially receptive to exploratory attention and enhanced magnitudes of LC-NA activation. As such, further addressing the absence of empirical links between inconsistency-induced arousal and subsequent behavioural activation less commonly utilised in the relevant literature, a measure of *abstraction* was examined as a function of inconsistency-induced arousal. Crucially, Study 3 also extends examinations of potential associations between dispositional mindfulness, bottom-up exploratory attention and proposed capacities for tonic LC-NA activation by utilising an alternative trait measure of mindful attentiveness / awareness and examining its moderative qualities in relation to proposed inconsistency-arousal-abstraction processes. It was hoped that the presented paradigm would augment tentative insights into relationships between mindfulness and inconsistency-induced arousal and further explore mindfulness as a proposed capacity for wakefulness through tonic LC-NA activation and bottom-up, exploratory attentional states.

Study 3 revealed that induced task inconsistency reliably initiated pupillary-inferred shifts into tonic LC-NA activation, validating AGT-predicted elevations in tonic LC-NA activity as a result of waning task utility and evidencing a robust link between inconsistency and arousal. There was also a clear association between inconsistency-induced arousal and subsequent *abstraction* behaviour, evidencing the first linkage between tonic LC-NA activation and behaviour indicative of enhanced capacities for exploration, such as pattern detection / learning of novel environmental signals, an adaptive relationship typically neglected by traditional perspectives of the upper end of the YD curve. Importantly, as predicted, dispositional mindfulness was associated with greater magnitudes of pupillary-inferred tonic LC-NA activity during waning task utility, indicating that mindful individuals exhibited more arousal in the face of reward-based inconsistency. Moreover, a theorised moderating role of mindfulness on associations between arousal and abstraction was observed, raising important implications for the conceptualisation of mindfulness as a capacity for alertness and wakefulness that can moderate exploratory / adaptive responses to distinct arousal states.

Introduction

Important insights into the biological processes associated with the detection of inconsistent information emerge from an “adaptive gain” framework (Aston-Jones & Cohen, 2005). As discussed in Chapter 1, AGT proposes that organisms harbour distinct noradrenergic-based attentional mechanisms designed to aid environmental navigation for the purposes of reward maximisation. Integral to this model is the regulation of specific reward strategies by the locus-coeruleus (LC), a neuromodulatory nucleus, situated in the pons of the brainstem, and the primary source of noradrenaline (NA) in the cerebral cortex. Adaptive gain theory (AGT) posits that the LC-NA system arbitrates the trade-off between exploitative and exploratory behaviours through adaptive adjustments in noradrenergic firing, which mediate attentional states characterised by two modes of cortical arousal: *phasic alertness mode* – short bursts of noradrenaline associated with an increased short-term readiness to respond to task-related signals for the *exploitation* of known reward avenues, and *tonic alertness mode* - a slow-changing level of arousal, promoting increased vigilance and *exploratory* mental preparedness to detect and respond to infrequent / novel environmental stimuli in the face of diminishing reward (Aston-Jones and Cohen, 2005). Owing to the preponderance of efferent projections to the LC from the OFC and ACC, which convey information regarding environmental rewards and costs, respectively, ongoing assessments of task utility are suitably placed to inform LC-NA activity. Specifically, due to the sensitivity of these cortical structures to persistent reward decrement and associated inconsistencies between task difficulty and ongoing reward allocation, OFC/ACC utility computations initiate a transition from a goal-relevant phasic mode of LC-NA activity to an uncomfortable tonic LC-NA mode when task utility persistently wanes (Gilzenrat et al., 2010**)**. This transition subsequently drives indiscriminate NA release via broad efferent projections to global cerebral targets and facilitates task disengagement and exploratory reward-seeking behaviour (Chandler, 2017; Sadacca et al., 2018; Yu and Dayan, 2005). As such, the inconsistency / conflict arising from OFC/ACC-detected mismatches between actual and expected cost/reward ratios evokes a tonic elevation in LC-NA activity, which plays a pivotal role in initiating enhanced exploratory motivation to attain new courses of action, goals or frameworks, in order to return the system to the more comfortable phasic LC-NA mode (Tritt & Inzlicht, 2012). Manipulations of task utility would therefore appear to offer a unique and robust method for establishing inconsistency-induced tonic LC-NA activation for the purposes of exploring associations between inconsistency, arousal and subsequent performance indicative of enhanced exploratory capacities (Figure 16a).

Diminishing Utility, Inconsistency and Arousal. Designed for the specific purpose of directly testing AGT predictions that LC-NA activity mediates adaptive shifts between exploitative / exploratory control states is the diminishing utility task (DUT, Gilzenrat et al., 2010), which implements systematic within-subjects manipulations of utility through regularly occurring trial epochs in which task difficulty outpaces reward accumulation (e.g., marked inconsistency / conflict between expected and actual reward contingencies). More specifically (and fully outlined in Methods / Figure 16b), the DUT presents participants with a series of tone pairs and informs participants that the goal is to maximise total points over the course of the task. Each trial presents pairs of tones requiring participants to discriminate between a reference tone and a comparison tone. The frequency distance between the two tones is reduced by half as each trial progresses until the tones become impossible to discriminate. Participants are required to press a key to indicate whether they think the comparison tone is higher ('?) or lower ('Z') than the reference tone. As each trial advances, potential point rewards increase, but prospective rewards are reset along with trial difficulty if the participants decide to disengage ('R'). If participants opt to escape, a new trial epoch begins, whereby the value of performance begins high (reward increase outpaces trial difficulty) but eventually declines as trials become more difficult (difficulty outpaces reward). Disengagement behaviours are expected when reference and comparison tones are experienced as too difficult to discriminate, in other words, when difficulty and remuneration become *inconsistent*. Such task-based inconsistency can be likened to the inconsistency observed in other tasks promoting incongruence (e.g., incongruent Stroop colour-word pairs, anomalous playing cards, etc. Proulx et al., 2017; Sleegers et al., 2015), and the associated disengagement / "escape" behaviours are predicted to promote a comparable inter-trial transition into an uncomfortable tonic mode of LC-NA activity representing an aversive arousal state (Aston-Jones and Cohen, 2005; Gilzenrat et al., 2010; Proulx et al., 2012). As such, the DUT can be utilised as a reliable induction of inconsistency and psychophysiological reactivity comparable to those employed in prior research (Proulx et al., 2017; Sleegers et al., 2015; Sleegers et al., 2021). Moreover, this novel induction explicitly links inconsistency-induced arousal with AGT-predicted transitions into exploratory attentional states and tonic LC-NA activity. This introduces a unique opportunity to explore relationships between inconsistency-induced modes of exploratory attention / tonic LC-NA arousal and subsequent behaviours potentially receptive to such states, insofar as the exploratory behaviour and tonic LC-NA activity initiated by DUT inconsistency can plausibly be linked to specific indices of exploratory behaviour associated with these states, such as abstraction (Proulx et al., 2012) (Figure 16a).

Baseline Pupillary Dilation as LC-NA Arousal Response to Inconsistency. As outlined in Study 2, intra-trial pupillary activity (task-evoked pupillary responses (TEPR)) represents a reliable marker of increased LC-NA activity in response to inconsistent / incongruent stimuli (Proulx et al., 2017; Sleegers et al., 2015). It was also demonstrated that overall levels of TEPR arousal were tentatively linked to subsequent compensatory affirmation, implying functional associations between arousal and palliative compensatory action. Building on this work, the present study utilises a distinct, AGT-predicted index of tonic LC-NA activity as a function of DUT-induced inconsistency to further explore relationships between inconsistency-induced tonic arousal and subsequent behavioural activation.

Assessing human tonic LC-NA activity associated with disengagement epochs is inescapably indirect, necessitating the use of a proxy measure of LC arousal - pupil diameter (PD) – which has been reliably demonstrated to track neural activity in the LC, with LC activations anticipating both naturally-fluctuating and externally-driven PD change (Jepma and Nieuwenhuis, 2011). Larger *baseline* (pretrial) PD is primarily associated with an enduring tonic mode of alertness, synonymous with rising indiscriminate NA release within the neocortex (Gilzenrat et al., 2010). Consequently, prior studies have reasonably viewed inter-task increases in baseline pupil diameter (bPD) as reflective of transitions from phasic to tonic LC-NA modes (Gilzenrat et al., 2010; Jepma and Nieuwenhuis, 2011). Indeed, greater magnitudes of bPD precede disengagement behaviours during waning DUT utility (Gilzenrat et al., 2010), thus providing a reliable psychophysiological index of AGT-predicted shifts from exploitative to exploratory attentional modes and justifying use of the DUT in the present study to establish repeated, robust and causal associations between perceived reward-based inconsistency (e.g., waning task utility) and an indirect proxy of tonic LC-NA activity (bPD). As such, converging these methods allows for a unique assessment of inconsistency-induced arousal through the lens of AGT-predicted neurocognitive processes, thus setting the stage for an examination of distinct behavioural responses potentially receptive to increased exploratory attention and associated tonic LC-NA states (Figure 16a).

Abstraction of Implicitly Learned Patterns as Exploratory / Compensatory Response. One species of proposed compensatory behaviour that remains relatively understudied in the inconsistency-compensation literature, and indeed, completely neglected in relation to the effects of inconsistency-arousal, is abstraction. Abstraction represents a distinct form of exploration that relies on the detection and retrieval of patterns amid noise, which may be particularly sensitive to repeatedly induced shifts into exploratory attentional states and associated enduring tonic modes of arousal (Proulx et al., 2012; Proulx and Heine, 2010). As such, inconsistency-induced exploratory motivation and tonic LC-NA arousal are likey conducive to compensatory abstractive efforts to alleviate this arousal. More specifically, when inconsistency is perceived, such as that induced by the DUT, the arousal signalling the detection of the anomaly (Proulx and Heine, 2008) prompts enhanced motivation to regain a sense of congruency through a variety of strategies. As outlined in Chapter 1, such strategies may involve affirming a commitment to an alternative meaning framework by focusing attention on something that remains meaningful (e.g., identifying more with one's culture after reading inconsistent word-pairs, Proulx et al., 2010). However, if an alternative isn't readily available, then one may abstract *novel* frameworks (e.g., learning novel, unrelated patterns following contradictory behaviour, Proulx and Heine, 2009).

However, despite the proposed central role of arousal in extant inconsistency-compensation frameworks (Proulx et al., 2012) and the demonstrable reliability of observing inter-task relationships between inconsistency inductions and subsequent abstraction indicative of enhanced receptivity this arousal (Randles et al., 2011; Randles et al., 2015), no study has yet attempted to converge all stages of the inconsistency-compensation process in order to explore whether inconsistency-locked arousal is associated with subsequent abstractive capabilities. Accordingly, the present experiment employs a two-task paradigm to examine whether individual propensities for increased tonic LC-NA arousal in response to increasing conflict / inconsistency during the DUT are differentially associated with subsequent performance outcomes indicative of enhanced abstraction, namely the detection of implicitly learned grammars**.**

Extant literature demonstrates the ability of inconsistency inductions to evoke explicit compensation involving conscious judgments (e.g., affirmation; setting a bond for a prostitute, as outlined in Study 1) but also demonstrates how inconsistency can evoke *implicit* compensation efforts (e.g., enhanced implicit learning and *abstraction* of novel patterns / frameworks, Proulx and Heine, 2009). Accordingly, the present study utilises implicit compensation outcomes to assess abstraction following inconsistency induction.

Although many of our abilities to learn and respond are explicit in nature, we also respond in a rule-like way without having conscious access to the principles that govern our behaviours. This implicit learning, which involves the unconscious learning of latent patterns and their subsequent abstraction in a two-tier process (Dienes and Scott, 2005), represents a capability that may be particularly receptive to an exploratory form of attention and associated activation of tonic LC-NA arousal (Gilzenrat et al., 2010). Specifically, the repeated induction of AGT-predicted tonic LC-NA modes and associated exploratory attention, states proposed as conducive to learning effectively about unfamiliar environmental patterns / reward contingencies (Aston-Jones and Cohen, 2005), may serve to prime individuals for the enhanced learning of covert environmental patterns and subsequent detection / abstraction of these patterns. Importantly, assessing capacities for implicit learning and novel pattern detection provides a unique opportunity to gauge levels of compensatory abstraction following inconsistency induction. Indeed, such implicit learning / abstraction can be reliably measured in an experimental setting using the artificial grammar learning task

(AGL), thus providing a novel opportunity to meaningfully link DUT-based inconsistency, bPD-inferred tonic LC-NA arousal and subsequent abstraction capabilities.

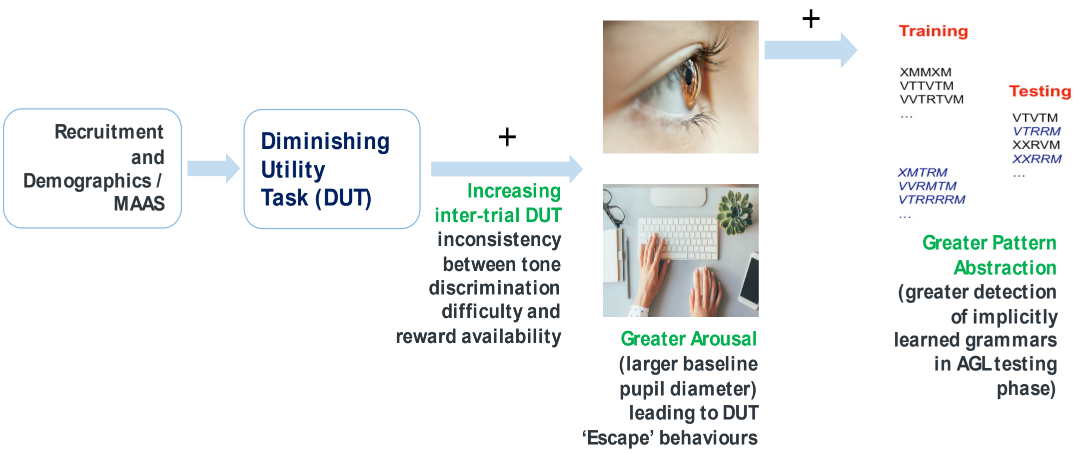
During the AGL[23], participants initially observe a series of letter strings during a *learning* phase and subsequently classify a new set of *testing* phase strings according to a specific set of latent learning-stage rules - usually a pattern-generating system in the form of a finite state grammar. Crucially, despite not being aware of the grammar during the learning stage, participants typically respond with around 65% accuracy in their classification of the testing stage strings, thus reflecting the recruitment of implicitly learned detection strategies in order to abstract novel environmental signals (Dienes and Scott, 2005; Poznanski and Tzelgov, 2010). As such, enhanced detection of novel articial grammars represents improved compensatory abstraction following DUT-based inconsistency. Indeed, heightened abstraction capabilities observed during the AGL have been reliably demonstrated to follow repeated inductions of inconsistency (Randles et al., 2011), further justifying utilisation of the AGL in the present study as an outcome measure for assessing inconsistency-induced abstraction.

Taken together, if AGT can explain the abstraction of implicitly learned signals as a function of increased exploratory attention / tonic LC-NA activation, and AGT-predicted attentional / arousal states can be assessed through bPD during epochs of attentional disengagement (e.g., exploration) during a task explicitly designed by AGT theorists to test these predictions, then reasonable assumptions can be made that the magnitude of escape-epoch arousal should be positively associated with enhanced AGL abstraction. Accordingly, the present experiment examines whether increased tonic LC-NA arousal (bPD) amid increasing DUT inconsistency is differentially associated with AGL performance (Figure 16a).

[23] See 'Materials' section.

Figure 16a.

Diagrammatic of hypothesised relationships between key constructs: inter-trial conflict / inconsistency induced by DUT is hypothesised to increase LC-NA arousal as assessed by pretrial pupil diameter, which is predicted to be related to enhanced AGL pattern abstraction in the testing phase.



Mindfulness as Moderator of Relationships Between Inconsistency-Arousal and Abstraction. As discussed in Chapter 1, dispositional variations in the synergy between tonic and phasic LC-NA function may reflect inter-individual contrasts in personality variables associated with vigilance and attentional control (Sorensen et al., 2018; Tang et al., 2015). As such, exploring specific traits potentially associated with enhanced capacities for adaptive shifts into tonic LC-NA modes may offer valuable insights into the impact of dispositional characteristics on AGT-predicted exploratory behaviour and palliative compensatory processes following inductions of inconsistency.

As well as being reliably linked to enhanced executive control in the face of inconsistency / incongruence (Josefsson and Broberg, 2011; Lin et al., 2018; Moore and

Malinowski, 2009), trait mindfulness has also been conceptualised as a capacity for ongoing alertness, vigilance and awareness (Britton et al., 2014), as notably reflected by improved performance implying ongoing vigilance during tests of alertness and sustained attention (Cheyne, Carriere and Smilek, 2006; Josefsson and Broberg, 2011; Schmertz, Anderson and Robins, 2009). Moreover, mindfulness-related capacities for vigilance, wakefulness and heightened awareness are likely linked to increased volume and activity in areas of the brain associated with enhanced tonic arousal (Britton et al., 2014; Sorensen et al., 2018; Tang et al., 2015; Zhuang et al., 2017). It is therefore possible that the increased attentional awareness associated with dispositional mindfulness is synonymous with an "awakening" at least partly induced by increases in tonic LC-NA activity, which, although neglected in the mindfulness literature, can be readily assessed through an examination of bPD (Gilzenrat et al., 2010).

Robust positive relationships have been observed between the Mindful Attention Awareness Scale (MAAS) and cortical thickness / surface area of the precuneus (Zhuang et al., 2017), an area heavily implicated in awareness of moment-to-moment experience, and which has been shown to be functionally connected to the LC in states of pharmacologically induced tonic LC-NA arousal (Song et al., 2017). As such, whereas Study 2 employed a trait measure of mindfulness (FFMQ) more reliably associated with neurobiological correlates of enhanced attentional control (Zhuang et al., 2017), the present experiment utilises the single-dimension measure of the MAAS, which is more strongly related to structures associated with an open and receptive awareness of moment-to-moment experience (Brown and Ryan, 2004; Zhuang et al., 2017). It was hoped that by utilising a measure more receptive to detecting the heightened awareness and open attention components of dispositional mindfulness, a more effective exploration of the proposed relationships between mindfulness and capacities for inconsistency-induced tonic alertness could be initiated. Specifically, if the MAAS represents a capacity for vigilance and an improved ability to enter a state of open awareness (e.g., 'outward tonic attention') then this capacity may translate into an increased awareness of rapidly diminishing task utility, thus enhancing the magnitude of adaptive shifts into the tonic LC-NA mode. By extension, greater potency of tonic LC-NA activation may be associated with downstream capacities for the detection of implicitly learned patterns as a result of DUT inconsistency inductions.

To summarise, in Study 2, I explored whether dispositional mindfulness was associated with enhanced awareness / detection of inconsistency, with the expectation that this would manifest as intra-trial elevations in inconsistency-induced arousal (TEPR). Moreover, I examined whether proposed capacities for mindful acceptance reduced the need to palliate this arousal, with the prediction that this would manifest as a subsequent reduction in compensatory *affirmation* (Brown et al., 2013; Teper and Inzlicht, 2013; Zhuang et al., 2017). In the present study, inconsistency-arousal is operationalised as an induction of an AGT-predicted *trial-by-trial* shift into the tonic LC-NA mode, which is typically associated with larger bPD (Aston-Jones and Cohen, 2005; Gilzenrat et al., 2010). Moreover, the current study employs a behavioural measure of abstraction that, although formulated by extant theoretical frameworks as an understudied *palliative compensatory* response to aversive arousal states (Proulx et al., 2012), may also represent an *adaptive capability* that is receptive to exploratory attentional states and associated elevations in LC-NA activity. As such, it is possible that any increase in tonic arousal and vigilance associated with trait mindfulness in the present study may also be related to *increased* abstraction that is receptive to these states.

As such, the general expectations of the present study were three-fold: 1), DUT-induced inconsistency will exert increased tonic LC-NA activity, consistent with AGT-predicted changes in control state, 2) greater magnitudes of inconsistency-induced tonic LC-NA arousal during exploratory states will be related to increased abstraction, and 3), dispositional mindfulness will moderate relationships between inconsistency, arousal and abstraction, insofar as greater levels of mindfulness will be associated with increased tonic arousal and enhanced performance-based abstraction.

Hypotheses

Primary aims therefore converge three lines of inquiry, AGT-predicted LC function, cost/reward inconsistency and implicitly learned pattern abstraction, thus allowing for a deeper examination of the proposed role of trait mindfulness in inconsistency-induced arousal processes. Utilising a within-subjects DUT/AGL eye-tracking study, tonic LC-NA responses to DUT inconsistency were therefore assessed in relation to MAAS scores and subsequent abstraction during the AGL task.

The first hypothesis aims to further qualify the link between inconsistency and arousal by replicating AGT-predicted shifts towards tonic LC-NA activity amid diminishing task utility (e.g., Gilzenrat et al., 2010), as inferred by increased bPD leading up to DUT escape behaviours (H1). Secondly, addressing the proposed function of aversive arousal in inconsistency-compensation processes (Proulx et al., 2012; Sleegers et al., 2021; Sleegers et al., 2015), and drawing from specific behavioural demonstrations of causal, inter-task relationships between induced inconsistency / incongruency and subsequent implicitly-learned AGL pattern abstraction (Randles et al., 2011), it was predicted that greater magnitudes of pre-escape bPD would be related to higher AGL scores (H2). A finding of this nature would be indicative of an association between elevated inconsistency-induced tonic LC-NA activity and enhanced artificial grammar abstraction. Thirdly, informed by prior research linking mindfulness with enhanced performance during tasks assessing tonic vigilance (Cheyne, Carriere and Smilek, 2006; Josefsson and Broberg, 2011) and with tonic arousal-related brain regions (Britton et al., 2014; Tang et al., 2015), and consistent with resultant contentions that dispositional mindfulness represents an enhanced tonic capacity for wakefulness, it was expected that MAAS would be associated with greater magnitudes of inconsistency-induced arousal (H3), insofar as more mindful individuals will exhibit greater bPD during DUT escape epochs. Finally, it was hypothesised that expected positive associations between inconsistency-induced arousal and subsequent AGL performance would manifest primarily at higher levels of MAAS (H4), thus demonstrating the utility of trait and state tonic capacities in facilitating adaptive exploratory outcomes.

Method

Participants

A convenience sample of eighty-eight students studying at Cardiff University in Wales (18-35 years of age; 18 male) participated in the study in return for course credit. Sample size was based on prior research using pupillometry to infer within-subject fluctuations of inconsistency-induced arousal (Gilzenrat et al., 2010; Jepma and Nieuwenhuis, 2011; Sleegers et al., 2021) and from inter-task examinations of inconsistency-induced improvements in AGL performance (Randles et al., 2011), with moderate effect sizes. These participants were not the same as those who'd participated in Studies 1 and 2, and indeed, each Study throughout the current thesis enjoyed a completely unique set of participants. Upon completion of the current experiment, post hoc power analysis for ANOVA-based linear mixed models using PANGEA software (Westfall, 2016) was conducted. For the obtained peri-escape pupil effect sizes (d = 1.42-1.54), .95 power was achieved.

Data Exclusions. First, participants with over 50 per cent missing eye tracker data prior to pre-processing were excluded to increase data reliability (*N* = 11). Second, participants who did not choose to escape at any point during the task were excluded (*N* = 12). Of primary interest were pupillary data for peri-escape trials, so only those participants who elected to escape provided viable responses. The administration of the second criteria is also a reflection of the fact that many participants either did not read, or did not understand, task instructions, which should be taken into account when considering the overall characteristics of the sample. Data from 65 participants remained eligible for analysis (*M* age = 20.41). The study presented in this manuscript was approved by the Ethics Committee at Cardiff University.

Materials

The Mindful Attention Awareness Scale (MAAS, Brown et al., 2003): To assess levels of trait mindfulness, I utilised the MAAS (see Appendix 0i). Higher MAAS scores imply higher dispositional mindfulness. Cronbach's alpha was good in the current sample (.89), and the sample scoring range for the MAAS was between 34 and 83, with an absolute range between 15 and 90.

Diminishing Utility Task (DUT, Gilzenrat et al., 2010)[24]: Taken from 'Experiment 3' of Gilzenrat et al. (2010), the 30-minute DUT employs the use of sinusoidal tone presentation pairs starting with an 850Hz reference tone for 250ms followed by a 300ms comparison tone of a maximal 64Hz difference. The task becomes progressively more

[24] See Figure 16 for DUT diagrammatic

difficult to differentiate between the reference and comparison tones due to a 50 per cent reduction in the difference in Hz with each sequential trial. Once the discrepancy between reference and comparison reaches 0.25Hz, subsequent tones are identical and considered impossible to discriminate. Trials are split evenly in terms of the comparison tone being higher or lower in frequency than the reference tone.

Artificial Grammar Learning (AGL, Dienes and Scott, 2005)[25]: Obtained from Dienes and Scott (2005), the AGL learning phase consists of 45 letter strings of between 5 and 9 characters sequentially displayed onscreen. The testing phase is made up of a further 60 letter strings. All of the training phase strings and half of the testing phase strings conform to the artificial '*Grammar A*', whereas the remainder of the testing strings conform to an alternative artificial grammar ('*Grammar B*'). Both sets of artificial grammar stimuli are identical to those found in Dienes and Scott's 2005 study.

Design and Procedure

Following methods utilised in comparable neurophysiological studies combining the implementation of DUT and eye-tracking techniques (Gilzenrat et al., 2010), a full within-subjects design was utilised in order to explore differential magnitudes of DUT-induced tonic LC-NA arousal and to examine how these psychophysiological variations relate to subsequent AGL performance outcomes.

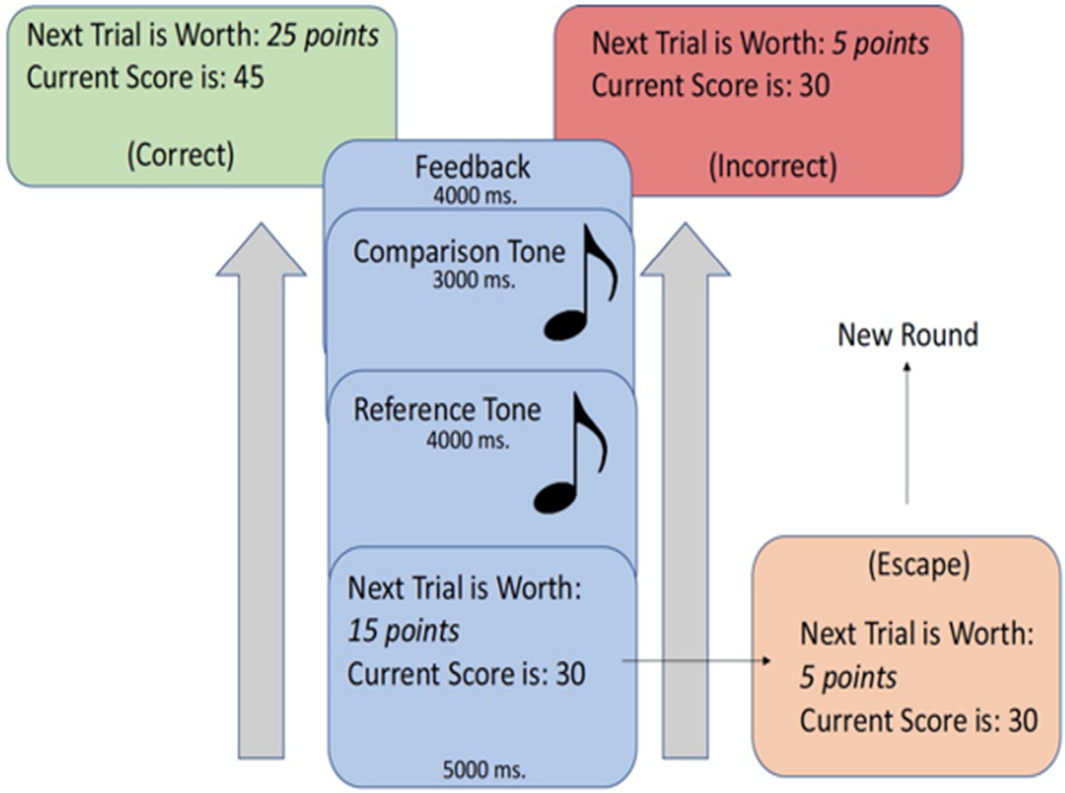
Participants were presented with an information sheet and consent form prior to completing demographic data (gender, age, education level) and the MAAS using E-Prime

[25] See Appendix 1 for training and testing phase stimuli of the AGL.

software. After 9-point calibration of the eye tracker, all participants completed the DUT, followed by the AGL task.

Figure 16b.

Diagrammatic of a Sample Trial in The Diminishing Utility Task (DUT).



Note. To ensure adequate resolution of pupillary responses to prior events, sufficient delays (pictured in ms.) between stimuli presentation were incorporated into the task. Baseline pupil diameter (bPD) was calculated as the average pupil size during the 100ms immediately preceding the score screen of a new trial. The DUT utilised in the present study is identical to that created by Gilzenrat et al. (2010).

During the DUT, participants were informed that the goal was to maximise their total points over the course of the experiment. Each trial presented pairs of tones requiring participants to discriminate between the reference tone and comparison tone. The frequency distance between the two tones was initially 64Hz, which was reduced by 50 per cent as each trial progressed (e.g., 64Hz, 32Hz, 16Hz) until the tones became impossible to discriminate (0.25Hz). Participants were required to press either '?' or 'Z' for each trial to indicate whether they thought the comparison tone was higher or lower than the reference tone, respectively. As each trial advanced, potential point rewards increased, but prospective rewards were reset along with trial difficulty if the participants decided to disengage/escape ('R'). When participants opted to escape, a new trial epoch began, where the value of performance was initially high (reward increase outpaces trial difficulty and task engagement is maintained) but eventually declines as trials become more difficult and errors increase (promoting task disengagement). Disengagement behaviours were expected when reference and comparison tones were experienced as too difficult to discriminate. Scores were tallied throughout the 30-minute trial period and participants could view their total score at the beginning of each trial. No breaks were offered due to the continuous, time-bound nature of the task. It was expected that trials leading up to an escape behaviour would be characterised by a trial-by-trial increase in baseline pupil diameter (bPD) and culminate in maximal bPD for escape trials, thus reflecting task disengagement and a shift toward an exploratory tonic state (Aston-Jones and Cohen, 2005; Cohen et al., 2007).

Subsequent to the DUT, participants completed the AGL task in two phases. The learning phase consisted of 45 letter strings displayed sequentially for 5 seconds per string. Participants were asked to write down each string on paper as it appeared on screen. After the learning stage was complete, participants were informed that the letter strings they had just copied followed a strict pattern. Participants then commenced the testing phase where 60 further letter strings were presented simultaneously, half of which followed 'Grammar A' and half followed 'Grammar B', and were asked to present an 'X' next to each string they thought followed the same pattern as the strings in the training phase. Correct Xs ('hits') and incorrect Xs ('false alarms') are calculated to obtain AGL scores for the assessment of overall AGL performance. It was expected that increases in pre-escape bPD during the DUT would predict improvements in these scores.

Data Preparation[26]

Baseline Pupil Diameter (bPD)

Consistent with methodological recommendations and with comparable research exploring inferred fluctuations in tonic LC-NA activity (Gilzenrat et al., 2010; Mahot et al., 2018; Unsworth and Robison, 2018), baseline pupil diameter (bPD) was computed as the average pupil size during the 1000ms interval prior to the onset of the score screen in each DUT trial. Of primary interest were the changes in tonic LC-NA activity leading up to behavioural expressions of minimal task utility (escape events). Accordingly, trials were averaged as a function of their position relative to escape behaviours. In order to assess epochs of sufficient task engagement, only escape events that were preceded and followed by a minimum of four non-escape trials were considered. This resulted in escape-trial epochs of nine trials representing subjective assessments of declining task utility. Importantly, once bPD was obtained for each trial leading up to an escape behaviour, bPD for the fourth trial preceding an escape (e.g., the earliest trial) was subtracted from escape-trial bPD (e.g., when

[26] See Appendix 0ii: 'Overview of Procedures and Data Preparation' for full details pertaining to eye-tracker calibration, generalised experimental protocol and behavioural / pupillary pre-processing techniques.

bPD was largest), thus providing an index of the magnitude of tonic LC-NA arousal leading up to task disengagement.

Response Latencies and Accuracy

Mean accuracy (percentage of successful pitch-comparison judgements) was inspected for extreme values, as determined by an exclusion threshold of values higher / lower than 3 standard deviations (SD) from the mean. No participants were excluded from analyses based on these criteria. Mean reaction time (RT) was averaged as a function of trials relative to escape behaviours (escape-trial epochs) (Gilzenrat et al., 2010).

Analytic Strategy

In order to provide an overall picture of the expected effects of trial epoch on bPD, linear mixed models (LMMs) were constructed (see Appendix 0iii, Study 3). LMMs were preferred in order to account for the repeated sampling of subjects within each escape-trial epoch.

Exploring the effects of dispositional mindfulness (MAAS scores) and arousal (bPD magnitude) on implicit learning (AGL performance), minimal LMMs were estimated, in which intercepts varied across subject. As such, potential moderative effects of mindfulness on arousal and compensatory behaviour could be examined.

Task Performance

AGL Performance as Compensatory Abstraction. AGL performance was assessed by calculating the total number of hits and false alarms for each participant. The ratio of hits to false alarms represents the ability to discriminate between signal and noise in the environment. Therefore, AGL score was calculated as hits / hits + false alarms, resulting in a core discriminability score for each participant, representing an improved ability to abstract implicitly learnt latent patterns. AGL score corresponds to the signal detection theory (SDT) index of signal sensitivity (*d'*), which ranges from 0-2 and measures the sensitivity to signal among noise. Accordingly, both AGL and *d'* scores were calculated to augment the robustness of present results, with higher scores on each measure representing enhanced AGL performance. The total AGL response rate (hits + false alarms) represents overall response likelihood. Higher total AGL responses have been described in prior studies as reflective of a general approach-based motivation - but not necessarily an enhanced ability - to perceive the presence of patterns (Randles et al., 2011), and therefore corresponds to the SDT index of response bias (*beta*). *Beta* reflects the observer's bias to say 'yes' or 'no' more generally, with higher values (> 1) representing a conservative bias and lower values (< 1) reflecting a more liberal bias. Taken together, the core AGL scores and SDT indices provide a rich insight into the ability to discriminate signal from environmental noise (AGL score and SDT *d'*) and the response strategies employed to maximise detection of the presence of patterns (total AGL responses and SDT *beta*).[27]

DUT Engagement. DUT engagement was gauged in terms of total points and escape behaviours. During the allotted 30 minutes for completing the DUT task, participants averaged 16.7 rounds (range, 2-41), opting to escape an average of 15.7 times (range, 1-40),

[27] See Appendix 0ii: 'Overview of Procedures and Data Preparation' for full details pertaining to SDT.

and amassing an average total score of 1,963 (range, 515-3800). Tones reached a 0.25Hz pitch discrepancy after seven trials. Although *objectively* impossible to discriminate, participants did not necessarily feel the need to disengage precisely on trial seven, either electing to escape beyond the point when trials became identical, or escaping before this juncture (see Appendix 0v for exploratory analyses relating to identical tone trials).

AGL Engagement. Participants averaged a detection rate of 15.5 AGL hits (range, 6-27) and a commission failure rate of 6.8 AGL false alarms (range, 0-25), with an average overall AGL score of 0.72. A wealth of prior research has indicated average AGL scores to be in the region of 0.65 (Reber et al., 2003, Van den Bos and Poletiek, 2015), rendering the post-DUT sample slightly higher by comparison. The average SDT *d'* index of signal sensitivity was 0.86 with a mean *beta* bias index of 1.73, indicating that participants in the sample were generally able to discriminate the signal over the noise above chance and that they tended to be more conservative with their responses.

Results[28]

Peri-Escape Pupils.[29] To demonstrate how LC-NA activity reliably tracks changes in control state (H1), *z* -transformed baseline pupil diameter (bPD) was analysed in terms of proximity to an escape trial, with trial-averaging locked to the escape event. Linear mixed models (LMMs) were utilised in which intercepts varied across participants and trial epoch was modelled as a random slope. As expected, there was an overall main effect of trial (F (8, 61.15) = 9.12, p <.001, $\eta 2p$ = 0.54, 95% CI = [0.33, 0.65], Figure 17 – *top panel*). Post hoc comparisons revealed that pupil sizes were largest for escape trials when compared to each of the four pre-escape and latter three post-escape trial pupils (all *ps* <.0001, Holm-adjusted *alpha*). There was a significant increase in bPD over the four trials leading up to an escape event, peaking on the escape trial, as revealed by linear trend analysis (t (63.5) = 5.70, p <.0001, d = 1.42, 95% CI = [0.87, 1.97]). The inverted U-shaped trend centred on the escape trial was significant, as indicated by quadratic contrasts (t (63.8) = 6.15, p <.0001, d = 1.54, 95% CI = [0.98, 2.09]).

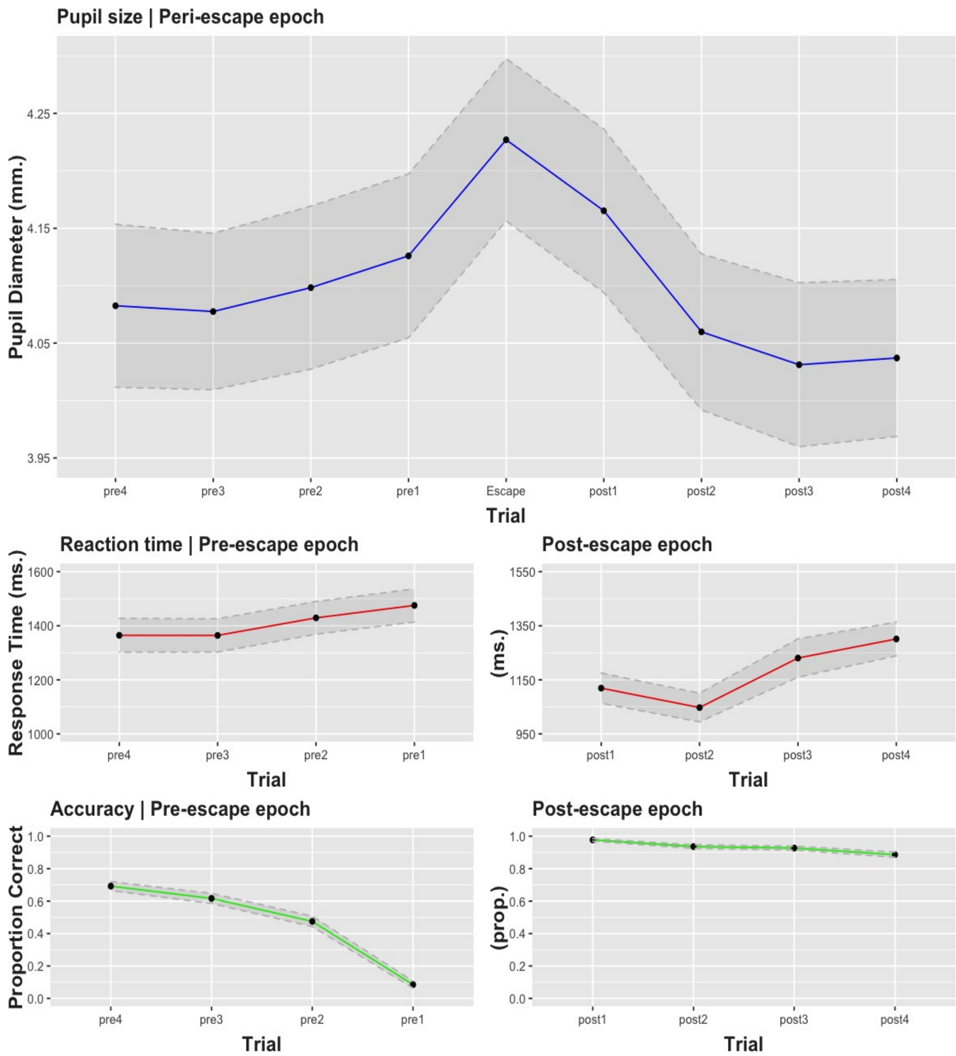
Peri-Escape Response Latencies and Accuracy. As outlined in Figure 17 (*middle* and *bottom panels*), there were significant decrements to performance in terms of slower reaction times (RT) and reduced accuracy leading up to escape events (all *ps* <.001), confirming our expectation that increased tonic LC-NA activity as a result of heightened task difficulty would be accompanied by increasingly poor performance. These findings confirm that our utility manipulation was effective.

[28] An alpha level of .05 was used for all tests. Effect sizes and 95% confidence intervals are reported. Effect sizes are reported as $\eta 2p$ for significant mixed model effects and as Cohen's d for t -tests.

[29] Exploratory analyses were also conducted on *objectively* assessed reductions in task utility, which are discussed in Appendix 0v in relation to inconsistency-induced arousal, mindfulness and compensatory action.

Figure 17.

Grand-Averaged Dependent Measures (Baseline Pupil Diameter (bPD), Reaction Time (RT) and Accuracy) for Peri-Escape Trials.



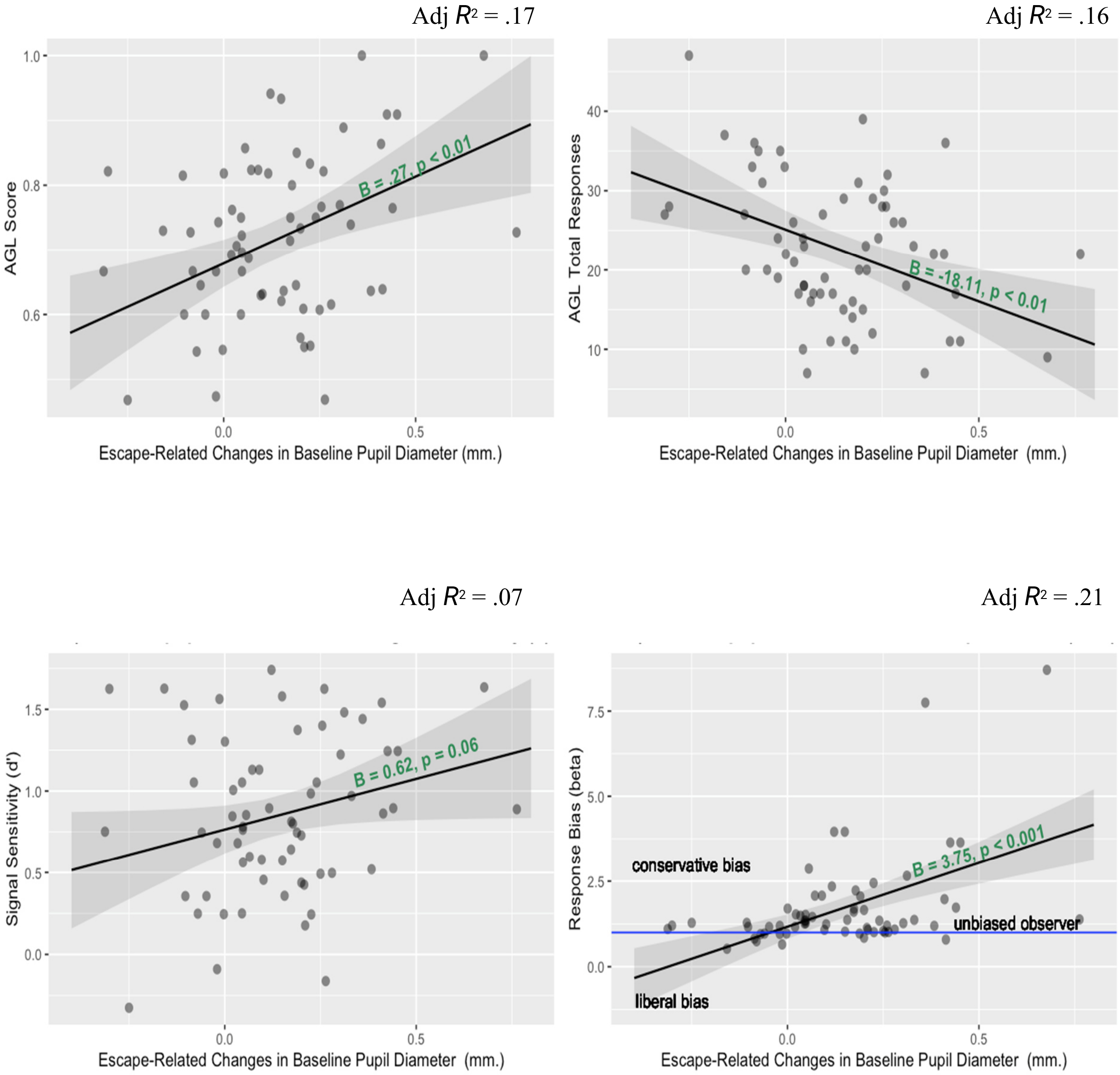
Note. Top panel: A clear increase in bPD was observed leading up to escape events before declining over post-disengagement epochs. Middle panels: RT during pre-escape (*left*) and post-escape (*right*) epochs. Bottom panels: Accuracy during pre-escape (*left*) and post-escape (*right*) epochs. Declining accuracy and slower RTs during pre-escape epoch confirms the effectiveness of our utility manipulation. Behavioural measures are not mapped onto Escape trials because no responses were recorded. Error ribbons reflect ±1 SEM.

bPD-inferred Tonic LC-NA Activity and AGL Performance. Having observed a reliable increase in tonic LC-NA amid declining utility, I subtracted bPD at the point of the fourth pre-escape trial from bPD at the point of the escape trial, thus providing an index variable representing the magnitude of utility-induced tonic arousal. This index was submitted to a mixed model as a predictor of AGL performance. Confirming the second hypothesis (H2), there was a significant effect of tonic bPD on AGL score (F (1, 62) = 7.58, p <.01, $\eta 2p$ = 0.11 (95% CI[0.01, 0.27]), Figure 18, *top left panel*). As expected, greater tonic bPD magnitude was associated with higher AGL scores, indicative of an enhanced ability to discriminate signal (hits) from noise (false alarms). There was also a significant effect of tonic arousal on total AGL responses (F (1, 62) = 8.84, p <.01, $\eta 2p$ = 0.12 (95% CI[0.01, 0.29]), Figure 18, *top right panel*). Greater bPD magnitude was associated with fewer total AGL responses, reflecting a generally diminished overall likelihood to respond at higher levels of tonic arousal.

In order to provide supplementary robustness to present results, I examined SDT indices of AGL performance, whereby *d'* signal sensitivity corresponds to AGL score and *beta* response bias corresponds to total AGL responses. The positive association between tonic arousal and *d'* sensitivity was not significant (F (1,62) = 1.93, p = .17, $\eta 2p$ = 0.03 (95% CI[0.00, 0.15]), Figure 18, *bottom left panel*). However, there was a significant effect of tonic bPD on SDT *beta* response bias (F (1, 62) = 14.84, p <.001, $\eta 2p$ = 0.19 (95% CI[0.05, 0.36]), Figure 18, *bottom right panel*). Specifically, increased tonic arousal was associated with a *conservative* response bias, as evidenced by the fact that *beta* surpassed the value of 1.0 more often at larger values of bPD, thus reflecting a more inhibitory / selective response strategy.

Figure 18.

Relationship Between bPD-inferred Tonic LC-NA Arousal and Indices of AGL Performance and SDT Response Strategies. Sample size: 65.



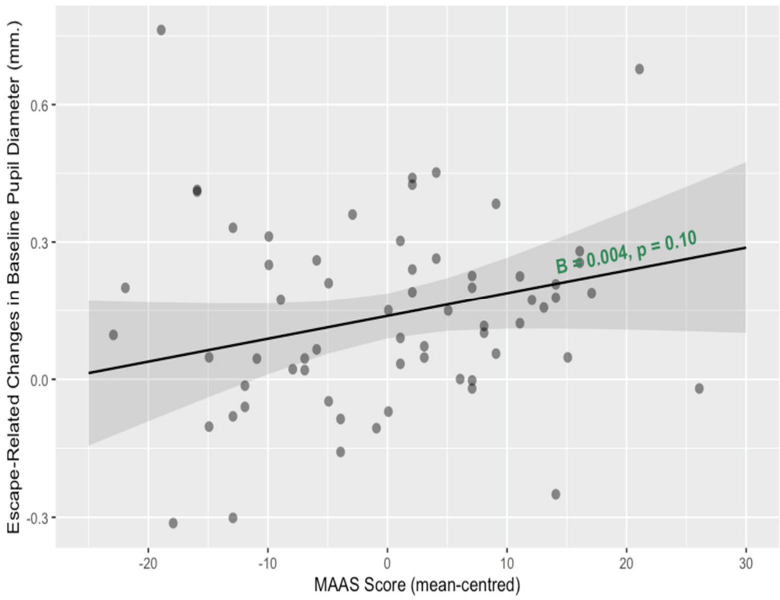
Note. Greater magnitude of bPD change associated with improved AGL scores (top left panel), reduced overall AGL responses (top right panel), a trending increase in *d'* signal sensitivity (bottom left panel), and an increased tendency to employ conservative response strategies (bottom right panel). Overall, enhanced signal discriminability and utilisation of inhibitory response strategies were evident at a higher tonic range. Coefficients and associated *p*-values are illustrated. Error ribbons reflect ±1 SEM.

Dispositional Mindfulness, bPD and AGL Performance. Addressing the third hypothesis (H3), I explored the relationship between trait mindfulness and bPD by submitting MAAS as a scaled continuous predictor to the model. A marginal effect of MAAS on bPD was revealed (F (1, 62) = 3.15, p = .08, $\eta 2p$ = 0.05 (95% CI[0.00, 0.19]), Figure 19). As expected, higher dispositional mindfulness was associated with greater magnitudes of pre-escape bPD.

Figure 19.

Higher MAAS Scores and Enhanced bPD-inferred Tonic LC-NA Activity. Sample size: 65.

Adj R^2 = .05



Note. Coefficient and associated p-value illustrated. Error ribbons reflect ±1 SEM.

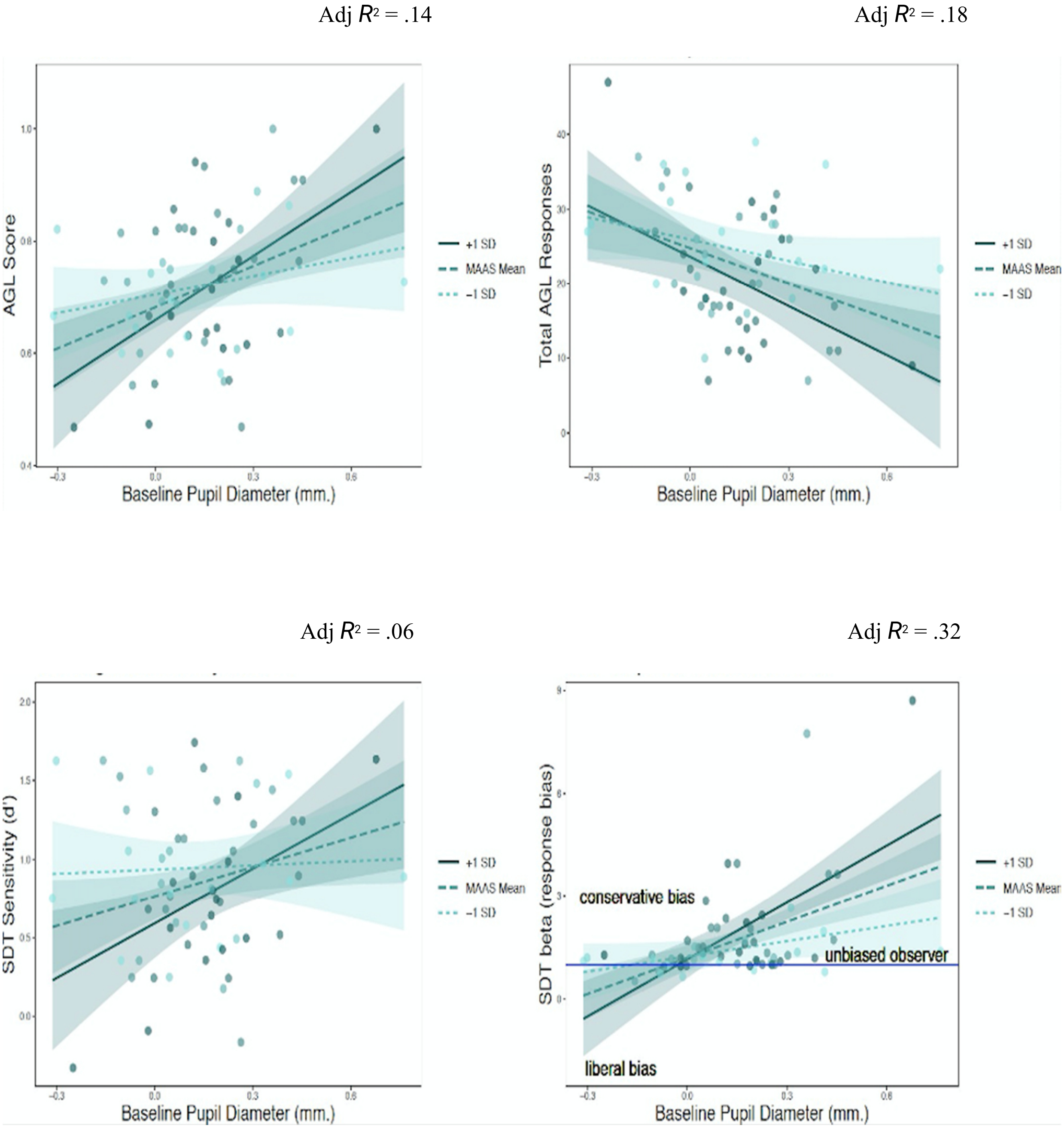
To investigate whether trait mindfulness played a role in moderating the observed relationship between bPD and AGL performance (H4), LMMs were constructed for each AGL and SDT outcome as a function of the MAAS / bPD interaction. Supporting the fourth hypothesis, the interaction was significant (F (1,62) = 5.16, p = .03, $\eta 2p$ = 0.08 (95%

CI[0.00, 0.23]), Figure 20, *top left panel*), revealing a greater observed effect of bPD on AGL scores at higher levels of MAAS. This effect was confirmed by simple slopes analysis, which revealed significance at average (mean) and high levels (+1SD) of MAAS, but not at low levels (- 1SD). Implementing the Johnson-Neyman (J-N) technique, the precise point on the MAAS continuum where the bPD slope became significant (controlling for Type I error rate) was 49.95.

The interaction for total AGL responses was not significant ($p = .13$, $\eta 2p = 0.04$ (95% CI[0.00, 0.17]), Figure 20, *top right panel*). Exploring the SDT index of signal sensitivity revealed a significant interaction between MAAS and bPD for d'scores (F (1, 60) = 5.01, p = .03, $\eta 2p = 0.08$ (95% CI[0.00, 0.23]), Figure 20, *bottom left panel*). The point on the MAAS continuum where the bPD slope became significant was 62, lending further support to the conclusion that dispositional mindfulness moderated the effect of tonic arousal on AGL performance. There was also an interaction for *beta* (F (1, 60) = 11.95, p = .001, $\eta 2p$ = 0.17 (95% CI[0.03, 0.34]), Figure 20, *bottom right panel*), with a significant bPD slope emerging at 47 on the MAAS continuum, suggesting that trait mindfulness also moderated the effect of arousal on response bias.

Figure 20.

Interactive Effects of Trait Mindfulness and bPD-inferred Tonic LC-NA Arousal on AGL Performance and Response Strategies.



Note. Dispositional mindfulness enhances the effects of arousal on AGL performance (top left panel), SDT signal sensitivity (bottom left panel) and conservative response bias (bottom right panel). There was a trending moderative effect of MAAS scores on the association between arousal and AGL total responses (top right panel). Overall, the effects of arousal on enhanced signal discriminability and increased utilisation of inhibitory response strategies manifest at mid-high ranges of trait mindfulness. Error ribbons reflect ±1 SEM.

Summary of Results

As predicted by adaptive gain theory (Aston-Jones and Cohen, 2005), present findings offer compelling evidence for the putative mediating role of LC-NA activity underlying transitions between exploit/explore control states amid rising task conflict, replicating the utility of pupil diameter in tracking these transitions. Specifically, evidenced here is a robust causal relationship between repeated intrasubject inductions of utility-based inconsistency and increased pre-escape bPD (H1), indicative of an inconsistency-induced tonic mode of LC-NA activity. Crucially, there was a positive relationship between the magnitude of escape-related bPD during the DUT and subsequent AGL performance (H2), thus demonstrating an association between inconsistency-induced tonic arousal and subsequent abstraction capabilities. Marginally greater bPD was observed for those scoring higher in the MAAS (H3) and there was also a moderative effect of trait mindfulness, whereby positive associations between bPD and successful AGL performance manifested primarily for higher MAAS scorers (H4).

To my knowledge, this is the first study illustrating such relationships, which taken together, offer novel implications for (a), extant inconsistency-compensation frameworks, (b), emerging conceptualisations of broader adaptive capacities receptive to tonic LC-NA activation, and (c) characterisations of trait mindfulness as a capacity for open and receptive awareness / alertness emerging from enhanced arousal states (Britton et al., 2014), which can facilitate adaptive exploratory behaviour. These findings and associated implications are discussed in more detail in Chapter 7.

Chapter 4: Exploring the Impact of Mindfulness-Based Interventions (MBIs) on Sustained Attention, Executive Function and Arousal (Studies 4-5)

Overview

Having considered the role of dispositional mindfulness and LC-NA activity in inconsistency-compensation processes across three studies, I decided to explore attentional and psychophysiological outcomes associated with structured mindfulness-based *interventions*. In order to address broader expectations that mindfulness represents an enhanced capacity for vigilance and wakefulness that is distinctly associated with arousal, I examined relationships between objectively assessed behavioural indices of sustained attention / vigilance and pupillary-inferred LC-NA activity as a function of mindfulness training. Considering discussed comparisons between mindfulness and mind wandering (Chapter 1), I was also interested in subjectively assessed fluctuations in sustained attention in the form of self-reported cognitive content and how these related to mindfulness and LC-NA arousal through the lens of AGT. I also assessed self-reported mindfulness and psychological wellbeing across studies to explore the broader benefits of mindfulness-based intervention.

If mindfulness is comprised of core dimensions pertaining to increased attentiveness, awareness and non-judging acceptance, then mindfulness-based interventions should enhance these components. Moreover, considering the documented augmentative impact of MBIs on neurobiological and behavioural indices of tonic alertness (Britton et al., 2014; Tang et al., 2015), combined with proposals that sustained attention and attentional control emerge from enhanced capacities for awareness and non-judging acceptance, one would expect MBIs to enhance performance on a range of attention tasks requiring tonic alertness, such as those relating to attention network efficiency and vigilance-based target detection. Relatedly, in terms if distinct cognitive processes associated with sustained attention and executive control, objectively assessed attentional benefits of MBIs should be augmented by subjectively reported attentional improvements that reflect increased awareness of task-related stimuli, namely greater on-task thoughts and reduced reports of non-alertness, distractibility and mind wandering. Crucially, if mindfulness can be conceptualised as a wakeful capacity for enhanced tonic LC-NA activity then this should be reflected in pupillary measurements during attentional performance. Firstly, bPD should be greater among MBI participants across trials relative to control participants, indicative of enhanced tonic arousal and greater overall levels of alertness and awareness. Moreover, *response-locked* TEPR to executive conflict should be diminished for MBI groups, consistent with discussed proposals relating mindfulness to increased acceptance and subsequent disengagement from any cognitive / psychophysiological reactivity arising from conflicting stimuli (Chapters 1 and 2). It was expected that the impact of MBIs on these outcomes may be bolstered through interactions between intervention and self-reported mindfulness.

Accordingly, in the present Chapter, I present two studies exploring the impact of two novel mindfulness-based interventions (MBIs) on facets of mindfulness, psychological wellbeing, sustained attention / vigilance, executive control and task-related / task-unrelated thought processes, whilst concurrently examining pupillary indices of distinct arousal-based signatures associated with these factors. Relationships between attentional and psychophysiological outcomes were also explored. The first study (Study 4) employs a paradigm utilising a four-week version of Acceptance and Commitment Therapy (ACT), specifically tailored towards university students. In this study, mindfulness, wellbeing, and behavioural / psychophysiological outcomes during the Attention Networks Task (ANT) and Sustained Attention to Response Task (SART) are examined as a function of intervention.

The second study (Study 5) builds on insights obtained during the ACT study by utilising a novel mindfulness-based training programme that I developed especially for the present research (Mindfulness-Based Cognitive Attention Training, MBCAT). This pilot study employs an extended version of the ANT, whereby an explicit SART-like measure of vigilance is incorporated into the task and alerting and orienting networks are more distinctly defined. As such, the present Chapter outlines two MBI studies intended to ascertain distinct attentional and psychophysiological outcomes associated with intervention-based change.

Across experiments, there was convincing evidence that the selected MBIs exerted beneficial effects on self-reported mindfulness and wellbeing, increased subjective reports of task focus, reduced disclosures of off-task thought and improved alerting / executive performance. Moreover, MBCAT impacted distinct arousal-based signatures associated with vigilance and attentional control, namely within conditions assessing tonic alerting and executive function. Taken together, the present chapter highlights the utility of different MBIs in facilitating psychological, attentional and psychophysiological outcomes through the lens of AGT-predicted LC-NA function, providing deeper insights into the wakeful properties of mindfulness.

General Introduction

The emergence of 'third wave' cognitive behavioural therapy (CBT) approaches to target various indicators of psychological distress has resulted in an accumulation of experimental attention being afforded to the effects of structured interventions emphasising the role of mindfulness in therapeutic discourse (Benfer, Spitzer & Bardeen, 2021; Ost, 2008). Crucially, established mindfulness-based interventions (MBIs) and related mindfulness-informed frameworks highlight the importance of experiential mindful processes during therapy as opposed to exclusively didactic behavioural methods (Hayes, 2004). For example, mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990), mindfulness-based cognitive therapy (MBCT; Segal, 2002) and acceptance and commitment therapy (ACT; Hayes, 1999) essentially utilise a comparable range of mindfulness techniques, which aim to train sustained attentional focus whilst nurturing a more non-judgmental and accepting awareness of internal and external experience (Britton et al,. 2018; Lutz et al., 2008). As such, common to most MBIs is the facilitation of structured mindfulness techniques believed to promote enhanced capacities for focused and 'open' attentional states, processes through which MBIs are believed to exert their beneficial effects on psychological wellbeing (Gallant, 2016; Gu et al., 2015).

However, although there exists consistent empirical support for the utility of MBCT, MBSR and ACT in reducing psychological distress - including symptoms of depression, (Chi et al., 2018; Kuyken et al., 2019; Zhenggang et al., 2020), anxiety (Gahari et al., 2020; Gloster et al., 2020; Zhou et al., 2020), substance misuse (Garland & Howard, 2018; Gloster at al., 2020), binge eating (Grohmann & Laws, 2021), and PTSD (Boyd et al., 2017; Pohar & Argaez, 2017) - the key active attentional and neurocognitive mechanisms underlying such changes are not fully understood (Schmidtman et al., 2017; Tang et al., 2015). Considering that, (a), extant conceptualisations of mindfulness cite attentional stability as a fundamental characteristic of effective mindfulness training (Lutz et al., 2008; Malinowski et al., 2013; Shapiro et al., 2006), (b), ongoing MBI participation affords frequent opportunities to nurture and strengthen attentional focus and exercise attentional control in the face of potentially difficult internal and external distractors (Hayes, 1999; Kabat-Zinn, 1990; Segal, 2002), and (c), MBI-induced improvements in wellbeing likely emerge from a combination of distinct psychological, cognitive and neural mechanisms of action (Shapero et al., 2018), there have been repeated calls from the domains of neuroscience and cognition to initiate a more extensive examination of the attentional and neurocognitive outcomes most receptive to MBI participation (Britton et al., 2018; Gu et al., 2015; Tang et al., 2015; Young et al., 2018). Specifically, increased emphasis has been placed on the importance of linking MBI-induced changes in sustained attention and attentional control with associated fluctuations in neural and psychophysiological activity. The existence of distinct arousal-based signatures accompanying specific attentional states (Geva et al., 2013; Aston-Jones & Cohen, 2005), coupled with the fact that relatively straightforward and non-intrusive methods exist to assess arousal during performance-based tests of attention, offers a unique opportunity to answer such calls. By converging MBI implementation, attention tasks and assessments of arousal, a unique opportunity exists to obtain a more comprehensive understanding of the neurocognitive mechanisms underlying the salutary effects of MBIs on wellbeing, which could potentially contribute to a more effective tailoring of emerging clinical interventions (Tang et al., 2015).

Surprisingly, however, concurrent assessment of attentional and psychophysiological outcomes in MBI research remains markedly underutilised, necessitating deeper experimental inquiry in the area. Accordingly, the present chapter outlines two studies converging a rich array of attentional, psychological and psychophysiological outcomes, duly assessed as a function of two novel mindfulness-based training programmes.

Mindfulness-Based Interventions (MBIs) as Attention Training

Inherent to most MBI frameworks are experiential mindfulness techniques aimed at training sustained attentional focus on an object (focused attention; FA) and subsequently nurturing an ‘open’ non-judgmental awareness and acceptance of internal and external experience through an emphasis on ‘stepping back’ from thoughts, emotions and sensory events and viewing them simply as transitory phenomena (open monitoring; OM) (Britton et al,. 2018; Lutz et al., 2008). Such techniques are explicitly trained during in-session practice and / or recorded home guidance as part of many MBI protocols (Britton et al., 2018), and would appear to represent suitable methods to augment attentional capacities that are easily assessable through attention tasks. Specifically, FA and OM techniques are theorised to enhance three attentional processes and their underlying neural networks: (i), the ability to sustain attentional focus on an object (e.g., the breath / task goals) whilst remaining vigilant to internal / external phenomena (e.g., mind-wandering / external distractors), (ii), the capacity to detect such distracting information and disengage from it, and (iii), the ability to return attention to the object in the presence of competing information (Lutz et al., 2008). Respectively, these processes pertain to the alerting network (governing sustained attention towards task-related objects / stimuli), the executive network (assessing distractor salience / incongruence without attachment) and the orienting network (facilitating attentional redirection in the presence of distractors) (Lutz et al., 2008; Malinowski, 2013; Posner, 2008). These attention networks can be reliably assessed through the utilisation of a range of performance-based tests of attention (Conners et al., 2000; Fan et al., 2002; Robertson et al., 1997). Moreover, enhanced abilities to detect internal / external distractors and repeatedly orient attention back to an attentional object would appear well-suited for the continual identification of cognitive processes (e.g., task-related / task-unrelated thoughts), which can also be assessed during attention tasks (Unsworth & Robison, 2016) as a function of MBIs.

Therefore, the marked similarity between the techniques nurtured during MBI delivery and the attentional capacities required for optimal performance during tasks of sustained and executive attention has prompted efforts to elucidate which attentional components and cognitive experiences are especially sensitive to structured and time-bound mindfulness training programmes.

Impact of MBIs on Performance-Based Tests of Attention

Accordingly, experimental endeavour in this respect has initiated exploration into the effects of standardised MBCT / MBSR protocols (typically consisting of eight weekly sessions of group-based guided mindfulness alongside daily home practice), as well as alternative MBI variants (ranging from three to six weekly sessions and daily home practice), on performance-based tests of attention. These protocols have been tested against passive control groups (waitlist / TAU) and / or structurally matched active control conditions (e.g., reading, writing or relaxation groups) (Casedas et al., 2020; Gallant, 2016; Im et al. 2021; Lao et al., 2016; Yakobi, Smilek & Danckert, 2021). Specifically, differences in attention network efficiency have been readily assessed by examining alerting, orienting and executive network components of the Attention Networks Task (ANT; Fan et al., 2002). Moreover, reaction time (RT), accuracy and interference effects during tasks such as the Continuous Performance Task (CPT; Conners, 2000), the Sustained Attention to Response Task (SART; Robertson et al., 1997), and the Stroop Colour and Word Test (Stroop, 1935) have each been utilised to gauge MBI-related changes in sustained attention, vigilance and the ability to exercise executive control / response inhibition in response to rare, conflicting or unexpected events. However, employing these and related tasks has yielded mixed results in the behavioural MBI literature.

Sustained / Selective Attention and Vigilance. Pertaining to sustained / selective attention and vigilance outcomes, several studies have evidenced small yet positive effects of MBCT / MBSR on ANT and CPT-based indices of sustained attention / vigilance (Hedge's g = .18, 95% CI[.03, .33] / g = .19, 95% CI[.06, .35]) relative to active and passive control conditions (interestingly, type of control group did not modulate MBI effects) (Yakobi, Smilek & Danckert, 2021). These findings suggest that MBI participation facilitates the ability to sustain and direct attentional focus during specific tests of attention. Conversely, exploring overall effects of MBIs among a diverse range of populations (healthy controls, depression relapse patients, ADHD adults and dementia caregivers) revealed no evidence for an enhancing effect of MBIs on sustained attention when compared to waitlist / TAU controls (Lao et al., 2016). However, a trend for pre-post enhancing effects on ANT alerting scores was observed among MBCT / MBSR groups, but not among controls (Cohen's d = .40, 95% CI[.07, .87]), implying that participation in intervention exerted beneficial effects on the ability to remain alert / vigilant throughout the ANT when compared to pre-intervention performance, although these results were not statistically / practically significant. Moreover, little support was obtained for the effectiveness of MBIs on attentional capacity during SART and CPT performance (Im et al., 2021). A mixture of significant and null effects were observed in relation to the impact of MBIs on orienting / selective attention when compared to active and passive control groups among healthy individuals (range; d = .12 to .43), illustrating variegated evidence regarding the effects of MBIs on selective attention (Lao et al., 2016). In summary, the literature pertaining to the impact of MBIs on behavioural indices of sustained / selective attention and vigilance is mixed, necessitating further intervention-based evaluation. For example, some studies have observed statistical hints of positive MBI effects on alerting network scores, whereas others have observed beneficial MBI effects for orienting scores, thus presenting ambiguity as to whether alerting or orienting is the more consistently augmented network of MBI participation. Compounding the issue is that ANT-based assessments of alerting and orienting commonly utilise the same cues to differentiate between the two networks. Addressing this, the present research employs a novel task operationalising more independent ANT-based measures of alerting and orienting. There also remains empirical ambiguity about whether SART and / or CPT-based indices of sustained attention / vigilance are receptive to MBI participation, with some studies supporting this contention and others reporting null findings. Accordingly, we employ an extended SART paradigm and an ANT-based vigilance component to further elucidate MBI-induced benefits. It was hoped that by implementing such tasks, the presented studies would serve to untangle some of the confusion pertaining to the effects of MBIs on sustained / selective attention.

However, there remains a relative paucity of endeavour explicitly focusing on alerting / orienting scores or distinct sustained attention outcomes during the SART / CPT, and of the MBI studies that do, sample sizes are typically (and necessarily, for group-based MBI delivery) constrained to a limited number. Such constraints likely explain the small effect sizes reported in the literature, further highlighting the need for additional research harnessing enhanced specificity of outcome to augment existing knowledge.

Executive Control | Response Inhibition and Cognitive Flexibility. There exists moderate yet positive evidence supporting the enhancing effects of MBIs on executive function, specifically when examining the core fractionated components of executive control in relation to response inhibition and cognitive flexibility (Casedas et al., 2020; Gallant 2016; Lao et al., 2016; Miyake et al., 2000). For example, examining the impact of MBCT / MBSR on tasks requiring the resolution of interference / tuning out of irrelevant or distracting information, and on the capacity for shifting attention between internal / external sets of information, Gallant (2016) demonstrated that MBI participation improved response inhibition and reduced interference effects in Go/No-Go and Stroop tasks. However, less convincing was evidence related to improvements in attentional set-shifting, implying that inhibitory control represented the most consistently improved executive function following MBI delivery. Conversely, Lao et al. (2016) observed preliminary evidence for improvements in cognitive flexibility as a result of MBCT (range; d = .69 / 1.09 / 1.31 / 1.81) but concluded that more studies were needed to allow for more robust conclusions to be drawn. Lao and colleagues also observed mixed results in relation to the impact of MBCT /

MBSR on executive inhibitory control during a Go/No-Go task and on incongruent response accuracy during a Stroop task, with only half of studies reporting positive outcomes (range; *d* = .68 / 1.05). No evidence was observed for an enhancing effect of MBCT / MBSR on executive function scores (derived from RT and accuracy) during the ANT (range; *d* = .13 / .19) (Lao et al., 2016). In a more recent systematic review and meta-analysis of exclusively RCT studies examining effects of MBCT, MBSR and comparably structured MBIs on inhibitory control and cognitive flexibility, Casedas et al. (2020) observed a small-to-medium enhancing effect of MBIs on inhibitory control (*g* = .42, 95% CI [.20, .63]), supporting the contention that MBIs do indeed enhance this distinct component of executive function. However, no effects were observed for cognitive flexibility (*g* = .09, 95% CI [-.13, .31]) (Casedas et al., 2020), consistent with the findings of Gallant (2016), but incongruent to those of Lao et al. (2016). Finally, Yakobi, Smilek & Danckert (2021) observed small yet significant enhancing effects of MBIs on executive attention, as assessed by a combination of measures, including SART No-Go trials , Stroop interference effects and ANT executive function scores (*g* = .17, 95% CI [.04, .31]), effects which were, interestingly, unaltered by the nature of the control group or duration of the intervention. In summary, the evidence for the effects of MBIs on executive function is more convincing, yet remains mixed in terms of the fractionated components that benefit the most (e.g., response inhibition and cognitive flexibility). Utilising similar assessments of executive control during variants of the SART and the ANT, the presented studies aim to lend credence to emerging proposals that response inhibition and reduced interference effects represent the most receptive core components of executive control to the effects of MBIs.

Overall, exploring the impact of MBIs on attentional outcomes has yielded variegated results, which, when combined with the myriad of methodological inconsistencies across studies (e.g., population variance, age range, experimental design, intervention content /

length, control group characteristics and outcome measures, see Table 1), poses a challenge for the interpretation of this corpus of findings. Such variance highlights the infancy of MBI-related cognitive research. Accordingly, the current experiments aim to augment existing empirical inquiry by exploring the effects of two distinct MBIs on specific variants of the most frequently employed neuropsychological tests in MBI research. Using a non-clinical, undergraduate student population in both studies, and a mixture of waitlist and active control conditions, it was hoped that meaningful attentional contributions to this methodologically diverse literature would be obtained.

Table 1.

Examples of pertinent study characteristics utilising mindfulness-based interventions and attention outcomes. Studies 4 and 5 compare two novel mindfulness interventions with active / waitlist control conditions in terms of comparable ANT / CPT / SART outcomes.

Study	Sessions	Intervention	Control Group	N	Sustained Attention	Executive Control
Anderson et al. (2007)	8	MBSR	Waitlist	71	CPT	Switching Task, Stroop
Giannandrea et al. (2019)	9	MBSR	Waitlist	37	SART, self-report	
Heeren et al. (2009)	8	MBCT	Waitlist	36		GoStop / Verbal Fluency
Jensen et al. (2019)	9	MBSR	Active (relaxation)	31	SART	
Jha et al. (2007)	4	MBSR / Retreat	Waitlist	51	ANT	ANT
Li et al. (2018)	8	MBCT	Waitlist	30	CPT	
Lymeus et al. (2017)	8	MBSR	Active (nature photos)	35	LDST	LDST
Schone et al. (2018)	8	Mindful breath	Active (relaxation)	34	MOT	
Zeiden et al. (2010)	4	Mindful breath	Active (listening)	49	n-back	
Zhu et al. (2019)	12	MBSR	Waitlist	48	CPT	Stroop

Impact of MBIs on Cognition

Fluctuations in objectively assessed attentional states during performance-based tests of sustained attention are reliably associated with changes in cognitive orientation (Schooler et al., 2014). For example, rates of self-reported mind wandering and off-task thought, which are typically collected using thought probes embedded within the task or through the use of retrospective self-report measures (Robison et al., 2019), show consistently high positive correlations with errors and reaction time variability during sustained attention tasks, such as the SART and CPT (Bastian & Sakur, 2013; Schooler at al., 2014; Smallwood & Schooler, 2006; Stawarczyk et al., 2014). Considering that MBIs have been shown to be effective in enhancing performance during such tasks (Yakobi, Smilek & Danckert (2021), one would also expect to observe MBI-induced reductions in closely associated mind wandering outcomes (Schooler et al., 2014). However, despite a rapidly growing literature investigating the effects of MBIs on attention and wellbeing, and increased experimental attention being afforded to relationships between mind wandering and attention (Smallwood & Schooler, 2006), empirical investigations into the effects of MBIs on mind wandering remain sparse. Recently, however, studies employing MBCT, MBSR and ACT-based interventions have demonstrated their utility in 'taming' a meandering attention during sustained attention tasks, as inferred by reduced probe-caught reports of mind wandering and off-task thought relative to controls (Giannandrea et al., 2019; Greenberg et al., 2019; Morrison et al., 2013; Rahl et al., 2017). These findings suggest that MBIs are also effective in targeting specific cognitive processes during sustained attentional performance. In an effort to extend endeavour in this area, I assessed probe-sampled thought reports as a function of MBI participation in order to explore the impact of mindfulness training on subjective accounts of attentional lapse, as well as the aforementioned task-based objective outcomes.

Psychological Mechanisms

MBIs have been shown to enhance levels of self-reported mindfulness (Frostadottir and Dorjee, 2019; Schanche et al., 2020), a demonstrable moderator of the effects of MBIs on depressive and anxious symptoms (Gu et al., 2015; van der Velden et al., 2015). Moreover, emerging research identifies mindfulness as a potential moderator of the effects of mindfulness training on attentional performance outcomes (Watier and Dubois, 2016). However, current knowledge about which mindfulness-based interventions work best for whom (e.g., individual difference moderators) in terms of both psychological wellbeing and attentional capacity remains limited (Tovote et al., 2017; Yakobi, Smilek and Danckert). Accordingly, the present research aims to qualify specific facets of the FFMQ as moderators of the effects of MBIs on psychological wellbeing and attentional outcomes.

Neurocognitive Mechanisms

Activation of various brain regions and networks has been shown to map onto specific attention functions. For example, the salience network (SN), which consists primarily of the anterior insula (AI) and the dorsal anterior cingulate cortex (dACC), is activated during the detection and further processing of salient stimuli, namely information that is deemed important to the attentional system such as threatening, pleasurable of inconsistent stimuli (Sara and Bouret, 2012). Moreover, the precuneus, temporoparietal junction (TPJ) and superior parietal lobule (SPL) are involved in the orientation of attention in space towards new stimuli (Cavanna and Trimble, 2006; Petersen and Posner, 2012). In relation to sustained attention, neuronal activity within the ACC has been shown to correlate with the ability to sustain attentional focus (Kerns et al., 2004; Wu et al., 2017). Moreover, the ACC is implicated in the detection of salient stimuli / conflicting information during performance-based tests of attention (Posner and Petersen, 1990) and is strongly connected to the dorsolateral prefrontal cortex (dPFC) and parietal cortex, as well as the motor system and frontal eye fields, rendering it a central executive processor of bottom-up and top-down stimuli for the exertion of cognitive control (Posner and Petersen, 1990). As such, ACC activation, specifically the dorsal portion, is prominent when cognitive effort or inhibitory control is required to complete a task successfully (Carter and Krug, 2012). Similarly, the ACC is activated in response to an array of inconsistent / expectancy-violating stimuli that are not linked to specific tasks (Sleegers and Proulx, 2015), such as incongruous word pairings (Randles, Proulx and Heine, 2011), anomalous playing cards (Sleegers, Proulx and van Beest, 2015) and uncanny / threatening pictorial human faces (Proulx, Sleegers and Tritt, 2017). The dPFC also exhibits functional and anatomical connections to attention network regions, namely those associated with top-down attentional direction to specific inputs (e.g., parietal cortices, SPL) and sustained monitoring of attention and redirection in response to salient stimuli during attention tasks (e.g., TPJ) (Taren, Gianaros, Greco et al., 2018). The dPFC is a key node of the executive attentional network, thus heavily implicated in the regulation of attention and decision-making processes (Bauer, Rosenkrantz, Caballero et al., 2020). Moreover, activation of the insula has been demonstrated to be involved in enhanced awareness, and has reciprocal connections to the ACC and dPFC, relationships between awareness, sustained attention, and executive control (Gibson, 2019).

The observed behavioural changes in sustained attention and executive function following MBI participation (Casedas et al., 2020; Yakobi, Smilek & Danckert, 2021) are potentially linked to neuroplasticity in these regions – proposed structural and functional changes in the brain as a result of regular mindfulness engagement. That is, consistent participation in MBI-related attention practices may serve to increase activation of brain regions most prominently receptive to the repeated and active training of one's attentional capacity (Gallant 2016).

Indeed, emerging evidence from magnetic resonance imaging (MRI) studies demonstrates structural and functional changes in areas of the brain associated with tonic alertness / vigilance, awareness, self-regulation, cognitive control and emotional regulation as a result of MBI participation. Specifically, increased activity has been observed within the ACC, the insula, the TPJ, the dPFC and the orbitofrontal cortex (OFC), as well as increased white matter density connecting the ACC to other brain structures, increased gray matter density in the insula, and increased functional connectivity between the ACC and dPFC (Allen et al., 2012; Fox et al., 2016; Gotnik et al., 2016; Holzel et al., 2011; Lutz et al., 2008; Mennon & Uddin, 2010; Tang et al., 2015; Young et al., 2018). The aforementioned role of the insula and ACC in awareness, interoception, goal-directed cognition, sustained attention, preparatory alertness and the detection of salient events (Totah et al., 2009; Wu et al., 2017), and the 'higher order' processes relating to attentional direction, conflict monitoring / resolution and self-regulation associated with ACC, dPFC and OFC activity (Fox et al., 2014; Tang et al., 2015; Young et al., 2018), would appear to indicate that MBI participation enhances capacities for awareness, alertness / vigilance and increased top-down resource recruitment to resolve conflict (Allen et al., 2012). Indeed, in relation to conflict monitoring, insights from studies utilising electroencephalogram (EEG) recordings to gauge changes in event-related potentials (ERPs) as a function of MBIs have identified distinct patterns of neural allocation to stimuli requiring conflict detection during executive components of attention tasks (e.g., incongruent stimuli). For example, larger N2 amplitudes - an ERP component occurring between 200ms-300ms after target onset and reliably implicated in conflict detection and executive attention - were observed for a mindfulness training group relative to a control group in response to incongruent ANT target trials, which was also accompanied by improved executive performance (Norris et al., 2018). Moreover, increased No-Go N2 and No-Go Pe amplitudes - ERP components associated with conflict monitoring and response inhibition respectively - were observed for an MBCT group relative to a control group during sustained CPT performance (Schoenberg et al., 2014). These results offer intriguing psychophysiological proposals that the beneficial effects of MBIs on executive control / improved inhibitory regulation during ANT and CPT completion were likely the result of increased neural allocation in relation to trials requiring awareness, executive attention and response inhibition. Indeed, as outlined in Chapters 2 and 3, mindful awareness likely serves to augment the detection of inconsistent / novel information, which should be expected to increase the initial arousal response to such stimuli (Teper and Inzlicht, 2013). Aforementioned MRI-assessed increases in activity within brain regions associated with such capacities would appear to support this contention. Importantly, EEG insights provide an empirical foundation to complement the MBI attention literature through the utilisation of additional psychophysiological methods, a core aim of the present research.

Additionally, the well-documented prophylaxis afforded by MBIs for enhancing psychological wellbeing and the reviewed findings pertaining to MBI-induced improvements in sustained attention / vigilance and cognitive control may also emerge from MBI-related changes in the default mode network (DMN). The DMN is known to be active during off-task thought and self-referential thinking, specifically in the generation of a “narrative” self-focus that is known to be conducive to the maintenance of psychological distress (Foland-Ross and Gotlib, 2012). Mindfulness training has been shown to exert deactivation of the DMN relative to controls (Brewer et al., 2011), nurturing a more “experiential” self-focus through enhanced activity in related brain areas (e.g., insula, ACC). Such deactivation likely underlies MBI-induced reductions in self-reported mind wandering (Giannandrea et al., 2019; Greenberg et al., 2019; Morrison et al., 2013; Rahl et al., 2017), offering novel opportunities to gauge rates of on-task and off-task thought whilst concurrently examining magnitudes of arousal indicative of task engagement.

Taken together, the discussed findings offer neurobiological and psychophysiological context to the reviewed MBI-induced effects on attentional performance, suggesting that neuroplasticity and neural allocation initiated and maintained through MBI participation may underlie behavioural outcomes. Such findings offer clear routes for further inquiry, specifically through the implementation of more accessible psychophysiological methods that can be measured concurrently alongside attention task performance. Accordingly, the present studies harness the utility of pupillometry to examine MBI-induced fluctuations in arousal associated with specific attentional states during performance-based tests of attention.

MBIs and the Locus Coeruleus-Noradrenergic (LC-NA) System

Interestingly, MBI participation has also been demonstrated to increase gray matter concentration in regions around the brainstem, including the pons, which harbours the LC-NA system. Considering that LC-NA neurons are responsible for virtually all of the synthesis and release of cortical noradrenaline (Aston-Jones & Cohen, 2005) and that dynamic fluctuations of NA occupy a theorised functional role in the interaction between tonic / phasic LC-NA arousal states, internal / external attentional focus and the overall 'breadth' of the attentional field (Holzel et al., 2011; Leech & Sharp, 2013; Singleton et al., 2014), MBI-induced increases in gray matter concentration in this area of the brainstem may provide a reliable structural proxy of differential LC-NA activity as a result of MBI participation. Moreover, marrying such observations with the implicated role of the LC-NA system in a range of cognitive and behavioural function and in clinical dysfunction (e.g., anxiety, depression) (Aston-Jones, 2002; Holzel et al., 2011) and with prior observations of reductions in psychological distress as a result of MBIs (Kuyken at l., 2019; Gahari et al., 2020; Boyd et al., 2017) serves to converge neurocognitive and clinical insights. This allows for reasonable assumptions to be made that the LC-NA system can plausibly be positioned as a salient underlying mechanism of the effects of MBIs on attention and wellbeing. However, due to the brainstem being one of the most challenging areas of the brain to examine, assessing real-time LC-NA activity during attention tasks as a function of MBI participation is inescapably indirect, necessitating the use of methods conveying a proxy for such activity. Assessment of pupil size fluctuation offers a reliable way to achieve this, thanks to the emergence of relatively cost-effective and accessible methods to gauge pupillary activity in tandem with attentional performance.

Baseline Pupil Diameter (bPD) and Task-Evoked Pupillary Responses (TEPR)

As discussed in previous chapters, specific pupillary indices have been used to infer distinct arousal states underlying associated attentional capacities in relation to the LC-NA system. They are included here[30] to help contextualise and aid clarity throughout this chapter.

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[30] Baseline (that is, pretrial) pupil diameter (bPD) is primarily used to gauge inter-trial / inter-task fluctuations of arousal indicative of tonic LC-NA function and vigilance during experiments measuring sustained attention and task engagement (Gilzenrat et al., 2010; Unsworth and Robison, 2016). Moreover, as outlined in Chapter 2, task-evoked pupillary responses (TEPR) during the presentation of inconsistent, incongruent or threatening stimuli are indicative of elevations in LC-NA activity associated with the experience of this type of information. Finally, TEPR also signifies ongoing task engagement during performance-based tests of attention, reflecting shorter-term arousal-based reactions to goal-related stimuli indicative of optimal task performance and phasic LC-NA responses in response to post-response cognitive effort (Geva et al., 2013, Aston-Jones and Cohen, 2005). As such, pre-response TEPR is generally elevated in response to warning signals / cues (indicative of enhanced preparatory alertness) and to incongruent targets (indicative of increased experience of cognitive conflict), whereas post-response TEPR is elevated following motor responses to incongruent executive targets (indicative of increased cognitive effort following a response requiring inhibition of distractors) (Geva et al., 2013). The present studies assess the impact of MBIs on both measures in order to examine proposed effects of MBIs on LC-NA activation.

TEPR and ANT. In relation to TEPR during the ANT, which has been validated with pupillometric assessment, three distinct pupillary signatures have been revealed (Geva et al., 2013); alerting TEPR (indicative of pre-response LC-NA elevations following alerting signals to aid behavioural performance), orienting TEPR (indicative of pre-response LC-NA elevations following spatially informative cues relative to central cues) and executive TEPR (indicative of post-response phasic LC-NA reactions to incongruent targets relative to congruent targets, representing increased cortical resources to resolve cognitive conflict relating to distractor inhibition and performance tracking) (Peterson and Posner, 2012). Comparing post-response TEPR between opposing orienting cues (e.g., valid vs. salient *invalid* locations) may also represent resource allocation to resolve the conflict between invalid cues and subsequent target location. Interestingly, Alerting TEPR can also be utilised to signify a spontaneous *readiness* to receive, and respond to, incoming environmental stimuli in the *absence* of any alerting signals (Tellinghuisen et al., 1999). As such, greater TEPR in these conditions would imply greater endogenous / tonic alertness, which was expected to be most pronounced for MBI participants, consistent with the characterisation of induced mindfulness as an augmented propensity for tonic LC-NA activity (Posner, 2008). Each of these outcomes are utilised during ANT performance in the present chapter.

In summary, if mindfulness training can be conceptualised as nurturing distinct attentional and psychophysiological outcomes during attention tasks, then one would expect MBIs to influence bPD and TEPR-based assessments of LC-NA activity during performance-based tests of sustained, selective and executive attention. However, such endeavour remains curiously absent from the MBI literature, offering important theoretical avenues for the present research to address.

Impact of Novel MBIs: Attention and Pupillary Dilation

Accordingly, across two studies, I explored the impact of two novel MBIs on outcomes pertaining to distinct attentional and psychophysiological processes. Converging endeavour from behavioural and neurocognitive domains, I aimed to provide further insights into the mechanistic processes underpinning MBI-induced improvements in sustained attention and executive function, in line with emerging recommendations (Casedas, 2020). In Chapter 1, I outlined how the preponderance of efferent projections to the LC from specific brain structures involved in sustained attention, salience detection and executive monitoring invites LC modulation in the face of repetitive, novel and conflicting environmental information for the purpose of optimal goal resolution and exploitative and exploratory decisions. To explore how such modulation manifests as a result of mindfulness training, I utilised a combination of attention tasks and pupillometry to infer LC-NA processes as a possible explanation of MBI-induced changes in attentional state.

General Predictions of Present Research

Based on the reviewed literature, there were four overarching predictions governing the specific hypotheses of each study (see below), consistent with emerging calls to; a) further clarify the specific attentional benefits of MBI participation, b) provide deeper insights into the impact of MBIs on cognitive content, and c) address the under-utilisation of concurrent assessments of attentional and psychophysiological processes associated with MBI participation (Greenberg et al., 2019; Schmidtman et al., 2017; Shapero et al., 2018; Tang et al., 2015):

1) MBIs will induce increased mindfulness and improved wellbeing, consistent with presently reviewed findings highlighting enhanced capacities for mindful

responding as a result of MBCT and ACT (Britton et al,. 2018; Lutz et al., 2008; Gallant, 2016; Gu et al., 2015) and reduced psychological distress (Chi et al., 2018; Gahari et al., 2020; Kuyken et al., 2019; Zhou et al., 2020). The presented studies aim to further elucidate which elements of mindfulness are most receptive to MBI participation through an exploration of distinct mindfulness facets.

2) MBIs will enhance sustained attention / vigilance, task-focus and attentional control, in line with proposed mindfulness-induced optimisation of awareness and acceptance of task-related stimuli (Slutsky et al., 2017; Teper and Inzlicht, 2013), and consistent with recent inquiry evidencing attentional benefits of MBIs (Casedas et al., 2020; Greenberg et al., 2019; Yakobi, Smilek & Danckert, 2021). The current research also addresses some of the pertinent contradictions emerging from the behavioural literature in this respect (Lao et al., 2016; Im et al., 2020).

3) MBIs will exert observable changes in pupillary-inferred LC-NA activity, consistent with optimal tonic physiological states associated with bottom-up exploratory strategies in the context of specific attentional demands, thus providing novel contributions to the reviewed neurocognitive MBI literature (Norris et al., 2018; Tang et al., 2015; Young et al., 2018). The presented experiments therefore aim to provide compelling evidence for the notion that MBIs represent active training programmes capable of augmenting attentional capacities through the modulation of cortical arousal states, thus linking AGT-predicted LC-NA function with interventions typically utilised in clinical / therapeutic settings (Aston-Jones and Cohen, 2005; Tang et al., 2015). As such, I hoped to address the broader claim of the thesis that mindfulness can be conceptualised as a distinct capacity for tonic LC-NA arousal.

4) Self-reported mindfulness will moderate the effects of MBIs on wellbeing and attentional performance, thus building on limited available knowledge about the moderative qualities of mindfulness on specific psychological and attentional outcomes (Gu et al., 2015; Tovote et al., 2017; van der Velden et al., 2015; Watier and Dubois, 2016).

The Mindfulness-Based Training Programmes

I implemented two novel training programmes based on established manualised MBIs (MBCT and ACT), namely 'ACTivate Your Life (ACT)' (Study 4) and 'Mindfulness-Based Cognitive Attention Training (MBCAT)' (Study 5), ensuring that each intervention was matched in terms of duration as a 'minimally effective dose' of four weekly 2-hour practitioner sessions (Teasdale et al., 2000) with similar taught / guided in-session and home practice exercises based on FA and OM techniques. Moreover, these programmes were delivered exclusively to a non-clinical, undergraduate population presenting with broadly similar age ranges (18-25). Importantly, in line with the presently reviewed literature, I intended to explore a range of attentional outcomes as a function of the interventions, thus incorporating the ANT, an amended SART with thought probes and an amended version of the ANT which included a CPT-like sustained attention / vigilance task. Pupillometry was utilised in both experiments to gauge pretrial baseline pupil diameter (bPD) and task-evoked pupillary responses (TEPR) during all tasks.

Study 4: Acceptance and Commitment Therapy (ACT) Exerts No Influence on Attention Network Efficiency, Sustained Attentional Focus or Arousal

Overview

In Study 4, I present an experiment pertaining to the effects of a novel mindfulness-based programme (Acceptance and Commitment Therapy (ACT)) on outcomes obtained from the Attention Network Task (ANT) and an amended Sustained Attention to Response Task (SART, with thought probes), which incorporate rich and reliable assessments of alerting, orienting, executive function, sustained attention / vigilance and on-task / off-task thought processes. Pupillometry was utilised to gauge bPD and TEPR-inferred LC-NA activity throughout each task. It was hoped that by implementing a novel and accessible mindfulness intervention developed specifically for the purposes of the present research, in conjunction with a comprehensive assessment of distinct attentional and psychophysiological outcomes, the study would offer novel opportunities to extend current knowledge about the effects of MBIs on sustained attention, executive control and arousal. By extension, it was hoped that valuable insights would be obtained in relation to the arousal-based mechanisms underlying conceptualisations of mindfulness training / practice as nurturing a capacity for wakefulness and alertness.

Hypotheses

I predicted that ACT delivery would enhance self-reported mindfulness (H1), consistent with extant MBI literature evidencing increases in specific facets of mindfulness as a result of intervention (Giannandrea et al., 2019; Shahar et al., 2010; van den Hurk et al., 2012; Verhoeven et al., 2014), namely Observing, Describing and Non-Reactivity (Baer et al., 2019; Schanche et al., 2020).

Consistent with conceptualisations of MBIs as attention and awareness training, which map onto specific attention network capacities (Britton et al,. 2018; Lutz et al., 2008; Malinowski, 2013; Posner, 2008), I predicted that ACT participation would enhance alerting (H2a), orienting (H2b) and executive behavioural performance (H2c), thus clarifying the beneficial effects of MBIs on distinct attention networks (Yakobi, Smilek & Danckert, 2021; Gallant, 2016; Lao et al., 2016; Verhoeven et al., 2014). I also hypothesised that ACT participation would enhance RT and accuracy-based indices of sustained attention (H2d), with a view to augmenting existing literature demonstrating improvements in SART / CPT performance as a result of mindfulness training (Yakobi, Smilek & Danckert (2021). By extension, due to previously observed reliable associations between objective and subjective measures of attentional lapse (Schooler et al., 2014), I predicted that ACT-induced improvements in sustained attention would be accompanied by increased on-task thoughts and reduced off-task thoughts (specifically, mind wandering) (H2e), consistent with prior examinations of the impact of MBCT / ACT on cognitive content (Giannandrea et al., 2019; Greenberg et al., 2019; Morrison et al., 2013; Rahl et al., 2017).

In relation to self-reported mindfulness, I hypothesised that mindfulness would exhibit beneficial associations with ANT performance (H3a), SART outcomes (H3b), and on-task thought processes (H3c), and would moderate expected effects of intervention on these outcomes (H3d).

Turning to arousal-based outcomes, due to the utility of baseline pupil diameter (bPD) measurements to reflect changes in vigilance and sustained attention (Aston-Jones and Cohen, 2005; Unsworth & Robison, 2016, 2018; Gilzenrat et al., 2010), I predicted that bPD would be associated with distinct ANT and SART performance outcomes / thought processes (H4a), and that enhanced performance during the ANT and SART as a result of ACT participation would be accompanied by distinct changes in bPD relative to controls, namely larger bPD across trials indicative of tonic LC-NA activation (H4b). Moreover, due to the specificity of task-evoked pupillary responses (TEPR) in the inference of task-related LC-NA processes (Aston-Jones and Cohen, 2005; Geva et al., 2014; Kahneman, 1973), I predicted that alerting, orienting and executive networks would display distinct TEPR signatures, insofar as alerting TEPR would be larger for double cue trials relative to no cue trials, orienting TEPR would be larger for spatial cue trials than for central cue trials, and that executive TEPR would be larger for incongruent targets relative to congruent targets, thus replicating prior research (H5a, H6a, H7a) (Geva et al., 2013). Importantly, I hypothesised that such TEPR components would be influenced by training condition, insofar as ACT would result in enhanced pre-response TEPR responses (e.g., awareness) to match improved performance in sustained attention / alerting, orienting and executive function, but reduced post-response cortical resource allocation, indicative of reduced mental capture (e.g., acceptance) by distractors. In this way, expected selective increases in tonic LC-NA activity would be consistent with extant neurocognitive literature in the area (H5b, H6b, H7b) (Fortenbaugh et al., 2017; Totah et al., 2009; Wu et al., 2017; Fox et al., 2014; Tang et al., 2015; Norris et al., 2018; Schoenberg, 2014; Holzel et al., 2011; Singleton et al., 2014).

Finally, I hypothesised that self-reported mindfulness would be associated with distinct psychophysiological markers (TEPR) of alerting (H8a), orienting (H8b), executive attention (H8c) and vigilance (bPD) (H8d), consistent with research evidencing associations between trait mindfulness and neural activity in cortical attention centres (Parkinson et al., 2019). I also predicted that mindfulness would moderate the effects of ACT on these outcomes (H9a, H9b, H9c, H9d), thus providing novel evidence for augmentative effects of ACT and self-reported mindfulness on distinct arousal processes.

Table 1.1 displays primary hypotheses with associated psychological, attentional and psychophysiological outcome measures.

Table 1.1

Primary hypotheses of the present study in relation to specific methods utilised to assess the impact of ACT intervention on mindfulness, attention, and arousal.

Hypotheses	Mindfulness	Attentional Performance (ACT Effects)	Thought Processes (ACT Effects)	Arousal
H1	ACT: Greater FFMQ			
H2a		Enhanced ANT Alerting		
H2b		Enhanced ANT Orienting		
H2c		Enhanced ANT Executive Control		
H2d		Improved SART RT / Accuracy		
H2e			Increased On-Task	
H2e			Reduced Off-Task	
H3a	FFMQ: Improved ANT			
H3b	FFMQ: Improved SART			
H3c	FFMQ: Greater On-Task			
H4a/b				ACT: Greater bPD
H5a/6a/7a				Network-specific TEPR
H5b/6b/7b				ACT: Greater Pre-Response TEPR
H5b/6b/7b				ACT: Diminishes Post-Response TEPR

Method[31]

Participants

Cardiff University students (N = 73) were recruited for the study via the Experimental Management System, receiving course credit as reward for their participation. Sample size was derived from prior research utilising ACT intervention for self-reported mindfulness and wellbeing outcomes (Waters et al., 2018; Waters et al., 2020). Additional recruitment methods included advertisements distributed through existing mailing lists, posters distributed around university buildings and social media sites accessed by university students (i.e. Facebook, Yammer, Twitter) (Appendix 2A outlines examples of flyers utilised). Students registering their interest were sent an information sheet about the study and their rights as a participant. Due to the inclusion of eye-tracking methods, only participants with normal or corrected vision were invited to take part. 49 participants took part in both sessions

[31] See Appendix 0ii: ‘Overview of Procedures and Data Preparation’ for full details pertaining to eye-tracker calibration, generalised experimental protocol and behavioural / pupillary pre-processing techniques.

of the study, with 21 in the ACT intervention condition and 28 in the waitlist control condition. All participants were aged between 18-25 (M_{age} = 22.3 [SD = 2.56]), 16.2% of which were male for the full sample. No significant differences existed between ACT and control groups on any demographic variable. Figure 20 outlines the CONSORT diagram detailing the flow of participants through the study.

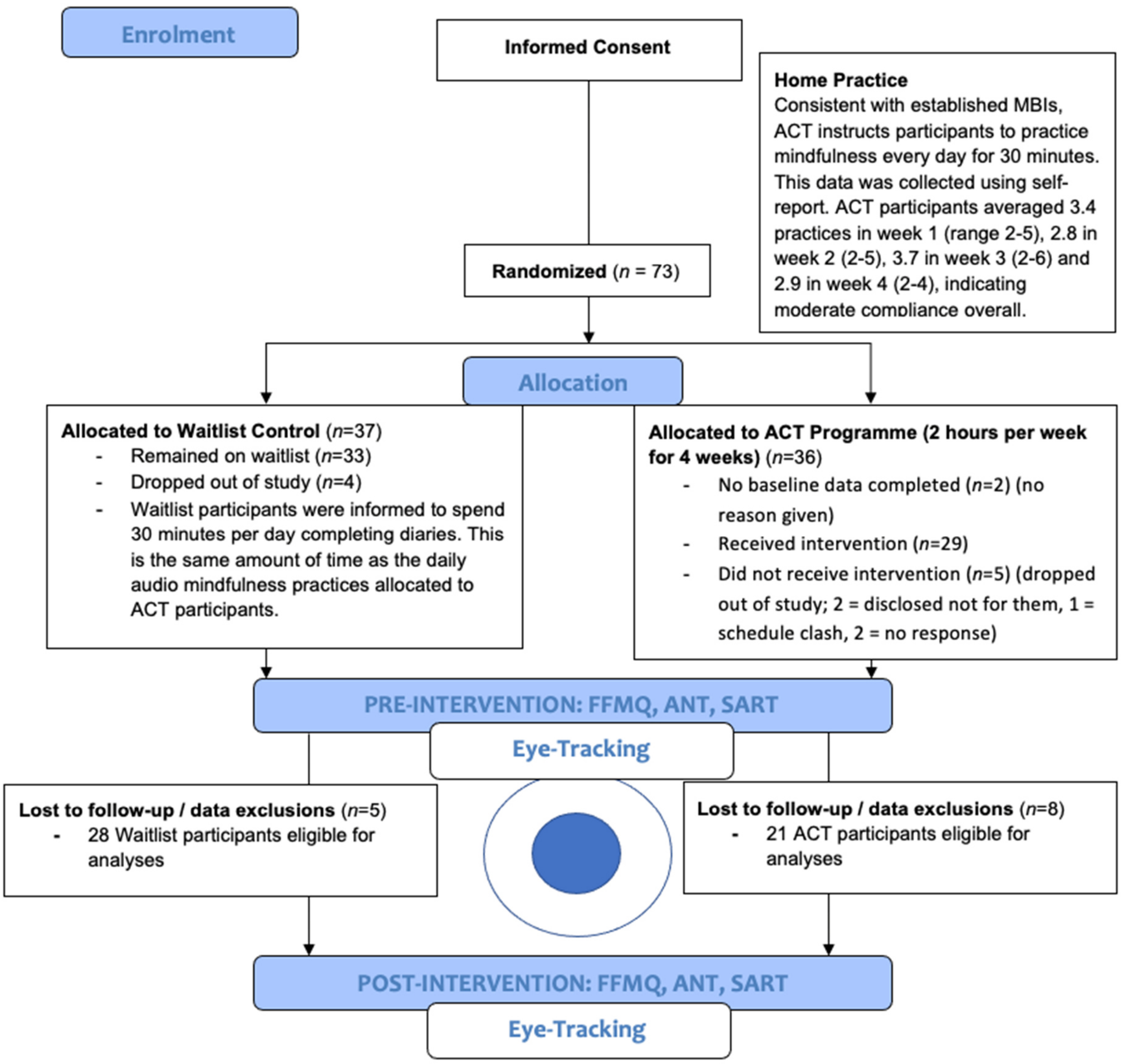
Materials and Procedure[32]

FFMQ (Baer et al. 2008). To test hypotheses pertaining to the effects of ACT on self-reported mindfulness, the FFMQ was utilised to assess mindfulness. Higher total FFMQ and subscale scores represent greater levels of mindfulness. In the present study, alpha coefficients for total FFMQ scores were excellent at pre-training (α=.92) and very good at post-training (α=.85).

[32] See Appendix 0i: 'Overview of Self-Report Measures' for full details pertaining to the mindfulness measures employed throughout this thesis.

Figure 20.

CONSORT Participant Flow Diagram for Phases of Parallel Randomised Control Trial Comparing ACT with Waitlist Controls.

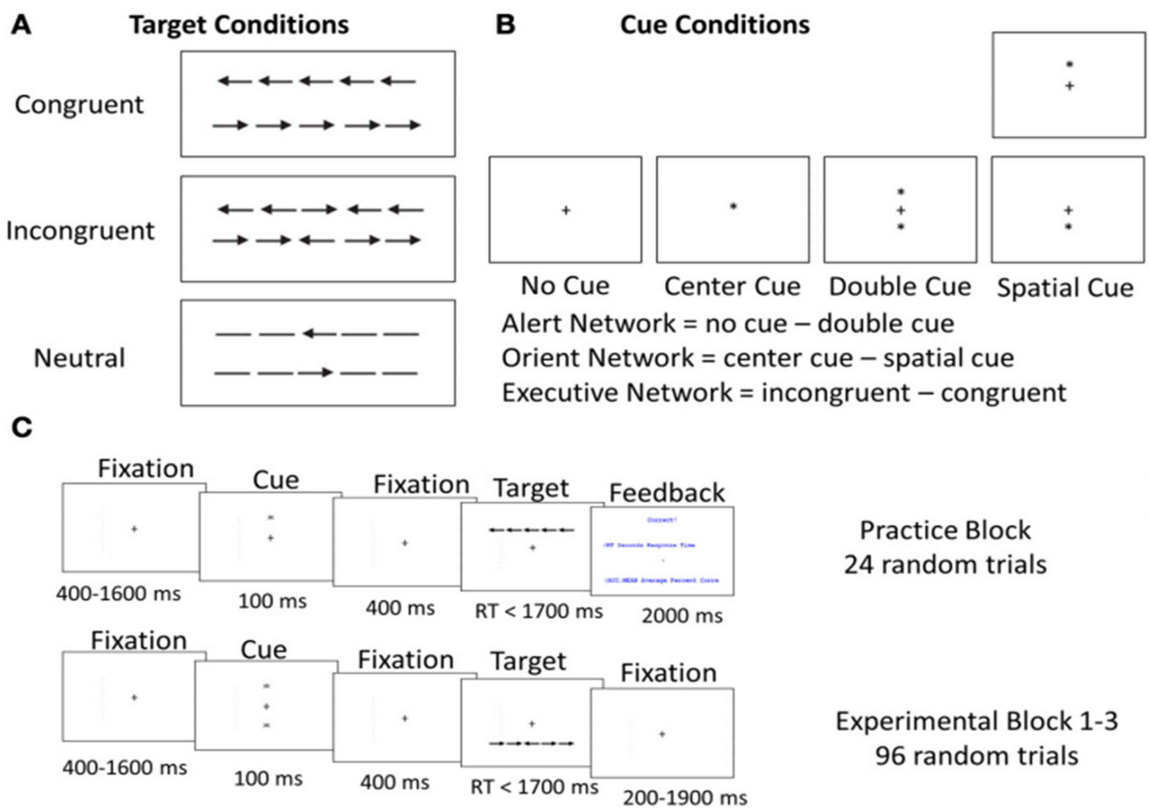


Attention Network Task (ANT) (Fan et al., 2002). A diagrammatic of the ANT used in the present study is presented in Figure 21. The ANT employs the use of seven conditions to measure each attention network, including four cue conditions (no cue, double cue, central cue and spatial [orienting] cue) and three target flanker conditions (congruent, incongruent, neutral). Target stimuli consist of five arrows (central target and 4 flankers) pointing either left or right. Congruent targets point in the same direction as the flanker arrows, incongruent targets point in the opposite direction and neutral targets point left or right with neutral flankers. Target stimuli are presented either above or below the fixation cross. Each trial consists of a combination of cued reaction-time tasks and flanker tasks. Different cues are presented to test the alerting network (no cue before target vs. double cue) and orienting network (central cue vs. spatial cue). The executive control network is tested by presenting congruent, incongruent or neutral flankers around the target arrow and participants are required to identify the direction of the central target by pressing ‘1’ (left) or ‘2’ (right) on the keyboard. During each trial, the fixation cross is replaced by a cue, informing the participant when and where the arrows will appear (Figure 1). Each experimental trial began with a fixation point (400-1600ms), followed by a cue, followed by a 400ms fixation, followed by target stimulus, followed by a 200-1900ms fixation period. Participants were presented with a practice block of 24 random trials followed by three experimental blocks containing 96 trials each. The task lasted approximately 25 minutes.

ANT performance: Alerting - enhanced efficiency of the alerting network is typically represented by greater alerting network scores, signifying the ability to utilise the existence of a warning cue to respond optimally to the target. This represents the *phasic* component of the alerting network. However, lower alerting network scores may also imply improved alerting efficiency, insofar as they may reflect improved *tonic* alerting, whereby attention is in a more readied state as a result of participants relying on their own internal alertness when no cues are available (Jo et al., 2016; Posner, 2008; Roca et al., 2011). As such, exploration of no cue and double cue conditions is important when determining alerting network efficiency. Orienting -greater orienting scores represent enhanced capabilities to utilises the spatial attributes of a warning signal. Executive – enhanced efficiency of the executive network is represented by reduced executive network scores, signifying the ability to identify and subsequently disengage from distracting (e.g., incongruent) stimuli for the optimal processing of the central target, thus implying greater conflict monitoring and attentional control.

Figure 21.

Experimental ANT Procedure and Stimuli



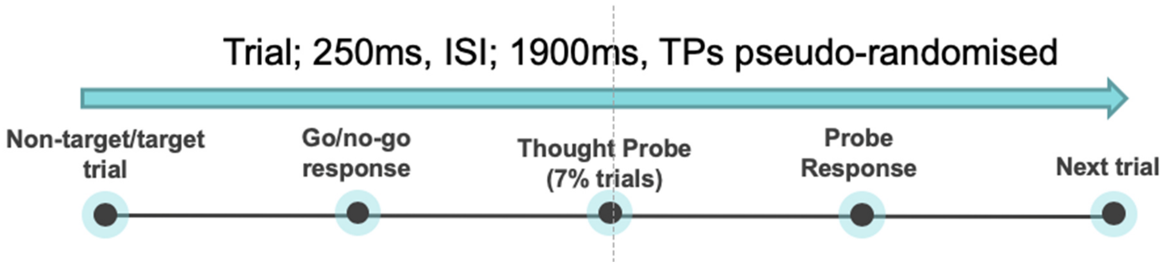
Note. (A) Target conditions, (B) Cue conditions, (C) Experimental procedure (obtained from Geva, R., Zivan, M., Warsha, A. & Olchik, D. [2013], 'Alerting, Orienting or Executive Attention Networks: Differential Patters of Pupil Dilations.' *Frontiers in Behavioural Neuroscience, 7:145, pp. 4*).

Sustained Attention to Response Task (SART) (Robertson et al., 1997). A diagrammatic of the SART used in the present study is presented in Figure 22. Participants were presented with a series of single digits (1-9) in random order. Traditionally, each number is displayed on screen for 250ms followed by a 900ms mask (Robertson et al, 1997). However, because previous work has related a longer pace of the task to increased occurrences of mind wandering (Christoff, et al, 2009, Smallwood et al, 2004), the pace of the task was extended by increasing the presentation time of the inter-stimulus interval (ISI) to 1900ms. During the SART, participants are required to respond to each digit as rapidly as possible without sacrificing accuracy by pressing the spacebar, apart from when they see the number 3, in which case they're required to withhold their response. Participants can respond during the stimulus display or during the mask period. Targets were presented on approximately 6% of trials (4 practice, 20 per experimental block). Trial order was pseudo-randomised so that target trials were always separated by at least one non-target trial. Participants were presented with 60 practice trials (practice block) and 662 experimental trials (2 x experimental blocks of 331), with a break period in between blocks. On occasion, thought probes were presented (Figure 23) requiring participants to press one of seven keys indicating what they were thinking about immediately prior to the appearance of the probes. Response one signifies on-task thought, seven represents non-alertness, two and three represent off-task thought and four, five and six represent mind wandering (Stawarczyk et al, 2011, McVay and Kane, 2012b). The probes extend those used in previous research investigating arousal and mind wandering (Unsworth and Robison, 2018) and pre-post mindfulness induction effects on mind wandering (Morrison et al, 2013) by differentiating between mind wandering and off-task thought and by specifying distinct *temporal* qualities of mind wandering. 51 probes were pseudo-randomly dispersed throughout the task (5 for practice trials, 23 per experimental block). Probes remained onscreen until participants made a response. The task lasted approximately 25 minutes.

SART Performance: The ability to sustain attentional focus and remain alert / vigilant to stimuli over time is critical for the successful completion of everyday tasks and the continued assessment of changing circumstances. In particular, the ability to constantly monitor and detect rare / novel environmental stimuli is conceptualised as a capacity for sustained vigilance (Rosenberg et al., 2013; Warm et al., 2008), which varies widely between individuals and is related to personality differences, brain structure, neurological health and other cognitive capabilities (Kanai et al., 2011; Robertson et al., 1997; Rosenberg et al., 2013). Traditional vigilance tasks such as the SART and CPT, therefore, assess an individual's ability to constantly monitor for salient / uncommon signals and make discriminations between frequent and infrequent stimuli (Ballard, 2001; Davies and Parasuraman, 1982). Failures to detect infrequent stimuli (e.g., false alarm responding to omission targets) or respond to repetitive stimuli (e.g., miss responses to commission stimuli) represent decrements to sustained vigilance (Rosenberg et al., 2013), which are also highly associated with task-unrelated thoughts and mind wandering (Christoff et al., 2009; Robertson et al., 1997; Smallwood et al., 2008). Considering known associations between mind wandering and psychological distress (Yamaoka, 2020) and inverse associations between mind wandering / vigilance decrements and mindfulness (Jha et al., 2007; Mrazek et al., 2012), exploring the effects of mindfulness-based strategies on sustained vigilance performance would appear to offer interesting cognitive-attentional and clinical implications.

Figure 22.

Modified Experimental SART Procedure and Stimuli



Note. Participants were required to press spacebar in response to every number except the number '3' (target trials). 33 thought probes were presented in a pseudorandom fashion approximately every 60 s.

Figure 23.

Thought Probes Interspersed Throughout SART.

Please characterise your current conscious experience:

1. I am totally focus on the current task.
2. I am thinking about my performance on the task or how long it is taking.
3. I am distracted by sights/sounds/temperature or by physical sensations (hungry / thirsty).
4. I am daydreaming / my mind is wandering about the past.
5. I am daydreaming / my mind is wandering about the present.
6. I am daydreaming / my mind is wandering about the future.
7. I am not very alert / my mind is blank or I am drowsy

Note. Probes adapted with permission from probe battery administered by Unsworth and Robison (2016).

Intervention Procedure

All demographics (age, gender, highest level of education) and questionnaire data were captured electronically using Qualtrics Online Questionnaires. The study compared a group-delivered active treatment condition (ACT) and a waitlist control condition (WL). A random number generator was used to assign participants to one of the two conditions (Figure 20). ACT intervention was delivered to students in the Cardiff University Psychology building over a one-month period (four sessions). Each weekly group intervention session was two hours long consisting of ACT-based psychoeducation and mindfulness exercises, which were facilitated by two assistant psychologists (one male, one female). Prior to post-ACT data exclusions and accounting for participant dropout rates (Figure 20), a total of 29 participants attended the ACT sessions each week, which were delivered in a quiet lecture studio using Powerpoint displayed on a large screen at the front of the lecture hall. The two facilitators stood at the front of the lecture room to deliver the content. At one-week pre-intervention and one-week post-intervention, participants were invited to complete a battery of questionnaires and a 60-minute eye-tracking session, whereby behavioural performance during the ANT and SART was measured using E-Prime alongside concurrent collection of PD markers to indirectly assess tonic and phasic LC-NA arousal. The study was approved by the University of Cardiff Ethics Committee, and informed consent was obtained prior to entry into the study.

ACT Intervention Condition. The current study employs the use of a novel ACT-based program - Activate Your Life - a group-based psychoeducation training programme that is designed to be engaging and accessible. Like mindfulness-based cognitive therapy (MBCT), ACT is an empirically driven ‘third wave’ behavioural therapy that incorporates mindfulness techniques to increase an individual’s capacity to manage negative thoughts and emotions through a cultivation of awareness and acceptance (Hayes et al, 2011). The ACT process places importance on the use of specific mindfulness strategies consistently cited as core mechanisms of mindfulness action designed to embrace a 'decentering' from one's thoughts and feelings, reduce attachment, become less emotionally reactive and increase psychological flexibility (Shapiro et al, 2006, Hayes et al, 2004, 2006). The intervention is mainly didactic in nature, with Microsoft PowerPoint used to deliver the content. Mindfulness skills are taught and discussed in session, and participants are encouraged to practice these techniques at home using the freely provided ACT audio CD containing both FA and OM techniques. Using facilitators to teach ACT content each week is directly informed by the original ACT framework (Hayes et al., 2006), which has been demonstrated to be effective for improving a range of psychological wellbeing outcomes (Hayes et al., 2011; Powers et al., 2009). Due to the manualised approach of the AYL programme and the range of mindfulness-based techniques employed, weekly practitioner contact was preferred over a purely self-guided approach in order to ensure that the cohort could familiaraise themselves with the required home practice techniques. Specifically, this approach provided the opportunity for participants to observe live demonstrations of the mindfulness-based processes involved through didactic, metaphor-based and experiential methods, which was deemed important for enhancing the adherence to the home practice elements of the programme (Waters et al., 2020). Moreover, some evidence suggests that group-based, practitioner-led mindfulness-based programmes exert stronger effects on psychological outcomes than purely self-directed programmes (Ma et al., 2018).

Intervention sessions were recorded using Panopto and were made available online to participants. Appendix 2B presents examples of the mindfulness techniques taught to participants throughout the programme.

Waitlist Condition. Participants in the waitlist condition completed the same questionnaires at identical time-points as the ACT group but did not attend weekly 2-hour

ACT sessions. Instead of mindfulness skills practice, participants were asked to complete daily diaries detailing notable activities of the previous week, which were discussed at with facilitators. All waitlist participants were informed that they would have the opportunity to receive the ACT intervention at a later date.

Data Preparation

Exclusions

Originally, 36 participants were randomised to the ACT and 37 participants were allocated to the waitlist condition. However, due to dropouts and data loss / exclusions (see Figure 20), the final sample size was 49 (21 ACT, 28 waitlist).

Behavioural and Pupillary Outcomes

Behavioural (response latencies and accuracy) and pupillary data preparation techniques (bPD and TEPR) for the present study are located in Appendix 0ii; 'Overview of Procedures and Data Preparation', pgs. 11-12). Generally, bPD was computed as the average pupil size during the final 200ms mask period of each SART trial, and during the 200ms fixation period that preceded each ANT trial (cue presentation). Fluctuations in participants' pupil diameter (TEPR) were also analysed across the pupillary time course for each ANT trial to gauge LC-NA activity within each network condition. Mean pupil sizes were calculated for alerting, orienting and executive networks, as displayed in respective TEPR graphs. Grand mean of RT was utilised to split time courses into pre-response and post-response trial epochs.

Analytic Strategy

All pertinent behavioural, psychophysiological and self-report outcomes were assessed as a function of the Condition (ACT / WL) x Time (Pre-intervention / Post-intervention) factorial design. Equivalence in age between ACT / WL was confirmed at baseline (see Results), so age was not included as a covariate in my models**.**

In order to analyse effects typically measured during the ANT task, mean correct RT, accuracy, bPD and TEPR were assessed as a function of alerting cues, orienting cues and executive targets. Attention network scores for behavioural variables were computed by obtaining the difference between network-specific conditions (phasic alertness; no cue - cue, orienting; central cue - spatial cue, executive; incongruent - congruent). Following procedures used in prior studies for both behavioural and pupillary measures (Geva et al. 2013), one-sample t-tests were used to test whether network scores were significantly different from 0, with linear mixed models (LMMs) implemented to analyse pupillary time courses throughout each network.

SART attentional performance was assessed by analysing RT to Go trials (non-targets), accuracy to Go and NoGo (target) trials, and specific thought probe responses. Off-task thought reports and both types of SART error (commission and omission) are associated with attentional lapse (Cheyne et al, 2009; Unsworth and Robison, 2018).

Unless otherwise stated, LMMs and generalised LMMs were employed to analyse RT and binomial accuracy / thought probe data as a function of training condition and network-specific stimuli. To account for the repeated sampling of subjects within cue and target conditions, LMMs were preferred, which were compared using AIC criterion (Appendix 0iii, Study 4).

Finally, individual differences in mindfulness were tested for associations with measures of performance and arousal, and where appropriate, explored in terms of their potential moderative effects.

Results

Equivalence Tests

No significant differences in age were observed between ACT and Control (Waitlist, WL) conitions (p = .52). I conducted MANOVA to assess for equivalence in levels of pre-induction self-reported mindfulness between ACT and WL conditions. There were no differences in relation to the FFMQ subscales ($V = 0.11$, $F(2, 47) = 1.43$, $p = .36$), which was confirmed by follow-up ANOVAs. These tests illustrate that all participants exhibited similar levels of mindfulness prior to the experiment.

Mindfulness

I assessed whether ACT intervention resulted in increased FFMQ subscale scores (H1). A marginal interaction was observed between session and training condition for FFMQ-Observing ($F(1,47) = 4.66$, $p = .04$), whereby descriptive pre-post fluctuations in observing between the WL condition ($M = 8.25$, $SD = 2.31$ to $M = 7.75$, $SD = 2.33$, $d = .21$) and the ACT condition ($M = 8.71$, $SD = 2.19$ to $M = 9.48$, $SD = 2.48$, $d = .33$) did not survive correction. This suggests that any changes in observing were potentially attributable to natural fluctuations with time rather than to the treatment conditions. A main effect of session for FFMQ-Awareness scores ($F(1,47) = 9.94$, $p = .003$) illustrated a pre-post increase in self-reported awareness across conditions (total M = 8..16, $SD = 2.41$ to $M = 9.00$, $SD = 2.41$, $d = .34$). Taken together, these results do not provide evidence that ACT intervention enhanced levels of mindfulness. Specifically, as there was an increase in FFMQ-awareness *across* conditions, and the fact that there was only a trending FFMQ-observing interaction that did not result in significant pre-post effects for either condition, presented results are likely attributable to natural temporal fluctuations in awareness and observation.

The Attention Network Task (ANT)

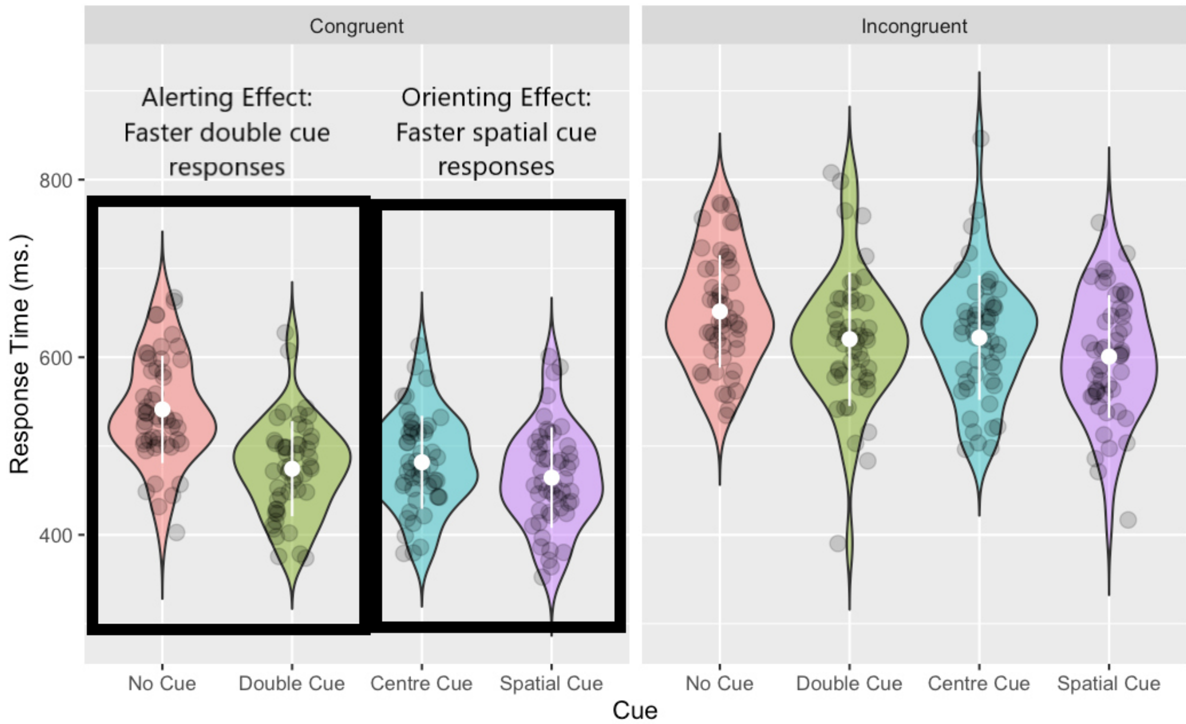
Response Latencies. I estimated a linear mixed model, which revealed that the main attentional effects of cue ($F(3, 69) = 96.50$, $p < .001$) and target on RT (F(1, 44) = 626.84, $p < .001$) were highly significant. Planned comparisons revealed expected alerting, orienting and executive network effects on RT, insofar as double cues elicited faster RT than no cue conditions ($p = < .0001$, $d = .34$), spatial cues elicited faster RT than central cues ($p = < .0001$, $d = .16$) and congruent targets elicited faster RT than incongruent targets ($p = < .0001$, $d = .1.02$) (Figure 24), consistent with prior research demonstrating that the utilisaiton of alerting and orienting cues enhances ANT performance, whereas the existence of flanker-induced conflict diminishes performance (Geva et al., 2013; Posner, 2008).

There was also a significant main effect of session ($F(3, 17868) = 48.92$, $p < .001$), whereby overall RT was faster in the second session than in the first session ($p < .0001$, $d = .16$), suggesting the existence of a significant practice effect on RT-based performance across intervention conditions. There was a significant interaction between session and cue ($F(3, 17869) = 3.14$, $p = .02$), whereby the magnitude of the pre-post RT reduction was slightly weaker for spatial cues ($p = .02$, $d = .12$) relative to the other cue types (*ps* < .0001). A significant interaction was also observed between session and target ($F(1, 17899) = 10.24$, $p = .001$), whereby the magnitude of the pre-post RT reduction was slightly weaker for congruent targets ($p < .01$, $d = .13$) than for incongruent targets ($p < .0001$). However, all observed alerting, orienting and executive effects persisted across sessions (all *ps* < .001), suggesting that practice effects exerted minimal influence upon the functioning of the three attention networks.

Contrary to expectations, there were no significant three-way interactions between session, condition and cue ($F(3, 17869) = .99$, $p = .40$, H2a/H2b) or between session, condition and target ($F(3, 17899) = .02$, $p = .90$, H2c, Figure 25), suggesting that ACT intervention did not facilitate improved alerting, orienting, or executive RT performance during the ANT. In light of the reviewed MBI literature, specifically pertaining to executive function, these results are surprising and are discussed in due course.

Figure 24.

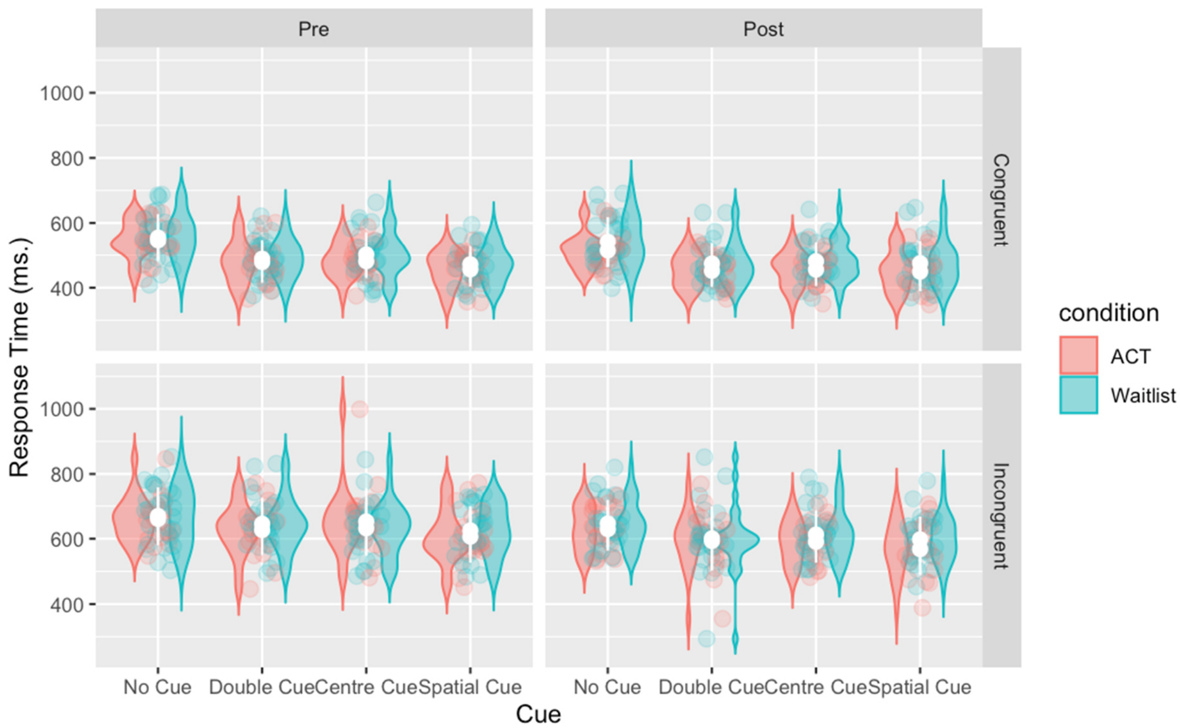
Mean Correct RT (ms) for the Factorial Design; 4 (Cue: No Cue/Double/Centre/Spatial) x 2 (Target: Congruent/Incongruent). Clear Effects of Alerting, Orienting and Executive Stimuli Observed.



Note. Left panel represents congruent targets, right panel represents incongruent targets. White spots represent mean values. Violins represent mirrored density plots and continuous distribution.
Note. Overall difference in RT between congruent and incongruent targets (left and right panels) represents the *executive* network effect (congruent RT faster than incongruent RT *across* cue types). Overall difference in RT between double cue and no cue (sage and pink violins) represents the *alerting* network effect (double cue RT faster than no cue RT *across* target type). Overall difference in RT between spatial cue and centre cue (purple and blue violins) represents the *orienting* network effect (spatial cue RT faster than centre cue RT *across* target type).

Figure 25.

Mean Correct RT (ms) for the Factorial Design; 2 (Session: Pre/Post) x 2 (Condition: ACT/Waitlist) x 4 (Cue: No Cue/Double/Centre/Spatial) x 2 (Target: Congruent/Incongruent).



Note. Left panels represent session 1, right panels represent session 2. Top panels represent congruent targets, bottom panels represent incongruent targets. White spots represent mean values. Violins represent mirrored density plots and continuous distribution.

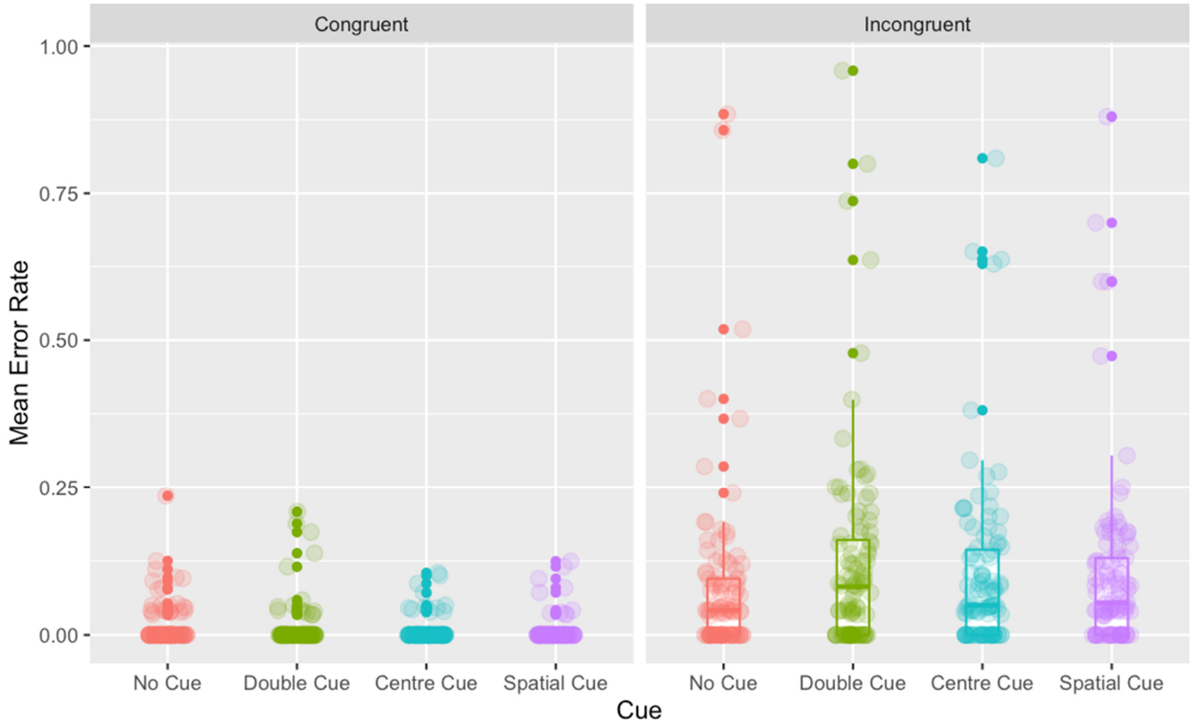
Accuracy. In terms of accuracy, I estimated a generalised linear mixed model for error rates. There was an overall main effect of target on error rates ($\chi2(1, N = 49) = 15.83$, $p < .0001$, $d = .41$) (Figure 26). As expected, there was a higher proportion of errors for incongruent targets (10.2%) than for congruent targets (1.1%), consistent with expected executive function effects on accuracy (Posner, 2008). However, there was no effect of cue

($\chi2(3, N = 49) = .25$, $p = .62$), with similar error rates across cue types (~5%) (Figure 26), inconsistent with expectations that double cues (alerting) and spatial cues (orienting) would result in fewer errors than no cue / central cue conditions (Posner, 2008).

Contrary to predictions, there were no significant three-way interactions between session, condition and cue ($\chi2(3, N = 49) = .70$, $p = .41$, H2a/H2b) or between session, condition and target ($\chi2(1, N = 49) = 2.30$, $p = .13$, H2c), suggesting that ACT intervention did not facilitate improved alerting, orienting, or executive accuracy performance during the ANT. These results are discussed in due course

Figure 26.

Mean Error Rates for the Factorial Design; 4 (Cue: No Cue/Double/Centre/Spatial) x 2 (Target: Congruent/Incongruent). Clear Effect of Executive Stimuli Observed.



Note. Left panel represents congruent targets, right panel represents incongruent targets. Boxplot lines represent median values among lower and upper IQRs (box extremity).

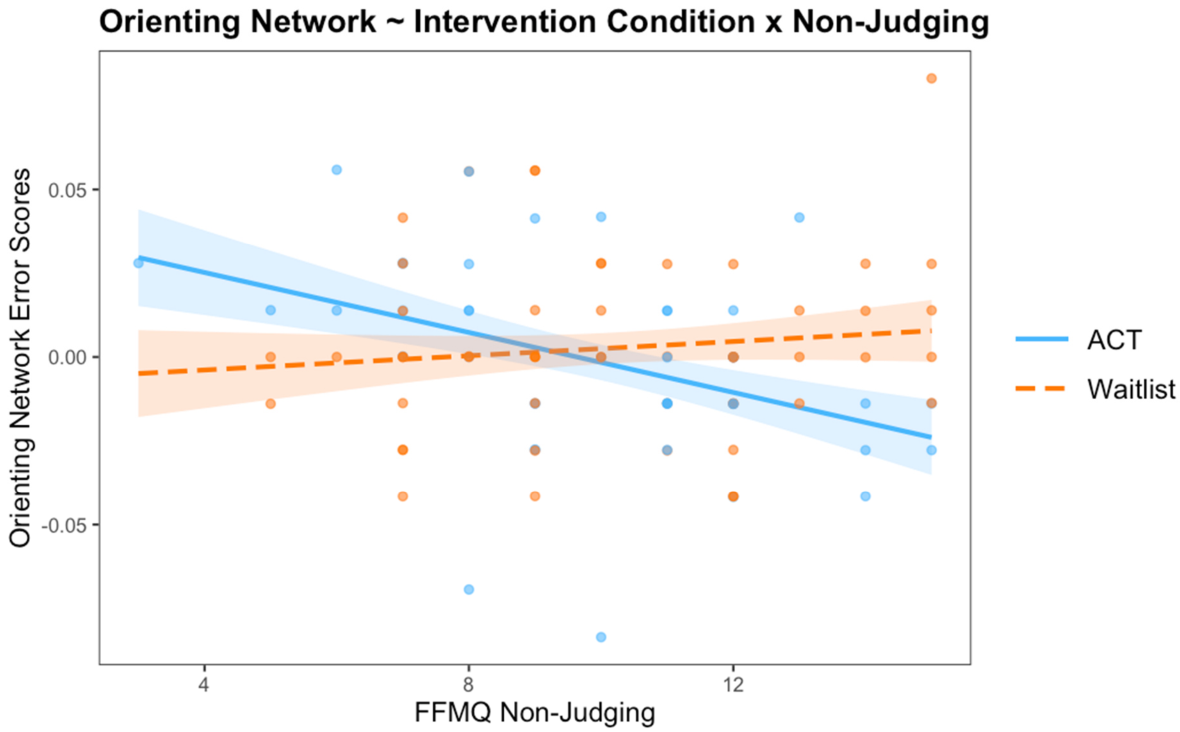
Mindfulness and ANT performance. Next, I explored relationships between self-reported mindfulness and ANT performance outcomes during session 1 (Appendix 4, Table 1). Interestingly, there was a significant positive association between executive network RT scores and FFMQ Awareness ($r = .22$, $p < .05$), indicating that higher levels of awareness were related to longer response latencies (e.g., incongruent target flankers exerted a greater negative effect on ANT RT). There were no additional pertinent associations. In relation to ANT network accuracy (Appendix 4, Table 2), there were no significant relationships observed between mindfulness and alerting, orienting or executive accuracy. These relationships were statistically similar when exploring session 2 outcomes.

Subsequently**,** I conducted a series of mixed models to explore interactions between intervention condition and baseline FFMQ scores on post-intervention network performance, which largely did not reveal interactive effects between intervention and Observing (*all* *ps* > .21), Describing (*all ps* > .20), Awareness (all *ps* > .18), Non-Judging (most *ps* > .18, but see below), Non-Reactivity (*all ps* > .24) and Total FFMQ scores (most *ps* > .31, but see below).

Interestingly (H3c), there was a significant interaction between intervention condition and Non-Judging for orienting network accuracy ($F(1, 45) = 7.74$, $p < .01$, Figure 27), insofar as higher levels of non-judging were associated with improved orienting accuracy if participants had taken part in the ACT programme ($p < .01$) relative to waitlist ($p = .41$), implying an augmentative effect of ACT intervention on the ability to make use of orienting cues for those higher in non-judgment. Similar, albeit weaker, interactive effects were observed for Total FFMQ scores ($F(1, 45) = 4.10$, $p = .04$, Figure 28), suggesting that this effect was also evident when aggregating FFMQ facets.

Figure 27.

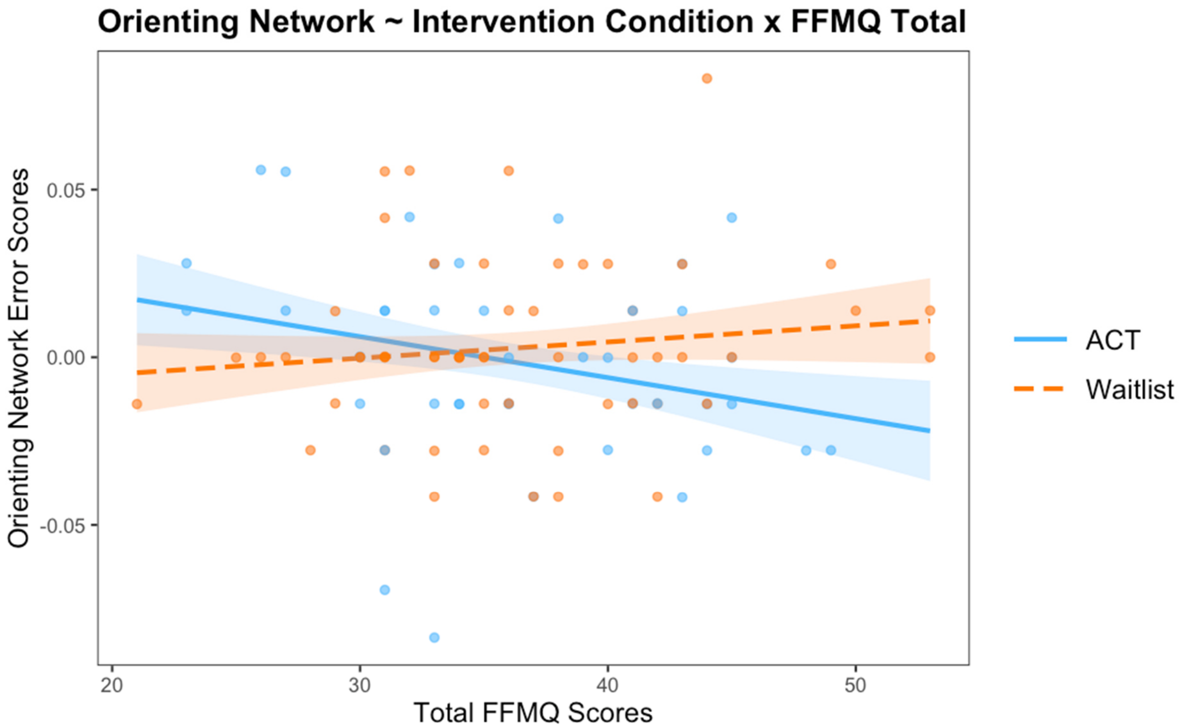
Orienting Network Error Scores as a Function of the Interaction Between Intervention Condition and FFMQ Non-Judging.



Note. Significant negative association between non-judging scores and orienting errors for ACT participants but not for waitlist control group participants. Shaded areas represent 80% confidence bands.

Figure 28.

Orienting Network Error Scores as a Function of the Interaction Between Intervention Condition and Total FFMQ.



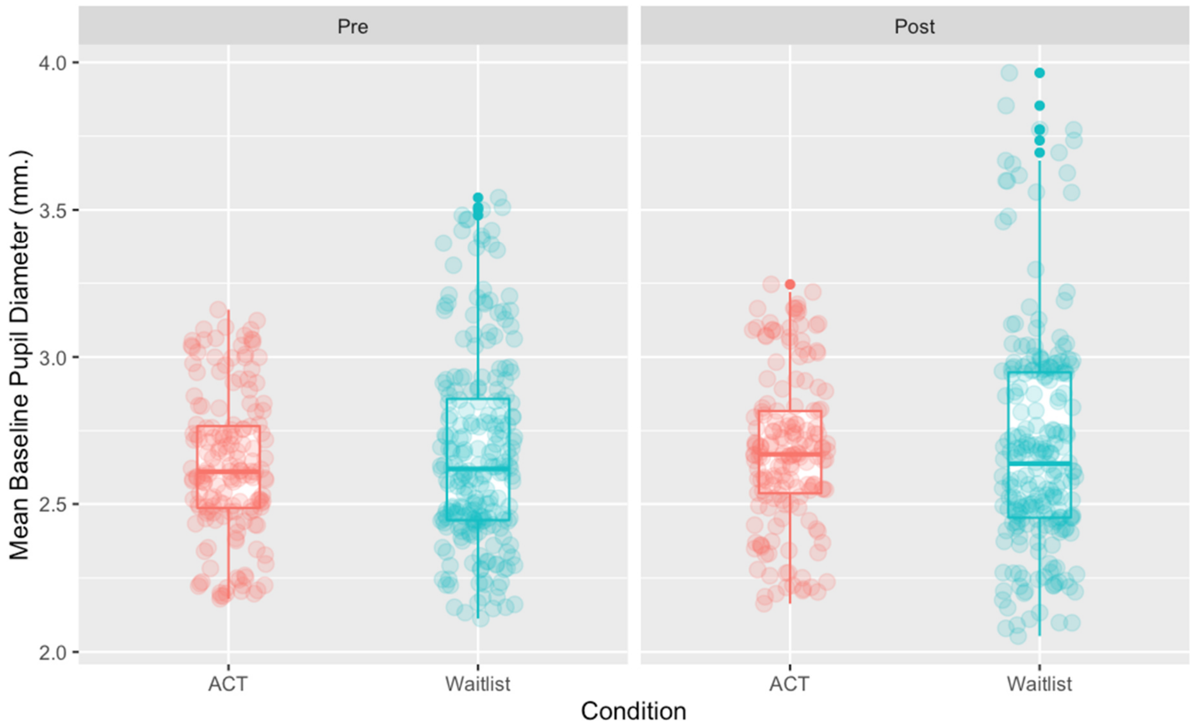
Note. Significant negative association between total FFMQ scores and orienting errors for ACT participants but not for waitlist control group participants. Shaded areas represent 80% confidence bands.

Baseline (Pretrial) Pupil Diameter (bPD). In terms of bPD, I estimated a linear mixed model to examine effects of session, condition and accuracy on bPD throughout the ANT. Against predictions (H4c), there was no significant main effect of session on bPD ($F(1, 50.10) = 1.10$, $p = .30$) and no interaction between session and condition ($F(1, 50.90) = .06$, $p = .80$), suggesting that levels of tonic arousal did not significantly fluctuate between sessions 1 and 2 or as a function of training condition (Figure 29).

Moreover, there was no three-way interaction between session, condition and accuracy ($F(1, 9288.56) = .02$, $p = .90$), suggesting that tonic arousal did not differentiate between correct and incorrect responses (H4a), which in turn was not influenced by session or ACT intervention (Figure 30). Taken together, these results suggest that ACT participation did not impact tonic arousal or accuracy during the ANT.

Figure 29.

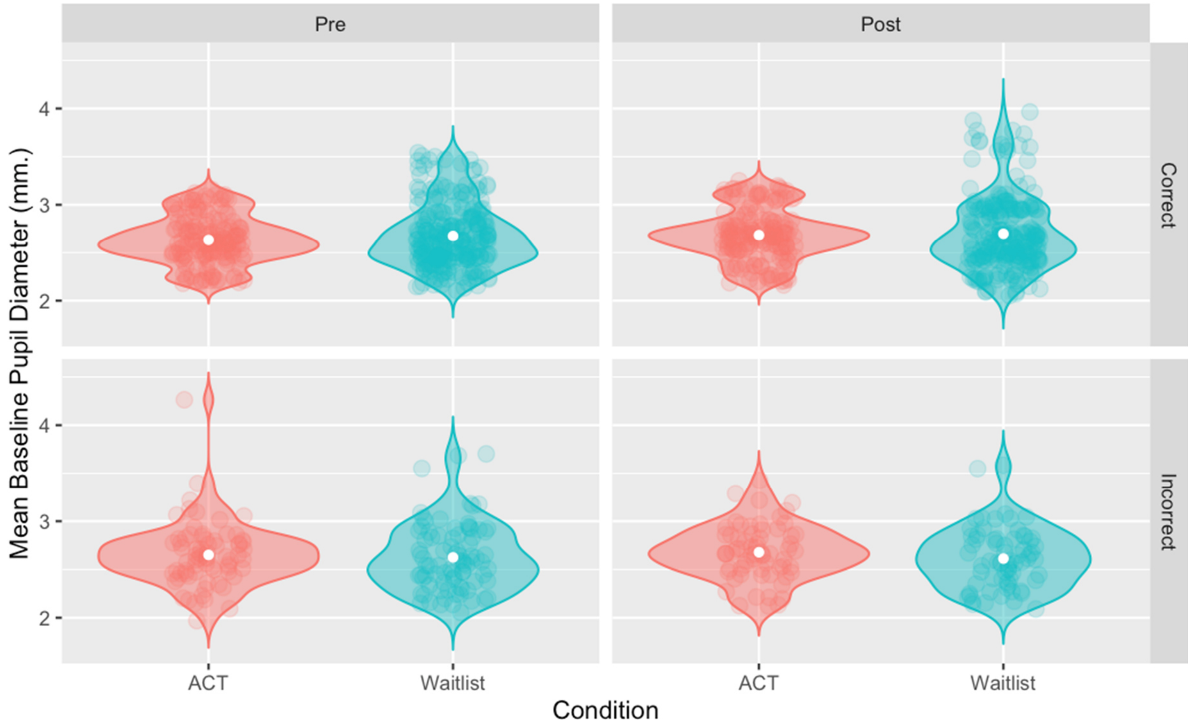
Mean Baseline Pupil Diameter (bPD, mm.) for the Factorial Design; 2 (Session: Pre/Post) x 2 (Condition: ACT/Waitlist).



Note. Left panel represents session 1, right panel represents session 2. Boxplot lines represent median values among lower and upper IQRs (box extremity).

Figure 30.

Mean Baseline Pupil Diameter (bPD, ms.) for the Factorial Design; 2 (Session: Pre/Post) x 2 (Condition: ACT/Waitlist) x 2 (Accuracy: Correct/Incorrect).



Note. Left panels represent session 1, right panels represent session 2. Top panels represent correct responses, bottom panels represent incorrect responses. White spots represent mean values. Violins represent mirrored density plots and continuous distribution.

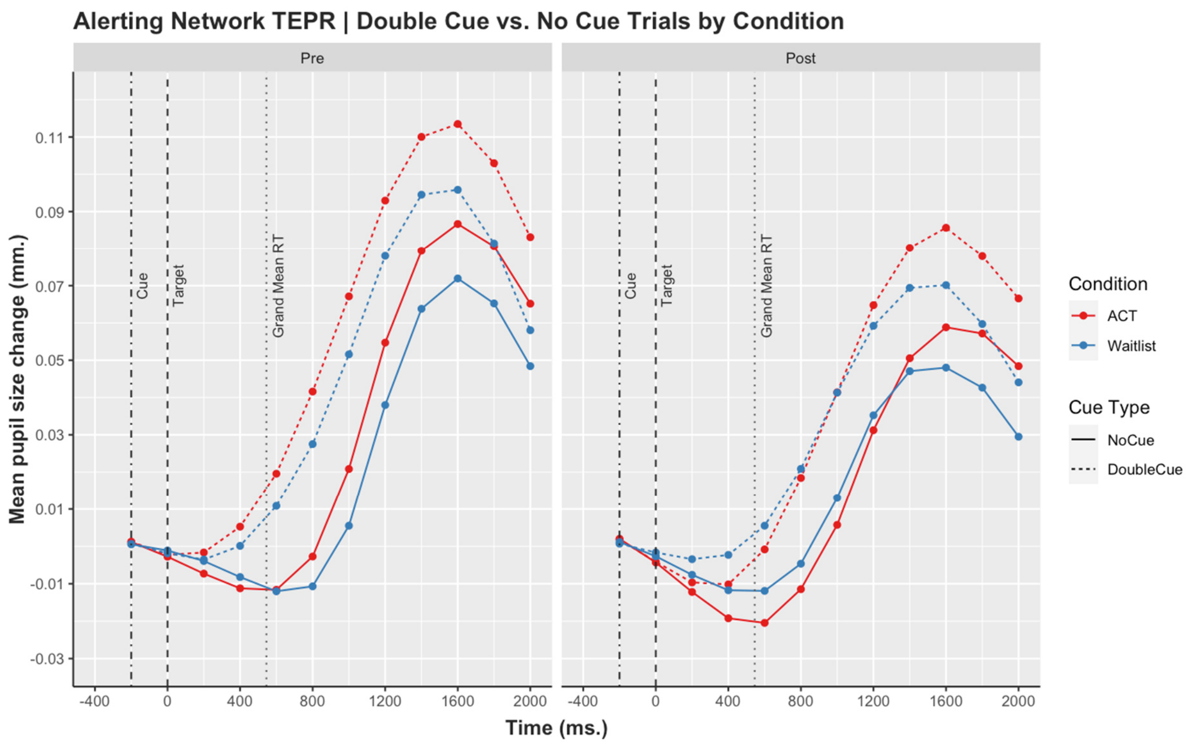
Alerting Task-Evoked Pupillary Responses (TEPR). To analyse subjects' pupil size fluctuations in the alerting network, pupillary trajectories were compared between double cue and no cue trials. Pre-response and post-response time windows were identified utilising the grand mean of RT. LMMs were constructed to explore alerting TEPR across the whole trial period, and for pre/post-response time periods, necessitating the inclusion of session, intervention condition, cue type and trial epoch (pre, post) in final models.

As expected (H5a), there was a main effect of cue type on TEPR trajectories for the full trial period in both sessions and training conditions ($F(1, 47.84) = 44.35$, $p < .001$, $d = .59$, Figure 8), insofar as double cues initiated greater TEPR than no cue conditions. This finding replicates prior endeavour evidencing a pupillary alerting response in the presence of non-specific warning stimuli (Geva et al., 2013). There was also a main effect of trial epoch ($F(1, 47.95) = 7.15$, $p = .01$, $d = .20$), insofar as post-response pupils were larger than pre-response pupils. However, visually inspecting TEPR trajectories (Figure 31) revealed that the alerting response was underway prior to motor responses being executed, directly resulting in greater magnitudes of post-response pupil size for double cue trials, thus further supporting previous findings evidencing pre-response initiation of alerting patterns (Geva et al., 2013). Interestingly, there was also a main effect of session ($F(1, 48.09) = 10.19$, $p < .01$, $d = .31$), insofar as session 2 whole-trial TEPR was smaller than session 1 whole-trial TEPR across cue types and intervention conditions, suggesting a diminished arousal response in both double cue and no cue conditions as a function of time, likely resulting from ANT practice.

However, contrary to expectations (H5b), there was no interaction between session and condition ($F(1, 48.09) = 1.72$, $p = .20$), implying that ACT intervention exerted no effects on arousal during the alerting network. All other two-way and three-way interactions were non-significant (all $ps > .23$).

Figure 31.

Baseline-Corrected TEPR as a Function of Alerting Condition.



Note. Left panel represents session 1, right panel represents session 2. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Double cue and no cue pupillary trajectories displayed over pertinent trial events (vertical lines), split into 100ms time bins (400ms increments displayed for clarity).

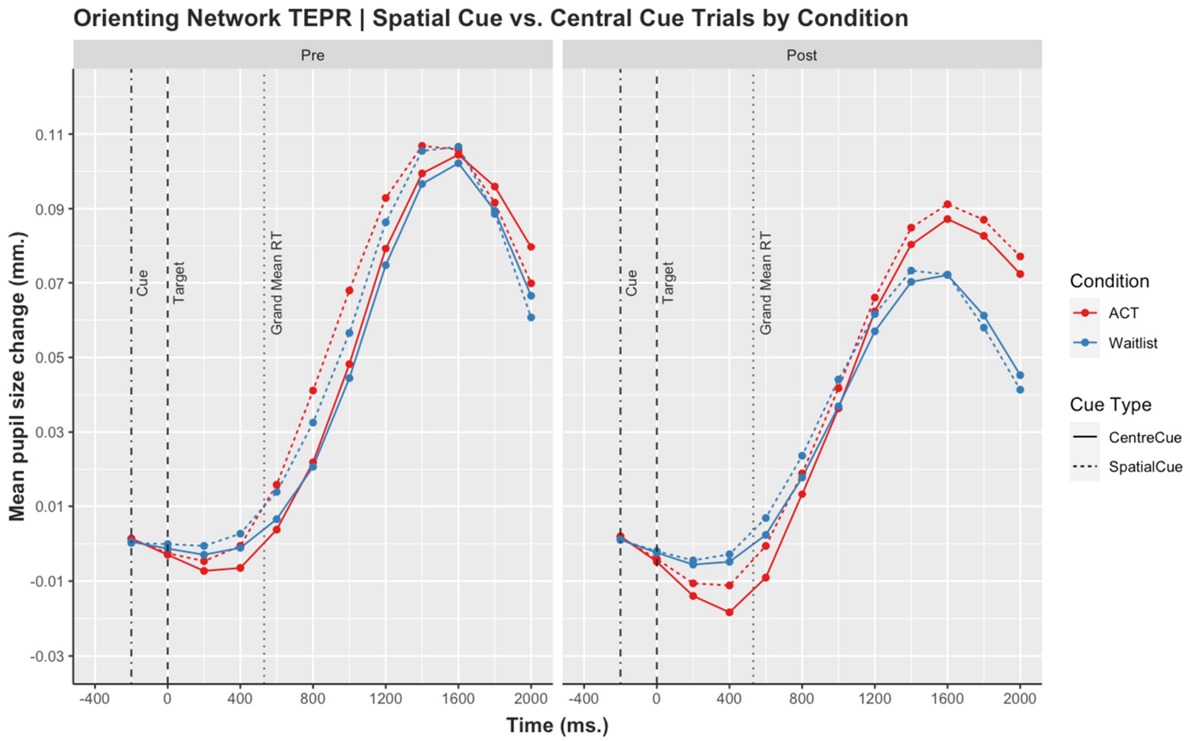
Orienting TEPR. To analyse subjects' pupil size fluctuations in the orienting network, pupillary trajectories were compared between spatial cue and central cue trials. LMMs were constructed to model effects of session, intervention condition, cue type and trial epoch (pre, post). As expected (H6a), there was a main effect of cue type on TEPR trajectories for the full trial period across sessions and training conditions ($F(1, 287.28) = 4.29$, $p = .04$, $d = .11$, Figure 32), insofar as spatial cues initiated greater TEPR than central cues. This finding replicates prior endeavour evidencing a pupillary orienting response in the presence of spatially informative warning stimuli (Geva et al., 2013). Interestingly, there was also a main effect of session ($F(1, 47.98) = 23.58$, $p < .001$, $d = .43$), insofar as session 2 whole-trial TEPR was smaller than session 1 whole-trial TEPR across cue types and intervention conditions, suggesting a diminished arousal response in both spatial cue and central cue conditions as a function of time, potentially as a result of ANT practice.

However, contrary to expectations (H6b), there was no interaction between session and condition ($F(1, 47.98) = .07$, $p = .79$), implying that ACT intervention exerted no effects on arousal during the orienting network. All additional two-way and three-way interactions were non-significant (all $ps > .18$), suggesting that visual differences in TEPR between intervention conditions in the post-response epoch of session 2 (Figure 32) were not statistically meaningful ($p = .46$).

Executive TEPR. To analyse subjects' pupil size fluctuations in the executive network, pupillary trajectories were compared between congruent and incongruent target trials. LMMs were constructed to model effects of session, intervention condition, target type and trial epoch (pre, post) in final models. As expected (H7a), there was a main effect of target type on TEPR trajectories for the full trial period across sessions and training conditions ($F(1, 283.96) = 23.93$, $p < .001$, $d = .37$, Figure 33), insofar as incongruent targets initiated greater TEPR than congruent targets. This finding replicates prior endeavour evidencing a pupillary executive response in the presence of environmental conflict (Geva et al., 2013) and suggests greater post-response allocation of attentional and cortical resources (Donohue et al., 2018). There was also a strong main effect of session ($F(1, 48.12) = 29.85$, $p < .001$, $d = .51$), insofar as session 2 TEPR was smaller than session 1 TEPR, suggesting a highly diminished arousal response in both congruent and incongruent target conditions as a function of time, potentially as a result of ANT practice. There was also a main effect of epoch ($F(1, 283.96) = 9.44$, $p < .01$, $d = .22$), whereby post-response TEPR was larger than pre-response TEPR across target types and intervention conditions, further replicating prior results demonstrating post-response arousal peaks following responses to executive targets (Geva et al., 2013).

Figure 32.

Baseline-Corrected TEPR as a Function of Orienting Condition.



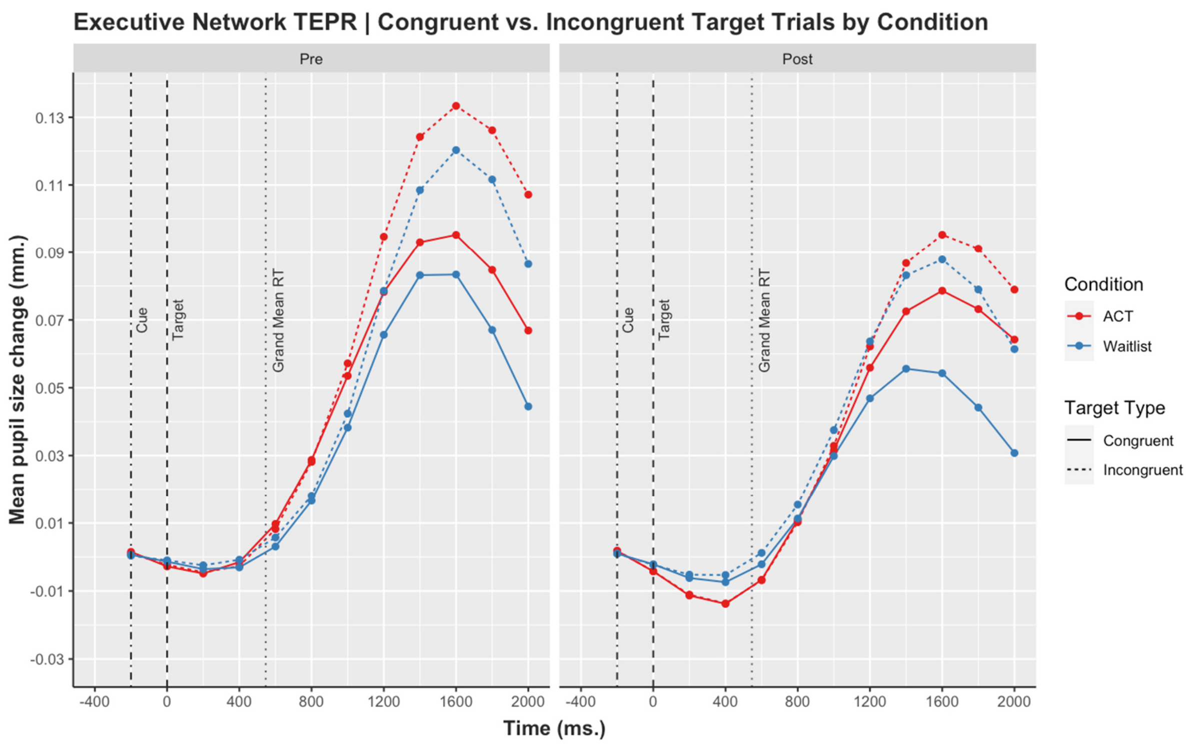
Note. Left panel represents session 1, right panel represents session 2. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Spatial cue and central cue pupillary trajectories displayed over pertinent trial events (vertical lines), split into 100ms time bins (400ms increments displayed for clarity).

However, contrary to expectations (H7b), there was no interaction between session, conditions and target ($F(1, 48.12) = 1.45$, $p = .23$), implying that ACT intervention exerted no effects on arousal during the executive network. All other two-way and three-way interactions were non-significant (all *ps* > .11), suggesting that visual differences in TEPR between intervention conditions and sessions in post-response epochs (Figure 33) were not statistically meaningful.

Mindfulness and ANT TEPR. Next, I explored relationships between self-reported mindfulness and TEPR for each ANT network during session 1. Contrary to expectations (H8a, H8b, H8c), there were no significant associations between facets of the FFMQ and alerting, orienting or executive TEPR scores (Appendix 4, Tables 3 and 4), suggesting that mindfulness was not related to network-induced arousal in the present study. Exploring associations in session 2 produced statistically similar results.

Figure 33.

Baseline-Corrected TEPR as a Function of Executive Condition.



Note. Left panel represents session 1, right panel represents session 2. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Congruent target and incongruent target pupillary trajectories displayed over pertinent trial events (vertical lines), split into 100ms time bins (400ms increments displayed for clarity).

Subsequently, I conducted a series of mixed models to explore interactions between intervention condition and baseline FFMQ scores on post-intervention TEPR (H9a, H9b, H9c), which revealed no interactive effects between intervention and Observing (all *ps* > .22), Describing (all *ps* > .27), Awareness (all *ps* > .20), Non-Judging (all *ps* > .45), Non-Reactivity (all *ps* > .62) or Total FFMQ scores (all *ps* > .23), suggesting that baseline levels of mindfulness were not differentially related to levels of network-induced arousal during the ANT as a function of intervention condition.

The Sustained Attention to Response Task with Thought Probes (SARTp)

Response Latencies. Turning to the SARTp analyses, I estimated a linear mixed model for 'Go' trial RT data as a function of session and condition. Contrary to predictions (H2d), there was no interaction between session and condition ($F(1, 46.96) = .03$, $p = .86$), suggesting that ACT intervention exerted no impact on 'Go' trials RT throughout the SART. However, vigilance during tasks of sustained attention is most reliably observed using accuracy outcomes (Lao et al., 2016), so error rates for both 'Go' (misses) and 'NoGo' trials (false alarms) were modelled as a function of session and condition.

Accuracy. Against expectations (H2d), there was no interaction between session and condition for error rates ($\chi2(1, N = 49) = .90$, $p = .34$), suggesting that ACT intervention exerted no effects on SART accuracy. Moreover, the interaction between session, condition and trial type was non-significant ($\chi2(1, N = 49) = .94$, $p = .33$), illustrating that the lack of an intervention effect was not dependent on whether sustained accuracy required the commission or inhibition of motor responses. As expected, error rates were higher for the rare inhibition trials (NoGo) than for the common motor response trials (Go) ($\chi2(1, N = 49) =

178.80, $p < .001$, $d = 1.40$), indicating that participants generally found it more difficult to withhold prepotent responses than to commit to consistent motor responses.

Baseline (Pretrial) Pupil Diameter (bPD). In terms of bPD, I estimated a linear mixed model to examine effects of session, condition and accuracy on bPD throughout the SART. As expected, there was a significant main effect of accuracy on bPD across sessions and conditions (H4a) ($F(1, 43.84) = 25.69$, $p < .001$, $d = 25$), insofar as bPD prior to incorrect trials was larger than bPD prior to correct trials.

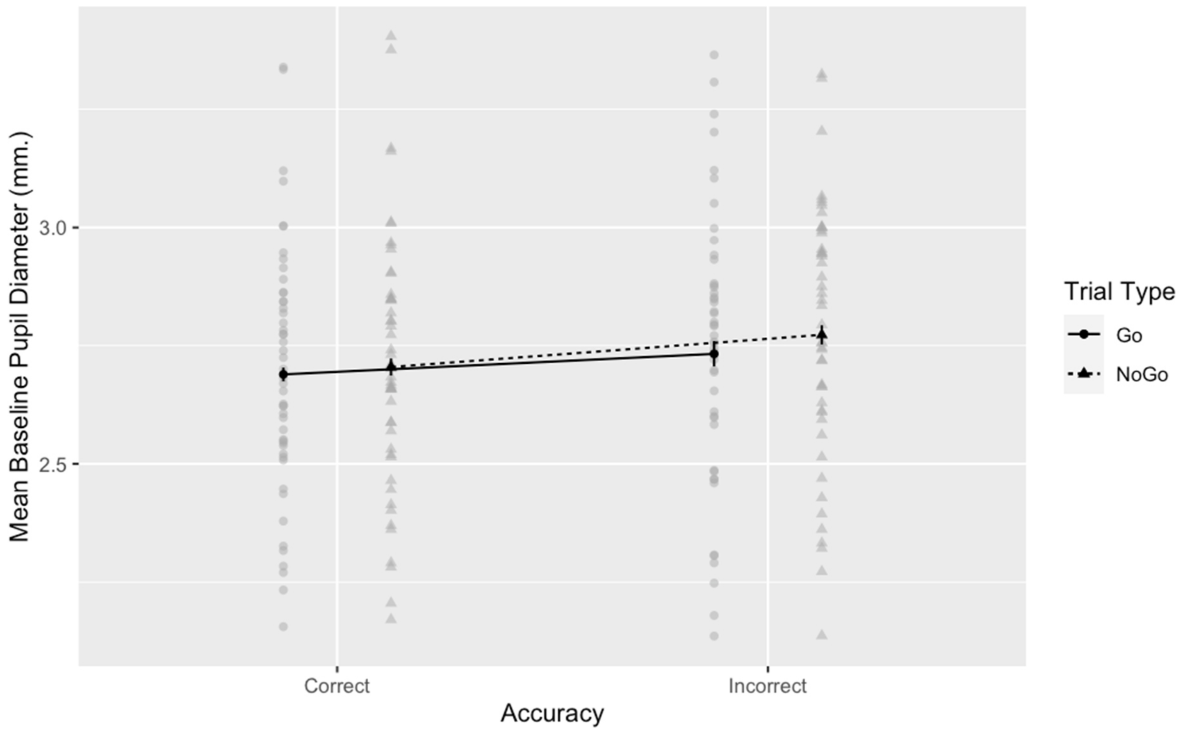
The significant two-way interaction between trial type and accuracy ($F(1, 13619.47) = 5.26$, $p = .02$) revealed that bPD was larger for incorrect NoGo trials than for incorrect Go trials ($p < .01$, Figure 36), suggesting that failures to inhibit prepotent responses were preceded by higher levels of tonic arousal than failures to commit motor responses.

Against predictions (H4c), there was no interaction between session and condition ($F(1, 48.09) = .05$, $p = .82$), suggesting that levels of tonic arousal did not significantly fluctuate between sessions 1 and 2 as a function of intervention. Moreover, exploring bPD as a function of session, condition, accuracy and trial type did not reveal significant three-way or four-way interactions, suggesting that ACT intervention had no effect on bPD, regardless of whether responses were accurate or inaccurate. Taken together, these results suggest that ACT participation did not impact tonic arousal or accuracy during the SART.

Figure 36.

Mean Baseline Pupil Diameter (bPD, ms.) for the Factorial Design; 2 (Trial Type:

Go/NoGo) x 2 (Accuracy: Correct/Incorrect).



Note. Mean values and within-subject error bars displayed as points and vertical lines respectively.

Thought Probes. Next, I examined mean response rates for each thought probe as a function of session and condition. There was a significant main effect of probe type across sessions and conditions on mean number of responses within each probe category (F(6, 42.02) = 12.43, p < .001). Overall, participants reported more thoughts indicating on-task focus than those indicating task-related interference (TRI) (p < .001 , d = 56), past-oriented mind wandering (pastMW) (p < .001, d = .59), present-oriented mind wandering (presentMW), (p < .0001, d = 87), external distraction (ED) (p < .01, d = .50), but not future-oriented mind wandering (futureMW) (p = .13, d = .32) or non-alertness (NA) (p = .98, d = .08), suggesting that participants were largely focused on the SARTp task. However, participants also reported more instances of NA than TRI ($p < .0001$, $d = .74$), pastMW ($p < .0001$, $d = .75$), presentMW ($p < .0001$, $d = 1.11$), ED ($p < .001$, $d = .64$) and futureMW ($p = .02$, $d = .45$), suggesting that the repetitive nature of the SART exerted detrimental effects on the ability to remain alert throughout the task. Finally, participants reported more futureMW than presMW ($p = .03$, $d = .75$) but not pastMW ($p = .38$, $d = .35$), suggesting that task-unrelated thoughts about the past and future were the most common species of mind wandering throughout the task. Overall rates of on-task thought, futureMW and NA were broadly similar, suggesting that participants spent the majority of their time either engaged in the task, thinking about the future or experiencing non-alertness.

The three-way interaction between session, condition and probe type was not significiant ($F(6, 324.12) = 1.85$, $p = .08$, Figure 38), implying no effects of intervention on thought reports during the SART. Due to the number of comparisons necessary as a result of the aggregate mean probe response model, generalised linear mixed models were utilised on non-aggregated binomial thought probe data to explore likelihoods of reporting each thought probe in relation to all other possible responses as a function of intervention condition. Consistent with expectations (H2e) and visualised outcomes (Figure 38), there was a highly significant interaction between session and condition for on-task thoughts ($\chi 2(1, N = 49) = 16.81$, $p < .0001$), manifesting in a trending pre-post session increase in on-task reports for the ACT group ($M = .36$, $SE = .15$, $p = .07$, $d = 11$; odds ratio $_{\text{session 1 versus session 2}} = 1.43$ (95%CI[.98, 2.10]) but a significant pre-post session reduction in on-task reports for the Waitlist group ($M = -.45$, $SE = .13$, $p < .01$, $d = 14$; odds ratio $_{\text{session 1 versus session 2}} = .64$ (95%CI[.45, .90]). This suggests that those who did not receive ACT intervention were more likely to exhibit reduced task focus during the SART than those who'd received intervention.

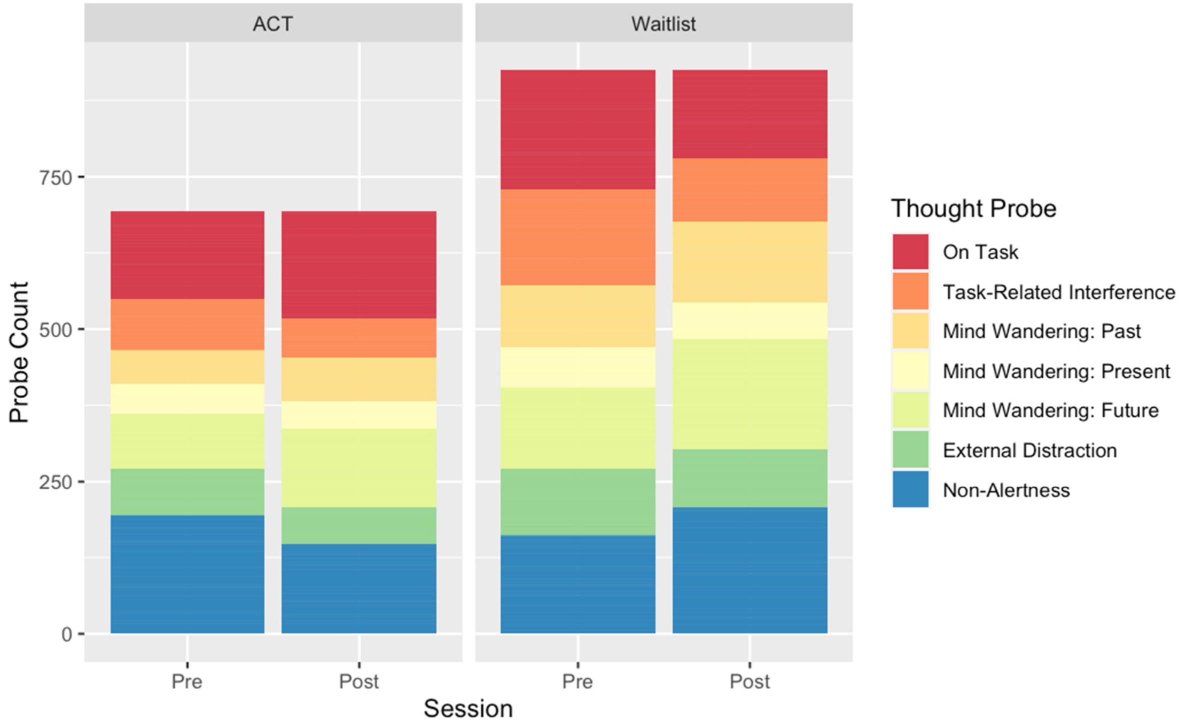
Moreover, there was a highly significant interaction between session and condition for non-alertness ($\chi 2(1, N = 49) = 19.65$, $p < .0001$), manifesting as a significant pre-post session reduction in non-alertness reports for the ACT group (M = -.44, SE = .14, $p < .01$, d = 16; odds ratio $_{\text{session 1 versus session 2}}$ = .64 (95%CI[.45, .91]) but a pre-post session increase in non-alertness reports for the Waitlist group (M = .39, SE = .13, p = .01, d = 13; odds ratio $_{\text{session 1 versus session 2}}$ = 1.47 (95%CI[1.10, 2.04]), suggesting that ACT intervention enhanced the ability to remain alert during the SART, whereas alertness waned over time for those who did not receive ACT. All remaining two-way interactions were non-significant (all $ps > .55$).

Taken together, these findings demonstrate that participation in the ACT intervention may have exerted weak effects on alertness during a novel version of a widely used and reliable test of sustained attention.

Figure 38.

Visualising Probe Counts for Each Level of Thought Probe, Session and Intervention

Condition.



Mindfulness and Thought Probes. Next, I explored relationships between self-reported mindfulness and probe response outcomes during session 1. Against expectations (H3b), there was a significant negative association between FFMQ Non-Reactivity and on-task thoughts ($p < .05$, Appendix 4, Table 5), indicating that higher levels of non-reactivity were related to reduced task focus during the SARTp. There were no additional significant associations.

Next, I conducted a series of mixed models to explore interactions between intervention condition and baseline FFMQ scores on post-intervention network performance, which revealed no interactive effects between intervention condition and Observing (*all ps* > .16), Describing (*all ps* > .35), Awareness (all *ps* > .19), Non-Judging (all *ps* > .23), Non-Reactivity (*all ps* > .17) and Total FFMQ scores (all *ps* > .29), suggesting that baseline levels of mindfulness were not differentially related to specific thought probe responses during the SART as a function of intervention condition.

Thought Probes and bPD. Partly in line with expectations (H4b), exploring bPD as a function of session, condition and probe type revealed a marginally significant main effect of probe type on bPD ($F(6, 392.10) = 2.19$, $p = .04$, Figure 39), manifesting as larger bPD prior to reports of external distraction than to reports of present-oriented mind wandering ($p = .02$, $d = .21$), suggesting that external distractibility was associated with greater levels of bPD-inferred arousal than thoughts about one's actions in the present moment. All other main effects (all *ps* > .63) and interactions (all *ps* > .37) were non-significant, suggesting that bPD-inferred tonic arousal did not differentiate between remaining thought probe responses.

Summary of Results

Contrary to expectations, ACT implementation exerted weak effects on self-reported mindfulness and appeared to have limited effect on on-task relative to off-task thought processes. Moreover, task performance and pupillary-inferred arousal states were unaffected by the programme, raising important questions about the conceptualisation of mindfulness-based interventions as (a) attentional training processes and (b) tools for nurturing vigilance and wakefulness in non-clinical populations. By extension, these results necessitate a careful evaluation of the potency of the selected intervention for inducing such changes. A comprehensive discussion based on these results and associated implications are located in Chapter 7.

Study 5: Mindfulness-Based Cognitive Attention Training (MBCAT) Exerts Limited Influence on Vigilance and Arousal, with No Impact on Alerting, Orienting or Executive Function

Overview

In the present experiment, I build on Study 4 by examining the attentional and psychophysiological effects of a novel mindfulness-based training programme (MBCAT), explicitly developed to include greater amounts of in-session guidance than the ACT programme and delivered by the PI - a trained MBCT facilitator, as opposed to practitioners with only psychoeducation experience. In this way, the MBCAT was more closely aligned with the most consistently employed intervention in the MBI literature (MBCT). I also implemented a unique extension of the ANT (ANTI-V), which incorporates a more clearly defined assessment of alerting and orienting than the ANT and a richer array of vigilance outcomes within one task, in accordance with calls to extend MBI and mindfulness research into more comprehensive ANT-based evaluations (Di Francesco et al., 2017; van den Hurk, 2011). It was hoped that by implementing a *guided* mindfulness-based programme specifically developed for the present research, in conjunction with a more comprehensive assessment of alerting, orienting and vigilance in the extended ANT, it would offer greater opportunities to observe expected effects of mindfulness intervention on sustained attention, executive control and arousal-based signatures of LC-NA activity throughout the task. In this way, it was hoped that expected findings would provide novel support for emerging conceptualisations of mindfulness as a trainable capacity for alertness and wakefulness in relation to distinct arousal states.

Hypotheses

I predicted that MBCAT delivery would enhance self-reported mindfulness (H1a), consistent with extant MBI literature (Giannandrea et al., 2019; Shahar et al., 2010; van den Hurk et al., 2012; Verhoeven et al., 2014). Moreover, I hypothesised that MBCAT participation would exert improvements in psychological health (H1b), consistent with prior observations that MBCT / MBSR participation improves general mental wellbeing (Solati et al., 2017). I also predicted that dispositional mindfulness would be associated with improved psychological health and that MBCAT would interact with mindfulness to exert beneficial psychological effects (H1c), consistent with prior research evidencing similar results (Orzech et al., 2009; Pots et al., 2014).

In terms of attentional outcomes, I predicted that MBCAT participation would enhance alerting (H2a), orienting (H2b) and executive behavioural performance (H2c/d), consistent with research showing beneficial effects of MBIs on sustained attention, alerting, orienting and executive behavioural processes (Yakobi, Smilek & Danckert, 2021; Gallant, 2016; Lao et al., 2016; Verhoeven et al., 2014). Turning to the vigilance component of the ANTI-V, I predicted that MBCAT participation would enhance signal sensitivity (H2e), in line with existing literature demonstrating enhanced signal detection as a result of mindfulness training in domains of visual and somatic perception (MacClean et al., 2010; Miram et al., 2013). Finally, I hypothesised that self-reported mindfulness would exhibit beneficial associations with ANTI-V attentional outcomes, moderating the effects of MBCAT (H2f).

In relation to arousal-based outcomes, due to the utility of baseline pupil diameter (bPD) measurements to reflect changes in vigilance and sustained attention (Aston-Jones and Cohen, 2005; Unsworth & Robison, 2016, 2018; Gilzenrat et al., 2010), I predicted that expected improvements in MBCAT performance during the ANTI-V would be accompanied by distinct changes in bPD relative to active controls (H3). Moreover, due to the specificity of task-evoked pupillary responses (TEPR) in the inference of task-related LC-NA processes (Aston-Jones and Cohen, 2005; Geva et al., 2014; Kahneman, 1973), I predicted that alerting, orienting and executive networks would display distinct TEPR signatures, thus replicating prior research and the findings of Chapter 4 (H4a, H5a, H6a) (Geva et al., 2013). Moreover, I hypothesised that such TEPR components would be influenced by training condition, insofar as MBCAT would result in greater pre-response TEPR indicative of preparatory alertness in line with the expectations of Chapter 2 (e.g., emerging from enhanced mindful awareness), but reduced post-response TEPR indicative of diminished cognitive reactivity toward motor response to incongruency (e.g., emerging from greater acceptance of distractors and associated responses). Such results would be broadly consistent with neurocognitive literature in the area evidencing enhanced activity in tonic alertness related brain areas as a result of MBIs (H4b, H5b, H6b) (Fortenbaugh et al., 2017; Totah et al., 2009; Wu et al., 2017; Fox et al., 2014; Tang et al., 2015; Norris et al., 2018; Schoenberg, 2014; Holzel et al., 2011; Singleton et al., 2014) and contribute to the broader aims of the thesis in relation to arousal-based outcomes of mindfulness-based training.

Method[33]

Participants

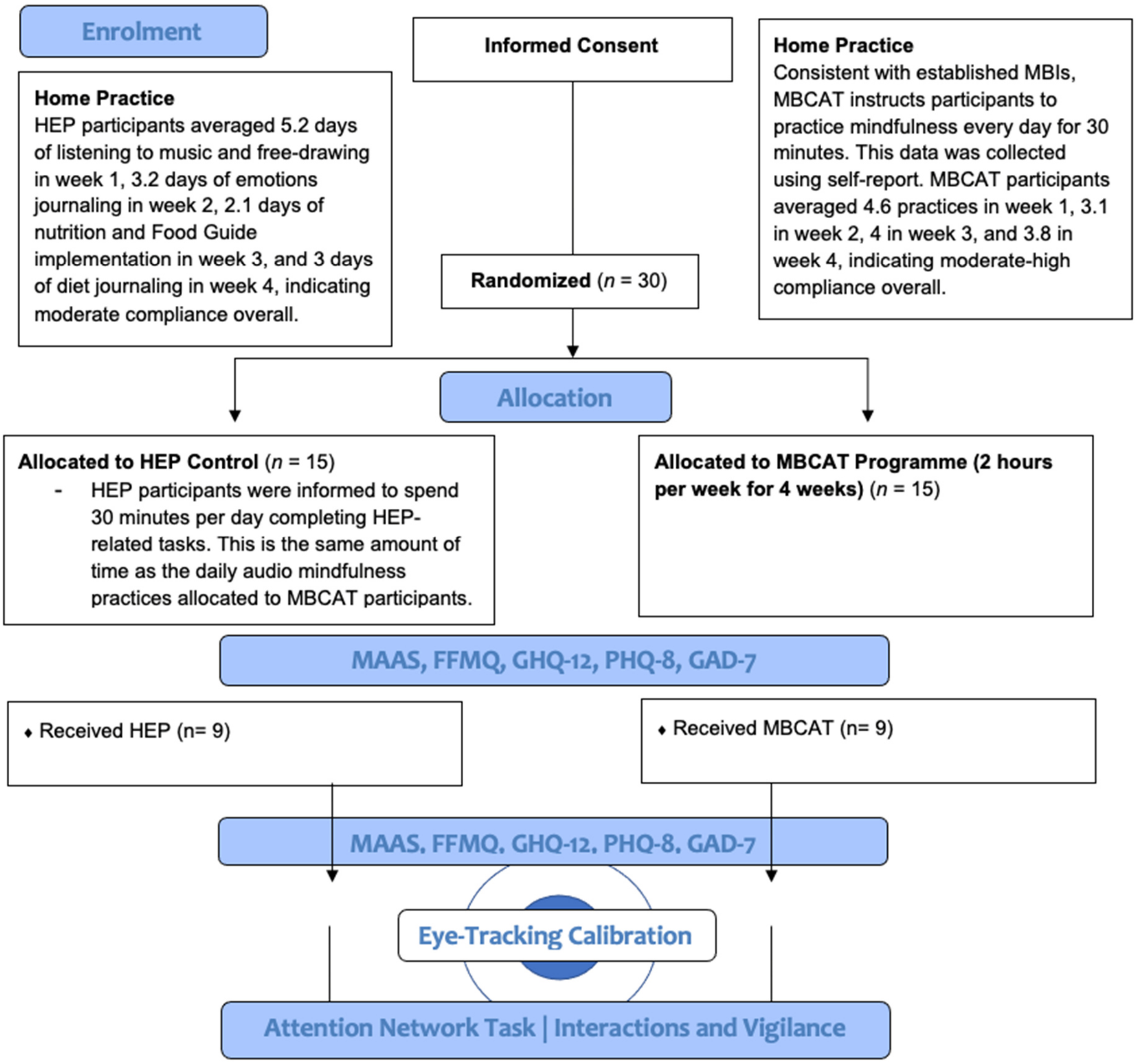
Cardiff University students were recruited for the study via the Experimental Management System (EMS), receiving course credit as reward for their participation. Other recruitment methods included advertisements distributed through existing mailing lists, posters distributed around university buildings and social media sites accessed by university students (i.e. Facebook, Yammer, Twitter) (Appendix 3A outlines examples of flyers utilised). Due to the inclusion of eye-tracking methods, only participants with normal or corrected vision were invited to take part. No additional exclusion criteria applied. Students registering their interest were sent an information sheet about the study and their rights as a participant. The nature of this group-based intervention necessitated a maximum of 30 recruited participants, 15 of which were allocated to the MBCAT condition and 15 to the Health Enhancement Programme (HEP) control condition. Most research on the efficacy of mindfulness-based interventions encompasses studies utilising these group sizes (Schroevers et al. 2016; van den Hurk et al., 2012). All active control group participants were given the option to be automatically enrolled onto the next wave of MBCAT. Of the 15 participants allocated to MBCAT, five withdrew prior to commencing the training and one participant withdrew after the first session, resulting in a programme retention rate of 90%. Of the 15 participants allocated to the HEP control condition, six participants withdrew prior to the first week of feedback and did not respond to study prompts. No reasons were given for participation cessation in either of the conditions. The final sample was heavily skewed by gender, with just 1 male (5.5%). Most participants were undergraduate students (83%), with 2

[33] See Appendix 0ii: 'Overview of Procedures and Data Preparation' for details pertaining to eye-tracker calibration, generalised experimental protocol and behavioural / pupillary pre-processing techniques.

postgraduates and 1 full-time worker. All participants were aged between 18 and 25 (M_{age} = 20.6 [SD = 2.30]). Figure 41 outlines the CONSORT diagram detailing the flow of participants through the study.

Figure 41.

CONSORT Participant Flow Diagram for Phases of Parallel Randomised Control Trial Comparing MBCAT with Active HEP Controls.



Materials and Procedure[34]

To test hypotheses pertaining to the effects of MBCAT on self-reported mindfulness and psychological wellbeing, the following measures were incorporated and administered at pre-training and post-training time points (Cronbach's alpha for each measure displayed in parentheses).

FFMQ (Baer et al. 2008). In the present study, alpha coefficients for total FFMQ scores were good at pre-training (α=.82) and acceptable at post-training (α=.77).

MAAS (Brown and Ryan, 2003). In the present study, alpha coefficients for the sample were good at pre-training (α=.89) and at post-training (α=.82).

The General Health Questionnaire 12 (GHQ-12, Goldberg et al. 1997). The GHQ-12 was administered to screen for symptoms of general psychological distress. In the present study, alpha coefficients for the GHQ-12 were good at pre-training (α=.88) and post-training (α=.84).

Patient Health Questionnaire 9 (PHQ-9, Kroenke et al., 2009). The PHQ-9 measures symptoms of depression during the previous two weeks. Higher scores represent greater depressive symptoms. In the present study, alpha coefficients for the PHQ-9 were satisfactory at pre-training (α=.76) and good post-training (α=.82).

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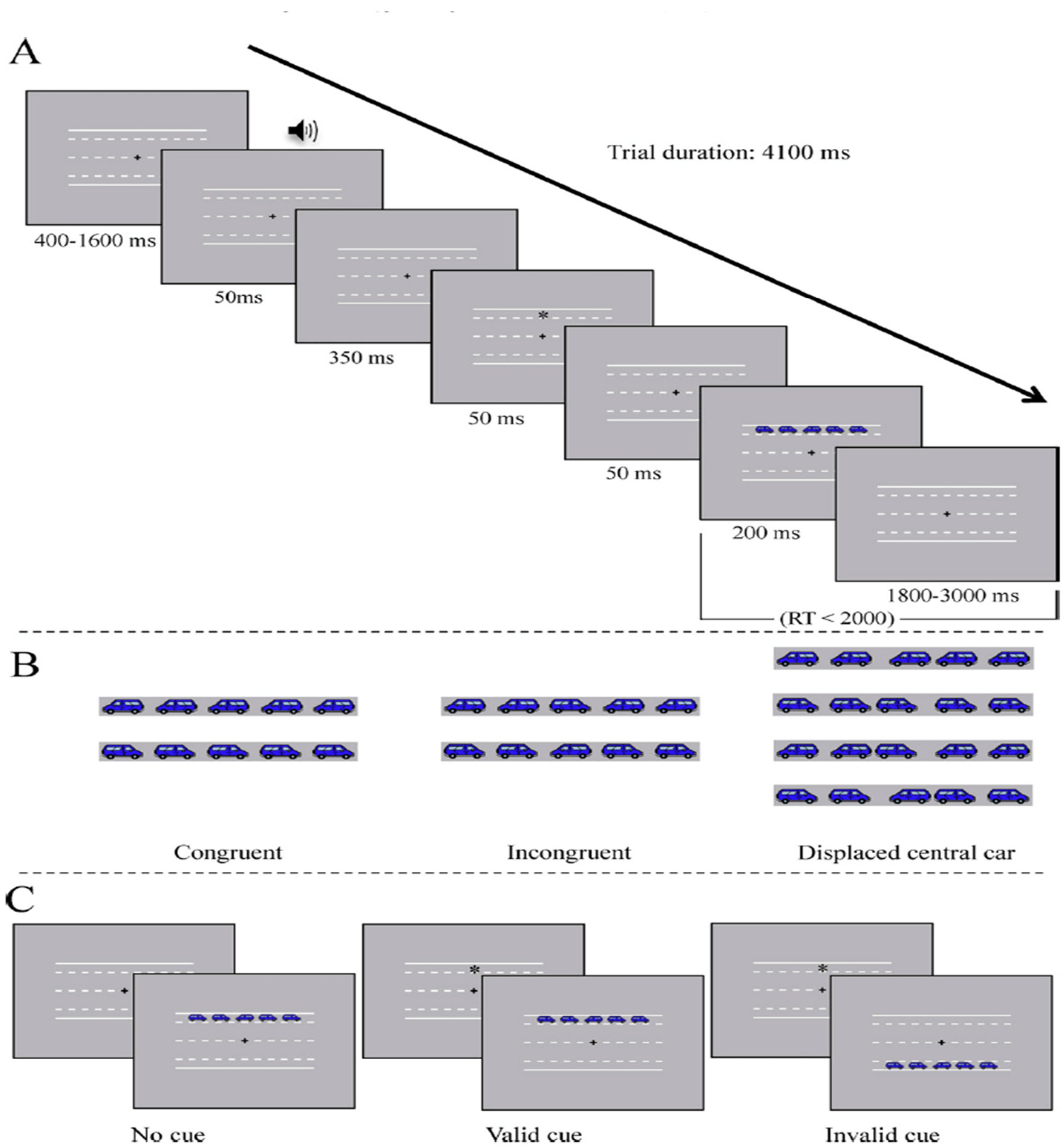
[34] See Appendix 0i: 'Overview of Self-Report Measures' for full details pertaining to the mindfulness and psychological wellbeing measures employed throughout this thesis.

Generalised Anxiety Disorder Scale 7 (GAD-7, Spitzer et al., 2006). The GAD-7 assesses participant anxiety levels during the previous two weeks. Higher scores represent greater anxiety. The GAD-7 showed strong reliability at pre-training (α=.85) and at post-training (.81).

Attention Network Task with Interactions and Vigilance (ANTI-V) (Roca et al., 2011). In this study, participants were tested using the ANTI-V (Figure 42), an amended version of the original ANT (Fan et al. 2002) with the inclusion of additional stimuli allowing for a greater distinction between alerting and orienting networks (Callejas, Lupiáñez, and Tudela 2004) and for the direct measurement of tonic vigilance (Roca et al. 2011). The task was described as a game to participants, whereby they imagined they were working in a Traffic Management Centre where driver's parking habits were being studied. Like the ANT, the ANTI-V is a robust and validated 'flanker task' (using pictures of cars instead of arrows for targets and flankers) that simultaneously measures sustained attention and attentional control through an evaluation of alerting, orienting and executive networks. The background road and fixation point appeared prior to the first trial commencing and remained visible throughout the experiment (Figure 42A). To ensure that participants remained uncertain about when each new trial would begin, the duration of the background screen prior to stimuli presentation varied between 400ms and 1600ms. The vertical and horizontal position of each car also changed from trial to trial (random variability between 0.07° and +0.07°), ensuring that the discriminability between the target and flanker cars remained challenging. Aside from utilising different flanker stimuli, all visual angles, spatial attributes and trial epochs were identicial to those in the original ANT described in Study 4. However, unlike the ANT, sustained attention is represented as reaction time in the 'alerting' network utilising *auditory* (2000Hz tone for 50ms, 500ms before target presentation) as opposed to *visual* alerting cues (e.g., reacting to a target with or without a warning tone). Moreover, the ANTI-V allows for an assessment of both endogenous *and* exogenous 'orienting' by including spatially reliable and *unreliable* cues, whereas the ANT includes only spatially reliable and *central* cues. It has been argued that participants can rely on endogenous capacities for orienting when spatial cues are always predictive of the incoming target. By including spatial cues that are not predictive of the incoming target, such reliance is no longer beneficial and serves to more effectively isolate exogenous orienting capabilities. As such, the ANTI-V differs from the original ANT by allowing for separation of alerting and orienting sensory modalities and adding more specificity to assessments of the exogenous elements of the orienting network. By extension, this ensures greater robustness and reliability of assessments of alerting and orienting capacities, and allows for evaluation of interactions between alerting and orienting function if required (Roca et al., 2011). Finally, although the alerting network is often viewed as synonymous with ongoing vigilance during the original ANT, the ANTI-V introduces a distinct measure of vigilance in the form of an uncommon, minimally displaced central car (Figure 42B, right panel), whereby participants are required to press a separate response if such displacement was evident on a given trial. Higher detection rates of the displaced car represent enhanced vigilance throughout the ANTI-V. As such, ANTI-V offers a more robust assessment of vigilance by including a SART-like task requiring the detection of rare events.

Figure 42.

Experimental ANTI-V Procedure and Stimuli



Note. (A) Overall representation of trial procedure; tone icon represents alerting trials (tone and no tone trials), (B) Target type; displaced cars represent vigilance trials, (C) Visual cue conditions. Adapted with permission from Roca, Castro, Ramon & Lupianez (2011, pp. 316).

Intervention Procedure

All demographics (age, gender, highest level of education) and questionnaire data were captured electronically using Qualtrics Online Questionnaires. Participants completed the Qualtrics questionnaires and the E-Prime ANTI-V eye-tracking task in a quiet room in the School of Psychology at Cardiff University. Whole ANTI-V trials were not excluded for missing data. The study utilised an RCT comparing a group-delivered training condition (MBCAT) with an active control condition based on the Health Enhancement Programme (HEP, MacCoon et al., 2011)) (Figure 41). An active control condition was used to address criticisms that MBI research often fails to adequately control for the level of participant contact, home task allocation and active engagement in session activities that is typically observed for those participating in mindfulness-based training (MacCoon et al., 2011). As such, matching HEP with MBCAT as closely as possible on these variables allows for any attentional or psychophysiological differences to be more robustly attributed to mindfulness training. A random number generator was used to assign participants to one of the two conditions. MBCAT was delivered to students in the Cardiff University Psychology building over a one-month period. Each weekly group intervention session was two hours long and facilitated by the principal investigator (PI). At one-week pre-intervention and one-week post-intervention, participants were invited to complete a battery of questionnaires using Qualtrics. At one-week post-intervention, participants completed a 45-minute eye-tracking session, whereby behavioural performance during the ANTI-V was measured using E-Prime alongside concurrent collection of PD markers to indirectly assess tonic and phasic LC-NA arousal. Throughout the MBCAT program, participants were asked to record their home practice sessions each week. A total amount of ‘plays ’was also collected through an online counter, which informed the experimenter how many times the guided practice was being used throughout a given week.

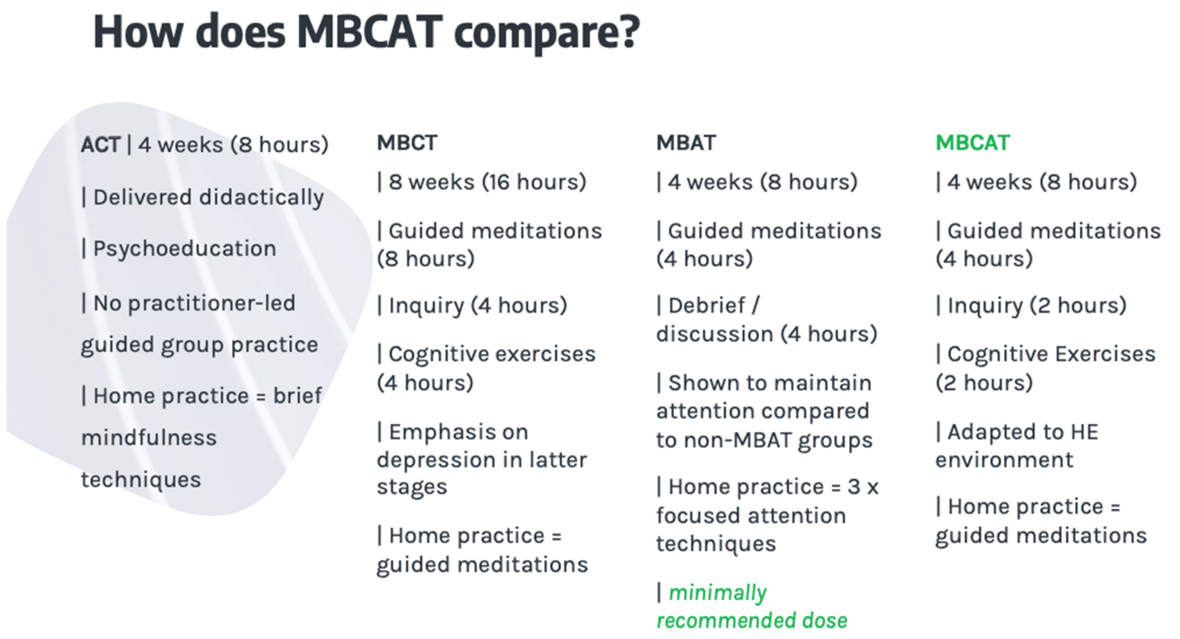
Mindfulness Training Programme (MBCAT). The current study employs the use of a novel mindfulness-based training program - Mindfulness-Based Cognitive Attention Training (MBCAT) - developed by the PI specifically for the purposes of the research project. MBCAT is a group-based intervention delivered for 2 hours per week over 4 consecutive weeks. The PI received ongoing Mindfulness-Based Cognitive Therapy (MBCT) training, subsequently fulfilling the requirements of the Oxford Mindfulness Centre MBCT framework allowing one to teach mindfulness-based training programs to non-clinical populations. MBCAT is based on the fundamental strategies of MBCT and MBAT and aims to teach participants a series of brief meditations and cognitive exercises each week (see Figure 43). Participants are required to engage in skills practice on a daily basis outside of the structured sessions and are given exclusive access to the accompanying MBCAT meditation library as a requirement for their home practice. Appendix 3B presents examples of the MBCAT Instructor Manual and online guidance library.

Health Enhancement Programme (HEP, MacCoon et al., 2011). The HEP was originally created for the specific purpose of developing an active control condition for the study of MBCT and MBSR. Rather than representing a "sham" treatment, the HEP has real benefits for participants, and allows for a flexible application of HEP materials depending on the length and duration of mindfulness-based intervention. Structurally, HEP was matched to the MBCAT programme, insofar as there was the same amount of class and homework time. Due to MBCAT omitting the physical yoga-like activities typically included in MBCT and MBSR, the physical activity elements of the HEP were also not administered. The home techniques utilised from the full HEP in the present study included listening to music whilst free-drawing, daily emotions journaling, learning about optimal nutrition and implementation (using the Food Guide Pyramid) and daily diet journaling, with participants being instructed to engage in each task type for 30 minutes per day (consistent with duration of MBCAT home meditation). Home tasks and general HEP experiences were reviewed weekly with the facilitator for a similar duration as the MBCAT sessions. Adherence to HEP home tasks was assessed utilising self-report records over the course of the previous week. Participants in the HEP control condition completed the same questionnaires and eye-tracking tasks at identical timepoints as the MBCAT group.

MBCAT and ACT. As outlined in Figure 43, the main differences between the ACT programme employed in Study 4 and the MBCAT programme utilised in the present study are related to the inclusion of guided meditation practice and inquiry (group reflection). The ACT programme was delivered didactically using Powerpoint, whereas the MBCAT training involved group meditation and group inquiry. As such, the MBCAT programme is much more aligned with the original MBIs, such as MBSR and MBCT, which currently enjoy the most consistent evidence base for augmenting attentional and wellbeing outcomes. Moreover, despite home practice being offered in both ACT and MBCAT protocols, the opportunity to learn from an experienced practitioner experientially in the MBCAT programme was predicted to enhance adherence to home practice and potentially lead to stronger cognitive effects.

Figure 43.

Comparing MBCAT with MBCT, Mindfulness-Based Attention Training (MBAT) and ACT.



Note. Displayed ACT description refers to ACT programme utilised in Study 4.

Data Preparation[35]

Exclusions

The behavioural data for one participant (HEP programme) was excluded due to only 26% of responses being recorded. Moreover, for this same participant, less than 50% of pupillary data were available. Data loss was roughly equal across ANTI-V conditions. Taken together, these findings imply near-complete disengagement from the task, necessitating the

[35] See Appendix 0ii 'Overview of Procedures and Data Preparation' for more details.

exclusion of this participant's data from analyses. Resulting sample sizes were 9 MBCAT and 8 HEP.

Behavioural and Pupillary Outcomes

Baseline Pupil Diameter (bPD), Task-Evoked Pupillary Responses (TEPR), RT and Accuracy Preparation are near-identical to preparatory processes for the ANT in Study 4 and are displayed in detail in Appendix 0ii; 'Overview of Procedures and Data Preparation', pg. 13.

Analytic Strategy

In order to analyse effects typically measured during the ANTI task, mean correct RT, accuracy, bPD and TEPR were assessed as a function of warning signal (tone, no tone), cue (valid, invalid, and no cue), and target conditions (congruent, incongruent). Attention network scores were computed by obtaining the difference between network-specific conditions (phasic alertness; no tone - tone for no cue trials, orienting; invalid cue - valid cue, executive; incongruent - congruent). Following procedures used in prior studies for both behavioural (Roca et al. 2011) and pupillary measures (Geva et al. 2013), one-sample t-tests were used to test whether network scores were significantly different from 0, with LMMs implemented to analyse pupillary time courses throughout each network.

Tonic vigilance performance was evaluated using the Signal Detection Theory (SDT) index of sensitivity (dprime(*d'*)) by calculating proportion of 'hits' (correct spacebar responses to infrequent 'go' trials in the vigilance component) and 'false alarms '(incorrect spacebar responses to frequent 'no-go' trials in the non-vigilance component). This score was tested for associations with other proposed indices of tonic alertness during the ANT, such as RT in notone / no-cue conditions and tonic bPD (Roca et al. 2011).

Unless otherwise stated, linear mixed effects models (LMMs) and generalised linear mixed models (GLMMs) were employed to analyse RT and binomial data as a function of training condition and network-specific conditions. To account for the repeated sampling of subjects within tone, cue, target and vigilance conditions, LMMs were preferred, which were compared using AIC criterion (Appendix 0iii, Study 5). Comparing the vigilance index (*d*') between training conditions required the construction of a binomial generalised linear mixed model (GLMM), whereby actual response was modelled as a function of an interaction term between condition and correct response.

Finally, individual differences in mindfulness and general wellbeing were tested for associations with all measures of tonic performance and arousal, and where appropriate, explored in terms of their potential moderative effects.

Results

Equivalence Tests.

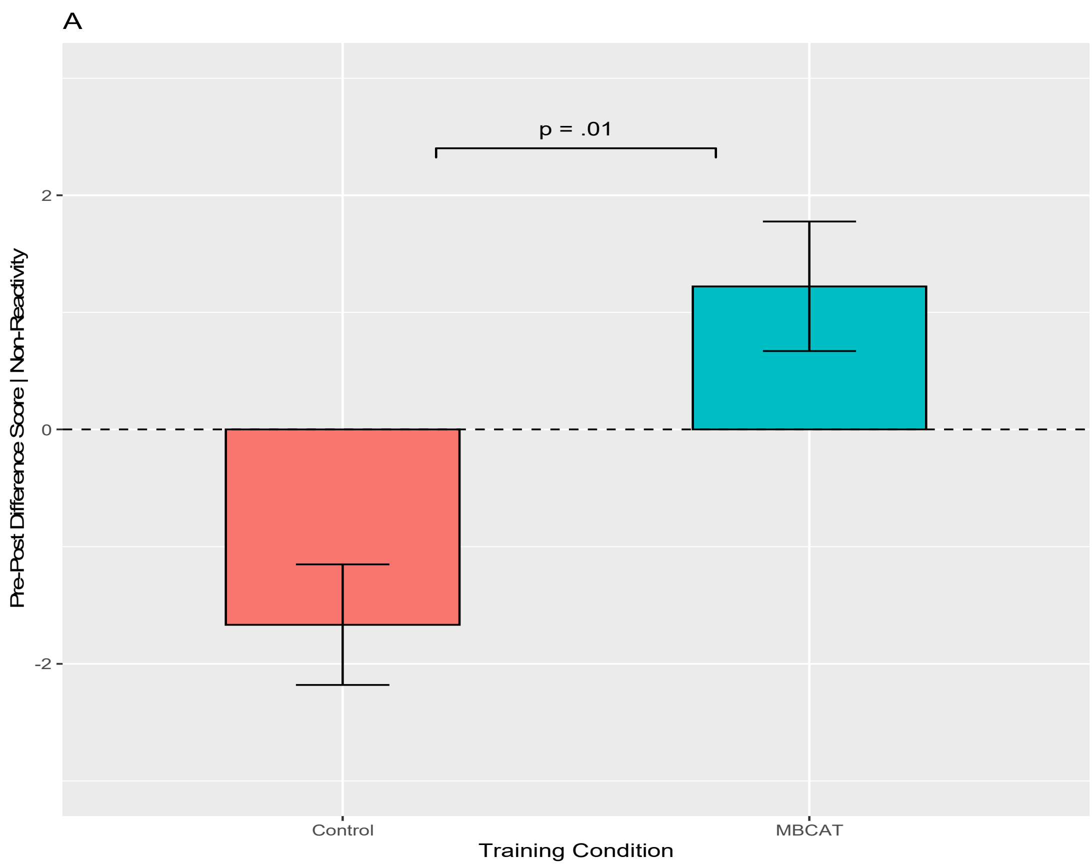
There were no significant differences in age between MBCAT and HEP groups ($p = .63$). I conducted MANOVA to assess for equivalence in levels of pre-induction self-reported mindfulness between MBCAT and HEP control conditions. There were no differences in relation to MAAS and FFMQ measures ($V = 0.18$, $F(2, 62) = 1.95$, $p = .17$) or wellbeing measures ($V = 0.26$, $F(3, 14) = 1.61$, $p = .23$).

Mindfulness and Wellbeing

MBCAT and HEP Control Group Differences: Mindfulness. In order to assess the effect of MBCAT on measures of mindfulness, independent *t*-tests were implemented for the full sample on pre--post difference scores (post minus pre-training scores) for each scale. As such, larger scores represent greater increases in self-reported mindfulness. As expected (H1a), MBCAT participants exhibited larger increases in mindfulness, specifically in the form of increased FFMQ-Non-Reactivity scores ($t(16) = 2.78$, $p = .01$, $d = 1.31$, Figure 44A) relative to HEP control participants, indicating that those who participated in MBCAT became less reactive relative to controls.

Figure 44.

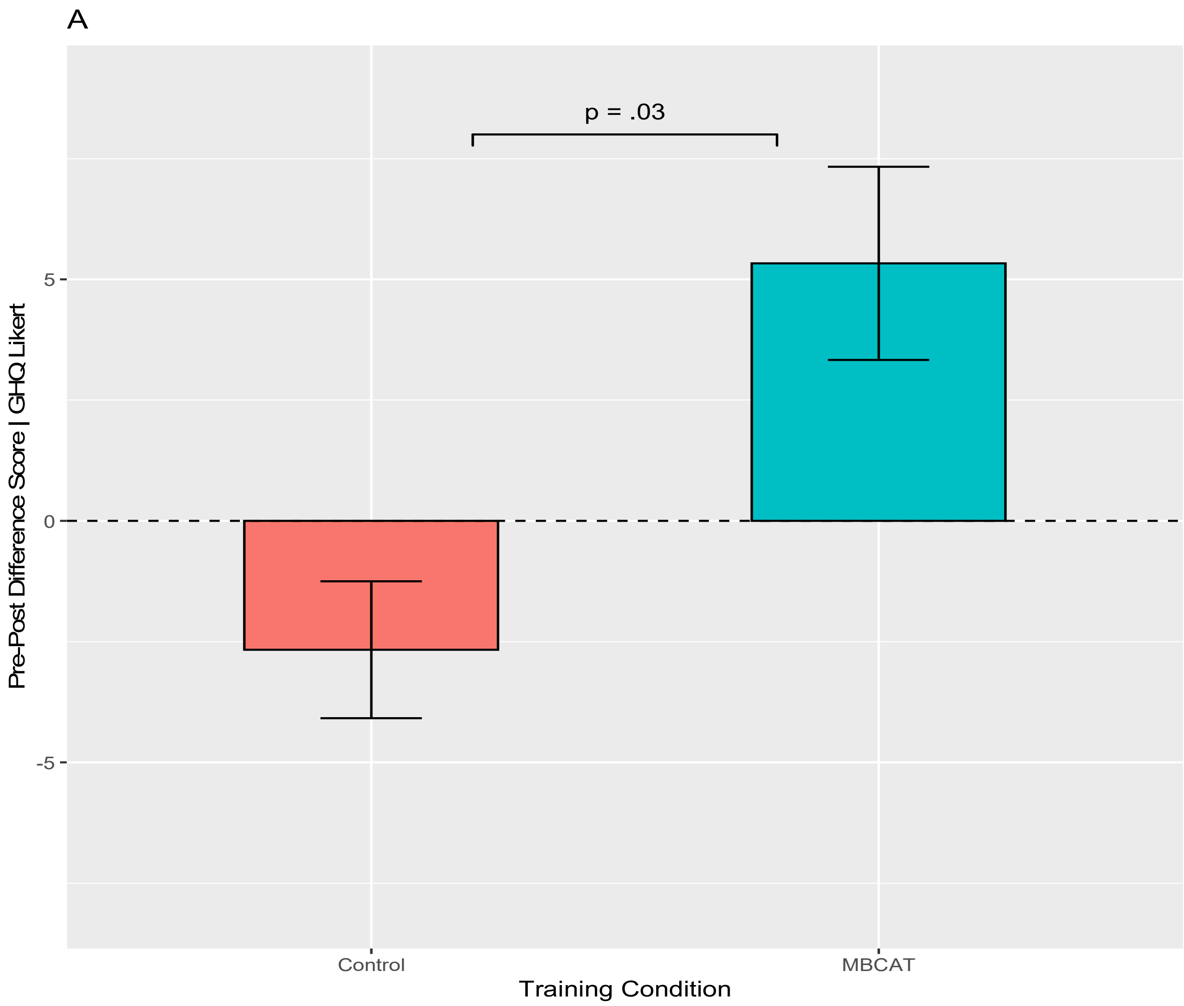
Pre−post FFMQ Difference Scores for MBCAT and HEP Control Groups.



MBCAT and HEP Control Group Differences: Wellbeing. In order to assess the effect of MBCAT on measures of wellbeing, independent *t*--tests were implemented for the full sample on pre--post difference scores (post - pre-training scores) for each scale. As expected (H1b), MBCAT participants exhibited a greater increase in wellbeing, specifically in the form of larger pre--post increases in GHQ likert scores ($t(14) = 2.37$, $p = .03$, $d = 1.11$, Figure 45A), indicating improved overall mental health and a significantly reduced likelihood of individuals reporting a level of psychological distress of potential clinical significance as a result of MBCAT. No effects of MBCAT on anxiety or depression were revealed ($ps > .45$), suggesting that, although the MBCAT was effective at influencing the GHQ which *screens* for indices of psychological distress that could potentially develop in severity, this did not extend to the detection of *diagnostic* indices of specific mood disorders. The relatively short nature of the training and the omission of cognitive exercises explicitly designed to target depression / anxiety (e.g., such as those included in MBCT) may explain this difference in results.

Figure 45.

Pre−Post GHQ Difference Scores for MBCAT and HEP Control Groups.



Note. Higher scores reflect pre-post increase in wellbeing. Negative scores reflect pre-post reduction in wellbeing. Error bars reflect +/− 1 SEM.

Mindfulness and Wellbeing. Next, I explored whether dispositional mindfulness was associated with wellbeing outcomes prior to training (Table 2). I also examined whether pre-post training fluctuations in mindfulness were associated with changes in wellbeing (Table 3). Although significance was not obtained for specific associations in multiple correlation analyses, the observed medium and strong associations warranted further exploration in relation to potential mechanisms underlying interventional effects.

Table 2.

Bivariate Correlations Between Baseline MAAS, FFMQ Facets and Wellbeing Outcomes.

Variable	Depression (PHQ-9)	Anxiety (GAD-7)	General Health (GHQ-12)
1. MAAS	-.53	-.26	.17
2. Observing	-.25	-.27	-.03
3. Describing	-.31	-.19	-.01
4. Awareness	-.48	-.39	.30
5. Non-Judging	-.43	-.43	.14
6. Non-Reactivity	-.06	-.21	.11
7. Total FFMQ	-.43	-.42	.18

Note. * indicates $p < .05$. ** indicates $p < .01$. Values adjusted for multiple tests.

Table 3.

Bivariate Correlations Between MAAS, FFMQ Facets and Wellbeing Outcomes (Difference Scores).

Variable	Depression (PHQ-9)	Anxiety (GAD-7)	General Health (GHQ-12)
1. MAAS	-.26	-.03	-.01
2. Observing	-.54	-.42	.26
3. Describing	-.30	-.33	-.14
4. Awareness	-.18	-.26	.07
5. Non-Judging	-.60	-.49	.54
6. Non-Reactivity	-.44	-.40	.29
7. Total FFMQ	-.58	-.55	.32

Note. * indicates $p < .05$. ** indicates $p < .01$. Values adjusted for multiple tests.

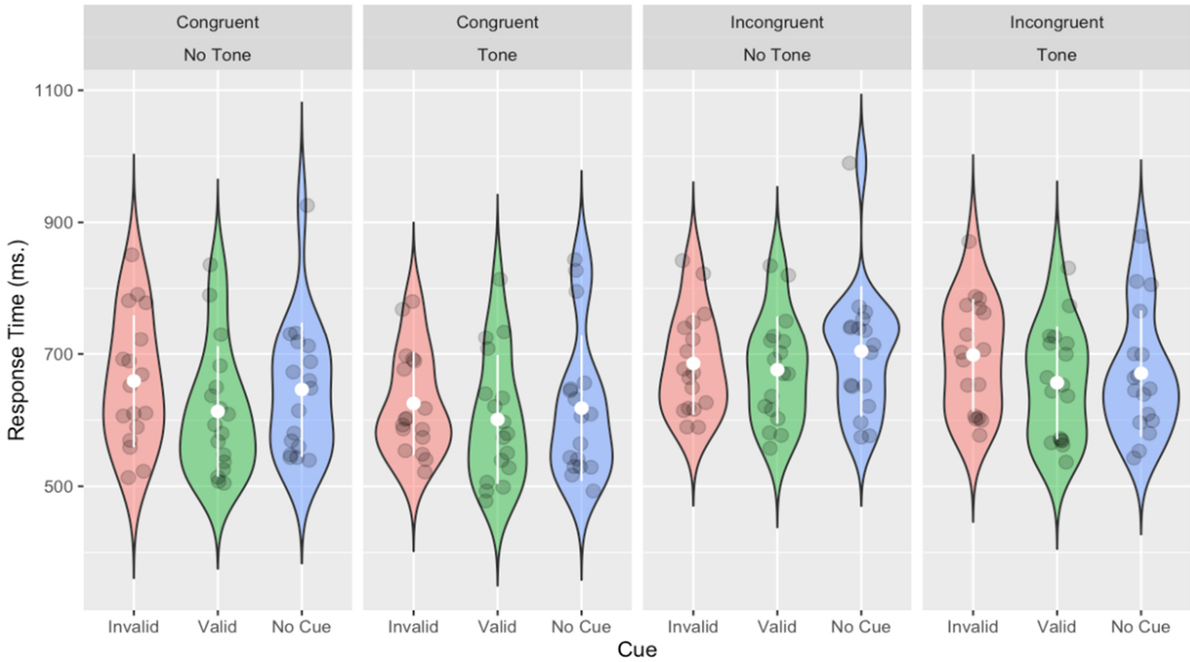
I utilised interactions between training group and mindfulness to investigate potential moderative effects of dispositional mindfulness on post-training wellbeing. Contrary to expectations (H1c), there were no interactions between training condition and trait mindfulness on post-training wellbeing outcomes (all *ps* > .10).

Attention Network Task with Interactions and Vigilance (ANTI-V)

Establishing the Attention Networks. As expected for the RT data, the main attentional effects of warning tone (F(1, 16.45) = 14.94, $p < .005$, $d = .12$), visual cue (F(2, 28.86) = 19.37, $p < .0001$) and target (F(1, 15.74) = 25.64, $p < .001$, $d = .32$) were highly significant (see Appendix 0iii, Study 5). Planned comparisons exploring differences between visual cues revealed faster reaction times for the valid cue condition than the invalid cue ($p < .0001$, $d = .18$) and no cue conditions ($p < .001$, $d = .14$). On average, participants were quicker to respond when an alerting tone had been presented, when cues were valid, and when targets were congruent (Figure 47; see also Appendix 5, Table 1). The interaction between tone and cue was significant (F(2, 3001.42) = 3.10, $p = .04$), suggesting an enhanced effect of alerting tone on RTs in the absence of a cue ($p < .0001$, $d = .20$). That is, participants benefitted more from a warning signal when there was no additional information presented about the spatial attributes of the target. The interactions between warning tone and target (F(1, 3001.42) = 2.29, $p = .13$), cue and target (F(2, 3000.94) = .34, $p = .71$) and between tone, cue and target (F(2, 3000.72) = 2.64, $p = .07$) were non--significant.

Figure 47.

Mean Correct RT (ms) for Factorial Design; 2 (Warning Tone: Tone/No Tone) x 3 (Cue: Valid/Invalid/No Cue) x 2 (Target: Congruent/Incongruent).

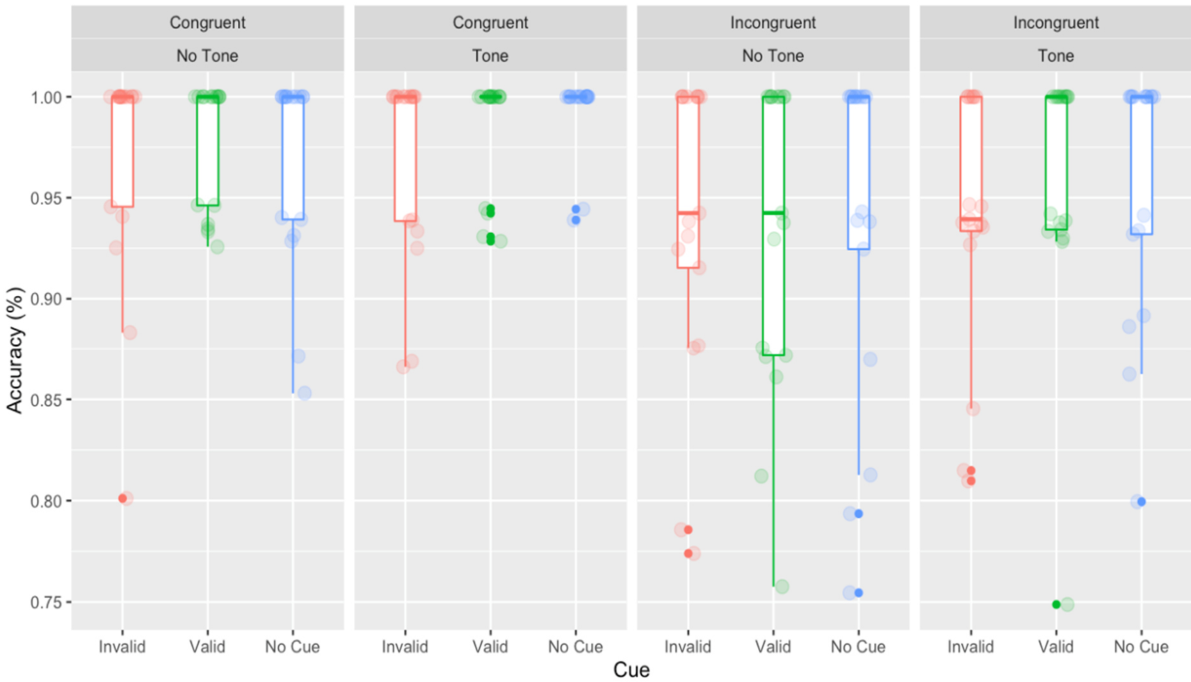


Note. Violins represent mirrored density plots and continuous distribution.

In terms of the accuracy data, there was a main effect of warning tone ($\chi2(1, N = 17) = 4.29$, $p = .04$, $d = .07$) and target ($\chi2(1, N = 17) = 4.51$, $p = .03$, $d = .17$) on error rates. As expected, there was a higher proportion of errors for no tone trials (4.4%) than for tone trials (3.3%), and for incongruent targets (5.5%) than for congruent targets (2.2%). Figure 48 outlines the differences in error rates between stimuli types (see also Appendix 5, Table 2). There was no main effect of visual cue on error rates ($\chi2(2, N = 17) = 2.44$, $p = .29$), although subjects performed marginally better for valid cue trials (3.6%) than for invalid cue trials (4.4%). Contrasting with prior research illustrating more pronounced cueing effects on error rates for tone trials, and greater congruency effects for valid and invalid cue conditions, there were no interactions between tone and cue (p = .22), tone and target (p = .42) or cue and target (p = .57). There was also no interaction between tone, cue and target (p = .50).

Figure 48.

Mean Accuracy for Factorial Design; 2 (Warning Tone: Tone/No Tone) x 3 (Cue: Valid/Invalid/No Cue) x 2 (Target: Congruent/Incongruent).

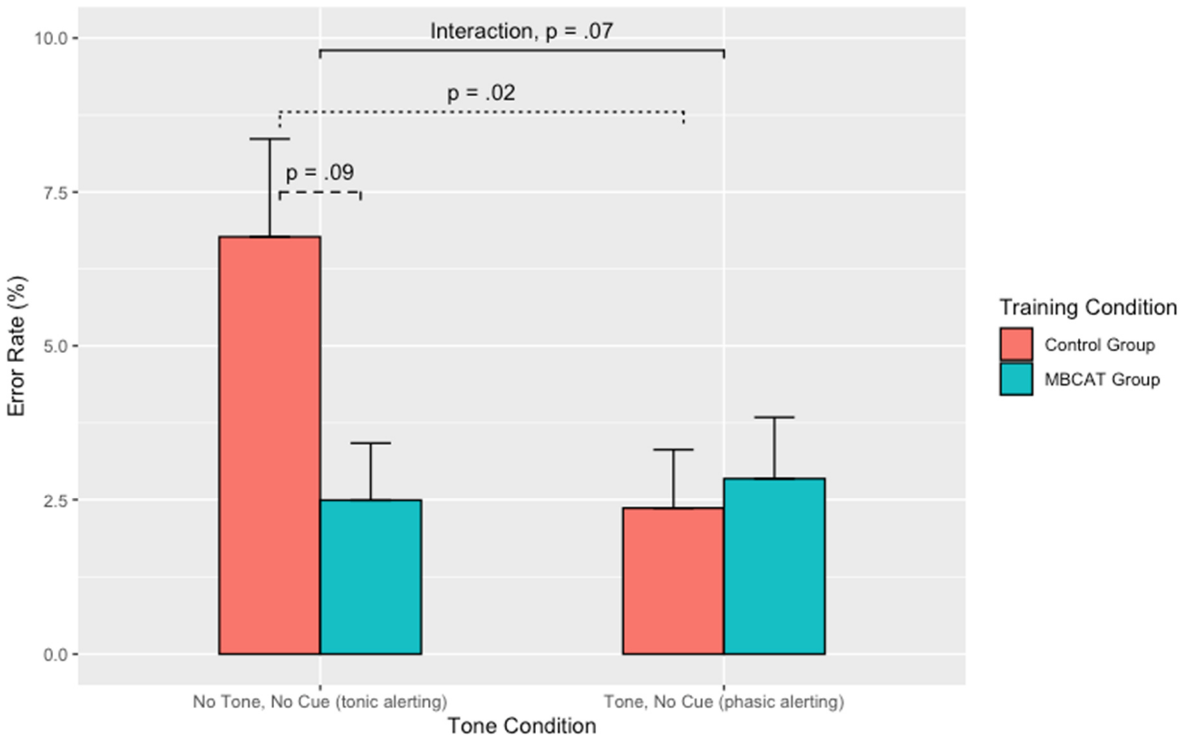


Note. Boxplot lines represent median values among lower and upper IQRs (box extremity).

Training Condition and ANTI-V Performance. Contrary to expectations (H2a/b/c), exploring differences in ANTI-V performance between MBCAT and HEP conditions during the ANTI portion of the ANTI-V (e.g., without the misplaced car 'vigilance' trials) revealed no overall effect of treatment on RT (p = .46) and no interactions with tone (p = .26), cue (p = .76) or target stimuli (p = .17) for RT. Examining the effect of MBCAT during phasic alerting (tone, no cue) and tonic alerting conditions (no tone, no cue) did not reveal a significant interaction between training and tone type ($\chi2(1, N = 17) = 3.19$, p = .07). Interestingly, however, visualising descriptive patterns appeared to reveal a benefit of alerting tone presentation on error rates for the HEP control group (6.8% vs. 2.3%, d = .21), whereas MBCAT group performance was similar in both tone and no tone trials (~2.5% across tone conditions, Figure 49A).

Figure 49A.

Effect of MBCAT on Accuracy in the Alerting Network.

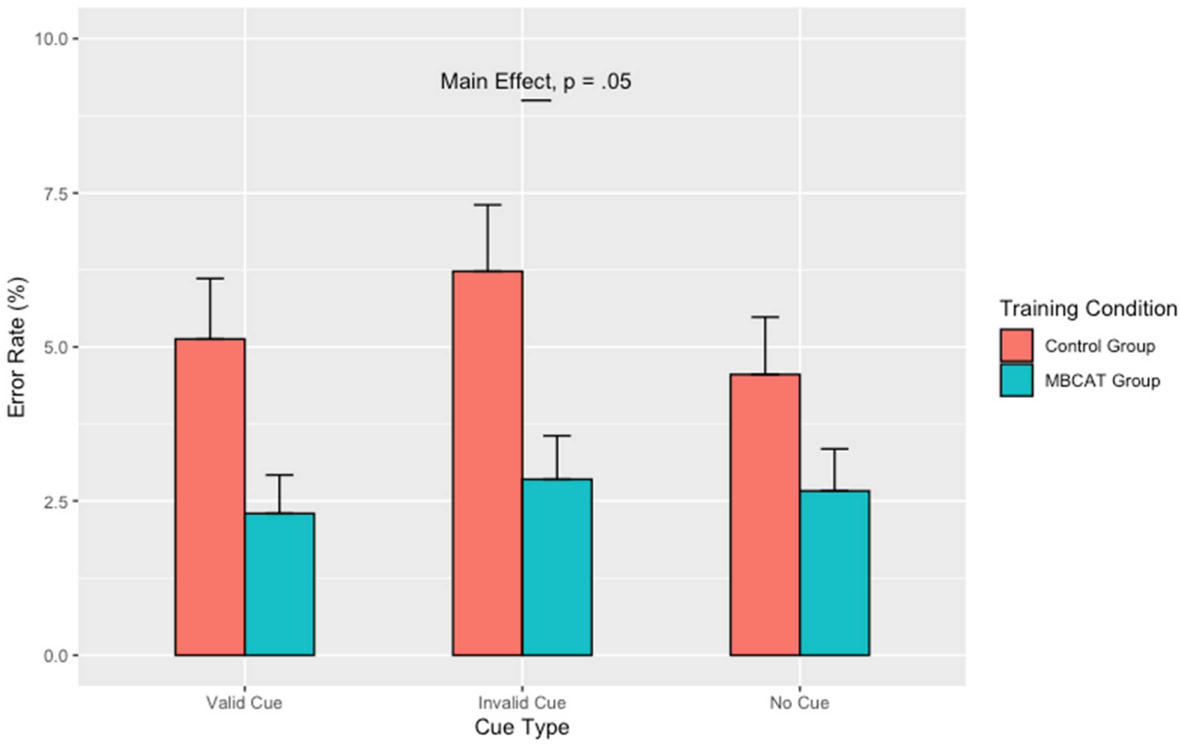


Note. Vertical axis indicates error rates for each training condition in response to tonic alerting and phasic alerting trials (Roca et al., 2011). Solid horizontal line; trending interaction between training condition and tone type. Dotted line; significant main effect of tone on overall accuracy. Dashed line; trending comparison between training conditions for no tone, no cue trials (NTNC). Error bars reflect +/- SEM.

Next, error rates were explored for orienting trials (valid cue, invalid cue, no cue), revealing a marginal main effect of training condition ($\chi 2(1, N = 17) = 3.19$, $p = .05$, Figure 49B). In line with predictions (H2b), MBCAT was marginally effective at improving accuracy in all cue conditions, suggesting that mindfulness training may have had a beneficial effect on performance during the ANTI-V, regardless of which orienting condition was presented.

Figure 49B.

Effect of MBCAT on Accuracy in the Orienting Network.



Note. Vertical axis indicates error rates for each training condition in response to valid, invalid and no cue trials. Small horizontal line; main effect of training condition. Error bars reflect +/- SEM.

For the executive function network (congruent, incongruent targets), there was no main effect of training condition ($\chi2(1, N = 17) = 2.79$, $p = .09$, $d = 14$) and no training condition x target type interaction ($\chi2(1, N = 17) = 2.15$, $p = .14$, Figure 49C). Contrary to expectations (H2c), there were no significant differences in error rates between MBCAT and HEP control groups depending on whether trials were congruent or incongruent.

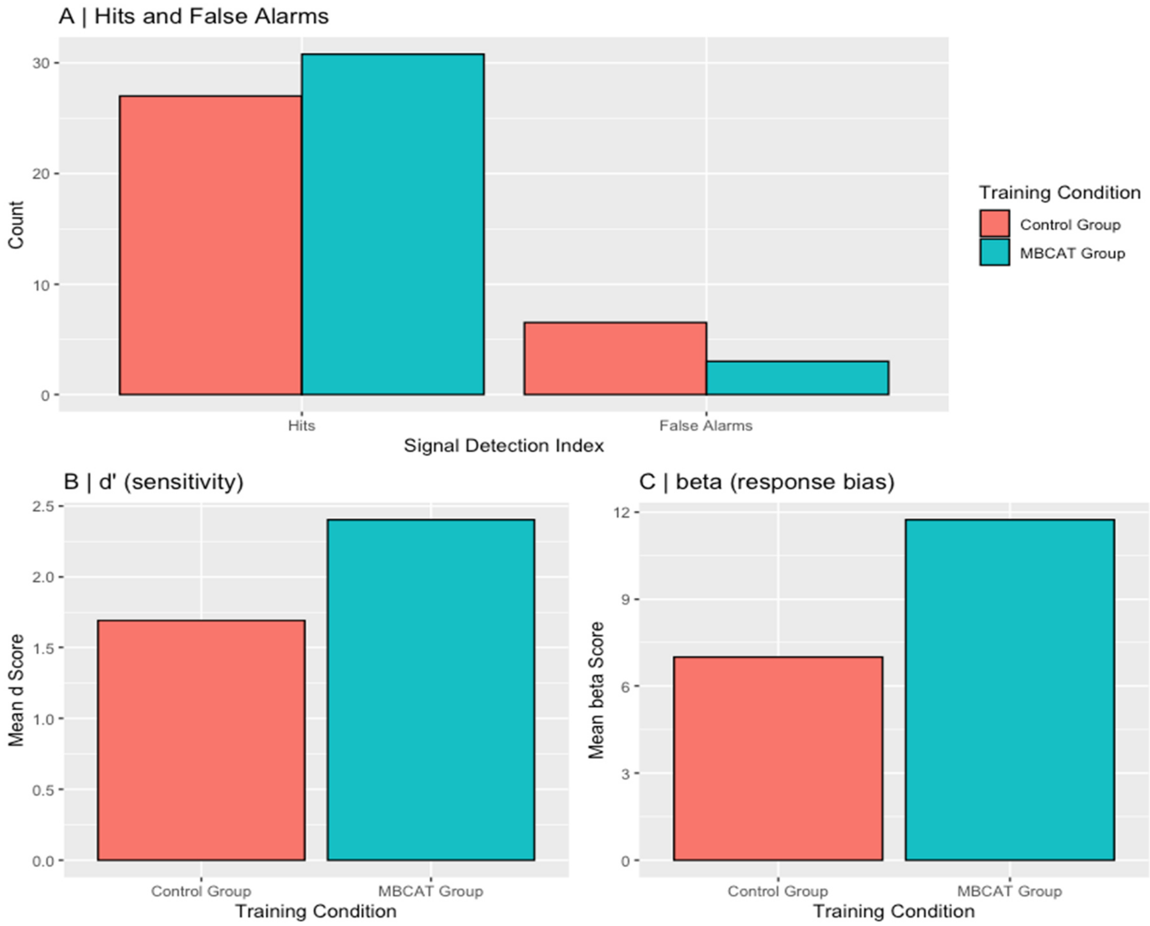
ANTI-V Attention Network Scores. One--sample *t*--tests revealed that all attention network scores were significantly different from zero for RT (all *ps* < .0001) and error rate data (*ps* < .0001), thus providing a reliable performance index for each network. Smaller RT and error network scores indicate improved efficiency of the executive function network as smaller differences in accuracy and RT indicated less distractor interference from incongruent flankers in the present study. Moreover, although larger differences between alerting conditions (tone, no tone) often represent enhanced abilities to capitalise on alerting stimuli (presence of tone) when responding to targets, larger scores could also represent reduced capacities to respond to targets in the *absence* of such stimuli, necessitating an exploration of *why* alerting scores are higher or lower in any given study. Following prior procedures (Ishigami and Klein 2011b; Roca et al. 2011), independent *t*-tests were implemented to assess all network scores as a function of training condition (Appendix 5, Tables 3, 4). No differences in network error scores were found between training conditions for the alerting network (H2a) ($t(15) = 1.58$, $p = .14$, $d = .76$ | $g = .72$). There were also no differences in network RT scores ($t(15) = 1.50$, $p = .15$, $d = .72$ | $g = .68$) or network error scores ($t(15) = 1.80$, $p = .09$, $d = .87$ | $g = .81$) between training conditions for the executive network (H2c), suggesting no differences in executive efficiency for MBCAT relative to HEP control participants.

Training Condition and Signal Detection Theory (SDT) Indices of Vigilance. In order to assess performance within the vigilance component of the ANTI--V, probabilities of hits in vigilance trials and false alarms in non--vigilance trials were computed and submitted for *d'* calculation (*z*-scored ratio of hits : false alarms). Prior to exploring *d'* as a function of training condition, I examined whether this measure of vigilance was associated with performance within the tonic component of the alerting network, in an effort to further demonstrate the reliability of using alerting network outcomes as a measure of tonic alertness and vigilance (Posner, 2008; Roca et al., 2011). There was a trending negative association between errors in the tonic alerting component of the ANTI-V (no tone, no cue trials) and *d'* scores ($r(15) = -.44$, $p = .07$), and a marginal negative association between alerting network scores and *d*' scores ($r(15) = -.50$, $p = .04$), suggesting reduced signal sensitivity as determined by the added vigilance component of the ANTI-V. There was also a trending negative association between alerting errors and *hits* ($r(15) = -.44$, $p = .07$) and a significant positive relationship between alerting errors and false alarms ($r(15) = .59$, $p = .01$), further reconciling the separate, but related, assessments of tonic alertness and vigilance in the ANTI-V. Meaningfully connecting the original portion of the ANT with the added vigilance component in this way serves to justify decisions to employ the ANTI-V in the present study and provides support for its continued implementation in place of the original ANT in future MBI studies interested in vigilance and network outcomes.

For the full cohort, the percentage of hits and false alarms were 49% and 2.47% respectively, resulting in an overall *d'* value of 1.93. This indicates that the sample as a whole exhibited a relatively high capacity for signal detection throughout the task. Exploring these values visually as a function of training condition (H2e) (Figures 51A, 51B) revealed a descriptively higher hit rate for the MBCAT group (54%) than the control group (44%) and a lower percentage of false alarms (1.5% vs. 3.4%, respectively), manifesting as a higher *d'* value for MBCAT vs HEP control group participants (2.3 vs. 1.7).

Figure 51.

Descriptive effects of MBCAT on SDT Indices of Vigilance

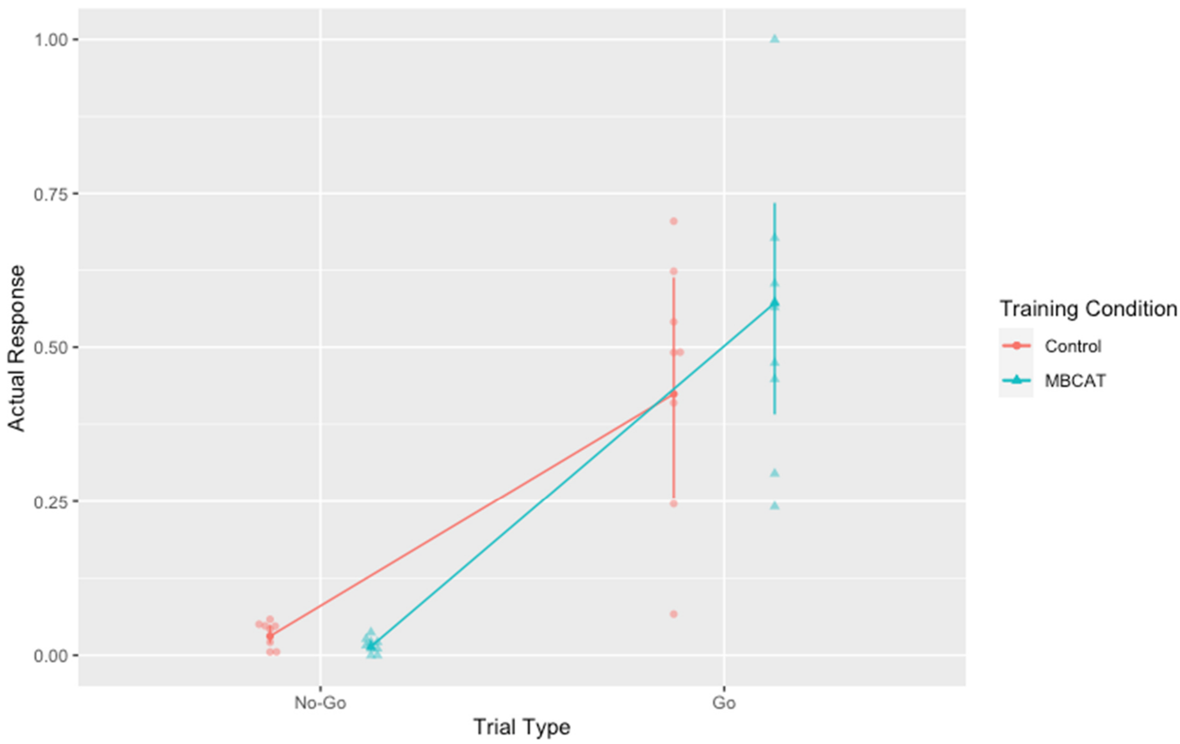


Note. (A) frequency of hits and false alarms, (B) mean signal sensitivity (d'), and (C) response bias scores (beta) during the ANTI-V. Error bars reflect +/- SEM.

To test if the difference in *d*' was statistically significant, a binomial generalised linear mixed effects model was constructed with *actual* response modelled as a function of an interaction term between training condition and *correct* response (e.g., required response / reality). As expected, there was a strong main effect of *correct* response on *actual* response ($\chi2(1, N = 17) = 33.32$, $p < .001$, $d = 1.25$), evidencing that subjects were not merely guessing during the vigilance component of the ANTI-V: when the correct response equalled ‘go’, subjects were more likely to correctly press spacebar than when the correct response equalled ‘no--go’, manifesting in a d’ sensitivity increase (Figure 6). More interestingly (H2e), there was a significant interaction between condition and required response on actual responses ($\chi2(1, N = 17) = 3.90$, $p < .05$). Driving this interaction was a reduced tendency for MBCAT subjects to commit an erroneous response / false alarm in the absence of a vigilance trial ($p < .05$, $d = .12$, Figures 51A, 52), manifesting as increased d’ sensitivity (Figure 51B). These results illustrate the effect of training condition on the discriminability of the two realities (correct response and actual response), thus suggesting a beneficial effect of MBCAT intervention on tonic vigilance throughout the task (H2e).

Figure 52.

Influence of Correct Vigilance / Non-Vigilance Responses (Required Responses) on Actual Responses During the ANTI-V.



Note. Error bars reflect +/- SEM.

Mindfulness and ANTI-V Performance. Next, relationships were explored between self-reported mindfulness and ANTI-V performance outcomes (H2f) (Table 4), with a view to identifying potential mindfulness moderators for subsequent interaction analyses of training effects. Of primary interest were relationships between mindfulness and outcomes previously shown to be impacted by MBCAT training (no tone errors, incongruent errors and valid / invalid cue errors). The only medium-sized correlations between mindfulness and ANTI-V outcomes involved FFMQ-Awareness, a facet of mindfulness which exhibited no sensitivity to MBCAT training, and which was actually associated with a direction of detrimental performance during the ANTI-V. As such, no mindfulness candidates were identified for their potential role in moderating the impact of training condition on ANTI-V network outcomes in the present study. However, in order to confirm intuitions that there would be no interactive effects of training condition and mindfulness on attentional outcomes, a series of linear mixed models were conducted utilising interaction terms between training condition and mindfulness facets. As expected, no collaborative effects of training and mindfulness were obtained (*all ps* > .37).

Table 4

Bivariate correlations Between MAAS, FFMQ Facets and ANT Network Scores.

Network	**Alerting**		**Orienting**		**Executive**	
Variable	Tone	No Tone	Valid Cue	Invalid Cue	Congruent	Incongruent
1. MAAS	.04	.06	-.17	.10	.03	.05
2. Observing	-.26	.12	-.14	.12	-.13	.01
3. Describing	.27	-.05	-.04	.03	.09	.05

4. Awareness	.29	.46	.26	.50	.38	.41
5. Non-Judging	.35	.02	.42	.01	.24	.09
6. Non-Reactivity	-.01	-.09	-.08	.20	.27	-.18
7. Total FFMQ	.37	.11	.19	.31	.42	.12

Note. * indicates $p < .05$. ** indicates $p < .01$. Values adjusted for multiple tests.

Pupillary Results

Baseline (Pretrial) Pupil Diameter (bPD) | hits, misses, false alarms and correct rejections. Exploring bPD as a function of accuracy (correct (hits) and incorrect (misses) responses) during the vigilance component of the ANTI-V revealed no main effect of accuracy on pupil size ($F(1, 705.46) = .41$, $p = .52$, $d = .06$), suggesting that bPD-inferred tonic arousal was not related to accuracy in the vigilance component of the ANTI-V. Moreover, there was no main effect of training condition on bPD (H3) ($F(1, 15.07) = 1.82$, $p = .20$, $d = .36$). There was a trending interaction between training condition and accuracy ($F(1, 705.46) = 3.10$, $p = .08$), but exploring this interaction revealed no pertinent comparisons between training groups for bPD prior to hits or misses (all *ps* > .25).

Exploring bPD as a function of accuracy (correct (rejections) and incorrect (false alarms) responses) during the non-vigilance component of the ANTI-V revealed no effect of accuracy on pupil size ($F(1, 2251.48) = .01$, $p = .97$, $d = .05$), suggesting that bPD-inferred tonic arousal was not related to accuracy in the non-vigilance component of the ANTI-V. Moreover, there was no main effect of training condition on bPD ($F(1, 15.56) = 1.98$, $p = .18$, $d = .38$), Finally, the interaction between training condition and accuracy was non-significant ($F(1, 2251.48) = .08$, $p = .77$).

Exploring bPD in relation to correct vigilance trials (hits) and incorrect non-vigilance trials (false alarms) as a function of training condition did not reveal a significant interaction ($F(1, 394.84) = 1.33$, $p < .25$).

Taken together, the present pupillary findings suggest that bPD was not associated with any index of ANTI-V accuracy, and that MBCAT participation exerted no impact on bPD during the ANTI-V, implying that mindfulness training and associated improvements in *d'* sensitivity were not related to increased levels of this reliable index of tonic arousal throughout the task (Gilzenrat et al., 2010; Aston-Jones and Cohen, 2005). As such, expected links between tonic LC-NA activity, mindfulness training and performance were not demonstrated.

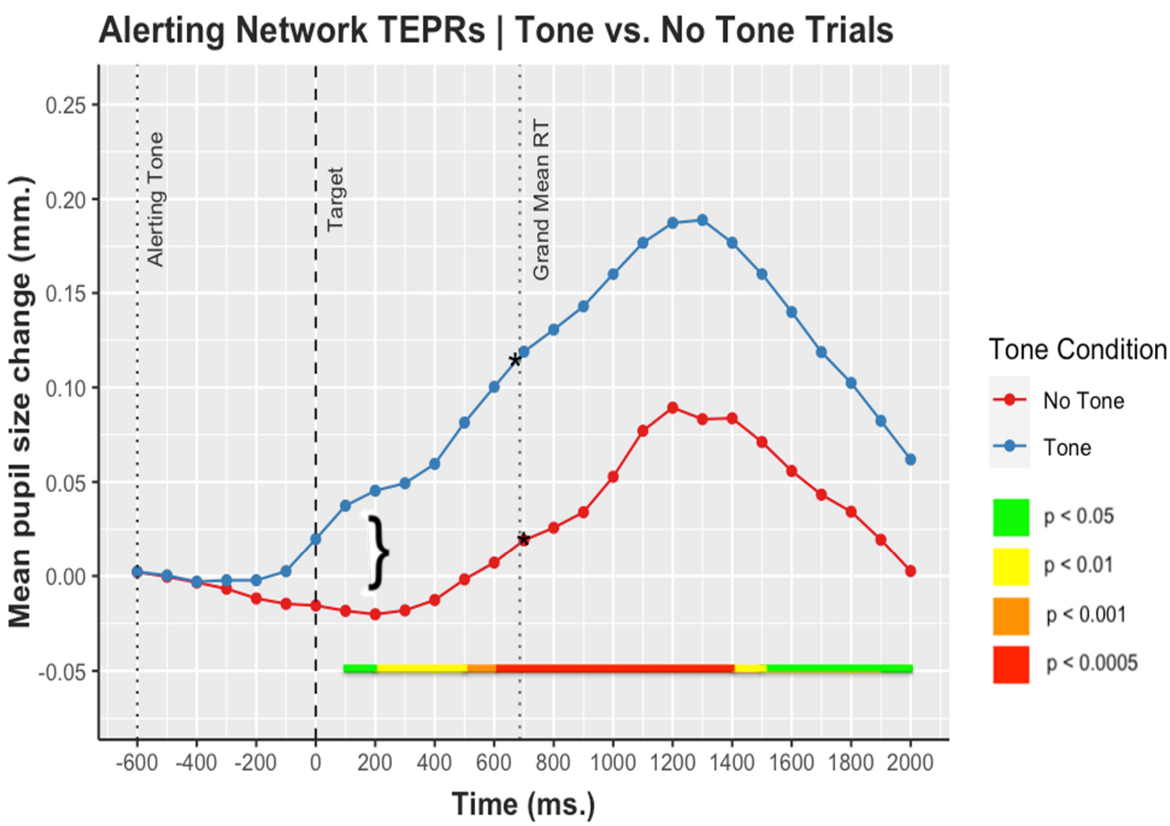
Task-Evoked Pupillary Responses (TEPR): Attention Network Trajectories

Alerting. To analyse subjects' pupil size fluctuations in the alerting network for the purpose of replicating previously observed alerting TEPR (Geva et al., 2013) (H4a), pupillary trajectories were compared between tone and no tone trials for the no cue condition only. Pre-response and post-response time windows were identified utilising the grand mean of RT. LMMs were constructed to explore alerting TEPR across the whole trial period, and for pre/post-response time periods, necessitating the inclusion of training condition, tone condition (tone, no tone) and trial epoch (pre, post) in final models. In line with prior research using the original ANT (Geva et al. 2013), there was a main effect of alerting condition on

TEPR, whereby tone TEPR were larger than no tone TEPR for the overall trial ($F(1, 15.00) = 14.85$, $p = .002$, $d = .70$, Figure 53), manifesting in both pre-response ($p = .03$) and post-response ($p < .001$) time windows. As such, I replicate an early pupillary alerting component to warning stimuli prior to behavioural engagement ('Pa', Geva et al., 2013). Entering time bin as a factor into identical LMMs revealed that the difference in initiation of pupillary reactivity manifested itself as early as 700ms after the alerting signal (approximately 600ms prior to any motor response) ($p < .05$, Figure 53), leading to an augmented pupillary response throughout the tone condition at a significantly higher level than the no tone condition.

Figure 53.

Baseline-Corrected TEPR as a Function of Alerting Condition.

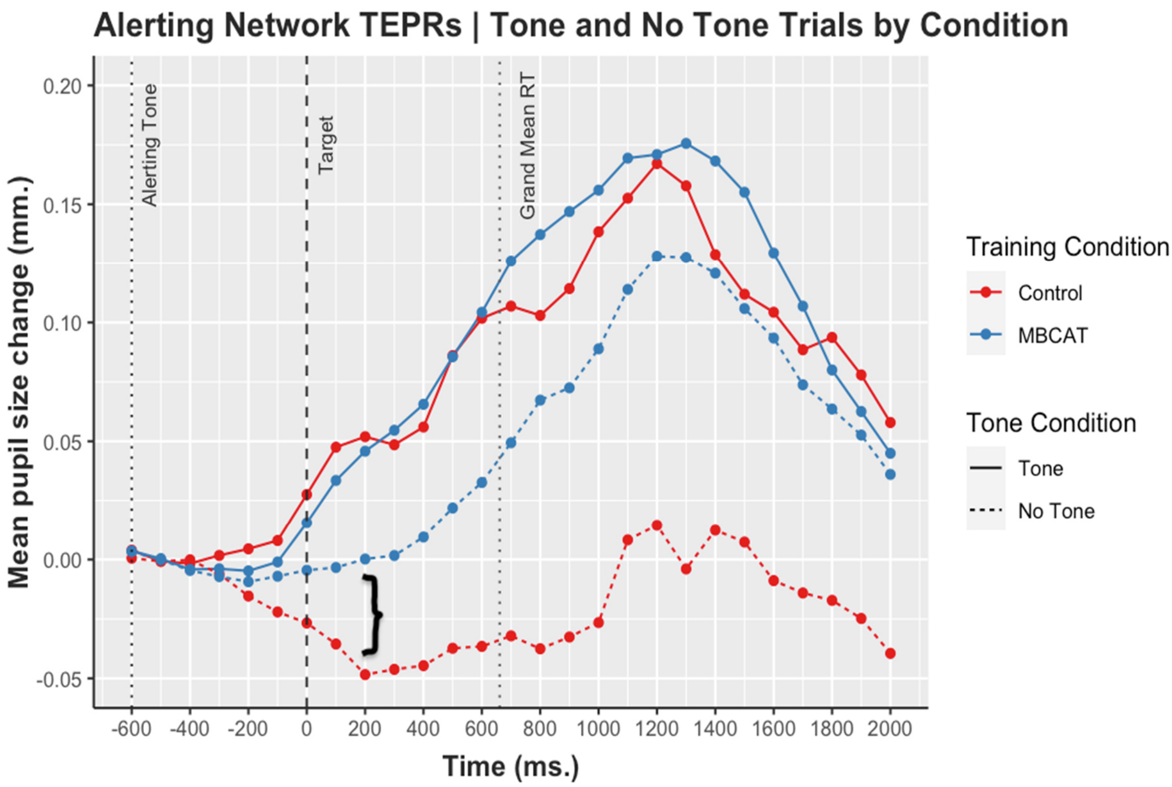


Note. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Tone and no tone pupillary trajectories displayed over pertinent trial events, split into 100ms time bins. Horizontal coloured bar represents significance level of differences between alerting conditions. Note that significance is reached 700ms after the presence / absence of an alerting signal, indicating a pre-response component of alerting arousal ('Pa', Geva et al., 2013). Black stars indicate RTs for tone / no tone trials.

Training Condition and Alerting. Having validated alerting network functionality for the pupil trajectories, alerting TEPR were examined as a function of training condition (H4b). The interaction between training condition and tone type for the overall trial period was non-significant (F(1, 15.00) = 3.60, *p* = .07, Figure 54). TEPR in response to tone and no tone trials were not significantly different between the two training conditions (*p* = .96, *d* = .06). However, the three-way interaction between training condition, trial epoch and tone type was significant (F(1, 814) = 4.71, *p* = .03), manifesting in a trend for larger no tone TEPR in the MBCAT group relative to the HEP control group in the post-response epoch (*p* = .08, *d* = .82). As such, it is possible that a psychophysiological mechanism existed serving to bolster an increased *sensitivity* to targets when no warning signal was presented for those in the MBCAT group (Posner, 2008; Roca et al., 2011). In relation to AGT-predicted LC-NA function and associated attentional states, this mechanism may correspond to an enhanced mode of tonic alertness and increased monitoring of incoming stimuli as a result of the FA and OM practices frequently trained during the MBCAT programme.

Figure 54.

Baseline-Corrected Alerting TEPR as a Function of Training Condition.



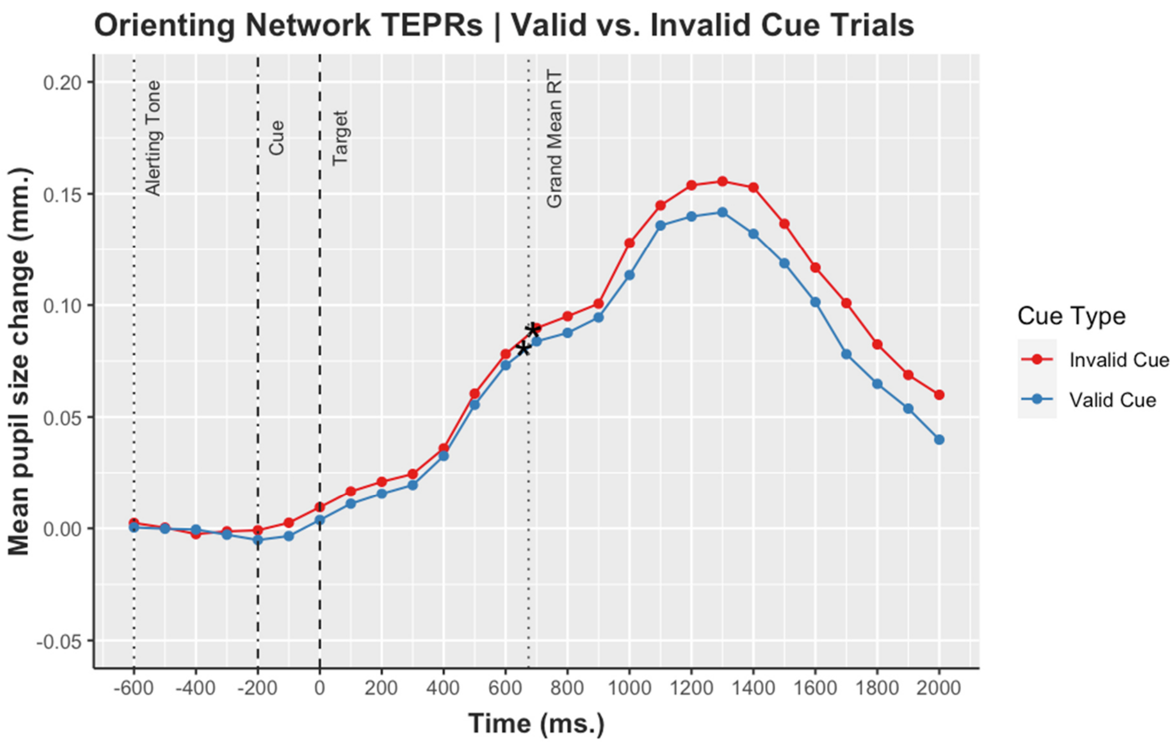
Note. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Tone and no tone pupillary trajectories displayed over pertinent trial events, split into 100ms time bins. Blue lines represent MBCAT TEPR. Red lines represent HEP control TEPR. Solid lines represent tone TEPR. Dashed lines represent no tone TEPR. Note that TEPR for no tone trials between MBCAT and control conditions diverge approximately 700ms after the presence / absence of an alerting signal, indicating a pre-response difference in endogenous tonic arousal between training conditions.

Orienting. To analyse subjects' pupil size fluctuations in the orienting network for the purpose of replicating previously observed orienting TEPR (Geva et al., 2013), TEPR trajectories for valid and invalid cues were compared (H5a). The model included training condition, cue condition (valid, invalid) and trial epoch (pre, post). There were no differences in mean TEPR between invalid cue and valid cue conditions during the overall trial period

(F(1, 830) = 3.42, *p* = .08, *d* = .16, Figure 55). There was also no interaction between cue and epoch (F(1, 830) = 3.36, *p* = .07). As such, these findings are contrary to prior demonstrations of an orienting pupillary response to spatially *informative* cues during the original ANT (Geva et al., 2013, also see Study 4).

Figure 55.

Baseline-Corrected TEPR as a Function of Orienting Condition.

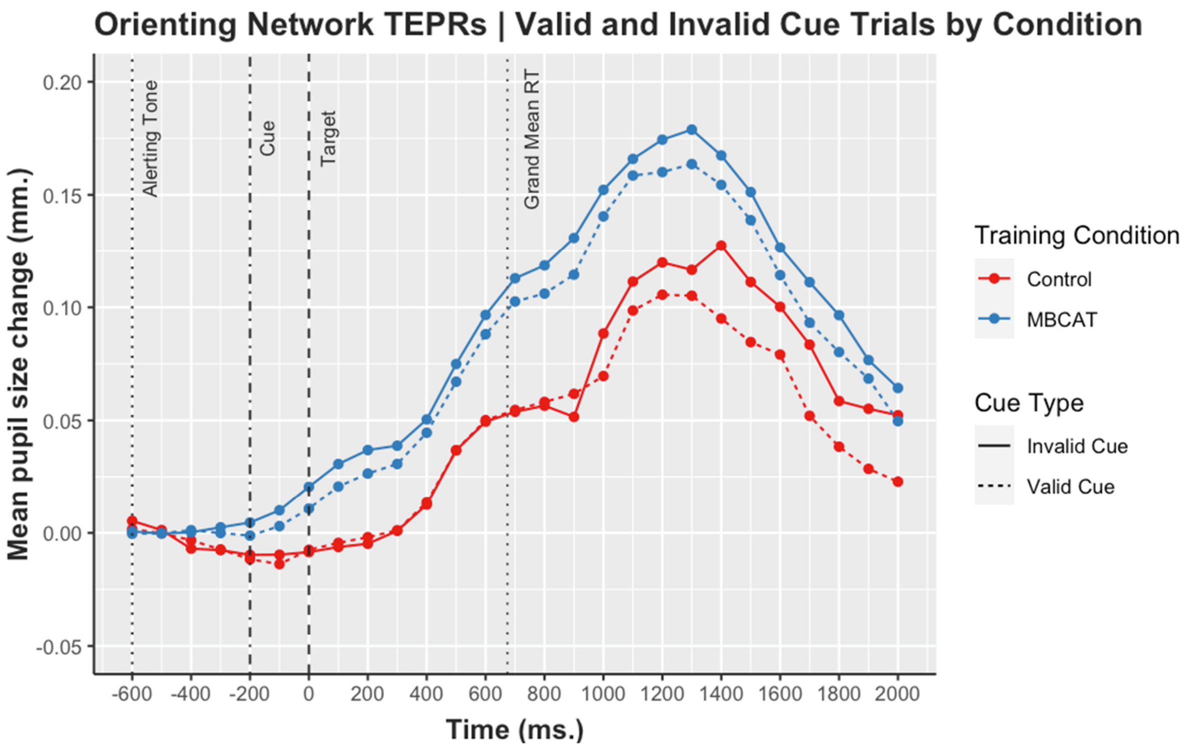


Note. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Valid and invalid cue pupillary trajectories displayed over pertinent trial events, split into 100ms time bins. Black stars indicate RTs for valid / invalid trials.

Training Condition and Orienting. TEPR to cues overall were examined as a function of training condition (H5b). Although no interaction between training condition and cue was observed (*p* .82), there was a significant interaction between training condition and epoch ($F(1, 828) = 10.53$, $p = .001$, Figure 56), manifesting in significantly larger overall TEPR for the MBCAT group relative to the HEP control group in the post-response epoch only ($p = .02$, $d = .53$). The three-way interaction between training condition, trial epoch and cue type was not significant ($F(1, 828) = .46$, $p = .50$). Taken together, these findings suggest that MBCAT participation augmented a pupillary response for all cue types in the orienting network, specifically within the post-response trial period. Due to the lack of cue specificity for the effects of training on arousal (e.g., the lack of an orienting effect between conditions), and the fact that analyses of orienting responses collapse across tone and no tone conditions, these findings may be the result of natural fluctuations of overall TEPR across the sample rather than MBCAT-induced changes to arousal within the orienting network specifically.

Figure 56.

Baseline-Corrected Orienting TEPR as a Function of Training Condition.



Note. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Valid and invalid cue pupillary trajectories displayed over pertinent trial events, split into 100ms time bins. Blue lines represent MBCAT TEPR. Red lines represent HEP control TEPR. Solid lines represent invalid cue TEPR. Dashed lines represent valid cue TEPR.

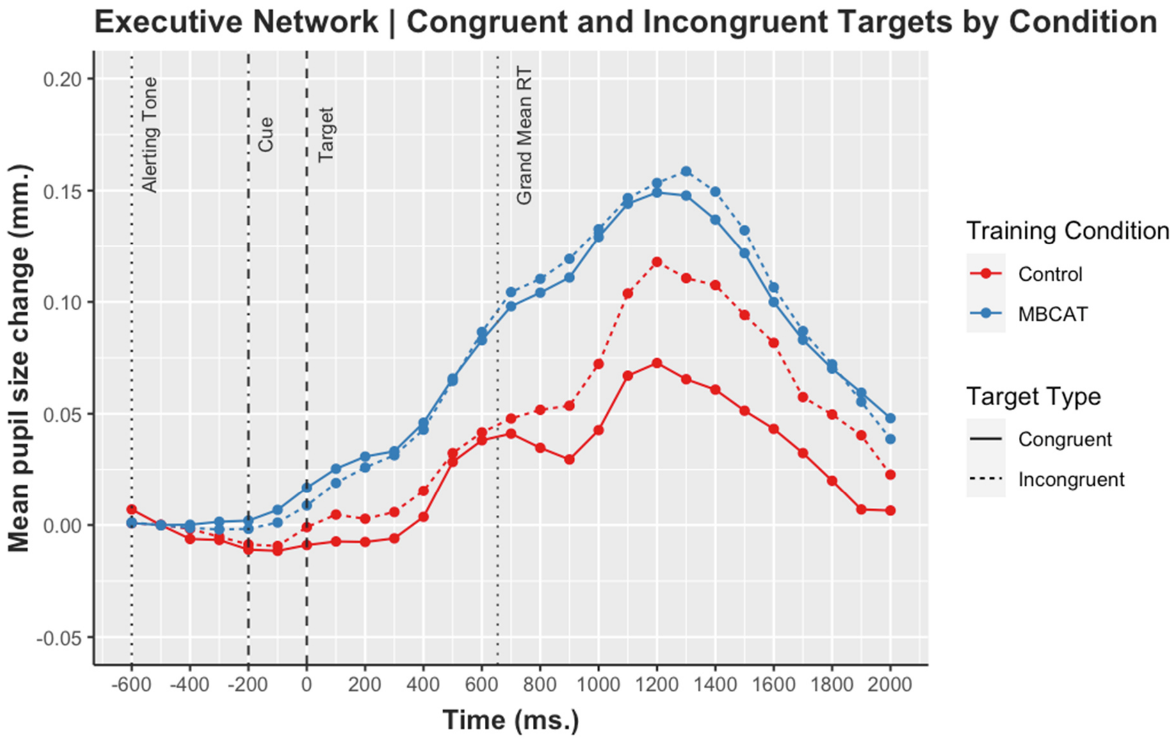
Executive Control. To analyse subjects' pupil size fluctuations in the executive network for the purpose of replicating previously observed executive TEPR (Geva et al., 2013) (H6a), TEPR trajectories for congruent and incongruent cues were compared. The model included training condition, target type (congruent, incongruent) and trial epoch (pre, post). No significant differences were observed between congruent target and incongruent target TEPR during the overall trial period ($F(1, 15.01) = 2.89$, $p = .11$, $d = .18$). However, differences between pupillary trajectories for each target type have previously been shown to manifest primarily in the post--response time window (Geva et al. 2013), so the epoch following behavioural engagement was of primary interest. There was a significant interaction between target and epoch ($F(1, 828) = 12.88$, $p < .001$), insofar as the difference in TEPR between targets was evident in the post-response epoch only ($p = .01$, $d = .31$). As such, I demonstrate a reliable post-response executive network effect ('Pe') on arousal, consistent with prior findings (Geva et al. 2013). These findings suggest that the conflict associated with incongruent targets initiated an enhanced arousal response, indicative of increased cortical resources being deployed to resolve such conflict for ongoing performance tracking.

Training Condition and Executive Control. Having validated executive network functionality for the pupil trajectories, executive TEPR were examined as a function of training condition. Contrary to expectations (H6b), there was no interaction between training condition and target type ($F(1, 15.01) = 2.74$, $p = .12$), suggesting that, for the whole trial period, MBCAT and HEP control groups exhibited no differences in arousal. However, there was a significant interaction between training condition and epoch ($F(1, 828) = 13.94$, $p < .001$), manifesting as larger overall TEPR for the MBCAT condition relative to the HEP control condition for the post-response epoch only ($p = .03$, $d = .53$). This suggests that MBCAT participants exhibited greater baseline-corrected psychophysiological activity in response to targets than HEP group participants, regardless of whether the targets were congruent or incongruent. This finding follows the general pattern of results, insofar as MBCAT participants exhibited an initiation of non-specific arousal following target presentation and response commission, culminating in significant post-response differences between groups. As such, the elevated levels of baseline-corrected executive TEPR for the MBCAT group relative to the HEP group in the post-response epoch could be a reflection of increased levels of preparatory alertness following stimuli presentation rather than an enhanced psychophysiological response to the conflict-related components of the task. Again, in relation to AGT-predicted LC-NA function and attentional states, this may be due to an enhanced mode of tonic alertness and increased monitoring of incoming stimuli as a result of the FA and OM practices frequently trained during the MBCAT programme, although present results fail to confirm this through alerting network analyses.

Most interestingly, namely in the context of present predictions that training condition would influence executive network arousal, there was a significant three-way interaction between training condition, trial epoch and target type ($F(1, 828) = 7.28$, $p < .01$). Larger TEPR was observed for incongruent targets relative to congruent targets for the HEP group, but not the MBCAT group, during the post-response epoch (p = .02, d = .63, Figure 58). Taken together, these findings suggest that the executive network effect on arousal was only evident among HEP group participants, implying that participants in the HEP group deployed more cortical resources to manage the post-response conflict associated with incongruent stimuli than those in the MBCAT group. This suggests that participation in the MBCAT training programme may have served to *diminish* post-response arousal indicative of phasic LC-NA reactivity to the conflict emerging from motor responses to incongruent stimuli. Such findings are consistent with the broader expectations of the present thesis that mindfulness represents an increased wakeful awareness towards incoming stimuli and an increased capacity for non-judging acceptance toward cognitive conflict, thus reducing the cognitive reactivity following motor responses to incongruent stimuli (as reflected by diminished post-response TEPR to incongruent targets).

Figure 58.

Baseline-Corrected Executive TEPR as a Function of Training Condition.



Note. Vertical axis indicates pupil dilation (mm.) relative to trial onset. Congruent and incongruent target pupillary trajectories displayed over pertinent trial events, split into 100ms time bins. Blue lines represent MBCAT TEPR. Red lines represent HEP control TEPR. Solid lines represent congruent target TEPR. Dashed lines represent incongruent target TEPR.

Mindfulness and ANTI-V bPD / TEPR. Next, I explored relationships between self-reported mindfulness and ANTI-V bPD and TEPR (H7), with a view to identifying potential mindfulness candidates for moderating the impact of training condition on ANTI-V arousal outcomes. All associations were non-significant and represented particularly negligible relationships (all *ps* > .43), rendering further moderative exploration unnecessary. These findings imply that dispositional mindfulness was not related to indices of tonic (Gilzenrat et al., 2010) or phasic arousal (Geva et al., 2013) during an assessment of attention network function. Therefore, it would appear that in Study 5, active mindfulness training was required to exert effects on arousal, rather than these variables being a natural result of harbouring greater mindful capacities.

NTNC TEPR and Performance

I explored whether pre-response TEPR mediated the effect of MBCAT training on NTNC errors. There was no indirect effect (β = -0.02 (0.02), p = 0.30, 95% CI [-0.06, 0.02]), suggesting that, although MBCAT was shown to marginally enhance pre-response NTNC TEPR (*a-path:* β = 0.03 (0.01), p = 0.05, 95% CI [0.01, 0.05]) and NTNC TEPR trended with improved NTNC error rates (*b-path:* β = 0.77 (0.43), p = 0.07, 95% CI [-1.62, 0.08]), the effect of MBCAT on arousal did not translate into reduced error rates. I also examined whether pre-response NTNC arousal was associated with signal sensitivtiy (*d'*) in the vigilance component of the ANTI-V. However, no relationship was observed ($r(15)$ = -.12, p = .65), and there was no mediatory effect of NTNC TEPR on the impact of training condition on *d'* responses (β = -0.52 (0.51), p = 0.30, 95% CI [-1.52, 0.48]).

In terms of arousal and performance within the orienting and executive networks, no significant or pertinent relationships were observed (*all ps* > .35), suggesting that accuracy in response to orienting cues and executive targets was not associated with an increase or decrease in arousal as a result of that response.

Summary of Results

Partly in line with expectations, MBCAT implementation exerted limited changes in self-reported mindfulness and psychological wellbeing and one improved sensitivity-based index of vigilance during the ANTI-V. Moreover, there were limited differences between MBCAT and HEP groups in relation to executive network arousal, but the majority of pertinent outcomes pertaining to attentional performance and pupillary activity were non-significant, casting questions over the utility of mindfulness interventions to augment attentional and psychophysiological outcomes during an expansion of a classic and comprehensive test of the human attention system. Although some of the present findings are consistent with – and serve to extend – crucial insights from the currently available literature, and may provide limited support for broader claims of the current thesis that mindfulness represents an increased awareness / alertness for the detection of incoming stimuli (e.g., enhanced signal sensitivity) and an enhanced capacity to disengage from the conflict induced by responses to incongruent information (e.g., conflict arousal evident in HEP but not MBCAT groups), the majority of hypotheses were not supported. As such, despite appearing to introduce a novel and potentially effective mindfulness-based training programme to the extant MBI landscape in terms of mindfulness and wellbeing, Study 5 is largely in line with Study 4 in terms of failing to find pertinent effects of mindfulness on attention and arousal. A comprehensive discussion of the results and associated implications are presented in Chapter 7.

Chapter 5: No Evidence that Long-Term / Consistent Vipassana Meditation Enhances Attentional Performance or Improves Task Focus.[36]

Overview

Studies 4 and 5 investigated whether the administration of two novel, timebound mindfulness-based interventions among meditation-naive participants served to induce changes in self-reported mindfulness, psychological wellbeing, arousal and subjective / objective indices of sustained attention and executive control. Emerging from a comprehensive evaluation of these studies were specific recommendations to examine similar attentional and psychophysiological outcomes as a function of longer-term mindfulness practice, in the hope that drawing from a broader experiential spectrum may provide deeper insights into the time course of pertinent psychological and neurocognitive change. Accordingly, the present study aimed to examine mindfulness, wellbeing and behavioural / psychophysiological outcomes as a function of i), meditator and non-meditator cohorts, ii), years of meditation experience and iii), hours of frequent practice duration. However, due to the emergence of COVID-19, inviting experienced meditators and non-meditators to the laboratory was not possible, thus stalling the ongoing collection of psychophysiological data central to core hypotheses. Instead, experienced and frequent meditators were recruited utilising online newsletters from UK-based Buddhist meditation / community centres and tested using two online versions of established tests of sustained attention and executive function (Attention Network Task (ANT) and the SART-like Continuous Performance Task (CPT)). Additionally, harnessing the opportunity to obtain insights into the mental health benefits of meditation and mindfulness in the context of the pandemic, symptoms of anxiety, depression, intolerance of uncertainty and COVID-specific distress were explored as a

[36] Portions of this Chapter inform the basis of a submitted manuscript (Hill, J. R. J., Haddock, G., and Proulx, T. 2021).

function of meditation experience / frequency. Originally intended to be integrated into the present Chapter (if capacity permitted), these outcomes are now contained in Appendix X in a separate manuscript.

Consistent with some predictions, greater magnitudes of meditative experience and practice resulted in several clinically relevant benefits, specifically enhanced mindful responding and reduced distress. Additionally, pertinent mediatory roles of mindfulness were observed among relationships between historical / frequent meditative practice and wellbeing (Appendix X). However, there were limited findings in relation to objectively assessed attentional outcomes and thought processes, which, although revealing several routes for additional inquiry, point to the conclusion that greater meditation practice was not associated with enhanced capacities for sustained / executive attention.

General Introduction

The oldest known record of Buddha's original teachings - the Pali Canon - represents the inception of one of the most prevalent meditative techniques in Theravada Buddhism - Vipassana – which emphasises a steadying of the "unstable mind" through a sustained focus on a specific meditative object, a vigilant awareness of the presence of internal and external distractors and the ability to return attention to the object whenever it becomes untethered from voluntary control (Amihai and Kozhevnikov, 2015; MacLean et al., 2010). During Vipassana meditation, one begins by focusing attention on a chosen object - typically the breath - in a sustained manner (focused attention, FA), before eventually expanding one's focus to encompass the full experiential field in an open, non-reactive and non-judgmental way (open monitoring, OM), without becoming caught up in responses to sensory or mental content (Slagter et al., 2007; Zanesco et al., 2013). Although some meditators only practice FA *or* OM, Vipassana practitioners incorporate both styles into their practice, with novices starting out with FA before moving onto OM as their meditation deepens (Cardena et al., 2015; Malinowski, 2013). In this way, Vipassana meditation directly informs the utilisation of FA and OM techniques in Western approaches to meditation practice, specifically mindfulness meditation, which has been defined by its developer as “mostly Vipassana practice” (Kabat-Zinn email cited in Gilpin, 2008, page 238). Indeed, although marked contrasts exist between traditional Buddhist views of mindfulness and modern Western psychological interpretations, there is consensus that cultivating levels of mindfulness requires a consistent form of mental training in the form of FA and OM practice (Malinowski, 2013). As such, Vipassana meditation techniques are central to the predominant mindfulness-based interventions (MBIs) utilised in extant clinical and training-based research (Jha et al., 2007; Kabat-Zinn, 1979; Segal et al., 2002), whereby most prior scientific studies examining the effects of regular meditative practice on neurocognitive, attentional and wellbeing outcomes (e.g., MBIs, brief mindfulness training, meditation retreats, meditator studies) have focused predominantly on Vipassana / mindfulness-based practices (Amihai and Kozhevnikov, 2015; Tang et al., 2015). Accordingly, the same proposed links between FA / OM techniques and specific attentional and neurocognitive processes discussed throughout this thesis (Chapter 1 / Chapter 4, Study 5; ‘MBIs as Attention Training’) can be applied to ongoing Vipassana meditation practice. The present study therefore aims to explore psychological and attentional effects of longer-term meditation practice using only Vipassana / mindfulness-based meditators.

Although the notion that mindfulness meditation improves attentional abilities has received substantial theoretical (Bishop et al., 2004; Kabat-Zinn, 2004; Shapiro et al., 2006) and empirical attention (Casedas et al., 2020; Yakobi, Smilek and Danckert, 2021), much of the research in the area has focused primarily on the effects of structured and timebound interventions, training regimes and meditation retreats (Lao et al., 2016; Norris et al., 2018; Jha et al., 2007). So far, relatively few scientific studies have explored associations between substantial meditative experience and attentional performance (Badart et al., 2018; Devaney et al., 2021; Kozasa et al., 2017), with fewer still dedicated to exploring the effects of practice frequency / duration and the underlying mechanisms of longer-term meditation-induced psychological and attentional change (Gallant 2016; Josefsson and Broberg, 2011). Such considerations are important, not least because much of the conclusions around the utility of MBIs / meditative programmes at improving sustained / executive attention remain ambiguous. Such ambiguity may be explained by the fact that a certain ‘dose’ or ‘intensity’ of mindfulness practice is necessary to achieve attentional and cognitive stability, necessitating a deeper examination into the broader time course of cognitive change (Brefcyznski et al., 2007; Gallant 2016; Lao et al., 2016). Moreover, the relative paucity of research combining experienced meditator cohorts and attention tasks has resulted in the use of instruments of variegated sensitivity, which may contribute to the mixed results in the area (Badart et al., 2018). Finally, no study has yet assessed the impact of meditation on wellbeing within the context of the current pandemic, a seemingly crucial addition to the literature when one considers the enthusiasm through which mindfulness meditation is currently being promoted as an effective tool for maintaining mental wellbeing during these uncertain times (Dahlkemper, 2020; NHS 2020). Accordingly, the present study seeks to explore an array of attentional, cognitive and clinically relevant outcomes among experienced / frequent meditators and non-meditators through the utilisation of established and novel assessments of psychological wellbeing, attentional performance and distinct cognitive processes. It was hoped that this approach would help to contextualise some of the mixed results in the literature and contribute to an understanding of the benefits of a broader range of mindfulness experience / duration, which may otherwise be missed when considering the effects of timebound interventions alone.

Insights From Neuroscience

Bolstering research interest in the attentional effects of long-term meditation practice, insights from neuroscience reveal that, relative to non-meditators, experienced meditators display differences in cortical activity when completing tasks assessing attentional capabilities. For example, meditators have exhibited increased connectivity between attentional regions associated with sustained attention / vigilance (Kozasa et al., 2017), increased modulation of P3 amplitudes during executive control tasks (Jo et al., 2016), greater phase consistency during target detection (which is potentially linked to prefrontal dopaminergic and / or noradrenergic function) (Lutz et al., 2009), reduced brain resource allocation in response to preceding targets during an attentional blink task (which is indicative of reduced mental capture by distractors) (Slagter et al., 2007), reduced theta band activity during NoGo vs. Go trials (indicative of more efficient conflict detection) (Andreu et al., 2019), enhanced activation of task-positive brain regions (dACC and dlPFC) and reduced activation of Default Mode Network (DMN) brain regions associated with self-referential processing and off-task thought (PCC and mPFC) (Brewer et al., 2011). These findings are consistent with the view that increased meditation experience and frequency can influence cortical resource allocation during sustained attentional focus and vigilance, attentional control / response inhibition, and on-task thought processes, consistent with conceptualisations of mindfulness meditation as an awake and alert mode of being (Britton et al., 2014; Tang et al., 2015). Moreover, although novice meditators have been shown to exhibit increased activation within the ACC (a cortical structure pertinently involved in sustained attention and the higher order process of conflict detection / resolution), longer-term meditators exhibit reduced ACC activity, implying that although meditators are more *aware* of incoming stimuli, they eventually exhibit more efficient processing in relation to cortical resource allocation for ongoing performance tracking and reactions to cognitive conflict (Brefcyznski-Lewis et al., 2007). This implies that capacities for sustained / executive attention are likely dose-dependent, necessitating an examination of diverse attentional outcomes as a function of broader experiential and frequency-based meditative engagement. Indeed, assessing the current empirical landscape pertaining to the attentional benefits of meditative experience and consistent meditative practice may yield valuable insights into which aspects of attention are most receptive to longer-term mindfulness-based meditation.

Impact of Meditation on Performance-Based Tests of Attention

Meditation and Sustained Attention. Examinations of meditating and non-meditating populations in relation to sustained attention outcomes have yielded mixed results. Experienced Vipassana meditators have been observed to exhibit fewer errors of commission relative to active and passive controls during a visual Go/NoGo task (Andreu et al., 2019). Moreover, longer-term meditators were observed to outperform shorter-term meditators and passive controls on a task of sustained auditory attention (Valentine and Sweet, 1999). Additionally, experienced meditators who averaged six years of experience were shown to outperform matched non-meditators in terms of accuracy during visual and auditory versions of a SART variant (Badart et al., 2018). Improved sustained visual attention and vigilance in the form of increased hits and reduced false alarms during a SART-like visual attention task has also been observed as a result of three months of Vipassana practice (MacLean et al., 2010). Finally, lower overall error rates during the ANT were observed among meditators (13 years average experience, three sessions per week) relative to matched non-meditators (Jo et al., 2016). These findings suggest that increased meditation experience / frequency is associated with superior attentional stability and alertness during continuous task performance, effects which appear to span sensory modalities.

Conversely, no differences in performance during a Multiple Object Tracking (MOT) sustained attention task were observed between experienced Vipassana meditators (seven years average experience, 14 x hour-long practice sessions per week) and matched non-meditators (Devaney et al., 2021). Moreover, experienced Vipassana meditators (six years average experience) did not outperform matched non-meditators during a CPT task (Lykins et al., 2012). Additionally, no differences were observed between experienced (six years average experience) and retrospectively matched non-meditators in relation to false alarms and omission errors during the SART, and no associations existed between length of meditation experience and SART performance outcomes (Josefsson and Broberg, 2011). These results imply that greater meditation experience does not enhance outcomes pertaining to improved capacities for sustained attention.

Meditation and Executive Function. Examinations of meditating and non-meditating populations in relation to executive control have also yielded mixed results. Experienced Vipassana meditators have been observed to exhibit fewer errors of omission relative to active and passive controls during a Go/NoGo task (Andreu et al., 2019). Moreover, experienced mindfulness meditators exhibited lower Stroop Interference Effects (SIE) in the form of reduced Stroop errors within a time-limited scenario relative to matched non-meditators (Moore and Malinowski, 2009). Additionally, combined FA and OM meditators responded with reduced SIE relative to age-matched non-meditators in a study where meditation frequency - but not meditation experience - was also associated with reduced SIE (Chan and Woolacott, 2007). Similarly, experienced meditators have been observed to exhibit reduced executive network scores during the ANT (Jha et al., 2007). Finally, associations have been observed between practice frequency / duration and improved inhibitory efficiency (Gallant, 2016), suggesting that length of experience / practice duration is important in terms of enjoying the benefits of mindfulness practice on executive control. These findings imply that experienced / frequent meditators exhibit improved executive function in the presence of competing distractor stimuli during ANT and Stroop tasks.

However, no SIE differences were observed between experienced meditators (three years average experience) and matched non-meditators, or between frequent meditators (three sessions per week) and matched non-meditators (Kozasa et al., 2017). Moreover, Josefsson and Broberg (2011) observed no differences between experienced meditators and retrospectively matched non-meditators in terms of SIE and Stroop errors. Meditation experience and current meditation frequency were also not associated with SIE or errors (Josefsson and Broberg, 2011). These results suggest that greater meditation experience exerts no pertinent benefits on executive control during the Stroop task.

These inconsistent findings warrant a deeper investigation into how meditation impacts attentional processing, specifically sustained and executive attention. Considering that length of meditation experience, practice frequency, non-meditator matching techniques and selected visual attention tasks / outcomes were equally variable *across* supporting / non-supporting studies, identification of distinct factors contributing to the contrasting findings is difficult. However, one important explanation for the mixed results in the literature could be that studies generally fail to account for the temporal distance between meditative practice and attentional assessment (Sumantry and Stewart, 2021). As such, the heterogeneity of results may reflect unaddressed confounds in relation to the variable impact of meditation practice on attention depending on how many days prior to assessment meditative engagement last occurred. In other words, the recency of practice may represent one of the more salient factors in the exertion of potent effects on attentional performance (Sumantry and Stewart, 2021). Accordingly, in addition to examining effects of historical meditation experience and current meditation frequency, I ensured that comparisons were made between "long-frequent" (long = 1-hour daily duration, frequent = min. 7 days per week) and matched non-meditators, thus increasing the chances that meditators would have meditated on the same day as attentional assessment, and addressing key questions in extant literature around temporal proximity between meditation and assessment (Sumantry and Stewart, 2021). Moreover, the fact that assessment is conducted online in the present study potentially reduces temporal disparities further, insofar as scheduling sequential laboratory slots was not necessary, allowing meditators to complete the tasks as soon as they had signed up to the study.

Another explanation for the mixed results in the literature may reside in the importance of exploring underlying processes involved in meditation-induced attentional change, potentially providing important insights into the hidden mechanisms contributing to mixed conclusions. As such, the present study assesses the role of mindfulness as a proposed psychological moderator of the impact of meditation on attention. Specifically, capacities for sustained attention and executive control are examined utilising online versions of the Attention Networks Task (ANT) and Continuous Performance Task (CPT) among experienced *and* frequent meditators whilst concurrently assessing the role of specific mindfulness facets[37] as psychological moderators.

Another salient factor when assessing the reviewed literature is that all studies present conclusions based on exclusively objectively assessed attentional outcomes. As outlined in

[37] Discussed in 'Psychological Mechanisms' section

Study 4, these methods may not represent a wholly sensitive method for gauging sustained attention and attentional control across paradigms within the meditation cohort literature. Rather, subjectively reported cognitive processes may represent a more sensitive method of detecting the attentional benefits afforded by meditation practice. As such, integrated into the present research are subjective measures of attention in the form of thought probes interspersed throughout the CPT. It was hoped that any observed effects of meditation experience / frequency on subjectively assessed changes in cognitive processes would serve to augment and contextualise the growing yet somewhat disparate literature on the benefits of meditation on sustained attention.

Impact of Meditation on Cognition

As illustrated in Chapter 4, fluctuations in attention are reliably associated with self-reported cognitive content (Schooler et al., 2014), insofar as mind wandering and off-task thought are consistently associated with errors and reaction time variability during tasks such as the SART and CPT (Bastian & Sakur, 2013; Schooler at al., 2014; Smallwood & Schooler, 2006; Stawarczyk et al., 2014). Considering that some evidence demonstrates superior performance during such tasks among meditators relative to non-meditators (Badart et al., 2018), one would also expect meditators to exhibit reduced instances of mind wandering (Schooler et al., 2014). However, there has been limited empirical attention afforded to the effects of longer-term meditation practice on mind wandering. Recent endeavour has attempted to address this by incorporating self-report and probe-sampling methods, garnering mixed results. For example, scale-based assessments of mind wandering among experienced meditators relative to non-meditators were initially shown to be markedly reduced, but these effects disappeared when controlling for age (Linares Gutierrez et al., 2019). Moreover, recent endeavour utilising probe-sampling methods has demonstrated that expert meditators reported less mind wandering than novice meditators *during* a period of FA meditation practice (Brandmeyer and Delorme, 2018; Rodriguez-Larios and Alaerts, 2020). However, these findings are limited to within-meditation states and do not provide insights into the broader temporal benefits of meditation on mind wandering. Moreover, the probes utilised were vague, insofar as the options to report mind wandering were limited (e.g., the option: 'I was thinking about something else' (Rodriguez-Larios and Alaerts, 2020) or Likert-type responses to: 'how much were you mind wandering?' (Brandmeyer and Delorme, 2018)). Taken together, these findings highlight the need to explore subjective attentional states among experienced / frequent meditators in more detail. To the present author's knowledge, no study has yet combined subjective and objective assessments of attention within long-term meditating cohorts by merging probe sampling with more "classical" performance-based tests of attention. Accordingly, I assessed probe-sampled thought reports during the CPT as a function of meditation experience / duration in order to explore the impact of Vipassana meditation on subjective accounts of attentional lapse, as well as the more objective task-based outcomes.

Psychological Mechanisms

Examining relationships between meditation, self-reported mindfulness and specific attentional outcomes may help to identify the mechanisms underlying the impact of meditation experience / frequency on capacities for sustained and executive attention. Such insights may also help to contextualise some of the mixed findings in the literature, insofar as different components of mindfulness may be nurtured by distinct types of meditative practice and may exert variegated effects on attentional outcomes, depending on which tasks are administered. Elucidating which mindfulness facets are most receptive to (a) longer-term meditative experience and (b) magnitude of current meditative practice, and how these relate to specific performance-based tests of attention, may serve to clarify some of the divergent findings in the literature.

Although dispositional mindfulness has been linked to attentional regulation in a theoretical manner, relatively few studies have empirically tested this relationship. For example, higher MAAS scores were associated with reduced errors of omission during the CPT, but were not related to RT (Schmertz, Anderson and Robins, 2009). Greater MAAS was also related to improved overall accuracy during the SART (Cheyne, Carriere and Smilek, 2006). Additionally, higher total FFMQ and FFMQ-Describe subscale scores were associated with reduced aggregate errors (commission + omissions) during the SART and reduced Stroop Interference Effects (SIE) (Josefsson and Broberg, 2011). FFMQ-Describe and Non-Judging scores were also shown to be associated with improved ANT orienting outcomes (Sorensen et al., 2018). Moreover, FFMQ-Awareness scores were related to reduced flanker interference effects through improved performance to incongruent targets (Lin et al., 2018). Finally, higher Kentucky Mindfulness Inventory Scores (KIMS) were associated with less Stroop interference (Moore and Malinowski, 2009) and reduced attentional lapses during the CPT (Galla et al., 2012). However, contrasting findings report no relationship between MAAS and SIE (Schmertz, 2006) and Lykins et al (2012) found no associations between FFMQ and a range of cognitive tasks. Moreover, no additional associations were observed between the majority of FFMQ subscales and executive function (Lin et al., 2018).

In an effort to address these inconsistencies and clarify the nature of relationships between mindfulness and attention, Quickel et al. (2014) conducted a multi-scale and multi-task study to explore a larger range of possible associations between mindfulness and performance. The authors observed no reliable relationships, leading to conclusions that available mindfulness scales do not capture the constructs of attentional focus / executive control, at least with how these components were measured in the study (Quickel et al., 2014). Curiously, the ANT, SART, CPT and Stroop were absent from the multi-task analysis, leaving open the possibility that, had these tasks been examined, inferences more consistent with the majority of outlined individual studies may have been reported.

As such, building on comparable associations (Cheyne, Carriere and Smilek, 2006; Schmertz, Anderson and Robins, 2009) and consistent with prior studies implementing two-task paradigms to combine self-reported mindfulness with assessments of sustained attention and executive function (Josefsson and Broberg, 2011), the present research examines relationships between the MAAS / FFMQ and attentional outcomes drawn from the ANT and CPT. In this way, it was hoped that potential mechanisms underlying the effects of meditation on attention could be identified. For example, consistent with broader expectations in the current thesis relating to distinct mindfulness components and attentional improvements, one proposed mechanism could be that increased attentiveness / awareness arising from meditation aids the detection of task-related stimuli, whereas increased meditation-induced acceptance towards cognitive reactivity to incongruency aids disengagement from distraction conducive to enhanced performance. Such mechanisms should be clearly detectable through the combination of self-report measures and attention tasks among meditator cohorts.

Accordingly, Study 6 incorporates two widely used measures of mindfulness (MAAS / FFMQ). Also included were two disorder-specific symptomology outcomes (PHQ-9, GAD-7), two measures of transdiagnostic uncertainty intolerance (IUS-P, IUS-I) and a COVID-specific measure of psychological distress (CAS), which were designed to further extend inquiry into the distinct benefits of longer-term / high-frequency meditation practice on mental wellbeing in the context of the pandemic. These analyses are not presented in the current chapter but can be located in Appendix X.

To the author's knowledge, there are no existing studies jointly assessing the direct and indirect effects of historical and current levels of meditation practice on sustained and executive attention, subjectively assessed on-task / off-task thought processes, self-reported mindfulness and specific indices of psychological distress in response to the COVID-19 crisis. Moreover, despite not being able to fulfil original intentions of utilising pupillometry to gauge levels of LC-NA arousal within meditating and non-meditating cohorts, the current research is nonetheless able to examine an array of important attentional processes indicative of sustained alertness / vigilance potentially indicative of elevated LC-NA activity. Taken together, any pertinent findings emerging from the present study are likely to represent informative additions to a diverse research landscape, spanning cognitive, clinical and attentional domains.

Hypotheses

Consistent with the multifaceted nature of the present research, the hypotheses span a variety of outcomes. First, it was predicted that meditators would report higher MAAS and FFMQ facet scores, specifically Observing, Describing and Non-Reactivity relative to non-meditators (H1a), consistent with extant comparisons (Brown and Ryan, 2003; Campos et al., 2019; Chambers et al., 2008; Josefsson and Broberg, 2011). Further, it was hypothesised that length of meditation experience and frequency of practice would be positively related to these indices of mindfulness (H1b) (Chambers et al., 2008; Josefsson and Broberg, 2011).

Turning to the attentional outcomes, it was predicted that meditators would exhibit improved performance during the ANT (H2a), supporting prior research evidencing improved overall ANT accuracy (Jo et al., 2016) and improved executive network scores (Jha et al., 2007). Building upon this research, and upon findings pertaining to improved alerting and executive performance as a result of MBCAT intervention, as previously outlined in the current thesis (see Study 5), it was hypothesised that greater meditation experience and frequency would be associated with improved alerting and executive network performance (H2b). As such, expected effects would serve to address recent calls to provide insight into the magnitude of historical experience / current frequency that is necessary to observe pertinent cognitive change (Lao et al., 2016). Owing to prior demonstrations of self-reported mindfulness being associated with improved ANT orienting / executive performance and incongruent flanker task performance (Lin et al., 2018; Sorensen et al., 2018), it was predicted that greater FFMQ scores would be associated with improved network outcomes during the ANT and would mediate the effects of meditation experience / frequency on these outcomes (H2c). Expected mediator effects would provide novel findings into the mechanisms underlying meditation-induced attentional change during the ANT.

In relation to CPT performance, it was predicted that meditator groups would exhibit improved sustained attention in the form of reduced overall error rates (H3a), consistent with findings drawn from comparable tests of attention (Andreu et al., 2019; Badart et al., 2018). Moreover, a comprehensive selection of CPT outcomes in the form of RT-inferred attentional lapses (Unsworth and Robison, 2016), false alarms and errors of omission[38] were utilised to provide a more detailed picture of the effects of meditation on sustained attention outcomes. It was also hypothesised that historic / current levels of

[38] As outlined in 'Method'

meditation practice would be significantly associated with improvements to these outcomes (H3b), thus providing novel dose-dependent contributions to the available literature (Lao et al., 2016). Owing to prior associations between mindfulness and improved accuracy during the CPT (Schmertz, Anderson and Robins, 2009) and SART (Cheyne, Carriere and Smilek, 2006; Josefsson and Broberg, 2011), it was predicted that greater MAAS and FFMQ scores would be associated with improved CPT performance and would mediate the effects of meditation experience / frequency on these outcomes (H3c). Mediator effects in the expected direction would provide novel findings into the mechanisms underlying meditation-induced enhancements to sustained attention outcomes during the CPT.

Finally, it was hypothesised that meditators would disclose more thought reports indicative of sustained attention (e.g., on-task) and less reports indicative of attentional lapse (e.g., mind wandering) relative to non-meditators (H4a), and that these reports would be differentially related to meditation experience and practice frequency (e.g., greater experience = more on-task reports) (H4b). As such, it was hoped that a more comprehensive and temporally related assessment of the impact of long-term / frequent meditative practice on subjective attentional states could be acquired, extending limited insights into thought content (Brandmeyer and Delorme, 2018; Rodriguez-Larios and Alaerts, 2020**)** and augmenting the current research landscape pertaining to the more "classical" objective measures **(**Andreu et al., 2019; Badart et al., 2018).

Method[39]

Participants

I recruited 75 participants (38 males, 37 females; M_{age} = 41 [SD = 17]; the approximate sample size for medium effect size was derived from comparable studies comparing meditators and non-meditators on attentional and self-report outcomes (Josefsson et al., 2011; Lykins et al., 2012). Moreover, Monte Carlo sample size estimation for multiple indirect effects assuming medium-sized pathways (Schoemann, Boulton and Short, 2017) resulted in a minimum recommended sample size of 65 for .80 power. Post-hoc Monte Carlo power analyses for my obtained sample and observed effects revealed power estimations of between .78 and .89 for my core comparisons and mediation models. My sample size and associated power calculations are in line with recommendations for achieving .80 power with medium mediatory effects using bias-corrected bootstrap tests (Fritz & MacKinnon, 2007), and consistent with prior studies using comparable sample characteristics, methods and analyses (Josefsson et al., 2011).

Consistent with recruitment methods of prior research (Lykins et al., 2012), 38 participants were recruited through the Gaia House Meditation Centre, based in South West England (17 males, 21 females; M_{age} = 54 [SD = 12.7]). The study was included in the Gaia House newsletter, which reaches meditation groups both nationally and internationally. All meditators disclosed their meditation type as either Vipassana or Mindfulness meditation. 37 participants were recruited via Prolific Academic (PA) (21 males, 16 females; M_{age} = 28 [SD = 9.2]), of whom eight declared prior meditation experience. The vast majority of those with

[39] See Appendix 0ii: 'Overview of Procedures and Data Preparation' for full details pertaining to generalised experimental protocol and behavioural pre-processing techniques.

meditation experience (87.5%) and most of those who'd never meditated (66.6%) had a university education. All participants received £10 for their participation.

Materials and Procedure[40]

All demographics (age, gender, highest level of education) and questionnaire data were captured electronically using Qualtrics Online Questionnaires. Participants completed the Qualtrics questionnaires and were subsequently directed to the Pavlovia online experimental platform (see https://pavlovia.org/) to complete the ANT and CPTp, which were designed using PsychoPy 3 (Pierce et al., 2019).[41]

To test hypotheses pertaining to the effects meditation experience / frequency on self-reported mindfulness, the following measures were employed.

MAAS (Brown & Ryan, 2003). The scale showed excellent reliability (α=.91).

FFMQ (Baer et al. 2008). Reliability of the Observe subscale was limited (α = .52). Removing the most problematic item resulted in only a marginal improvement (α = .61). Nonetheless, the Observe scale was included in all analyses. Reliability of total FFMQ scores was good (all α = .83).

Attention Network Task (ANT) Stimuli and Procedure (Fan et al, 2002). I created an online version of the Attention Network Task based on Fan et al. (2002), which was identical to that employed in Study 4. The three attention networks are assessed in the same way.

[40] See Appendix 0i 'Overview of Self-Report Measures' for full details of the mindfulness and wellbeing measures employed in the present study.
[41] All general online procedures and technical considerations relating to the design and implementation of attention tasks are outlined in Appendix 0ii; 'Over of Procedures and Data Preparation'.

Continuous Performance Task (CPT) Stimuli and Procedure (Conners, 2000). I also created an online version of the classic Continuous Performance Test (CPT; Conners, 2000). The CPT is a target-detection task and is cited as one of the most frequently used tasks to assess sustained attention and vigilance in both research and clinical contexts (Roebuck et al., 2017). During the CPT, participants are presented with a series of letters (Targets) in random order. Each letter is displayed on screen for 1000ms. Participants are required to respond to each letter as rapidly as possible by pressing the spacebar, without sacrificing accuracy. When participants see the infrequent letter "X", they're required to withhold their response. Non-target trials ("X" trials) are presented on approximately 12% of trials and trial order is pseudo-randomised so that targets are always separated by at least one target trial. Participants are presented with 24 practice trials (practice block) and 600 experimental trials spread over four experimental blocks. Sustained attention and vigilance are operationalised as response events, which include correct target responses (hits), incorrect target omissions (misses), correctly withholding responses to non-targets (correct rejections) and erroneously committing to non-targets (false alarms). Moreover, RT-inferred indices of attentional lapse utilised in different tasks (Unsworth and Robison, 2016) were also employed in the CPT, whereby the slowest quintile of RT was classified as a 'lapse'. For present purposes, attentional lapses, errors of commission ('false alarms') and errors of omission ('misses') were utilised to assess sustained attention. Studies have demonstrated that sustained attention outcomes utilising the CPT are enhanced in individuals higher in self-reported mindfulness (Keith et al., 2018; Schmertz et al., 2017) and those who participated in mindfulness-based interventions (Bueno et al., 2015; Rice & Liu, 2017; Semple, 2010). As such, examining differences in CPT outcomes between meditator and non-meditator cohorts offers an opportunity to extend research on mindfulness and meditation in relation to enhanced attentional outcomes.

Thought Probes (Unsworth and Robison, 2016). I incorporated identical thought probes into the CPT as those administered by Unsworth and Robison (2016). These probes are similar to those used in Study 4 but instead utilise the original mind wandering item (as opposed to dividing mind wandering into three temporally distinct categories). The decision to treat mind wandering as one item was made in order to render the present study more closely aligned with comparable research utilising probe sampling to assess thought report differences between meditators and non-meditators. Participants were asked to press one of five keys to indicate what they were thinking immediately prior to the appearance of the probe. Thought probes were employed to assess the prevalence of on-task and off-task thought throughout the task. The probe screen is illustrated in Figure 59. Fourteen probes (4.2% of trials) were pseudo-randomised to appear approximately once per minute throughout the task.

Figure 59.

Thought Probes Interspersed Throughout the CPT.

Please characterise your current conscious experience:
(press the corresponding number)

1) I am totally focused on the current task.
2) I am thinking about my performance on the task or how long it is taking.
3) I am distracted by sights/sounds/temperature or by physical sensations (hungry/thirsty)
4) I am daydreaming/my mind is wandering about things unrelated to the task.
5) I am not very alert/my mind is blank or I'm drowsy.

Note. Probes adapted with permission from probe battery administered by Unsworth and Robison, 2016.

Meditation Group Procedure

Meditation experience was measured in several ways. Firstly, overall meditation experience was assessed by asking how many years participants had been meditating. Daily meditation duration was also measured by asking how much time per day participants spent meditating. Finally, perceived meditation experience was assessed by asking participants to indicate their own level of meditation experience (none, novice, experienced, expert). Appendix 6.1 illustrates the number of participants per cohort within each category of objective and perceived meditation experience. Appendix 6.2 presents significant differences between cohorts in terms of meditation experience and practice. Since some members of the primarily non-mediating cohort exhibited meditation experience, I divided the total sample into several different groups. Firstly, participants who reported no meditation experience were classed as *non-meditators* (15 males, 13 females; $M_{\text{age}} = 29$ [$SD = 10.2$]) and all those participants with a minimum of 2 years prior meditation experience (including those in our PA cohort who disclosed meditation experience) were categorised as *meditators* (19 males, 20 females; $M_{\text{age}} = 52$ [$SD = 15.0$]). Note that the meditating group included three PA participants who reported 3-4 years of prior experience (Appendix 6.1). I also divided participants into *Long-frequent meditators* and *matched non-meditators* based on responses regarding *current daily practice*. *Long-frequent meditators*, which consisted of 19 meditators who reported meditating at least 1 hour per day, 7 days per week (5 males, 14 females; $M_{\text{age}} = 49$ [$SD = 9.54$]), were compared with 16 *matched non-meditators* who were matched as closely in age and gender as possible (7 males, 9 females; $M_{\text{age}} = 35$ [$SD = 9.14$]). These matching methods were directly informed by comparable prior research (Josefsson and Broberg, 2011).

Consequently, I was able to compare levels of self-reported mindfulness, mental well-being and attentional performance between groups defined by meditation experience (*n* = 67) and current meditation practice (*n* = 35) before further exploring meditation experience and daily meditation duration as continuous predictors within mediation models for the whole sample (*n* = 75).

In addition to meditation experience and level of current practice, the age and gender of participants was also recorded, consistent with prior research controlling for these variables (Josefsson et al., 2011). However, lifestyle factors, such as sleep habits, alcohol consumption, exercise frequency, smoking and perceived physical health were not assessed, which may represent important confounds when considering relationships between meditation and attention / wellbeing. These omissions are evaluated accordingly when discussing present results.

Analytic Strategy

Performance and sustained attention during the attention tasks was assessed using measures of reaction time, response accuracy and experience sampling methods[42].

I conducted Multivariate Analysis of Covariance (MANCOVAs) and follow-up ANCOVAs to explore differences in self-reported mindfulness and attention performance between (a) meditators and non-meditators, and (b) long-frequent meditators and matched non-meditators. Pillai's trace is reported for all MANCOVAs due to unequal sample sizes.

Unless otherwise stated, LMMs and generalised LMMs were employed to analyse RT and binomial accuracy data as a function of network-specific stimuli (Appendix 0iii, Study 6). To account for the repeated sampling of subjects within cue and target conditions, LMMs

[42] Data preparation for behavioural outcomes is displayed in Appendix 0ii, pg. 15.

were preferred, which were compared using AIC criterion. I also estimated LMMs for all RT analyses and generalised LMMs for non-aggregated binomial accuracy data, CPT attentional performance outcomes and probe response analyses. Age and gender were controlled for in all analyses, and subject was included as a random intercept in all minimal models.

Finally, to inform potential mediation analyses, inter-correlations, controlling for age, were utilised to explore whether ANT network scores and indices of CPT performance were associated with continuous measures of meditation (meditation experience, frequent daily meditation duration) and self-reported mindfulness.

Demographics Analyses

To explore whether demographic characteristics were related to meditation experience, self-report measures and attentional outcomes, MANCOVAs and partial correlations were conducted. First, gender differences for all measures were explored in relation to meditation condition, followed by correlational analyses to examine relations among age and meditation experience, daily meditation duration and perceived meditation experience. Partial correlations were subsequently implemented to assess whether age was associated with trait mindfulness (MAAS and FFMQ scales), attention network performance and CPT performance, controlling for meditation experience. Since meditators were significantly older than non-meditators ($t[65] = 7.62$, $p < 0.001$), and since gender differences existed for some mindfulness measures within meditating and non-meditating groups, age and gender were controlled for in all analyses.

ANT. MANCOVA revealed no effect of gender on attention network scores ($p = .14$). Nonetheless, gender was controlled for in all further analyses, in line with comparable meditation studies (Josefsson et al., 2011). Age, controlling for meditation experience, was not related to alerting or orienting network scores, but was positively associated with executive network RT scores ($r[63] = 0.33$, $p = 0.01$). Age was also negatively associated with accuracy (proportion correct), specifically in response to double cues within the alerting network (trending, $p = .07$) and to central cues within the orienting network ($p = .03$). Accordingly, age was controlled for in all analyses exploring the effects of meditation on attention network scores and accuracy.

CPT. MANCOVA revealed no effect of gender on overall CPT RT ($p = .71$) or accuracy ($p = .58$). Nonetheless, gender was controlled for in all further analyses, in line with comparable studies into the effects of meditation on attentional performance. Age, controlling for meditation experience, was not related to reaction time or overall accuracy during the CPT (*p*s > .10). However, due to observed associations between age and several indices of ANT performance, age was controlled for in all analyses exploring the effects of meditation on CPT outcomes.

ANT Analyses

In order to analyse ANT-specific outcomes, identical procedures were used as those outlined in Studies 4 and 5.

CPT Analyses

Lapses of attention and errors during the CPT were measured in several ways. First, RTs from fastest to slowest were ranked ordered and placed into quintiles. The slowest quintile was taken as a lapse (consistent with prior studies (Unsworth et al. 2010, 2016). Moreover, omission errors (missed non-targets) and false alarms (incorrect commission responses to targets) were used to assess sustained attention and vigilance throughout the task in the form of error propensity. Finally, exploring the nature of task-related and unrelated thought, on-task and off-task thoughts were assessed through an exploration of proportions of each thought probe response in the whole sample and within meditating sub-samples.

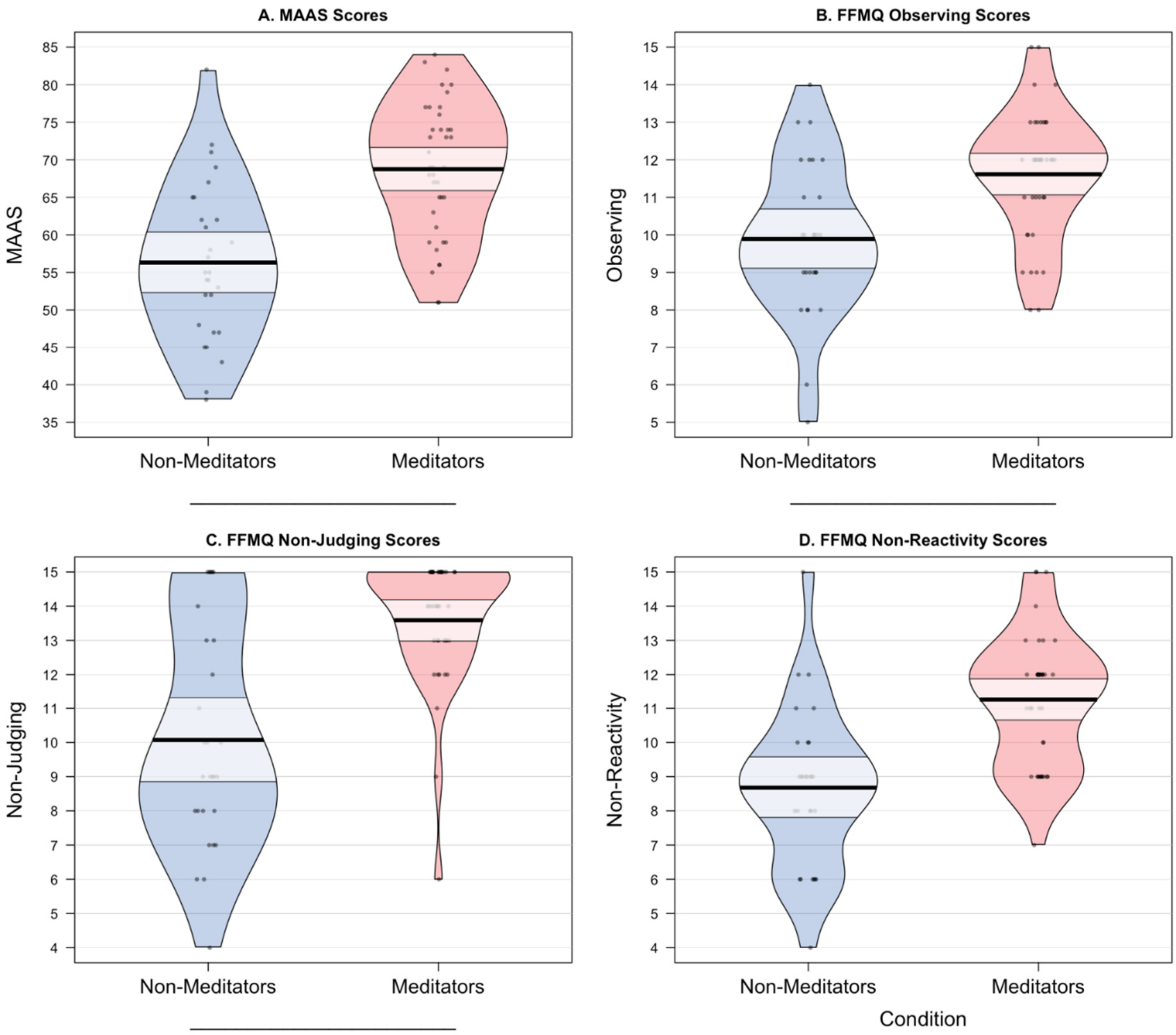
Results

Mindfulness

Mindfulness (Cohorts, H1a). As expected, MANCOVA modelling all mindfulness outcomes as a function of overall meditation condition, controlling for age and gender, revealed several statistically significant differences between meditators and non-meditators in terms of MAAS and FFMQ subscale scores (Figure 60). As expected (H1a), there was a significant effect of meditation experience on composite mindfulness scales ($V = 0.31$, $F(5, 59) = 5.38$, $p < .001$). Follow-up univariate ANCOVAs (Table 4) revealed significant effects of meditation on MAAS, Observing, Non-Judging, Non-Reactivity and Total FFMQ scores (Figure 60A:60D). Similarly, MANCOVA modelling the same mindfulness outcomes as a function of meditation frequency condition revealed significant differences between long-frequent meditators and matched non-meditators (Appendix 6.4). As expected (H1a), there was a significant overall effect of current meditation practice on composite mindfulness scales ($V = 0.39$, $F(6, 26) = 2.74$, $p = 0.03$). Follow-up univariate ANCOVAS (Table 4) revealed significant effects of meditation on MAAS, Observing, Non-Judging, Non-Reactivity and Total FFMQ scores (Appendix 6.4).

Figure 60.

Mindfulness Differences Between Experienced Meditators and Non-Meditators.



Note. A) MAAS, (B) FFMQ Observe, (C) FFMQ Non-Judging and (D) FFMQ Non-Reactivity Scores, controlling for age and gender. Inference bands reflect 95% confidence intervals. Total FFMQ comparisons not displayed. See Appendix 6A.4 for results pertaining to similar differences between long-frequent meditators and matched non-meditators.

Table 4.

Meditator Cohorts and Self-Reported Mindfulness.

Meditators vs. Non-Meditators	*F*	*p*	*Cohen's d*	LCI - UCI
1. MAAS	12.82	<.001	.90	.38 - 1.42
2. Observing	7.45	<.01	.69	.18 – 1.31
3. Non-Judging	10.90	<.01	.83	.31 – 1.34
4. Non-Reactivity	5.90	.02	.61	.10 – 1.11
5. Total FFMQ	10.46	<.01	.81	.30 – 1.33

Long-Frequent Meditators vs. Matched Non-Meditators	*F*	*p*	*Cohen's d*	LCI - UCI
1. MAAS	8.40	<.01	1.04	.27 – 1.76
2. Observing	8.10	<.01	1.02	.27 – 1.76
3. Non-Judging	6.98	.01	.96	.20 – 1.68
4. Non-Reactivity	3.81	.06	.70	.22 – 1.70
5. Total FFMQ	7.24	.01	.97	.22 – 1.70

Note. Follow-up ANCOVAs illustrating significant effects of meditation experience and frequency / duration of meditation practice on self-reported mindfulness. Effect sizes displayed as *Cohen's d* with associated confidence intervals.

Mindfulness (Associations, H1b). As hypothesised (H1b), partial correlations, controlling for age and gender, revealed positive associations between meditation experience and MAAS (r[72] = 0.26, p = .03) and Non-Reactivity scores (r[72] = 0.25, p = .03), and between daily meditation practice and all mindfulness measures except FFMQ-Describe and FFMQ-Awareness (Table 5).

Table 5.

Meditation Experience / Frequent Duration and Self-Reported Mindfulness.

Meditation Experience (Years)	*r*	*p*
1. MAAS	.26	.03
2. Observing	.16	.20
3. Describing	-.10	.43
3. Non-Judging	.11	.33
4. Non-Reactivity	.25	.03
5. Total FFMQ	.13	.26

Daily Meditation Duration (hours)	*r*	*p*
1. MAAS	.38	<.001
2. Observing	.16	.03
3. Describing	.11	.36

3. Non-Judging	.33	<.01
4. Non-Reactivity	.30	<.01
5. Total FFMQ	.35	<.01

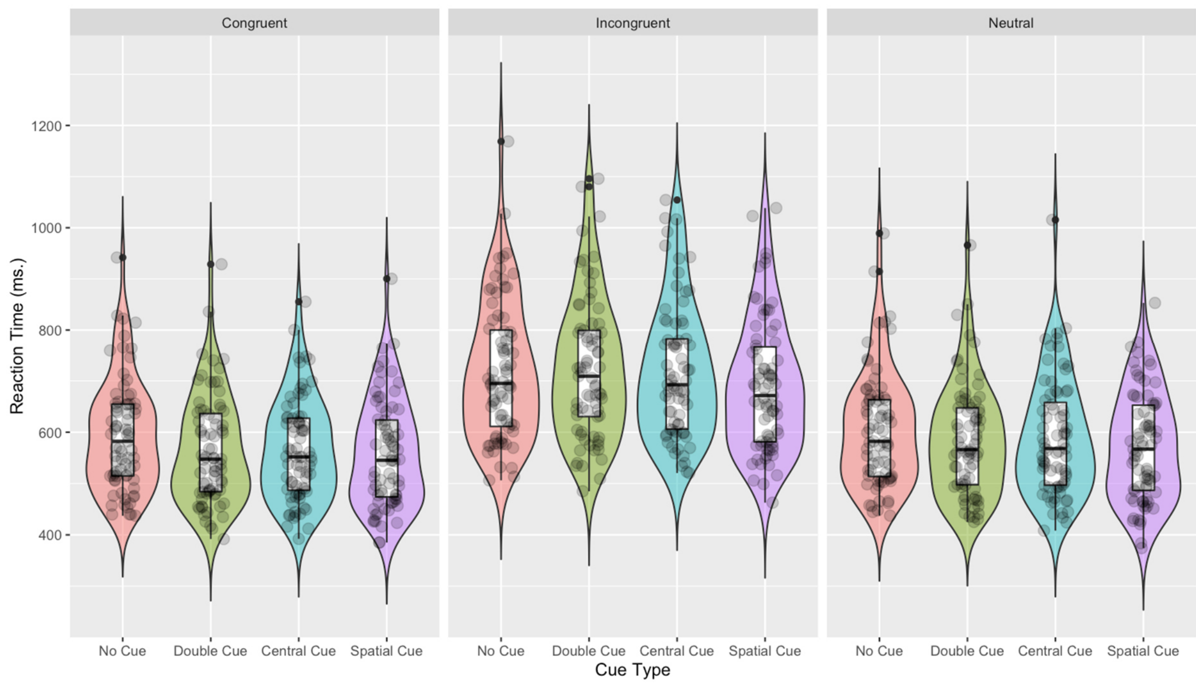
Note. Partial correlations between continuous meditation variables and self-reported mindfulness, controlling for age and gender N = 75.

ANT Performance

Establishing the Attention Networks. Turning to the ANT outcomes, my first aim was to validate the existence of the three attention network effects, which was particularly important in the present study due to the inherent confounds of implementing an online version of the ANT away from the laboratory. Figure 64 conveys differences between each cue and target type in terms of response latencies. Clear descriptive differences, consistent with the lab-based ANT in studies 4 and 5, were observed between cues and targets. Indeed, LMMs (Appendix 0iii, Study 6) revealed significant effects of cue type ($F(3, 72.96) = 35.44$, $p < .001$) and target type ($F(2, 66.61) = 465.58$, $p < .001$) on response latencies, suggesting that the online ANT was a justifiable method to differentiate between the three attention networks. As expected, reaction times were faster in response to double cue trials (M = 621ms, SD = 160ms) than to no cue trials (M = 637ms, SD = 153ms, $p < .0001$, $d = .10$), supporting the existence of an alerting effect. Moreover, faster reaction times were observed in response to spatial cues (M = 604ms, SD = 152ms) than to central cues (M = 621ms, SD = 155ms, $p < .0001$, $d = .11$), supporting the presence of an orienting effect. Finally, reaction times in response to congruent targets (*M* = 570ms, *SD* = 128ms) were faster than those in response to incongruent targets (*M* = 720ms, *SD* = 163ms, $p < .0001$, $d = 1.01$), suggesting the existence of an executive network effect. The interaction between cue type and target type was significant ($F(6, 19117.30) = 13.30$, $p < .001$), whereby the alerting effect (double cue vs. no cue) was only evident for congruent ($p < .0001$, $d = .22$) and neutral targets ($p < .0001$, $d = .13$). The orienting effect (spatial cue vs. central cue) persisted across all target types (*ps* < .05).

Figure 64.

ANT Response Latencies by Cue and Condition



Note. ANT RT as a function of cue (x-axis) and target condition (panels). Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Generalised LMMs exploring likelihood of correct ANT responses revealed a significant effect of target type on ANT accuracy, whereby participants were more accurate in response to congruent targets (99.6%) than to incongruent targets (89.3%, $\chi 2(2, N = 75) = 37.55$, $p < .0001$, $d = .46$; odds ratio $_{\text{congruent versus incongruent targets}} = 16.22$ (95%CI[5.50, 48.20])). Cue type did not influence task accuracy ($X2(1, N = 75) = 2.43$, $p = .49$) indicating equal distribution of correct responses across cue conditions. The interaction between cue and target was not significant ($X2(1, N = 75) = 5.72$, $p = .46$).

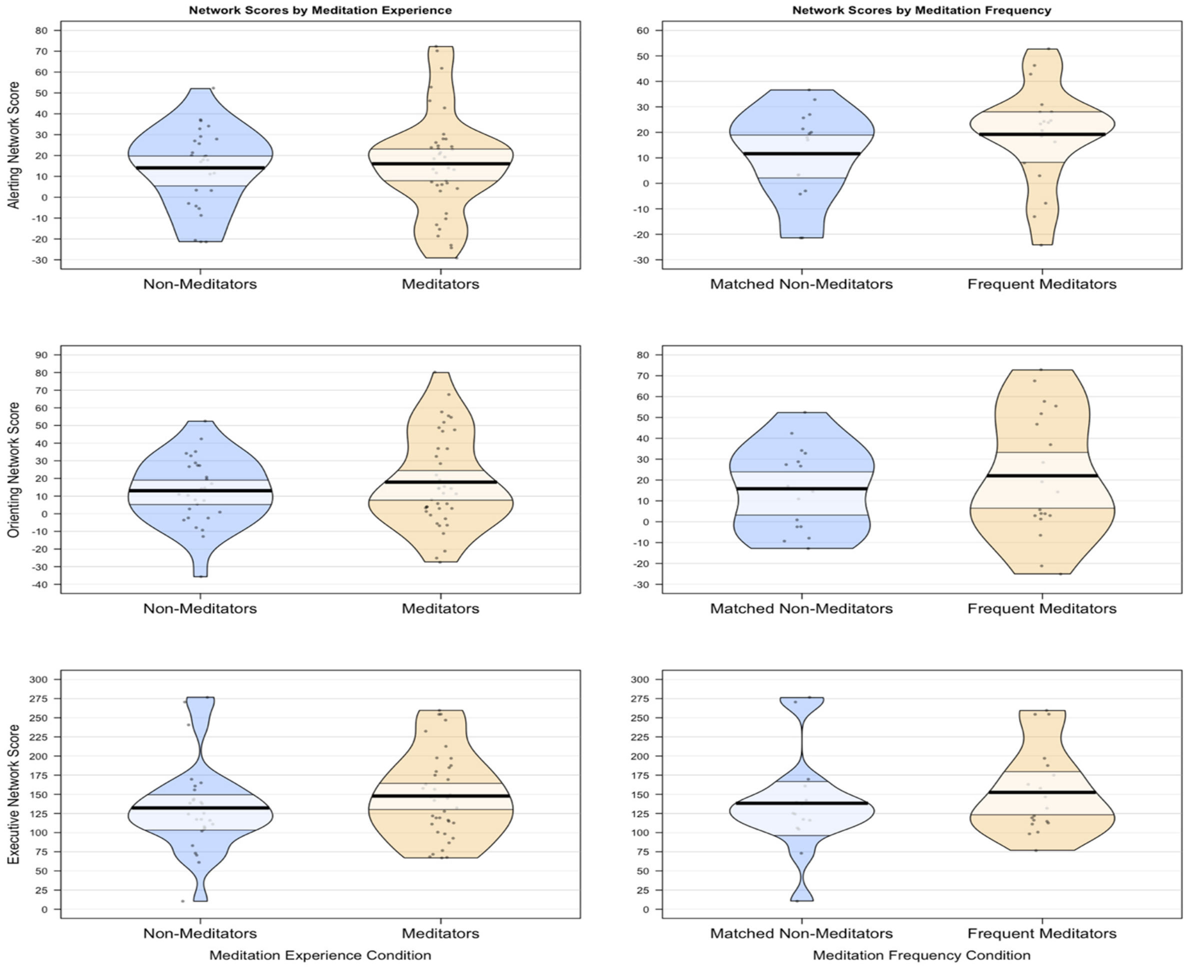
Attention Network Scores. Having established stimuli-specific ANT effects on RT and accuracy, I calculated alerting (no cue – double cue), orienting (central cue – spatial cue) and executive attentional network scores (incongruent target – congruent target). One-sample *t*-tests revealed that all attention network scores were significantly different from zero (*ps* < .0001), further validating use of the online ANT to gauge efficiency of each network.

Demographic Characteristics. Gender and age were controlled for in all analyses exploring the effects of meditation on attention network scores and accuracy.

Meditation Cohorts and ANT Network Scores (H3a). Figure 66 illustrates attention network scores for each meditation experience and meditation frequency condition. Contrary to predictions (H2a), MANCOVA modelling network scores as a function of (a) meditation experience condition and (b) meditation duration condition, controlling for age and gender, did not reveal statistically significant differences between experienced meditators and non-meditators ($V = 0.05$, $F(3, 59) = 1.01$, $p = .40$) or between long-frequent meditators and matched non-meditators ($V = 0.12$, $F(3, 28) = 1.23$, $p = .31$).

Figure 66.

Meditation Groups and ANT Network Scores



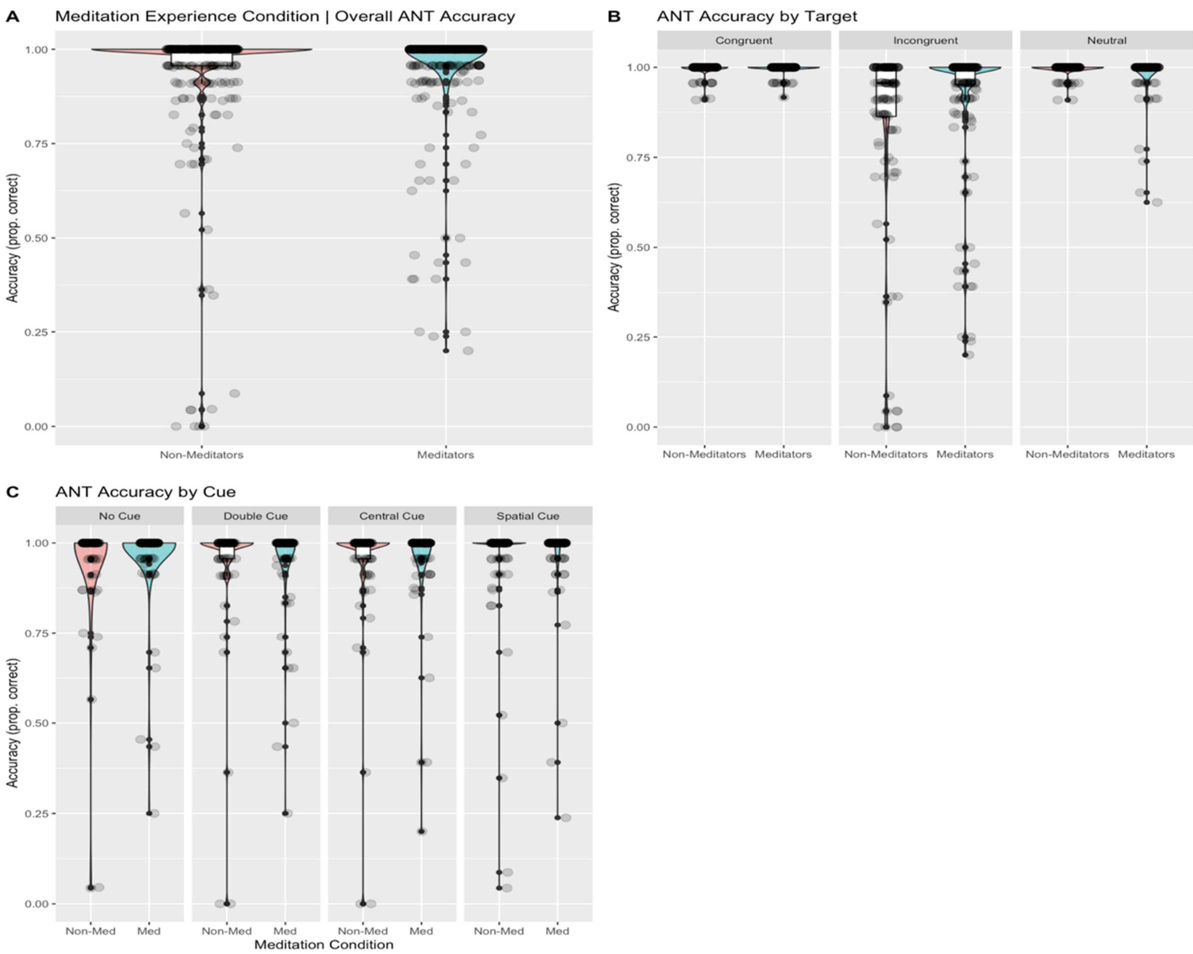
Note. ANT network scores as a function of meditation condition. Means (horizontal lines) and 95% CIs (inference bands) displayed. Beans represent density plots.

Meditation Cohorts and ANT Accuracy (H2a). Figure 67 outlines differences between experienced meditators and non-meditators in terms of accuracy during the overall ANT (A), and in response to specific targets (B) and cues (C). Descriptively, overall ANT accuracy, cue accuracy and incongruent target accuracy differences were in the expected direction, insofar as accuracy appeared higher for meditators than for non-mediators (a similar pattern was observed for meditation frequency condition, illustrated in Appendix 6.9).

However, contrary to expectations (H2a), GLMMs did not reveal a main effect of meditation experience condition on overall accuracy ($\chi 2$ (1, N = 67) = 0.03, p = .87, d = .11). Interactions between meditation condition and cue type ($\chi 2$ (3, N = 67) = 3.16, p = .37) and between meditation condition and target type ($\chi 2$ (2, N = 67) = 0.96, p = .34) were non-significant. Exploring effects of meditation frequency, controlling for age and gender, did not reveal a main effect of meditation on overall accuracy ($\chi 2$ (1, N = 35) = 0.03, p = .27, d = .17). Interactions between meditation condition and cue ($\chi 2$(3, N = 35) = 0.93, p = .82) and between meditation condition and target ($\chi 2$(2, N = 35) = 1.60, p = .45) were non-significant.

Figure 67.

Meditation Groups and ANT Accuracy



Note. ANT accuracy as a function of meditation experience condition. (A) overall ANT accuracy, (B) target accuracy and (C) cue accuracy. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Attention Network Scores (Associations, H2b). To explore whether continuous meditation variables (meditation experience in years, frequent meditation duration in hours) were associated with attention network scores, I conducted partial correlations, controlling for age and gender (Table 7). Contrary to predictions (H2b), there were no associations between meditation experience and executive network scores ($r[73] = -0.24$, $p = .08$). This relationship was weaker when age was not controlled for ($r[71] = 0.05$, $p = .68$). All other associations between meditation and attention network scores were non-significant.

Table 7

Meditation Experience / Frequent Practice Duration and ANT Network Scores

Meditation Experience (Years)	*r*	*p*
1. Alerting	-.08	.51
2. Orienting	.08	.50
3. Executive	-.20	.08
Daily Meditation Duration (hours)	***r***	***p***
1. Alerting	.10	.40
2. Orienting	.15	.20
3. Executive	.04	.70

Note. Partial correlations between continuous meditation variables and ANT network scores, controlling for age and gender N = 75.

Mindfulness and Attention Network Scores (H2c). Next, I explored relationships between self-reported mindfulness and attention network scores, with a view to exploring the potential mediatory role of mindfulness on attention network outcomes (Table 8). All associations between self-reported mindfulness and attention network scores were non-significant, and indeed, represented notably weak / negative relationships. As such, further mediation analyses utilising these variables (H2c) were deemed unnecessary.

Table 8.

Mindfulness and ANT Network Scores

	Alerting	Orienting	Executive
1. MAAS	-.10	-.11	-.07
2. Observing	-.17	.02	.08
3. Describing	-.19	-.20	-.06
4. Non-Judging	-.08	-.05	.10
5. Non-Reactivity	-.05	-.10	-.03
6. Total FFMQ	-.15	-.14	.02
7. Age	-.06	.07	.26

Note. Bivariate correlations between MAAS and FFMQ facets and ANT network scores, adjusted for multiple tests. N = 75.

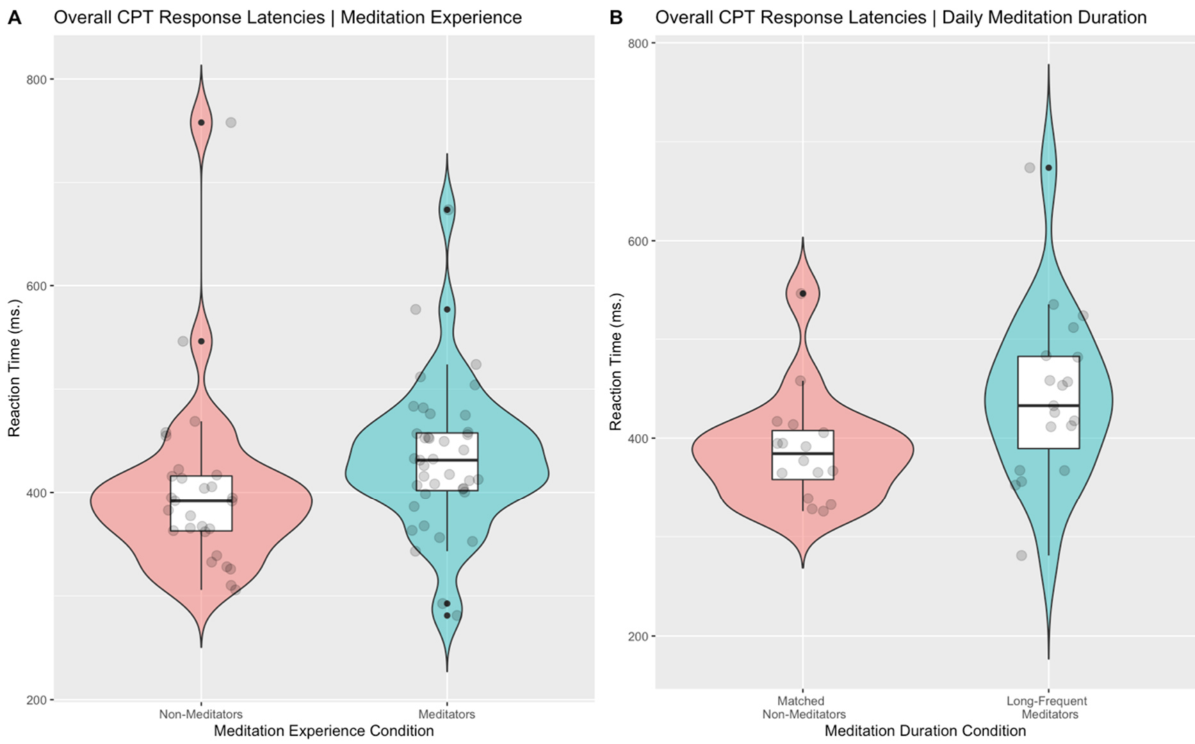
CPT Performance

Meditation Cohorts and Overall CPT Performance (H3a). Figure 68 outlines differences between groups defined by (A) meditation experience and (B) meditation frequency in terms of overall CPT RT. Contrary to expectations, there were no differences between experienced meditators and non-meditators (F(1, 62.86) = 0.20, p = .65, d = .40)) or between frequent meditators and matched non-meditators in terms of overall RT (F (1, 31) = 0.17, p = .69, d = .54).

Figure 69 outlines differences between meditators and non-meditators in relation to overall CPT accuracy. The descriptive pattern of overall CPT accuracy across all trial types (targets and non-targets) implies that meditators were more accurate than non-meditators. However, contrary to expectations (H3a), GLMMS did not reveal a greater likelihood for experienced meditators to respond more accurately than non-meditators **(**$\chi 2$**(**1, N = 67) = 0.02**,** p = .90, d = .11; odds ratio $_{\text{non-meditators versus experienced meditators}}$ = .97 (95%CI[.57, 1.64]), or for frequent meditators to respond more accurately than matched non-meditators **(**$\chi 2$**(**1, N = 35) = 0.38, p = .54, d = .002**);** odds ratio $_{\text{matched on-meditators versus long-frequent meditators}}$ = 1.23 (95%CI[.64, 2.40])**.**

Figure 68.

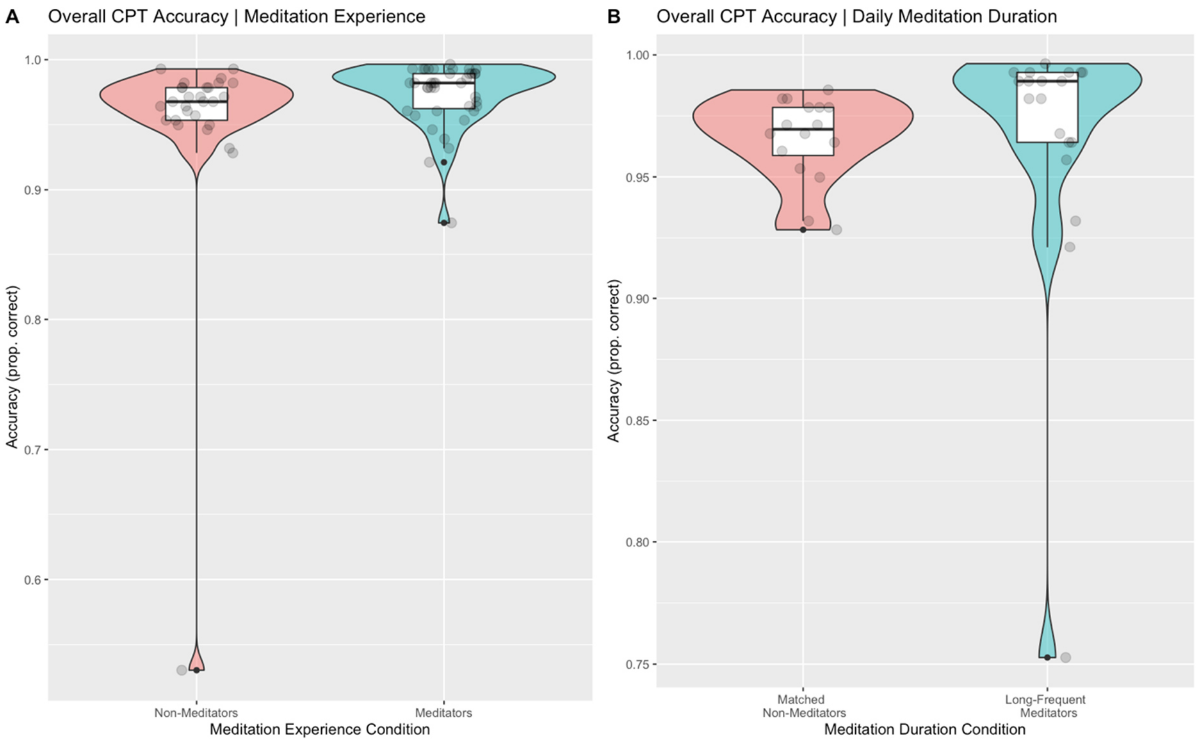
Meditation Cohort and Overall CPT RT



Note. CPT RT as a function of (A) meditation experience and (B) frequent meditation duration. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Figure 69.

Meditation Cohort and Overall CPT Accuracy



Note. CPT accuracy as a function of (A) meditation experience and (B) frequent meditation duration. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Meditation Cohorts and Attentional Lapses, False Alarms and Errors of Omission (H3a). Next, I explored whether meditators and non-meditators differed in relation to attentional lapses, false alarms and omission errors (misses). Table 9 outlines proportions of these outcomes across the whole sample and between meditation groups. Against expectations (H3a), non-meditators were no more likely to exhibit an attentional lapse than experienced meditators ($\chi 2(1, N = 67) = 0.04$, $p = .83$, $d = .30$); odds ratio $_{\text{non-meditators versus experienced meditators}}$ = 0.83 (95%CI[.15, 4.71]) or frequent meditators ($\chi 2(1, N = 35) = 0.04$, $p = .85$, $d = .36$)**;** odds ratio $_{\text{matched non-meditators versus long-frequent meditators}}$= 1.27 (95%CI[.11, 14.70]). The likelihood of responding with a false alarm was not significantly different between experienced meditators and non-meditators ($\chi 2$(1, N = 67) = 0.51, p = .48, d = .04; odds ratio $_{\text{non-meditators versus experienced meditators}}$ = 0.86 (95%CI[.57, 1.30]) or between frequent meditators and matched non-meditators ($\chi 2$(1, N = 35) = 0.06, p = .81, d = .06; odds ratio $_{\text{matched non-meditators versus long-frequent meditators}}$ = 1.06 (95%CI[.65, 1.72]). The same was true for errors of omission, that is, no differences were observed between experienced meditators and non-meditators ($\chi 2$(1) = 1.82, p = .18, d = .14; odds ratio $_{\text{non-meditators versus experienced meditators}}$ = 3.40 (95%CI[.58, 20]) or between frequent meditators and matched non-meditators ($\chi 2$(1) = 0.01, p = .91, d = .10; odds ratio $_{\text{matched non-meditators versus long-frequent meditators}}$ = 1.14 (95%CI[.13, 9.77]).

Meditation and CPT Performance (Associations, H3b). Partial correlations examining whether continuous meditation variables were associated with sustained attention outcomes during the CPT did not reveal significant associations between meditation experience and CPT performance (Table 10, top panel) or between frequent practice duration and CPT performance (Table 10, bottom panel).

Table 9.

Meditation Cohort and Sustained Attention During CPT

	Lapses	False Alarms	Omission Errors
Full Sample	.20 (.40)	.02 (.15)	.01 (.11)
Experienced Meditators	.25 (.43)	.02 (.15)	.01 (.07)
Non-Meditators	.13 (.34)	.03 (.16)	.02 (.14)
Long-Frequent Meditators	.26 (.44)	.02 (.14)	.02 (.12)
Matched Non-Meditators	.12 (.33)	.03 (.17)	.01 (.07)

Note. Proportions of each sustained attentional performance outcome during the CPT. SDs displayed in parentheses.

Table 10.

Meditation and Sustained Attention During CPT

Meditation Experience (Years)	*r*	*p*
1. Attentional Lapse	.10	.38
2. False Alarms	-.11	.32
3. Omission Errors	.04	.70
Daily Meditation Duration (hours)	***r***	***p***
1. Attentional Lapse	.10	.40
2. False Alarms	-.03	.78
3. Omission Errors	.01	.96

Note. Partial correlations between meditation experience (top panel) / daily mediation duration (bottom panel) and CPT sustained attentional performance outcomes.

Mindfulness and CPT Performance (Associations, H3c). Given that meditation was significantly associated with elevated mindfulness scores, I explored relationships between self-reported mindfulness and CPT performance, with a view to examining the potential indirect mediatory role of mindfulness on CPT outcomes (Table 11). Contrary to predictions (H3c), the majority of associations were non-significant, with the exception of a significant positive relationship between total FFMQ scores and attentional lapse. Given the existence of several small, non-significant associations between FFMQ subscales and CPT performance, and the fact that daily meditation duration was positively associated with several facets of the FFMQ, I conducted multiple mediation analyses to explore the potential combined mediatory role of FFMQ subscales on the relationship between daily meditation practice and CPT outcomes. Contrary to expectations (H3c), multiple mediation models including all FFMQ subscale mediators simultaneously for each CPT outcome (see Appendix 6.10) did not reveal significant specific, multiple indirect or total effects of daily meditation duration on CPT performance.

Table 11.

Mindfulness and CPT Performance

	Attentional Lapse	False Alarms	Omission Errors
1. MAAS	.27	.02	-.10
2. Observing	.10	-.17	.01
3. Describing	.21	-.10	-.05
4. Non-Judging	.26	-.10	-.15
5. Non-Reactivity	.34	-.25	-.11
6. Total FFMQ	.37*	-.14	-.07
7. Age	.44**	-.35*	-.17

Note. Bivariate correlations between MAAS and FFMQ facets and CPT performance outcomes, adjusted for multiple tests. N = 75. **$p < 0.01$; *$p < 0.05$.

Finally, contrary to expectations, meditation experience and frequency were not associated with higher levels of on-task thought or reduced levels of off-task thought (Table 12).

Table 12.

Meditation Cohort and Thought Probe Responses During CPT

	On-Task	TRI	ED	MW	Non-Alert
Full Sample	.54 (.50)	.31 (.48)	.05 (.22)	.05 (.21)	.04 (.20)
Experienced Meditators	.62 (.48)	.24 (.43)	.05 (.21)	.04 (.20)	.05 (.21)
Non-Meditators	.36 (.48)	.45 (.50)	.07 (.26)	.06 (.24)	.05 (.22)
Long-Frequent Meditators	.66 (.47)	.20 (.40)	.06 (.23)	.02 (.15)	.06 (.23)
Matched Non-Meditators	.40 (.50)	.42 (.50)	.06 (.24)	.05 (.21)	.07 (.26)

Note. On-task; on-task thoughts, *TRI;* task-related interference, *ED*; external distraction, *MW*; mind wandering, *Non-Alert*; inattentive / non-alert. Standard deviations in parentheses.

Summary of Results

In an attempt to broaden existing insight into the impact of meditation practice on psychological, cognitive and attentional outcomes, the present study examined a variety of direct and indirect effects of the magnitude of two temporally-based assessments of meditative engagement; historical experience and duration of frequent practice. As expected, greater levels of meditation were associated with enhanced mindfulness and reduced psychological distress. However, the absence of significant effects of meditation on objective indices of sustained / executive attention and on-task / off-task thought processes would appear to cast uncertainty around the utility of consistent and longer-term meditative engagement at enhancing attentional outcomes, at least with how they were assessed in the present study. As such, despite examining distinct attentional outcomes as a function of the broader experiential spectrum of meditative experience / practice, I did not find that meditation augmented attentional outcomes indicative of the increased wakefulness / alertness proposed as underlying mindful traits and states (Britton et al., 2014). A comprehensive discussion of present results and associated implications is outlined in Chapter 7.

Chapter 6, Study 7: Brief Online Mindfulness Meditation (MBCAT) Exerts No Influence on Coronavirus Anxiety, Vaccine Hesitancy, Sustained Attention or Executive Control.

Overview

In Study 7, my primary aim was to examine whether the temporal *proximity* of meditative practice to task completion represented a salient predictor of enhancements to vigilance and attentional control, utilising the same attention tasks as those used in my previous study. In Study 6, I demonstrated that longer-term meditation experience and extended frequency / duration of practice was associated with enhanced mindfulness, improved wellbeing and increased subjective indices of task focus. However, only limited effects were observed in relation to objectively assessed attention task outcomes. Moreover, an examination of potential psychological mechanisms underlying relationships between meditation and attentional performance revealed no interactive effects. The mixed nature of these findings is consistent with the heterogeneity of results observed within the broader literature, prompting a deeper consideration of the unaddressed confounds potentially contributing to the variability of attentional differences between long-term meditators and non-meditators. One possible candidate in this respect was identified as the variation in temporal *proximity* of meditative engagement in relation to experimental participation, insofar as the recency of practice may represent one of the more salient factors in the exertion of potent effects on attentional performance. Indeed, having explored the attentional impact of longer-term meditative practice and timebound MBIs, examining the effects of single-session meditation immediately preceding task engagement would serve to extend broader inquiry into the impact of different magnitudes and temporal qualities of meditation. Moreover, considering the observed direct and indirect effects of MBIs and meditation on wellbeing and COVID-related distress in Studies 5 and 6, isolating the impact of brief and proximal meditation practice on related outcomes may harbour important implications for the maintenance of wellbeing, especially during these uncertain times.

Accordingly, the present study examined mindfulness, COVID-specific anxiety and attentional performance as a function of a brief mindfulness meditation (MM), which was induced immediately prior to the experiment. The induction was based on my MBCAT programme utilised in Study 5 and the attention tasks were identical to those utilised in Study 6, thus converging prior endeavour to provide insights into the nature of brief meditation-induced change.

Overall, the effects of brief MM on COVD-related distress, sustained attention and cognitive content were limited, raising important considerations about the effectiveness of single-session MMs on psychological and attentional outcomes, at least with how each of these components were measured in the present study.

Introduction

Although there has been a burgeoning empirical interest in the impact of mindfulness meditation over the past few decades, particularly in terms of exploring the effects of mindfulness-based interventions (MBIs) among clinical populations, less attention has been devoted to the benefits of brief and low-intensity forms of mindfulness meditation among non-clinical populations, particularly in relation to their effects on cognitive processes (Heppner & Shirk, 2018). Indeed, the vast majority of published studies exploring the effects of mindfulness training on attentional control, sustained attention and psychological wellbeing have typically utilised immersive retreat-like experiences or extensive 8-week interventions (Brewer et al., 2011b; Hofmann et al., 2010; Norris et al., 2018; Tang et al., 2007), with a smaller subset of studies implementing less intensive training programmes of between 4-8 sessions over the course of 2-4 weeks (Zeidan et al., 2010a,b,c). Nonetheless, there is accumulating evidence that even shorter mindfulness interventions, typically lasting less than two weeks, exercise beneficial effects on cognition, emotional regulation, sustained attention, pain management and the promotion of health behaviours (Ainsworth et al., 2013; Arch and Craske, 2006; Heppner & Shirk, 2018; Mrazek, Smallwood and Schooler, 2012; Zeidan et al., 2010a,b,c). This raises the question of what "dose" of mindfulness is sufficient for improving attentional and emotional stability, prompting suggestions that a more comprehensive exploration of the effects of single-session or brief multi-session mindfulness interventions on cognitive and clinical outcomes is necessary for a clearer understanding of how long, and how often, one needs to engage in mindfulness to begin to see positive change (Tang et al., 2015).

Such endeavour is important, not least because extensive and immersive mindfulness-based training programmes and retreats may not be suitable, relevant, or accessible for all individuals in non-clinical contexts, who may otherwise benefit from a less intensive mindfulness-based approach (Howarth et al., 2019; Norris et al., 2018). Moreover, illustrating the benefits of brief meditative techniques may serve to enhance continued adherence to meditation early on in practice among those trying to establish a consistent regime. Similarly, exploring interactions between dispositional mindfulness and brief mindfulness interventions may further elucidate the utility of mindfulness practice across trait characteristics. Additionally, current operational definitions of mindfulness are nebulous, and broad mindfulness-based interventional packages lack the specificity to directly and independently test the specific facets of mindfulness practice implicated in these interpretations (Britton et al., 2018). Experimental utilisation of brief mindfulness interventions offers a way to test how distinct components of immersive MBIs (e.g., FA and OM techniques) independently impact on specific cognitive processes (e.g., executive control and mind wandering), allowing for a more precise understanding of which aspects of MBIs are most conducive to clinical and cognitive change (Heppner and Shirk, 2018). Finally, demonstrating limited or null effects of brief mindfulness interventions can highlight the need for a more cautious approach when communicating the benefits of brief mindfulness practice, especially during the current unprecedented period of heightened anxiety and uncertainty, whereby the virtues of mindfulness continue to be enthusiastically extolled within business, education, government and healthcare (Purser, 2019).

The question of what constitutes a “brief” mindfulness intervention remains conducive to further debate, but single-session inductions of 20 minutes or less, or total participation in mindfulness practice occurring over a short time period (e.g., less than a week) are generally considered to be brief enough to be distinct from the more extensively used MBIs (Heppner & Shirk, 2018). More specifically, in an effort to standardise nomenclature concerning brief interventional research, Heppner & Shirk (2018) define the following types of mindfulness manipulation: (a) mindfulness inductions / brief mindfulness meditations (hereafter, termed MMs), defined as short (<= 1 hour), single-session mindfulness exercises designed to experimentally induce a transient state of mindfulness in experimental, non-clinical research; (b) brief mindfulness interventions / trainings (hereafter, termed MIs), defined as longer, multi-session mindfulness training over a short period of time (<= 2 weeks) designed to induce more extensive mindfulness states in non-clinical populations; and (c) mindfulness-based interventions / therapies (here, termed MBIs), defined as more intensive and immersive training over the course of weeks or months (typically <= 12 weeks) designed to promote long-lasting increases in mindfulness among clinical populations. In the present study, I employ a single-session, 15-minute MM to augment the existing literature pertaining to the impact of MMs on distinct attentional outcomes.

Impact of Brief Mindfulness Meditation Inductions (MM) on Performance-Based Tests of Attention

Although the current research landscape is surprisingly sparse when it comes to the cognitive effects of single-session MMs, a handful of recently-published studies utilising a variety of performance-based tests of attention have started to formulate a picture of the impact of MMs on attentional processes (Asli et al., 2021; Banks et al., 2019; Jankowski and Holas, 2020; Johnson et al., 2015; Larson et al., 2013; Mrazek et al., 2012; Norris et al., 2018; Somaraju et al., 2021; Watier & Dubois, 2016; Wenk-Sormaz, 2005).

MM and Executive Attention. For example, in terms of executive function, as little as 10 minutes of listening to a recorded MM versus an educational control condition (listening to a 10-minute reading of a National Geographic article about giant sequoias) was shown to improve overall reaction times (RTs) and enhance accuracy to incongruent targets within the executive network of the Attention Network Task (ANT), manifesting as reduced flanker / interference effects (Norris et al., 2018). Moreover, 10-20 minutes of MM has been demonstrated to reduce interference effects during variants of the Stroop task when compared to several active control conditions (e.g., arithmetic, free mind-wandering), with dispositional mindfulness being shown to moderate these effects, insofar as the impact of brief MM was stronger for those higher in trait mindfulness (Watier & Dubois, 2016; Wenk-Sormaz, 2005). Faster overall RTs during an attentional switch task were also observed as a function of a 25-minute MM when compared to worry and free mind-wandering conditions (Jankowski & Holas, 2020).

Contrarily, no differences were observed between a 14-minute MM and an educational control condition in terms of overall RT, accuracy or executive control scores during a flanker task (Larson et al., 2013). Moreover, relative to worry and mind-wandering control conditions, 10 minutes of MM did not reduce the "switch cost" (difference in RT between 'no switch' and 'switch' trials) during a task assessing capacities for attentional set-shifting (Jankowski & Holas, 2020).

MM and Objectively and Subjective Assessed Sustained Attention. In relation to sustained attention and objective indices of lapsed attention / mind wandering (MW), 8 minutes of MM resulted in improved accuracy and reduced response time coefficient of variance (RTCV; a periodic speeding and slowing of RT throughout the task) relative to passive relaxation and reading conditions during the Sustained Attention to Response Task (SART) (Mrazek, Smallwood and Schooler, 2012). These SART outcomes represent substantially disruptive task disengagement (accuracy; commission and omission errors) and minimally disruptive task disengagement (RTCV), typically indicative of diminished attentional focus and increased MW throughout the task. As such, findings were interpreted as MM-induced improvements in sustained attention and objectively assessed MW (Mrazek, Smallwood & Schooler, 2012). Subjectively assessed indices of mind wandering, as obtained through experience-sampling methods (asking participants throughout the task what they were just thinking about), and which are reliably and consistently associated with impaired task performance (Smallwood & Schooler, 2006), have also exhibited sensitivity to brief MM and mindfulness. For example, MW of negative valence was diminished among those completing a 15-minute MM relative to relaxation and waitlist control groups (Banks et al., 2019). Moreover, dispositional mindfulness, as assessed by the MAAS and FFMQ, has been shown to be negatively related to both objective and subjective indices of attentional lapse and mind wandering (Banks et al., 2019; Mrazek, Smallwood & Schooler, 2012; Watier & Dubois, 2016). These latter findings underscore the need to explore independent and interactive effects of dispositional mindfulness and brief MMs on sustained attention / mind wandering outcomes.

Conversely, no differences were found between a 15-minute MM condition, a relaxation condition and a waitlist control / reading condition in terms of RTCV, commission / omission errors, rates of neutral and positive off-task thought, or self-reported MW during the SART (Banks et al., 2019; Somaraju et al., 2021). Finally, no differences were observed between a brief MM and an educational control condition in terms of sustained attention in the form of tone counting (Asli et al., 2021), or during more general performance-based tests of working memory, concentration, attention and distractibility (Johnson et al., 2015). Clearly, there is a need to augment existing inquiry through a more extensive exploration of the impact of brief MMs on specific attentional outcomes.

Given the lack of consensus in the literature, and the methodological variability among existing MM studies, I aimed to investigate the effects of a brief FA-based MM on sustained attention, executive control and subjectively assessed mind wandering. Suitably, and consistent with prior endeavour, the present study combines the use of attention tasks that have been suggested as the most receptive and sensitive to brief mindfulness practice (Johnson et al., 2015). This is consistent with the tasks utilised throughout this thesis, which are positioned as valid objective assessments of capacities for enhanced alertness and wakefulness (Tang et al., 2015). Additionally, I utilised a brief MM as closely matched in terms of length (15 minutes) and instructional guidance (focused breathing and negotiating mind wandering) as those implemented in directly comparable prior research (Banks et al., 2019; Mrazek, Smallwood & Schooler, 2012; Somaraju et al., 2021). Crucially, I extend prior scrutiny in several important ways. Firstly, in line with Norris et al. (2018), I implemented the ANT to assess the effects of my brief MM on the executive control network. However, Norris and colleagues did not examine the alerting or orienting networks of the ANT, necessitating further analyses of these outcomes and rendering the present study methodologically congruent to my prior studies. Indeed, in Study 5, I evidenced improved alerting performance as a result of my brief MBI (MBCAT), a programme from which the present MM was appropriated. As such, considering that alerting represents the central component of sustained attention and vigilance within the ANT (Fan et al., 2002; Roca et al., 2011), I assessed the impact of MM on the ability to remain alert and vigilant throughout the task, serving to address broader predictions of the current thesis that mindfulness can be characterised as a wakeful capacity. To my knowledge, this is the first study to explore the effects of a single-session online MM on alerting and orienting scores within the online ANT.

Secondly, consistent with prior studies (Mrazek, Smallwood & Schooler, 2012, Banks et al., 2019), I measured the impact of MM on sustained attention utilising a Go/NoGo paradigm in the form of the CPT to examine errors and RTs as objective measures of attentional lapse and mind wandering throughout the task. This task was identical to that employed in Study 6, whereby I incorporated experience-sampling methods designed to obtain a richer array of off-task thought than those explored in prior MM research. It is possible that previously observed null effects of brief MM on subjectively assessed MW reflect the relative lack of sensitivity emerging from assessing off-task thought as one construct. Considering that specific sub-types of off-task thought, such as external distraction, mind wandering, and task-related interference, are associated with distinct attentional and psychophysiological signatures (Unsworth & Robison, 2016), it seemed pertinent to explore the effects of MM on these sub-types, thus providing important contributions to existing literature on MMs and mind wandering (Mrazek et al., 2012, Banks et al., 2019). Finally, I explored the interactive effects of MM induction and dispositional mindfulness on each attentional outcome in order to examine precisely for *whom* the brief MM was most affective.

Impact of Brief MM on Wellbeing

In terms of wellbeing, there is convincing support for the ameliorative effects of single-session MMs on psychological distress, emotional dysregulation and negative affect, especially in terms of anxiety and depressive symptoms (see Howarth et al, 2019 for a review). Moreover, it's been demonstrated that trait mindfulness is negatively associated with anxiety, stress and depression in the context of COVID-19 (Dillard & Meier, 2021). However, there is a paucity of research on the independent and interactive effects of dispositional mindfulness and brief MMs on COVID-specific distress and attitudinal outcomes. As such, the utility of adopting MM to address psychological distress within the context of the current pandemic and associated vaccination drive has not been adequately tested. Accordingly, I examined the impact of my 15-minute MM on coronavirus-related distress and, considering the temporal context of the study, vaccine hesitation among a non-clinical population. Additionally, I investigated whether trait mindfulness mediated expected effects of MM induction. Instead of the measure of COVID-specific distress utilised in Study 6, which did not appear to be receptive to meditation experience / practice, I utilised an alternative measure to assess coronavirus-related anxiety. To my knowledge, this is the first study to explore the effects of MM on these outcomes in the context of the pandemic.

Consistent with the multi-faceted nature of the present research, my hypotheses pertain to the effects of brief MM induction on coronavirus-related distress, performance-based tests of attention and task-related and task-unrelated thoughts. Accordingly, I converged one of the single-session MBCAT recordings utilised in Study 5 with the online ANT and CPTp outcomes employed in Study 6[43] in order to assess sustained attention, executive control, mind wandering, and coronavirus-related distress as a function of brief MM induction.

Firstly, I predicted that MBCAT induction would result in reduced COVID-related anxiety and vaccine hesitancy relative to an educational control condition (H1a) and that greater levels of trait mindfulness would be negatively associated with COVID anxiety / positively associated with vaccine acceptance (H1b), consistent with extant research demonstrating ameliorative effects of brief MM on anxiety and depressive symptoms (Howarth et al., 2019) and negative relationships between dispositional mindfulness and psychological distress in the context of the pandemic (Dillard & Meier, 2021).

In relation to sustained alertness / vigilance during the ANT, and primarily based on the findings of Study 5, I hypothesised that MM induction would result in more efficient alerting network scores relative to controls, in the form of enhanced cue and / or no cue

[43] See study-specific ‘Method’ sections. More generally, see relevant Chapter 1 footnotes regarding attention tasks.

performance (H2a). Moreover, I predicted that MBCAT participants would exhibit lower executive network / interference scores (e.g., improved executive function) compared to control group participants (H2a), consistent with prior research demonstrating enhanced efficiency of the ANT executive network (Norris et al., 2018) and reduced interference effects in a Stroop task (Wenk-Sormaz, 2005) as a result of brief MM. I also predicted that trait mindfulness would be associated with improved alerting and executive function during the ANT (H2b) and would moderate (e.g., enhance) the effects of MBCAT induction on alerting and executive network scores (H2c), augmenting prior observations that dispositional mindfulness moderates the impact of brief MMs on distractor interference (Watier & Dubois, 2016).

Similarly, I hypothesised that the MBCAT group would exhibit lower error rates (e.g., false alarms and omission errors) and reduced RT-inferred attentional lapses relative to the control group during the CPTp (H3a), consistent with previous findings utilising comparable outcomes in the SART (Mrazek, Smallwood & Schooler, 2012). I also hypothesised that dispositional mindfulness would be negatively associated with these outcomes (H3b) and would moderate the effects of MBCAT induction (H3c), further supporting extant demonstrations of beneficial associations between mindfulness and sustained attention / task focus (Mrazek, Smallwood & Schooler, 2012) and the moderative qualities of trait mindfulness on attentional performance (Watier & Dubois, 2016).

Finally, I predicted that the MBCAT group would report increased on-task thought and lower instances of distinct types of distractibility / off-task thought (e.g., probe-caught numeric responses indicating task-related interference, external distraction, non-alertness and mind wandering) relative to the control group (H4a), consistent with findings demonstrating similar effects on on-task / off-task thought processes as a result of MBI (Study 4) and longer-term / frequent meditation practice (Study 6). Moreover, by increasing the specificity of the types of off-task thought that participants could report, results to this effect would offer an explanation as to why prior studies may have been unable to elucidate an effect of brief MM on task-unrelated thought when treated as a singular variable (Banks et al., 2019; Somaraju et al., 2021). I also hypothesised that dispositional mindfulness would be negatively associated with subjective indices off-task thought (H4b) and would moderate the effects of MBCAT induction on these outcomes (H4c), further supporting extant demonstrations of beneficial associations between mindfulness and broader indices of mind wandering (Mrazek, Smallwood & Schooler, 2012).

Method[44]

Participants

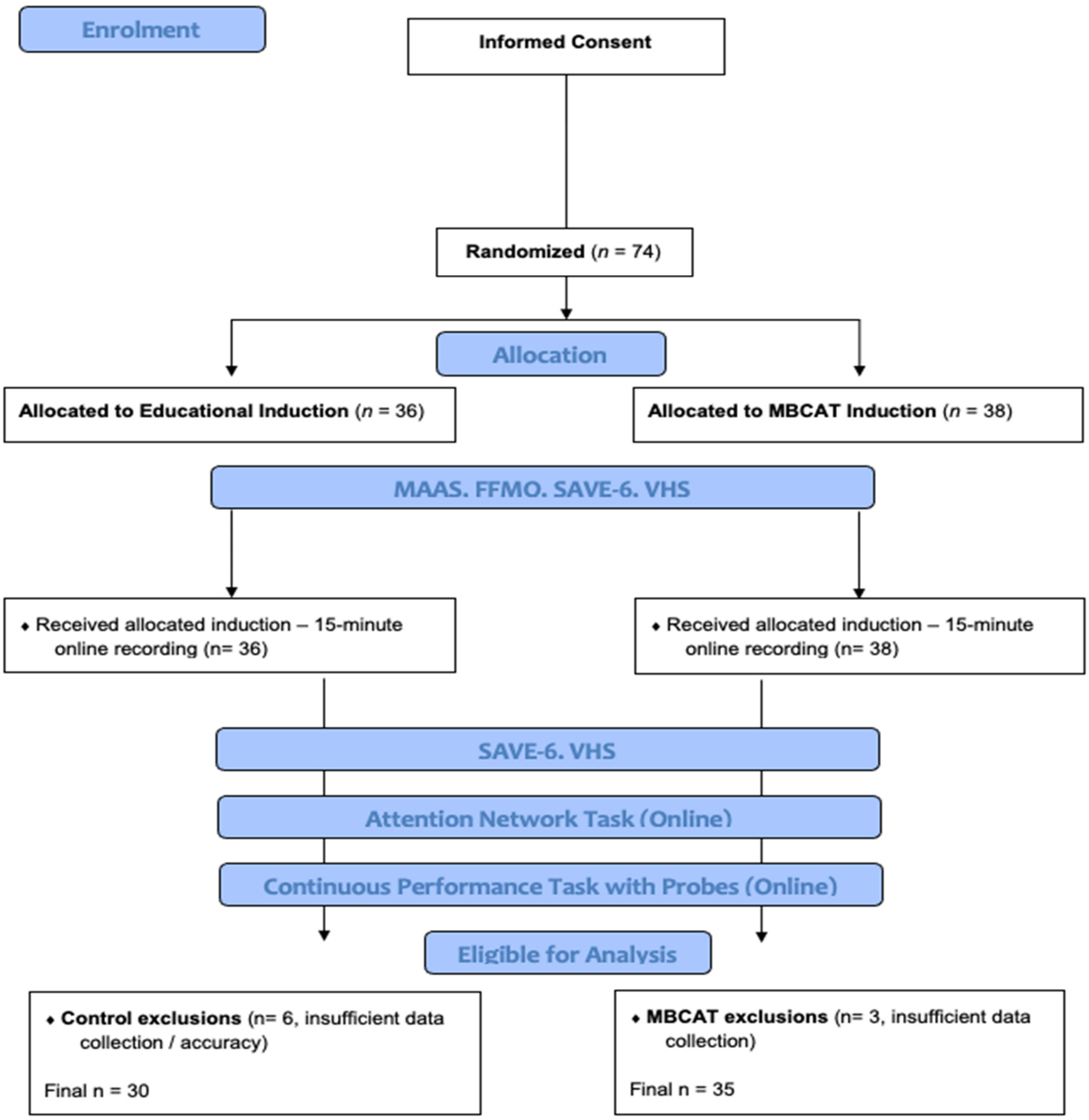
I recruited 74 participants (19 males, 55 females; M_{age} = 26 [SD = 8.4]) through Prolific Academic. All participants received £7.50 for their participation. Informed consent was obtained from all individual participants. All participants had normal vision. Participants were randomly assigned to the MBCAT induction or educational extract condition (see Figure 70). Seven participants were excluded from analyses due to technical issues with recording their data or failing to respond during the tasks. Two further participants were excluded because their accuracy performance in both tasks was below 50%, indicating random responses. The final number of participants was 65 (16 males), 35 in the MBCAT group and 30 in the control condition. The approximate sample size for medium effects was derived from prior studies using comparable sample characteristics, methods and analyses for attentional outcomes (Jankowski and Holas, 2020; Larson et al., 2013) and from sample size and associated power calculations using G*Power (Faul et al., 2009) given an analysis

[44] Details pertaining to the generalised experimental protocol of the online attention tasks and behavioural pre-processing techniques are identical to those outlined in Study 6.

involving two within-subjects levels, two between-subjects levels, a 5% alpha level, 80% power and a moderate effect size. All questionnaire data were captured electronically by Qualtrics Online Questionnaire. Participants were also asked their age, gender and educational level.

Figure 70.

CONSORT Participant Flow Diagram for Phases of Parallel Randomised Control Trial Comparing MBCAT MM Induction and Educational Control Groups.



Materials and Procedure[45]

I utilised the same mindfulness measures as those discussed throughout my thesis, namely the MAAS (Brown & Ryan, 2003, α=.89) and the FFMQ (FFMQ, Baer et al., 2008, α=.76). Moreover, due to the ongoing coronavirus pandemic and subsequent vaccine rollout, I decided to include the following scales:

Stress and Anxiety to Viral Epidemics Scale (SAVE-6, Ahn et al., 2020). Instead of the coronavirus anxiety scale (CAS) utilised in Study 6, I incorporated the SAVE-6 to assess anxiety responses to the pandemic. Higher scores represent greater stress / anxiety. Strong reliability was observed for this study sample (α=.88).

COVID-19 Vaccine Hesitancy Scale (VHS, Freeman et al., 2020). I also utilised a seven-item measure designed to assess hesitancy toward the COVID-19 vaccines. Higher scores represent more favourable attitudes and greater motivation to receive vaccination. Strong reliability was observed for this study sample (α=.90).

Attention Tasks

I utilised the same attention tasks as those discussed in Study 6 exploring differences between meditators and non-meditators, namely the Attention Network Task (ANT) (Fan et al, 2002) and the Continuous Performance Task (CPT) (Connors, 2000) with thought probes (Unsworth and Robison, 2016) (CPTp).

[45] See Appendix 0i: 'Overview of Self-Report Measures' for full details pertaining to the individual difference measures employed throughout this thesis.

Induction Procedure[46]

The study utilised a paradigm comparing an online MM (MBCAT) with an educational control condition. A random number generator was used to assign participants to one of the two conditions (Figure 70). Immediately after listening to the MM / control induction, participants completed the online ANT followed by the CPTp (~50 minutes in total), whereby behavioural performance was collected within the secure Pavlovia database for later extraction. The brief MBCAT MM and educational extract were hosted by SoundCloud (see https://soundcloud.com/) and URLs were integrated into Qualtrics.

MBCAT-Based Brief MM Induction (Hill, J. R. J., 2020). I created a brief mindfulness meditation induction based on my Mindfulness-Based Cognitive Attention Training (MBCAT) programme, which in turn contains exercises adapted from classic mindfulness instructions in Mindfulness-Based Cognitive Therapy (Zindel, Williams and Teasdale, 2002). The recording utilised was an FA-based guided induction called 'The Breath, The Body and The Mind', whereby participants were guided through a 15-minute mindfulness exercise during which they were instructed to focus on the sensation of breathing, and to bring attention back to the breath whenever they noticed mental events, emotions, bodily sensations or external distractions arise. For example, instructions included statements such as "…not trying to control the breath, or change it in any way, but simply observing it…as it is…without judgment…allowing the breath to breathe itself…and tuning in to each in-breath, and each out-breath" and "…allowing all experiences to be as they are, without trying to hold on to them or get rid of them…and gently bringing your attention back to the breath, and back to the present moment, whenever you realise the mind has wandered."

[46] All general online procedures and technical considerations relating to the design and implementation of attention tasks were identical to those utilised in Study 6. See Appendix 0ii; 'Over of Procedures and Data Preparation'.

As such, the guidance was comparable to focused-attention type meditations utilised in previous brief mindfulness induction studies (Banks et al., 2019; Johnson et al., 2015; Mrazek et al., 2012). The guidance was uploaded to Soundcloud and linked to Qualtrics.

Educational Extract. Subjects in the educational extract condition were instructed to listen to a 15-minute Librivox recording of an extract of Lysander Spooner's 1852 book *Trial by Jury,* concerning the relationship between taxation, consent and traditional common law trial by jury. This recording was selected due to its comparable length with the MBCAT meditation, similar vocal qualities of the narrator, and its relatively non-arousing subject matter. Moreover, it is consistent with prior studies utilising educational extracts as control conditions and can be seen as an ecologically valid way of comparing mindfulness inductions to real-world situations where mind wandering / attentional lapses may occur due to the lack of mindfulness-specific instructions (Larson et al., 2013; Norris et al., 2018). The recording was uploaded to Soundcloud and linked to Qualtrics.

Data Preparation and Analytic Strategy

Performance and sustained attention during the attention tasks was assessed using identical measures of reaction time, response accuracy and experience sampling methods as those administered in Study 6. I also utilised identical pre-processing steps for RT and accuracy data.

I conducted Multivariate Analysis of Covariance (MANCOVA) and follow-up ANCOVAs to explore post-induction differences in anxiety responses to the COVID-19 pandemic and attitudes / hesitancy towards vaccination between MBCAT Online and Control Groups, controlling for corresponding pre-induction measures. I also implemented

MANOVA and follow-up ANOVAs to assess for differences in attention performance between MBCAT and Control conditions. Pillai's trace is reported for all MANCOVAs/MANOVAs due to unequal sample sizes.

I estimated linear mixed effects models (LMMs) for all RT analyses and generalised linear mixed effects models (GLMMS) for non-aggregated binomial accuracy data, CPTp attentional performance outcomes and probe response analyses (Appendix 1, Study 7**)**. Subject was included as a random intercept in all minimal models.

The analytic strategy specific to ANT and CPTp performance outcomes as a function of induction group is identical to that employed for categorical analyses of meditators and non-meditators in Study 6.

Results

Demographics Analyses.

There were roughly equal numbers of males and females between MBCAT and Educational Control groups (MBCAT; *9 males, 26 females*: Educational; *7 males, 23 females)* and no significant differences in age between conditions (t = -1.10, p = .30). Correlational analyses were implemented to assess whether age was associated with trait mindfulness (MAAS and FFMQ scales), revealing no pertinent associations (all *ps* > .25). Relationships between age and attention network performance / CPT performance outcomes are displayed in respective demographics sections. Age was controlled for in all subsequent analyses.

Equivalence Tests.

I conducted MANOVA to assess for equivalence in levels of pre-induction self-reported mindfulness between MBCAT and Educational Control conditions. There were no differences in relation to MAAS and FFMQ measures ($V = 0.04$, $F(2, 62) = 1.46$, $p = .24$) or SAVE-6 and VHS measures ($V = 0.07$, $F(2, 62) = 2.70$, $p = .18$).

ANT. MANOVA revealed no effect of gender on aggregate attention network scores ($p = .25$). Age was positively associated with orienting network scores ($r[63] = 0.34$, $p < 0.01$) and executive network scores ($r[63] = 0.38$, $p < 0.01$). Accordingly, age was controlled for in all analyses exploring the effects of MBCAT induction on attention network scores and accuracy.

CPT. MANOVA revealed no effect of gender on overall CPT RT ($p = .25$) or accuracy. Age was positively associated with overall CPT RT ($r[65] = 0.40$, $p < .001$) and negatively associated with overall CPT accuracy ($r[65] = -0.48$, $p < .001$), suggesting decrements to CPT performance as age increased. Age was also positively related to the proportion of misses (failing to respond to non-target letters) during the CPT ($r[65] = 0.53$, $p < .001$), suggesting that it was the failure to commit motor responses that influenced the effect of age on overall CPT accuracy. Accordingly, age was controlled for in all analyses exploring the effects of MBCAT induction on CPT outcomes.

Induction, Mindfulness and COVID-related anxiety

MBCAT and Educational Control Group Differences. MANCOVAs, modelling post-induction COVID-19 anxiety and vaccine hesitancy outcomes, controlling for corresponding pre-induction measures, did not reveal statistically significant differences between MBCAT and control conditions ($V = 0.001$, $F(2, 60) = 0.02$, $p = .98$) (H1a), suggesting that MBCAT induction did not influence levels of coronavirus-related anxiety or vaccine hesitancy in the current sample. Indeed, changes COVID-related anxiety and vaccine acceptance across induction conditions were negligible (see Table 14), resulting in no significant changes over time within MBCAT or Control groups (*ps* > .78). It should be noted that pre-induction and post-induction SAVE-6 scores in the present study were well below thresholds for mild-moderate anxiety responses to the pandemic (mild-moderate anxiety: >= 15, Chung et al., 2021), potentially reducing the likelihood of detecting induction-specific effects.

Contrary to expectations (H1b), self-reported mindfulness was not related to either COVID-related anxiety or vaccine hesitancy (all *ps* > .56).

Table 14.

Covid-Related Anxiety and Vaccine Acceptance Across Induction Conditions

COVID-Related Anxiety (SAVE-6)	Pre-Induction *M (SD)*	Post-Induction *M (SD)*	Pre-Post Difference
1. MBCAT MM Induction Condition	10.37 (5.36)	9.74 (5.10)	-.63
2. Educational Extract Condition	7.87 (4.10)	7.60 (4.34)	-.27
Vaccine Acceptance (VHS)	**Pre-Induction *M (SD)***	**Post-Induction *M (SD)***	**Pre-Post Difference**
1. MBCAT MM Induction Condition	11.10 (5.17)	11.54 (5.55)	.44
2. Educational Extract Condition	15.57 (6.10)	16.10 (6.91)	.53

Attention Network Task (ANT)

Establishing the Attention Networks. Consistent with Study 6, the three attention network effects for the online ANT were validated. LMMs (Appendix 1, study 7) revealed significant effects of cue type ($F(3, 54.83) = 47.94$, $p < .001$) and target type ($F(2, 56.61) = 299.90$, $p < .001$) on response latencies, further justifying use of the online ANT to differentiate between the three attention networks. Alerting ($p < .0001$, $d = .11$), orienting ($p < .0001$, $d = .11$) and executive RT effects ($p < .0001$, $d = 1.01$) were observed[47]. Moreover, GLMMs revealed executive accuracy effects ($p < .0001$, $d = .54$).

Attention Network Scores. Having established stimuli-specific ANT effects on RT and accuracy, I calculated alerting (no cue – double cue), orienting (central cue – spatial cue) and executive attentional network scores (incongruent target – congruent target), which were created from aggregate RT outcomes for each stimuli type. One-sample *t*-tests revealed that all attention network scores were significantly different from zero (*ps* < .001), thus providing a reliable performance index for each network.

Induction Condition and Attention Network Scores. Figure 73 illustrates attention network RT scores for MBCAT and Control conditions. Contrary to predictions (H2a), MANCOVA modelling network RT scores as a function of induction condition, controlling

[47] *A note on online vs. lab-based effect sizes.* It's worth noting that the effect sizes for each attention network in experiments utilising online versions of the ANT (Study 6 and present study) were very similar, whereby small effect sizes were obtained for alerting and orienting networks (average $d = .11$) and large effect sizes were observed for the executive network ($d = 1.02$). Effect sizes obtained from lab-based implementations of the ANT in the present thesis were slightly larger (average alerting $d = .23$, orienting $d = .17$, executive $d = 1.04$), suggesting marginally stronger network effects during laboaratory-based inquiry relative to online implementation. Such considerations are important when making inferences about the impact of each type of mindfulness / meditation condition on specific attention networks, as more formal experimental settings may invite stronger effects based on identical conditions and onscreen stimuli.

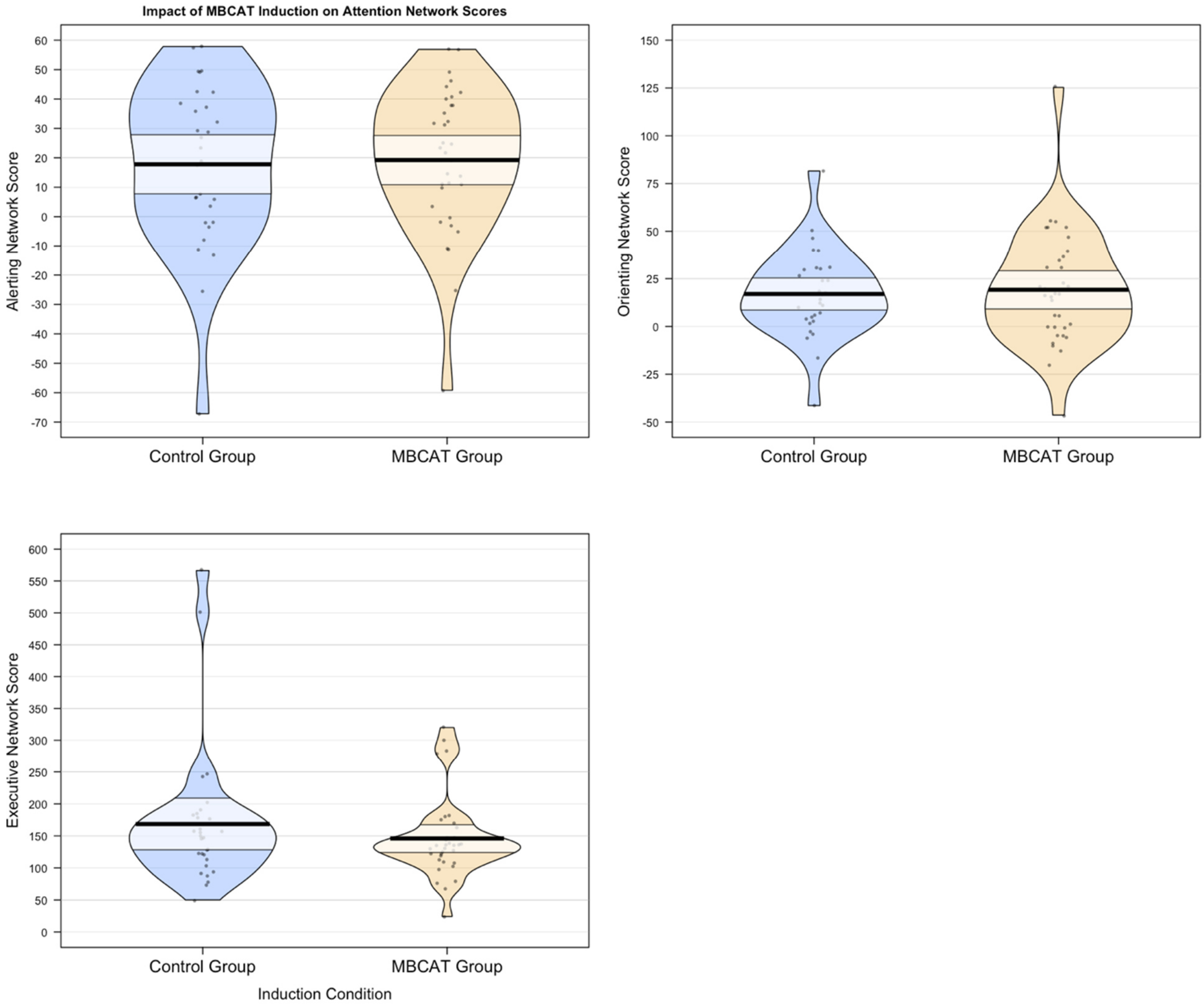
for age, did not reveal statistically significant differences between MBCAT and Control group participants ($V = 0.04$, $F(3, 60) = 0.94$, $p = .43$).

MANCOVA modelling network accuracy scores as a function of induction condition, controlling for age, did not reveal statistically significant differences between MBCAT and Control group participants ($V = 0.03$, $F(3, 60) = 0.56$, $p = .64$).

Induction Condition and Attention Network Accuracy. Figure 74 outlines differences between MBCAT and Control group participants in terms of accuracy during the overall ANT (A), and in response to specific targets (B) and cues (C). Descriptively, overall ANT accuracy, cue accuracy and incongruent target accuracy differences were in the expected direction, insofar as accuracy appeared higher for MBCAT participants than for Control participants. However, contrary to expectations (H2a), GLMMs exploring effects of MBCAT induction on non-aggregated binomial accuracy responses, controlling for age, did not reveal a main effect of induction group on overall accuracy ($\chi2$ (1, $N = 65$) = 0.26, $p = .61$, $d = .05$). The interaction between induction group and cue type was non-significant ($\chi2$ (3, $N = 65$) = 0.35, $p = .95$), as was the interaction between induction group and target type ($\chi2$ (2, $N = 65$) = 1.52, $p = .47$).

Figure 73.

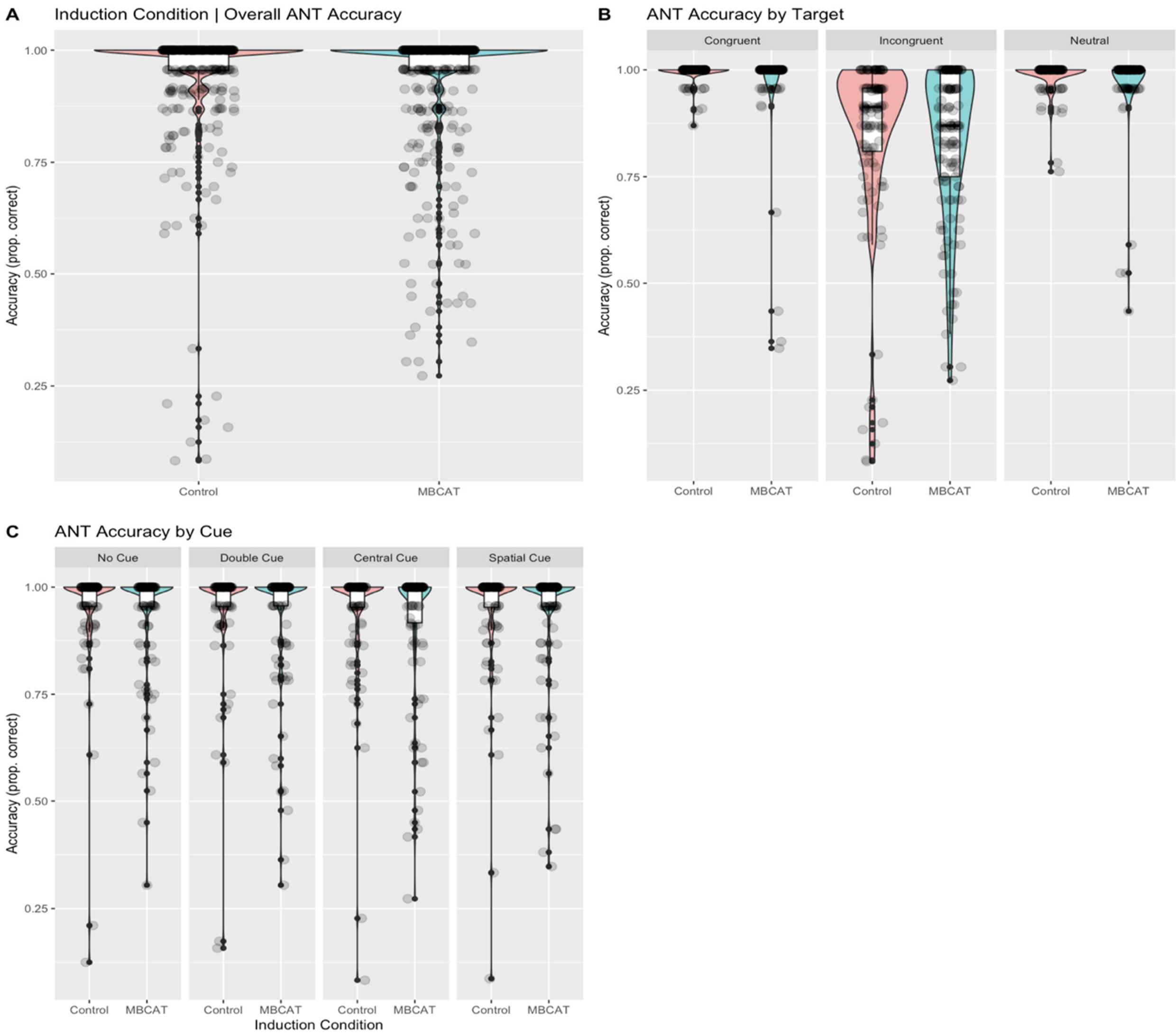
ANT Network Scores by Induction Condition



Note. Means (horizontal lines) and 95% CIs (inference bands) displayed. Beans represent density plots.

Figure 74.

ANT Network Accuracy by Induction Condition



Note. (A) overall ANT accuracy, (B) target accuracy and (C) cue accuracy. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Mindfulness and Attention Network Scores. Next, I explored relationships between self-reported mindfulness and attention network scores (H2b) (Table 15), with a view to identifying associations that may be moderated by MBCAT induction. All associations between mindfulness and attention network scores were non-significant. However, due to several correlations approaching moderate magnitudes for FFMQ Observing, Describing and Non-Judging in relation to respective attention network scores, I utilised interactions between induction group and FFMQ facets to investigate potential moderative effects.

Table 15.

Bivariate correlations Between MAAS, FFMQ Facets and ANT Network Scores.

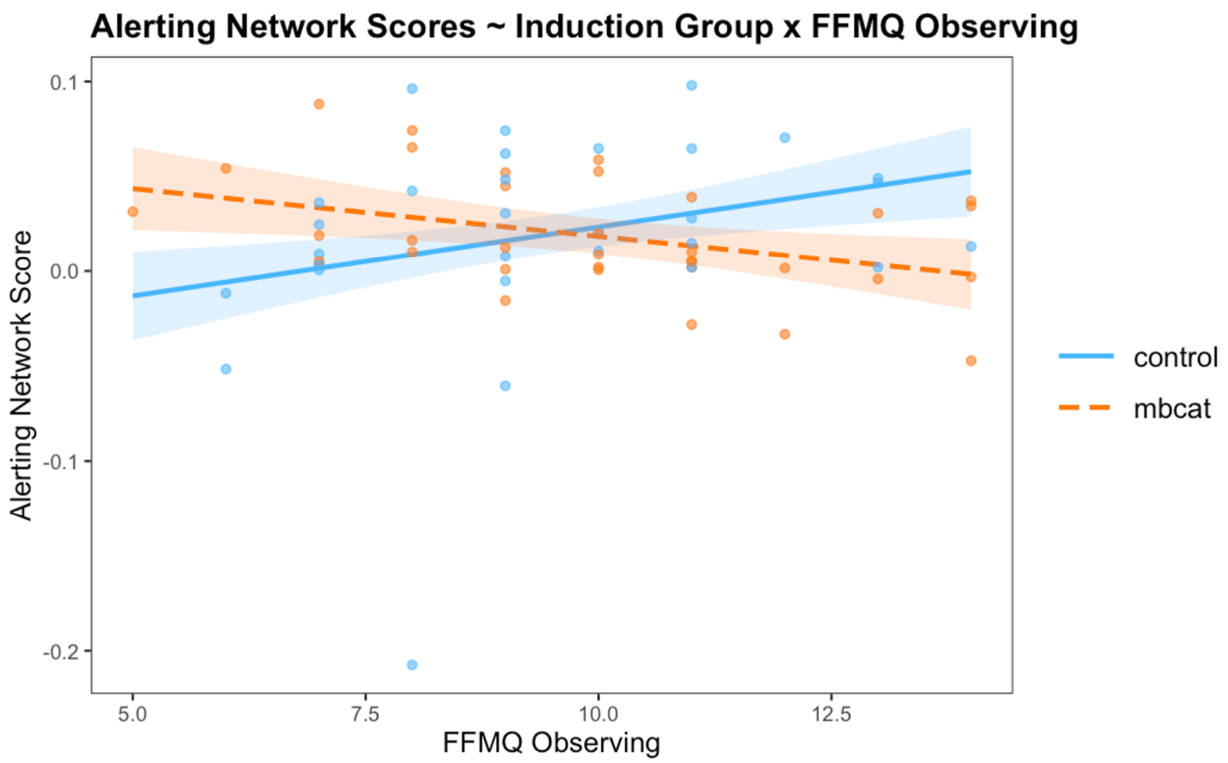
Network	**Alerting**	**Orienting**	**Executive**
1. MAAS	-.18	-.05	.06
2. Observing	.01	.26	.19
3. Describing	-.09	.29	.07
4. Awareness	.17	-.08	-.16
5. Non-Judging	-.27	-.05	-.23
6. Non-Reactivity	.05	.19	.03
7. Total FFMQ	-.07	.23	-.12

Note. * indicates $p < .05$. ** indicates $p < .01$. Values adjusted for multiple tests.

Consistent with expectations (H2c), there was a significant interaction between induction group and FFMQ Observing in relation to alerting network scores ($F(1,61) = 6.72$, $p = .01$, Figure 75). Higher observing was associated with lower (e.g., improved) alerting network scores for MBCAT participants ($b = -.01$, $t = -2.01$, $p = .05$) but not Control group participants ($b = .01$, $t = 1.64$, $p = .11$). A marginal interaction was also observed between induction group and FFMQ Non-Reactivity $F(1,61) = 4.04$, $p = .05$, Figure 76), whereby there was a non-significant trend for non-reactivity to be associated with improved alerting network scores for the MBCAT group ($b = -.01$, $t = -1.81$, $p = .08$) but not the Control group ($b = .01$, $t = .97$, $p = .34$).

Figure 75.

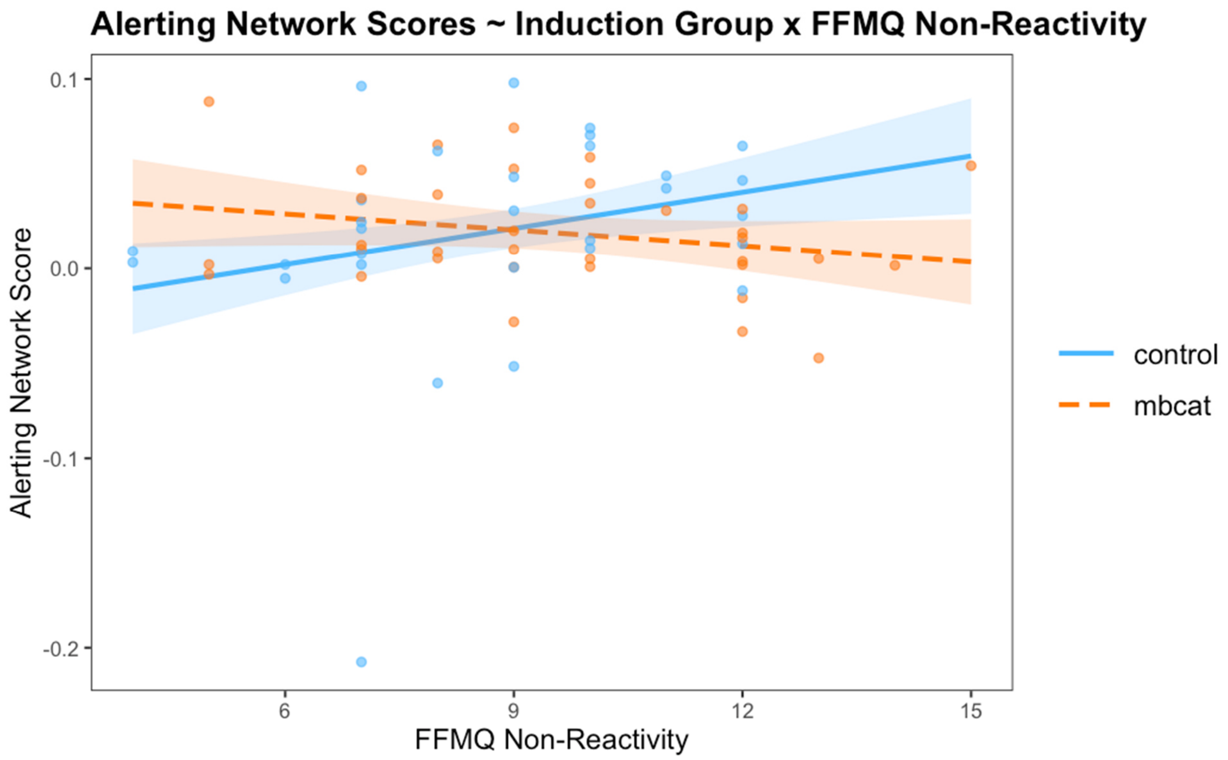
ANT Alerting Scores by Induction x Observing Interaction



Note. Higher observing scores associated with improved alerting network scores for MBCAT participants but not for Control group participants. Shaded areas represent 80% confidence bands.

Figure 76.

ANT Alerting RT Scores by Induction x Non-Reactivity Interaction



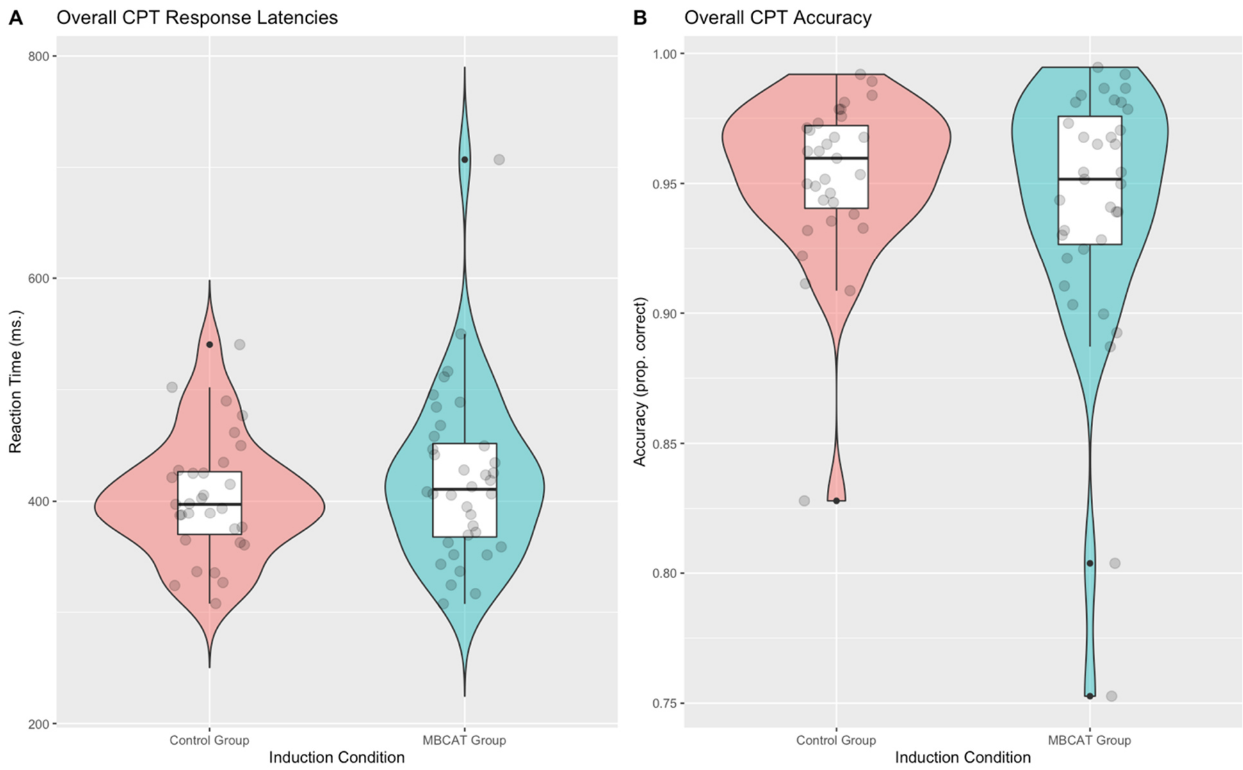
Note. Higher non-reactivity scores associated with improved alerting network scores for MBCAT participants but not for Control group participants. Shaded areas represent 80% confidence bands.

Continuous Performance Task + Probes (CPT)

Induction Condition and CPT Response Latencies (RT) and Accuracy. Figure 77 outlines overall CPT RT for MBCAT and Control groups. Contrary to expectations (H3a), there were no differences between MBCAT and Control groups in terms of CPT RT (F (1, 62.92) = 0.35, p = .56, d = .11). GLMMs exploring effects of MBCAT induction on non-aggregated binomial accuracy responses, controlling for age, did not reveal a main effect of induction group on overall accuracy ($\chi 2$ (1, N = 65) = 0.73, p = .40, d = .16); odds ratio $_{\text{MBCAT group versus control group}}$ = 1.25 (95%CI[.75, 2.07]).

Figure 77.

Overall CPT Response Latencies (RT) and Accuracy by Induction Condition



Note. Response latencies (**A**) and accuracy (**B**) as a function of induction condition. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.

Induction Condition and Attentional Lapses, False Alarms and Errors of Omission. I also utilised GLMMs to explore the effect of meditation group on attentional lapse (defined as the slowest 20% of reaction times), false alarms and omission errors, enabling a random intercept for each subject and controlling for age. Table 16 outlines proportions of these outcomes across the whole sample and between induction groups. Contrary to my predictions (H3a) those in the control condition were not more likely to exhibit an attentional lapse than those in the MBCAT condition ($\chi 2(1, N = 65) = 0.19$, $p = .67$, $d = .10$); odds ratio $_{\text{MBCAT group versus control group}} = 0.81$ (95%CI[.32, 2.08]). The likelihood of responding with a false alarm was not significantly different between induction groups ($\chi 2$(1,

$N = 65) = 0.11$, $p = .74$, $d = .01$; odds ratio $_{\text{MBCAT group versus control group}} = 0.95$ (95%CI[.68, 1.31]). The same was true for errors of omission, that is, there were no differences between induction groups ($\chi 2(1, N = 65) = 0.01$, $p = .97$, $d = .21$; odds ratio $_{\text{MBCAT group versus control group}} = .97$ (95%CI[.36, 2.70]).

Table 16.

Induction Condition and Sustained Attention During CPT

	Lapses	False Alarms	Omission Errors
Full Sample	.20 (.40)	.03 (.18)	.03 (.18)
MBCAT Induction	.22 (.41)	.03 (.18)	.05 (.22)
Educational Control	.18 (.38)	.03 (.17)	.01 (.11)

Note. Proportions of each sustained attentional performance outcome during the CPT. SDs displayed in parentheses.

Induction Condition and Thought Probes. Next, I examined proportions of thought-probe responses in the whole sample and within MBCAT and Control induction conditions (Table 17). There was a significant effect of probe type on numbers of responses within each probe category ($F(4, 201) = 9.46$, $p < .001$). Overall, participants reported more thoughts indicating on-task focus ($M = 4.66$, $SE = .32$, 95% CI[4.02, 65.29]) than those indicating external distraction ($M = 2.17$, $SE = .41$, 95% CI[1.36, 2.99], $t(184) = 4.732$, $p < .0001$, $d = 1.12$), non-alertness ($M = 2.86$, $SE = .44$, 95% CI[1.99, 3.72], $t(183) = 3.30$, $p = .01$, $d = 0.70$)

and mind wandering (M = 2.51, SE = .38, 95% CI[1.75, 3.26]), $t(180) = 4.29$, $p < .001$, d = 0.90). However, there were no differences between on-task reports and task-related interference (M = 4.19, SE = .30, 95% CI[3.61, 4.77]), $t(155) = 1.10$, $p = .82$, $d = .18$). The interaction between probe type and induction condition was not significant (H4a) ($F(4, 202) = .21$, $p = .93$), suggesting no differences between MBCAT and Control groups in relation to on-task and off-task thoughts.

Table 17.

Induction Condition and Thought Probe Responses During CPT

	On-Task	TRI	ED	MW	Non-Alert
Full Sample	.33 (.47)	.35 (.48)	.10 (.29)	.12 (.33)	.11 (.31)
MBCAT Induction	.36 (.48)	.36 (.48)	.08 (.26)	.11 (.31)	.10 (.30)
Educational Control	.29 (.45)	.34 (.47)	.12 (.32)	.14 (.35)	.12 (.32)

Note. On-task; on-task thoughts, *TRI;* task-related interference, *ED*; external distraction, *MW*; mind wandering, *Non-Alert*; inattentive / non-alert. Proportions displayed. Standard deviations in parentheses.

GLMMs were utilised on non-aggregated binomial thought probe data to explore likelihoods of reporting each thought probe in relation to all other possible responses as a function of induction condition. Although MBCAT participants reported a higher proportion of on-task thoughts than Control group participants (Table 17), this difference was not significant in binomial analyses ($\chi 2$(1, N = 65) = 1.61, p = .21, d = .16; odds ratio $_{\text{MBCAT group versus Control group}}$ = .55 (95% CI [.21, 1.39]). In terms of mind wandering responses, there were no significant differences between MBCAT and Control groups ($\chi 2$(1, N = 65) = .83, p = .36, d = .10; odds ratio $_{\text{MBCAT group versus Control group}}$ = 1.51 (95% CI [.62, 3.65]). Finally, in terms of the observed descriptive differences in relation to external distraction, there were no significant differences between MBCAT and Control groups ($\chi 2$(1, N = 65) = 2.33, p = .13, d = .15; odds ratio $_{\text{MBCAT group versus Control group}}$ = 1.96 (95% CI [.83, 4.63]).

Mindfulness and CPT Performance. Next, I explored relationships between self-reported mindfulness and CPT outcomes (H3b) (Table 18), with a view to identifying associations that may be moderated by MBCAT induction. The majority of relationships were non-significant (all *ps* > .33), although there were significant associations between FFMQ Awareness scores and overall CPT RT ($p < .05$) and attentional lapses ($p < .05$), insofar as higher levels of awareness were associated with longer RTs and more attentional lapses. However, exploring interactions between induction group and mindfulness in relation to each CPT outcome (H3c) did not reveal moderative effects (all *ps* > .26), suggesting that MBCAT induction was no more / less effective at improving CPT performance for those higher / lower in dispositional mindfulness.

Mindfulness and Thought Probes. Considering the descriptive differences between induction groups in relation to on-task thought and external distraction, I explored relationships between dispositional mindfulness and specific probe responses in order to identify potential mindfulness candidates for condition-based moderation analyses.

Consistent with predictions (H4b), there were significant negative relationships between MAAS and mind wandering (p = .05) and FFMQ Total scores and mind wandering (p = 0.03), insofar as higher mindfulness scores were associated with reduced mind wandering during the CPT. Indeed, the majority of associations between mindfulness and mind wandering reflected medium-sized negative relationships (Table 19). However, exploring interactions between induction condition and mindfulness (H4c) did not reveal any moderative effects (all *ps* > .25), suggesting that MBCAT induction was no more / less effective at influencing cognitive content for those higher / lower in dispositional mindfulness.

Table 18.

Mindfulness and CPT Performance

	Attentional Lapse	False Alarms	Omission Errors
1. MAAS	.14	-.06	.08
2. Observing	.13	-.07	.20
3. Describing	-.05	.001	.19
4. Awareness	.36*	-.24	.07
5. Non-Judging	.04	.12	.13
6. Non-Reactivity	-.05	.04	.18

7. Total FFMQ	.09	-.01	.21
8. Age	.03	.09	.53**

Note. Bivariate correlations between MAAS and FFMQ facets and CPT performance outcomes, adjusted for multiple tests. N = 65. ***p < 0.01; *p < 0.05.*

Table 19.

Mindfulness and Proportions of Probe Responses

	On-Task	TRI	ED	MW	Non-Alert
1. MAAS	.37	-.06	-.08	-.38*	-.16
2. Observing	.03	.28	-.04	-.18	-.15
3. Describing	.13	.13	-.04	-.34	-.15
4. Awareness	.28	-.07	-.19	-.34	-.11
5. Non-Judging	.07	-.08	-.01	-.14	.06
6. Non-Reactivity	.11	.31	-.03	-.33	-.06
7. Total FFMQ	.23	.09	-.09	-.41*	-.09

Note. Bivariate correlations between MAAS and FFMQ facets and thought probe proportions, adjusted for multiple tests. N = 65. ***p < 0.01; *p < 0.05.*
Note. On-task; on-task thoughts, *TRI;* task-related interference, *ED*; external distraction, *MW*; mind wandering, *Non-Alert*; inattentive / non-alert. Proportions displayed. Standard deviations in parentheses.

Summary of Results

The present study aimed to investigate the effects of a brief mindfulness induction on sustained attention, executive control, mind wandering and COVID-related measures of psychological distress. By extending previously utilised methodologies in several unique ways, I hoped to facilitate a deeper examination of the effects of MMs on key attentional outcomes and provide clarity to the current research landscape. Specifically, I examined mindfulness, COVID-specific anxiety, and attentional performance during the ANT / CPT as a function of brief FA-based mindfulness meditation (MM), which was induced immediately prior to the experiment. Overall, the effects of MM on COVD-related distress, sustained attention and cognitive content were limited, raising important considerations about the effectiveness of single-session MMs on psychological and attentional outcomes, at least with how each of these components were measured in the present study. From a broader perspective, I obtained no evidence that brief mindfulness induction enhanced performance-inferred capacities for alertness / vigilance, suggesting that the wakefulness associated with mindfulness may not be nurtured by single-session practice. I discuss these results and their wider implications in detail in Chapter 7.

Chapter 7: General Discussion

Overview

In the final chapter of my thesis, I integrate and discuss the key findings obtained across seven experiments. I begin by outlining the primary aims of the present research, which involved examining mindfulness as a unique capacity for wakefulness and tonic LC-NA activation through the lens of adaptive gain theory (AGT). I then provide a detailed discussion around the principal results emerging from each of my empirical chapters in relation to the broader aims of the thesis. Specifically, I discuss, (i) the role of trait mindfulness in inconsistency-arousal-compensation processes, (ii) the impact of dispositional mindfulness on AGT-predicted shifts into tonic LC-NA modes of arousal and exploratory attentional states, (iii) the effects of mindfulness-based interventions on sustained attention, vigilance, arousal and cognitive content, and (iv) the assessment of comparable attentional and cognitive outcomes as a function of meditation experience, frequent meditative practice and brief mindfulness induction. These discussions are accompanied by a consideration of their respective implications and limitations.

The main aim of my thesis was to explore mindfulness as a distinct capacity for wakefulness and awareness toward internal and external phenomena, with specific reference to the human attentional and noradrenergic systems. Specifically, I wanted to investigate the precise attentional and arousal-based features associated with mindfulness in relation to two distinct theoretical perspectives on human environmental negotiation - inconsistency-compensation and adaptive-gain theory. Overall, across seven experiments harnessing novel inductions of inconsistency, established performance-based tests of attention and pupillary assessments of noradrenergic activity, I examined whether mindfulness was related to an array of attentional and psychophysiological outcomes, with the aim to embellish our current understanding of mindfulness as a capacity for wakefulness, awareness and improved attentional control.

Study 1: Mindfulness Exerts No Influence on Relationships Between Stroop Inconsistency and Compensatory Affirmation

Stroop Effects, Mindfulness and Compensatory Affirmation (H1a/b / H2a/b). No effects of the Stroop task, regardless of difficulty, were observed in relation to compensatory affirmation responses. These findings contrast with extant literature demonstrating a range of compensatory reactions to various forms of inconsistent / incongruent / expectancy-violating information (Proulx, Inzlicht and Harmon-Jones, 2012; Randles, Proulx, Heine and Vohs 2010; Proulx and Heine, 2008; Proulx and Heine, 2010; Sleegers et al., 2021**).**

Mindfulness was unrelated to all measures of compensatory affirmation in this study, indicating that increased capacities for observation, awareness, non-reactivity and non-judgment did not manifest as reduced punitive action or diminished potency of political / moral beliefs. These results are surprising, insofar as dispositional mindfulness has previously been associated with reduced punitive / prejudicial attitudes and increased political conciliation (Ramstetter, 2021). Indeed, reductions in punitive judgments were expected to be particularly receptive to increased capacities for non-judgment, but this was not the case. Examining whether dispositional variations in mindfulness were differentially related to compensatory outcomes as a function of inconsistency revealed some interesting moderative effects. Firstly, harsher bond severity was observed following Stroop-based conflict for individuals harbouring greater capacities for non-reactivity, suggesting that non-reactive dispositions were related to greater punitive action after being confronted with inconsistent information. The fact that high non-reactivity individuals in the control group exhibited the opposite pattern suggests that the inclusion of inconsistency served to override any dispositional effects on compensatory reactivity. These findings would appear to violate intuitions that less reactive individuals are presumably less likely to react to inconsistency /

conflict and associated underlying arousal states thanks to proposed early disengagement capabilities (Lutz et al., 2008; Malinowski, 2013). Indeed, non-reactivity has been associated with reduced cognitive biases / ruminations following brief inductions of conflict / stress (Paul et al., 2013), nurturing expectancies that such capacities would extend favourably into inconsistency-compensation processes. The contrary findings of this study highlight the necessity of examining specific sub-facets of mindfulness in relation to these processes before making generalised conclusions about beneficial attentional effects, which raises important questions about the broader utility of dispositional mindfulness in facilitating attentional control when conceptualised as a singular component. More generally, these findings offer unique insights into the impact of dispositional variations in inconsistency-compensation processes and harbour broader implications for the role of inconsistent / incongruent information in shaping and / or revealing previously dormant / unknown associations between dispositional qualities and political / moral affirmations.

Limitations and Future Directions. Although Stroop incongruence is positioned as a valid and effective low-level induction of inconsistency / conflict, a more ecologically valid tool may have provided stronger effects, especially in relation to the social judgement content of the compensatory frameworks made available to participants. Specifically, inconsistent / uncanny socially related stimuli (e.g., incongruent playing cards or facial features) may have represented a stronger induction of inconsistency than Stroop-based incongruence, which in turn may have evoked stronger arousal responses and compensatory behaviour. Follow-up studies should employ these and similar inductions to examine potential changes in the severity of punitive action and political / moral adherence. Accordingly, in my next study (Study 2) I incorporated pictorial faces to induce inconsistency.

Moreover, due to the online nature of this study, indirect means of measuring arousal

– a central component of understanding threat-compensation processes – were not implemented. Utilising psychophysiological methods (e.g., pupillometry) to examine whether different levels of Stroop-induced conflict provoked differential magnitudes of arousal would have provided additional information to help contextualise present findings. As such. concurrent psychophysiological assessment should be administered in comparable future studies exploring inconsistency-compensation processes, a recommendation duly addressed in my next study.

Finally, as is the reality of online research, there were a range of confounds that could not be controlled for in this study, such as the time and setting of the experiment, the equipment utilised (specifically in terms of the inherent variance of visual display units, considering the nature of the Stroop task) and the ability of the experimenter to address emerging technical issues / participant concerns in real-time. Future laboratory-based explorations of inconsistency-compensation processes would help ameliorate these issues, as was the case in my successive experiment (Study 2).

Conclusion. Overall, Study 1 revealed no evidence that Stroop inconsistency influenced compensatory affirmation in the form of punitive action or stricter adherence to political / moral beliefs, implying that the Stroop task in this study was not a sufficiently potent method for inducing inconsistency and associated arousal states. Moreover, dispositional mindfulness was not associated with reduced compensatory affirmation, although Non-Reactivity did exert interesting effects on inconsistency-induced behaviour. In order to gain further insight into such processes, I addressed the discussed methodological limitations in my next study.

Study 2: Mindfulness Exerts No Influence on Relationships Between Expectancy Violation, Compensatory Affirmation and Arousal

In line with predictions (H1a), I replicate specific findings evidencing an expectancy bias for upside-down relative to angry faces (Proulx et al., 2017), thus confirming the validity of the chosen stimuli for inducing inconsistency and associated arousal signatures. Moreover (H2b), upside-down angry Thatcherised faces exerted greater arousal than upside-down neutral faces during the cognitive conflict time window, implying enhanced potency of inconsistency on arousal when combining inherently incongruous features with threatening features (angry expressions). These findings are consistent with proposals that a dominant expectancy bias is observed towards the greatest degree of inconsistent information (Grupe and Nitschke, 2011; Proulx et al., 2017). Moreover, between-subjects comparisons revealed that expectancy-violating information induced greater cognitive conflict arousal than threatening information alone (H1b) (Proulx et al., 2017). Overall, these findings are consistent with the notion of an attentional and psychophysiological expectancy bias to inconsistent stimuli, validating an inconsistency-induced arousal component suitable for further analyses in relation to compensatory affirmation and dispositional variations in inconsistency-compensation processes.

Having validated an important and well-studied tenet of inconsistency-compensation frameworks (Proulx et al., 2017; Proulx et al., 2012; Sleegers et al., 2015; Sleegers et al., 2021), experimental attention was afforded to the decidedly more neglected second tenet; that such arousal will be linked to compensatory behaviour. Partly in line with expectations (H3a/b), greater inconsistency-induced arousal was associated with increased tendencies to affirm alternative meaning frameworks. However, the fact that there were no interactions between epoch-specific arousal and face type indicates that compensatory efforts were not exclusively related to inconsistency-induced arousal, but rather emerged from an overall level of psychophysiological reactivity to salient stimuli. Nonetheless, this research is among the first to demonstrate links between arousal and compensatory behaviour, consistent with comparable endeavour evidencing links between arousal and compensatory hindsight bias (Sleegers et al., 2021) and offering unique insight into the impact of socially pertinent visual information on distinct arousal states and compensatory affirmation.

Addressing the under-examined role of dispositional factors in physiological responses to salient stimuli and resultant downstream effects on compensatory behaviour, trait mindfulness was explored as a potential moderating factor. Against expectations (H4a), mindfulness was not associated with changes in cognitive conflict arousal in response to inconsistent / incongruent faces, which runs contrary to conceptualisations of mindfulness as a capacity for wakefulness and awareness towards the experiential field. Moreover, no evidence was observed for an expected moderative role of mindfulness on arousal-compensation relationships (H4b), suggesting that greater mindful dispositions exerted no reductive influence on the motivation to ameliorate arousal-based discomfort. These results call into question the moderative utiliy of dispositional mindfulness in inconsistency-arousal-compensation relationships, potentially necessitating a more comprehensive exploration of how different sub-facets of mindfulness may influence behavioural / compensatory reactions to specific arousal states.

Limitations and Future Directions. Study 2 utilised, and further validated, a specific measure of arousal to infer elevated LC-NA activation in the face of inconsistent stimuli, namely an intra-trial arousal response (TEPR). This is consistent with existing methods examining inconsistency-arousal-compensation processes (Proulx et al., 2017; Sleegers et al., 2015; Sleegers et al., 2021). However, research has demonstrated that when participants are afforded an opportunity to *reset* a level of inconsistency that is explicitly linked to task performance (e.g., increased difficulty / diminishing rewards), it is possible to repeatedly induce elevations in inconsistency-arousal leading up to decisions that are intrinsically linked to AGT-predicted shifts into exploratory attentional modes and tonic LC-NA activation (Gilzenrat et al., 2010). Such endeavour would more robustly tie inconsistency-induced arousal processes with AGT-predicted LC-NA function. Moreover, examining subsequent behavioural responses to performance-based inconsistency that are potentially receptive to exploratory attention, heightened awareness and associated psychophysiological markers of increased vigilance (e.g., compensatory *abstraction*, Proulx et al., 2012) offers a unique opportunity to contribute to a more comprehensive understanding of the links between mindfulness and AGT-predicted LC-NA function. Accordingly, my next study (Study 3) utilised such methods by incorporating unique and repeated inductions of task-based inconsistency with a novel behavioural test of abstraction.

Additionally, it is worth considering that the most widely used measures of dispositional mindfulness (FFMQ and Mindful Attention Awareness Scale (MAAS)) have been demonstrated to activate distinct areas of the brain associated with specific cognitive / attentional capacities. For example, facets of the FFMQ have variously been associated with multiple prefrontal brain regions associated with emotion regulation and attentional control, whereas the MAAS has been more strongly associated with increased grey matter volume of the right precuneus, which is heavily related to awareness (Zhuang et al., 2017). These and comparable distinctions between the FFMQ and MAAS suggest that different measures of mindfulness relate to specific components of attention, thus harbouring the potential to exert differential moderative qualities on reactions to inconsistent / incongruous stimuli. Future studies should incorporate alternative measures of mindfulness to examine such possibilities. As such, in my successive experiment (Study 3) I utilised the MAAS to assess the impact of dispositional mindfulness on inconsistency-arousal processes.

Conclusion. Importantly, the results of Study 2 provide tentative support for the often theorised, yet empirically neglected, linkage between inconsistency-induced arousal and subsequent compensatory behaviour. However, mindfulness was not revealed as an efficient moderator of inconsistency-arousal-compensatory affirmation processes, inviting future inquiry to converge similarly validated methods of inconsistency induction with alternative measures of mindfulness and compensatory / exploratory behaviour. As discussed, these methodological recommendations were addressed in Study 3.

Study 3: Inconsistency-Induced Arousal Associated with Enhanced Implicit Pattern Abstraction, Moderated by Mindfulness

Emerging from Study 2 were distinct recommendations to more closely link inconsistency-induced arousal processes with AGT-predicted transitions into tonic LC-NA modes and to examine subsequent behavioural features potentially more receptive to the bottom-up, exploratory attentional capacities associated with tonic arousal. As such, if mindfulness can be conceptualised as an adaptive capacity for increased tonic LC-NA activity and a reduced threshold to *enter* these tonic modes, then this should be reflected by greater magnitudes of inconsistency-induced tonic LC-NA arousal and enhanced exploratory performance for those higher in trait mindfulness.

Inconsistency, Arousal and Abstraction (H1, H2). As predicted by adaptive gain theory (Aston-Jones and Cohen, 2005), a putative mediating role was observed of LC-NA activity underlying transitions between exploit/explore control states amid rising task conflict, replicating the utility of pupil diameter in tracking these transitions (H1), indicative of an inconsistency-induced tonic mode of LC-NA activity. Crucially, magnitudes of such activity were positively associated with subsequent AGL performance (H2), demonstrating an association between inconsistency-induced tonic arousal and subsequent abstraction capabilities. Not only do these findings support proposals that a biologically based pattern of aversive arousal follows from all types of inconsistency and motivates all compensatory action (Proulx et al., 2012), they also represent significant contributions to the inconsistency-compensation landscape. Although there are demonstrable links between inconsistency and arousal (Mendes et al., 2002; Moor, Crone & Van der Molen, 2010) and between inconsistency and subsequent compensatory behaviours (Proulx and Major, 2013; Sleegers et al., 2015), theorised associations between inconsistency-induced arousal and successive compensatory action remain to be substantially borne out empirically (Sleegers at al., 2021). As such, by explicitly testing predictions of AGT that exploratory attention and associated tonic arousal states induce search-and-detect behaviours for the attainment of new reward contingencies (Aston-Jones and Cohen, 2005), present research is among the first to demonstrate an *adaptive* quality of the tonic LC-NA mode by evidencing enhanced abstraction of implicitly learned signals. Considering that the adaptive utility of this mode has been relatively neglected in the extant literature (Aston-Jones and Cohen, 2005; Hanoch and Vitouch, 2004), these findings harbour interesting implications for the value of tonic LC-NA arousal for longer-term adaptation and performance optimisation on a broader scale.

For example, enhanced efficiency of exploratory decisions and improved cognitive flexibility towards changing environmental demands - outcomes known to arise from elevated tonic LC-NA activity (Delgado et al., 2011; Kane et al., 2017; Lapiz et al., 2007; Pajkossy et al., 2017; Pajkossy et al., 2018; Seu et al., 2009; Tse and Bond, 2003) - likely reflect motivational drives to obtain more rewarding goal-pursuit strategies in order to shift away from an uncomfortable tonic LC-NA mode and towards a task-locked phasic LC-NA mode (Tritt and Inzlicht, 2012). These motivational efforts would appear to be directly comparable to the compensatory drives recruited as palliative attempts to alleviate the aversive tonic LC-NA mode arising from environmental inconsistency (Proulx et al., 2012). As such, thanks to the use of a task specifically designed by AGT theorists to induce tonic LC-NA activity and associated exploratory attentional states, the present study provides suitable rationale for further investigations into the adaptive utility of the tonic LC-NA mode through the lens of inconsistency-compensation frameworks.

Mindfulness, Arousal and Abstraction (H3, H4). Importantly, there was a significant moderative effect of trait mindfulness on this relationship, whereby positive associations between bPD and AGL performance compensatory behaviour manifested primarily for those reporting greater MAAS (H4). This novel finding addresses the under-examined role of dispositional factors in inconsistency-arousal-exploratory processes (Proulx et al., 2012) by demonstrating that dispositional mindfulness moderates the impact of inconsistency-induced arousal on compensatory pattern abstraction. This implies that the greater potency of tonic LC-NA activity following environmental inductions of inconsistency among high-trait mindfulness individuals was augmentatively associated with improved abstraction capabilities. As such, enhanced associations between inconsistency-induced arousal and abstraction following transitions into exploratory attentional states may have emerged from an increased observation and awareness of present-moment experience associated with mindfulness (Brown and Ryan, 2004), which may have augmented the subjective potency of implicitly learned patterns (Teper and Inzlicht, 2013). This suggests that the moderative qualities of the MAAS on inconsistency-abstraction processes reflect an important role for dispositional tendencies to interact with the impact of arousal on behaviour, harbouring interesting implications for future endeavour. For example, the question remains whether trait mindfulness or mindfulness intervention can influence effects of arousal on attentional performance, an area duly investigated throughout the remainder of this thesis.

Overall, the findings relating to mindfulness in Study 3 align remarkably well with conceptualisations outlined at the beginning of this thesis that mindfulness and its central dimensions of awareness and acceptance represent capacities for 'outward' (*awareness* of implicitly-learned patterns) and 'inward' (*acceptance* of arousal with no increase in behavioural reactivity (e.g., 'escapes') exploratory attentional modes, which are distinctly associated with tonic LC-NA activation (interactions with bPD in relation to AGL performance).

Limitations. The inherent limitations regarding the correlational nature of these results are acknowledged. It is of course possible that individuals innately proficient in the detection of implicitly learned patterns are also more likely to exhibit enhanced tonic LC-NA arousal during the DUT and to score highly on the MAAS. However, the theory-driven nature of the current study, specifically in terms of demonstrating links between inconsistency, tonic LC-NA activity and compensatory abstraction, fully relied on an ability to test and support specific hypotheses following from adaptive gain theory (AGT), which required measuring baseline PD during a task that was explicitly devised by AGT theorists to evoke tonic LC-NA activity. As such, a central requirement was to first induce tonic LC-NA activity through repeated manipulations of inconsistency during the DUT, a method which also ensured the collection of reliable psychophysiological data as a robust index of inconsistency-induced arousal. Employing AGT-predicted arousal manipulations allowed for associations between bPD-inferred tonic LC-NA activity and subsequent pattern detection outcomes to be conceptualised as abstraction arising from (a), inconsistency-induced arousal and (b), LC-NA-induced exploratory modes of search-and-detect, allowing for broader applicability of present findings.

Moreover, these results are not the first to explore and infer inter-task associations between PD in ‘task 1’ and subsequent cognitive and attentional outcomes in ‘task 2’ (Smallwood et al, 2012, Naber et al, 2013). There are many observed associations between psychophysiological phenomena / implied arousal states and temporally distinct psychological outcomes, which don’t necessarily rely on immediate temporal proximity to infer functional associations (Barnard et al, 2010, Samuel et al. 1978, Pallak et a. 1975). Moreover, the fact that there existed a *discrete* relationship between the proxy of tonic LC-NA activity and AGL performance, insofar as bPD during *subjectively* assessed increases in task difficulty (escape-trial epochs) but not *absolute* increases (identical-tone epochs) were associated with higher AGL scores, provides further support for the specific hypothesised association between inconsistency-induced tonic LC-NA arousal and immediately-successive performance indicative of compensatory abstraction (see Appendix 0v).

Interestingly, residual elevations in cortical NA have previously been shown to persist for around 20 – 40 minutes (Garber et al. 1976), meaning that global tonic projections of the LC - specifically to areas that facilitate remapping processes favouring the development of persistent facilitatory changes for the creation of new associations (e.g., ACC/OFC) – likely facilitate downstream shifts toward exploratory cognitive processes and search-and-detect behaviours beyond the trials within which tonic LC-NA is induced (Sadacca et al, 2017, Tervo et al. 2014, Sara, 2009). It therefore seems reasonable to suggest that the repeated manipulations of inconsistency-induced tonic LC-NA activity throughout the 30-minute DUT did, in fact, result in residual NA-related enhancements of exploratory states and exploratory abstraction processes during the immediately successive AGL.

Finally, overall AGL performance in the current study was relatively high (72%) when compared to many other AGL studies (~64%). This implies that, in addition to the specific associations between bPD and AGL performance, there may have also been an overall general effect of DUT participation on AGL scores, thus further supporting the contention that DUT-induced inconsistency and associated tonic LC-NA shifts may have served to facilitate abstraction capabilities. For these reasons, the assertion is maintained that observed associations between inconsistency-induced tonic LC-NA activity and immediately successive abstraction is a unique and novel finding in and of itself, contributing meaningfully to the extant literature by merging methods pertaining to inconsistency induction, AGT-predicted arousal and successive abstraction.

Conclusion. At first glance, tone-discrimination difficulty, AGT-predicted tonic LC-NA activity, and implicitly learned artificial grammars appear to share little in common, but they can each be viewed as representing distinct stages of a process involving inconsistency, arousal and exploratory abstraction. Inducing inconsistency in the form of waning task utility resulted in AGT-predicted elevations in tonic LC-NA activity, evidencing a robust link between inconsistency and arousal (stages 1 & 2, Proulx et al., 2012). As such, observed associations between magnitudes of inconsistency-locked arousal and successive compensatory abstraction capabilities offers a novel and significant insight into the proposed role of arousal in inconsistency-compensation processes (stage 3). Moreover, in demonstrating these findings utilising a task borne out of a complementary theoretical framework (AGT), the present study harbours meaningful implications for the adaptive nature of exploratory attentional states and associated modes of tonic LC-NA activity in terms of enhanced search-and-detect abstraction strategies. Finally, current results contribute to emerging conceptualisations of trait mindfulness as an enhanced state of alertness /

wakefulness, suggesting that the “awakening” commonly attributed to mindful traits and practices is more than mere metaphor (Britton et al., 2014) and may manifest as enhanced arousal-related behavioural capabilities. Crucially, these findings also provide the rationale for examining the effects of mindfulness *practice* on LC-NA function in relation to a broader array of attentional and cognitive outcomes, which will likely provide much-needed insight into the understudied nature of mindfulness as a distinctly wakeful capacity. Indeed, this line of inquiry was initiated in Chapter 4.

Study 4: Acceptance and Commitment Therapy (ACT) Exerts No Influence on Attention Network Efficiency, Sustained Attentional Focus or Arousal

Mindfulness (H1). Contrary to expectations (H1), ACT participation did not result in pre-post increases in mindfulness. These results are inconsistent with prior observations that three facets of the FFMQ are consistently impacted by MBI participation, namely observing, describing and non-reactivity (Baer et al., 2019), thus potentially rendering the present ACT intervention less potent than the more established and longer-term MBIs (e.g., MBCT), specifically in terms of inducing increased mindfulness. Despite the techniques / practices taught in-session and encouraged at home during the ACT programme (see Appendix 2B), this did not appear to be conducive to nurturing mindfulness skills through repeated instructions to follow and notice sensations, to adopt an observant stance when engaging in everyday activities and to actively notice patterns of the mind on a daily basis (e.g., ‘Being Mindful’ session). These findings raise important questions about the potency of the present intervention and the utility of conducting purely didactic sessions in place of experiential, guided practice.

ANT Behavioural / Performance Outcomes (H2a/b/c). In relation to the ANT, I demonstrated distinct attention network effects - participants exhibited clear alerting, orienting and executive effects on RT and accuracy across sessions, consistent with expected outcomes (Posner, 2008; Roca et al., 2011). Interestingly, there appeared to be a practice effect on ANT performance, manifesting as improved overall RT and slightly diminished network effects between sessions. In terms of error rates, only an overall executive network effect was observed, contrary to the expected influence of double cues (Alerting) and spatial cues (Orienting) on accuracy (Posner, 2008). This finding may be attributed to the fact that overall levels of accuracy were extremely high across cue conditions, potentially representing a ceiling effect on the ability to detect network differences (Wang et al., 2015). These results may also reflect ANT limitations in relation to alerting and orienting network scores, insofar as they're both obtained from cueing conditions, thus rendering an assessment of their independent effects and interactions problematic (Roca et al., 2011). Indeed, the power to find significant and independent alerting and orienting effects has been demonstrated to be variable across these networks, which may be attributed to the fact that their assessment during the ANT utilises inter-dependent stimuli (Lawrence et al., 2010). Such considerations may also contribute to the fact that there were no network RT or accuracy differences between ACT and waitlist conditions (H2a/b/c), results which contrast with meta-analytic research demonstrating small yet significant MBI-induced executive enhancements (Yakobi et al., 2021) but which are consistent with literature evidencing no such MBI-related network differences (Lao et al., 2016). The lack of observed affects may also be attributable to the fact that all participants were novices in terms of mindfulness / meditation experience. Considering that MBI-induced improvements to ANT network efficiency have been shown to emerge among participants with a minimum of six months' meditation experience prior to intervention (Jha et al., 2007), the limited experience of the present sample may not have been extensive enough to enjoy the full attentional benefits of ACT participation. Moreover, the lack of observed differences between groups may be attributed to the limited potency of the utilised training programme, which is discussed in due course.

Mindfulness and ANT Performance (H3a). Although most mindfulness facets were not related to ANT performance (see Study 5 discussion), Awareness was associated with increased executive network scores (greater discrepancy in RT between congruent and incongruent flankers, indicating increased interference from incongruent information and poorer behavioural performance). These results are consistent with prior examples of Awareness being associated with slower executive RT during the ANT (Di Francesco et al., 2017), suggesting that individuals higher in Awareness were slower to respond to the conflict associated with incongruent target-flanker combinations. In light of this evidence, increased Awareness could be viewed as an elevated focus on one's current activities and of ongoing mental processes contributing to behavioural decisions. In this respect, individuals higher in Awareness may have harboured a heightened sensitivity to the cognitive processes informing eventual behavioural responses, thus prompting a prolonged assessment of relevant courses of action. These findings demonstrate that, although self-reported mindfulness has been associated with improved ANT performance more generally (Tang et al., 2007), caution should be exercised when extolling the attentional virtues of mindfulness as a singular component, as some key facets of mindfulness are associated with diminished ANT performance outcomes (Di Francesco et al., 2017). The fact that not all components of mindfulness are related to increased attention network efficiency may also help to contextualise the mixed results pertaining to MBIs on executive function (Lao et al., 2016; Yakobi, Smilek and Danckert, 2021), insofar as the inherent methodological variance among MBI protocols within existing systematic reviews may exert contrasting effects on attentional capacities, depending on which aspects of mindfulness they serve to augment.

Interestingly**,** Non-Judging scores were associated with improved orienting accuracy for the ACT group only, implying an augmentative effect of ACT intervention on the ability to make use of orienting cues for those higher in Non-Judging. FFMQ Non-Judging assesses the capacity to refrain from restrictive self-talk about what one should be thinking, feeling or doing, and instead promotes a form of cognitive flexibility (Baer et al., 2008). It is possible that harbouring an enhanced capacity to adopt a non-judgmental stance toward inner and outer experience enabled participants to more fully engage in the taught components of the ACT sessions and in home mindfulness practice without judging how 'well' the teaching / practice was going or chastising oneself for drifting away from the object of focus during meditative practice. As such, high Non-Judging ACT participants may have been more likely to enjoy the benefits of mindfulness practice in relation to noticing and making use of orienting information to aid performance, as has been observed in prior MBI research (Lao et al., 2016; Yakobi et al., 2021).

Taken together, these findings are among the first to address calls to explore potential mindfulness-based mechanisms underlying observed attentional effects of MBIs (Dunning et al., 2019; Yakobi, Smilek and Danckert, 2021). They also serve to augment extant clinical endeavour exploring interactive effects of MBCT and FFMQ outcomes on wellbeing (Orzech et al., 2009; Pots et al., 2014; Rubin et al., 2021) by suggesting that MBIs may also reserve their most potent *attentional* effects for those harbouring more mindful dispositions.

ANT Task-Evoked Pupillary Responses (TEPR).

Alerting (H5a). The study replicates evidence for an alerting arousal component by demonstrating a distinct pupillary signature associated with the alerting network. The augmented trajectory was clearly initiated prior to response commission, specifically around 400ms-600ms after cue presentation, which is broadly consistent with previous findings utilising pupillometry (Geva et al., 2013), skin conductance (Murphy et al., 2011) and ERP

(Neuhaus et al., 2010). This suggests that the arousal response to non-specific stimuli supports a mode of phasic alertness toward spatially ambiguous incoming targets, consistent with a stimuli-locked, phasic LC-NA response predicted by adaptive gain theory (AGT) (Aston-Jones and Cohen, 2005). Importantly, alerting TEPR appeared to diminish as a result of time (session 1 to session 2), implying that practice effects may have diminished psychophysiological reactions to familiar ANT stimuli, which may have impacted the ability to detect MBI-related TEPR fluctuations.

Orienting (H6a). Spatially informative cues marginally enhanced whole-trial pupillary responses relative to central cues, broadly replicating previously observed orienting patterns (Geva et al., 2013). Therefore, not only did individuals exhibit psychophysiological activation in response to non-specific signals (alerting) about incoming targets, but also to spatially informative signals about where these targets would appear. Once again, overall TEPR responses were diminished as a result of time, indicating practice effects on arousal-based signatures of the orienting network.

Executive Function (H7a). As expected, incongruent targets exerted greater increases in post-response TEPR than congruent targets**,** specifically around 1500ms after target onset, which replicates with prior results (Geva et al., 2013). These findings are consistent with extant EEG and PD literature demonstrating distinct patterns of neural allocation in response to incongruent stimuli (Norris et al., 2018; Schoenberg et al., 2014; van Steenbergen et al., 2015) and with the general concept that increased magnitude / amplitude of Pe likely reflects the degree of invested effort and top-down processes implemented to manage the cognitive load associated with conflict (e.g., through post-response executive monitoring and the inhibition of background 'noise' / prepotent response tendencies) (Geva et al., 2013; Kahneman, 1973; Laeng et al., 2011). Present findings therefore reflect the recruitment of mental resources required to monitor performance and limit errors following response to incongruent stimuli, which corresponds to an AGT-predicted exploitative attentional mode associated with response-locked phasic LC-NA peaks (Aston-Jones and Cohen, 2005). Executive TEPR diminished as a function of time, indicating practice effects on arousal-based signatures of the executive network.

ACT and ANT Network TEPR (H5b/H6b/H7b). Contrary to expectations, ACT intervention exerted no impact on alerting, orienting or executive network TEPR, suggesting that stimuli-induced arousal throughout the ANT was not receptive to ACT participation. As such, it may be fruitful to examine executive network performance and associated pupillary responses further, specifically as a function of a more intensive MBI intervention, which is indeed what I did in my next study (Study 5).

More generally, the lack of an observed effect of ACT intervention on network arousal during the ANT may have been due a dampening of overall arousal responses between sessions 1 and 2, implying that practice effects may have served to conceal any true effects as a result of intervention. Indeed, despite network-specific TEPR effects remaining significant, they were notably weaker in session 2. To address this, future studies might employ robust randomisation and active control procedures in order to explore the impact of MBIs on a single session of the ANT, whereby the novelty of the task would ensure that arousal responses were at their highest levels. Indeed, such recommendations were addressed in Study 5.

Although no significant ACT-induced effects were observed, the present experiment nonetheless represents one of only two existing studies demonstrating distinct pupillary trajectories for each of the ANT attention networks (Geva et al., 2013), affording an additional layer of psychophysiological insight into the mechanisms underlying the human attention system.

SARTp Behavioural / Performance Outcomes (H2d). Contrary to predictions, ACT intervention exerted no impact on SART performance, suggesting that mindfulness training did not result in improved capacities for sustained attention / attentional control (Go trial response and NoGo inhibition). These results contrast with findings evidencing improved capacities for sustained attention (Yakobi, Smilek & Danckert, 2021) and response inhibition (Casedas et al., 2020; Gallant, 2016) as a result of MBIs, but are consistent with meta-analytic research concluding null effects during the SART and CPT (Im et al., 2021; Lao et al., 2016). One explanation for these results could be that the mindfulness techniques taught during ACT, like in many MBIs, are designed to nurture sustained attention toward *internal* representations (e.g., breathing, sensing, tendencies of the mind), whereas the SART is a task of *visual* perception requiring motor responses. It is possible that such tasks do not adequately capture the full range of attentional improvements that may be induced by MBI participation. Additionally, the mean treatment duration for studies included in reviews exploring MBI-related SART and CPT outcomes is around 16h (Im et al., 2021), substantially more than the 8 contact hours provided by the ACT programme, which due to necessity and available resources was required to adhere to a minimally recommended dose. Moreover, established MBIs include considerable *in-session* guided meditation, whereas ACT conveyed primarily didactic psychoeducation processes about mindfulness techniques. As such, it is likely that a greater amount of practice and the repeated inclusion of in-session guidance is necessary to induce meaningful changes in performance during tasks of sustained and executive attention. To this effect, research utilising interventions more closely linked to the more established, intensive and guidance-based MBIs (MBCT, MBSR) and / or enhanced longitudinal designs should be implemented to examine the intensity-based characteristics and broader time course of pertinent cognitive change. Moreover, exploring cognitive / attentional outcomes in relation to mindfulness experience / duration (e.g., among experienced / expert meditators) may provide further insights into the historical / current "dosage" of meditation that is most likely to provide attentional benefits. These recommendations are explicitly addressed over the next two studies of my thesis.

SARTp Baseline Pupil Diameter (bPD) (H4a/c). As expected, sustained attention performance was associated with elevated tonic arousal. That is, incorrect responses were associated with larger bPD. Specifically, the failure to inhibit prepotent responses during SARTp NoGo trials was preceded by significantly larger bPD than the failure to commit motor responses to Go trials, implying that committing a 'false alarm' was associated with greater levels of tonic arousal than 'missing' a response. This finding makes intuitive sense, insofar as missing a repeated response to common stimuli presumably reflects a state of non-alertness (e.g., lower arousal), whereas actively committing a 'false alarm' to rare stimuli implies distractibility (e.g., higher arousal) (Yerkes-Dodson, 1908). Indeed, self-reported inattentive states have been robustly linked to smaller bPD, whereas larger bPD has been shown to precede distracted states (Unsworth and Robison, 2016). Moreover, tonic pupil diameter has been demonstrated as being larger prior to false alarms (van den Brink et al., 2016) and smaller when engaging with repeated / common stimuli (Milne et al., 2021). Taken together, present findings contribute to the emerging utility of pupillometry to reliably assess specific indices of attentional lapse during continuous task performance. Moreover, these results appear to support broader assertions that bPD can be used as a sensitive index of AGT-predicted LC-NA function, insofar as larger bPD reflects the inherent distractibility and *task-specific* performance detriments associated with tonic LC-NA arousal.

No effects of ACT intervention on bPD were observed (H4c), implying that tonic LC-NA arousal did not fluctuate as a function of ACT participation throughout the task. Considering that arousal was linked to SARTp performance, which was also not receptive to ACT participation, the null findings pertaining to bPD are not surprising in light of the accumulating behavioural observations. As such, similar considerations as those discussed in relation to SARTp performance may explain the lack of MBI-induced effects on tonic LC-NA arousal, considerations that are duly addressed in Study 5.

Thought Probes (H2e). Overall, participants spent much of their time either focused on the task or experiencing non-alertness. These results are consistent with extant literature evidencing on-task dominance throughout a sustained attention task among non-clinical populations (Unsworth and Robison, 2016) but demonstrate an *additional* primary tendency to become non-alert during the SARTp. ACT intervention significantly influenced the frequency of these reports (H2e) in the form of reduced instances of non-alertness, whereas the waitlist group exhibited the opposite pattern. These results imply that ACT intervention reduced non-alertness / fatigue during the SARTp, supporting existing evidence that MBIs reduce probe-caught reports of off-task thought relative to controls (Giannandrea et al., 2019; Greenberg et al., 2019; Morrison et al., 2013; Rahl et al., 2017). As such, present findings position the novel ACT programme as a promising MBI capable of influencing cognitive content during sustained attentional performance.

To summarise, although the ACT programme did not influence objective indices of attentional engagement (e.g., RT and accuracy), it did exert limited changes in subjectively reported cognitive outcomes, which have been reliably associated with objective measures (Bastian & Sakur, 2013; Schooler at al., 2014; Smallwood & Schooler, 2006; Stawarczyk et al., 2014). This implies a differential degree of intervention potency depending on the attentional outcome being assessed, insofar as the utility of ACT to exert report-based attentional benefits did not extend to the domain of visual attention. As discussed, the techniques taught during ACT primarily focus on training attention internally, representing a form of sustained attention that may not be detectable through RT and accuracy-based assessment. However, obtaining self-disclosed thoughts of one's internal mental processes would appear to be a more receptive method of gauging attentional improvements, insofar as learning how to notice and observe sensations and thoughts presumably aided an ability to report internal attentional states throughout the SARTp, thus rendering the probe-caught method a more sensitive way of assessing sustained attention.

Thought Probes and bPD (H4b). As expected, tonic arousal was differentially related to specific thought processes throughout the SARTp, namely that external distraction was associated with larger bPD than present-oriented mind wandering. This implies that external distractibility was preceded by greater levels of tonic arousal than thoughts about one's actions in the present moment. These results are consistent with those discussed in relation to arousal and false alarms / distractibility and with the explicit predictions of the Yerkes-Dodson (1908) and AGT-predicted LC-NA curve (Aston-Jones and Cohen, 2005) (e.g., greater distractibility = greater tonic arousal).

Returning to the broader expectations of the present thesis, observed relationships between bPD-inferred tonic LC-NA activity and external distraction appear to support conceptualisations of distractibility as an elevated arousal state (Unsworth and Robison, 2016; Yerkes-Dodson, 1905). The fact that bPD was also elevated in response to task errors further supports the proposed decoupling of perception from task-related endeavour associated with off-task thought (Smallwood and Schooler 2014) and arousal (Gilzenrat et al., 2010). Moreover, dismantling the broader category of 'off-task thought' into smaller components (e.g., mind wandering, external distraction etc.) and uniquely relating these sub-categories to fluctuations in arousal may also provide an explanation as to why treating 'off-task' thought as one category has received mixed results in the literature (e.g., some studies demonstrate larger on-task bPD than off-task bPD (Unsworth and Robison, 2016;

Grandchamp et al., 2014; Mittner et al., 2014), whereas others demonstrate the opposite pattern (Franklin et al., 2013)).

The fact that ACT intervention influenced the frequency of non-alert reports throughout the SARTp but not attentional performance / arousal suggests that ACT may have been an effective intervention for more sensitive measures of attention, yet not potent enough to induce objectively assessed attentional improvements and / or increased LC-NA activity.

Limitations. As such, one of the central limitations of Study 4 concerns the strength of the employed intervention as a mindfulness training programme. The ACT utilised MS PowerPoint to facilitate didactic delivery of mindfulness techniques in a lecture format, with the expectation that participants would use the techniques taught in-session in their own time. Moreover, the intervention was delivered by practitioners with little to no experience of guided mindfulness practice, which, while not essential for didactic delivery, may have diminished some of the more subtle emphases on ways to more easily embody mindful practices. Such considerations are important to remedy, as most of the more established mindfulness-based interventions (e.g., MBCT, MBSR) involve in-session guidance to help orient meditation-naïve participants towards the practice and to explore any concerns / difficulties that may arise using post-practice inquiry before participants are required to practice at home. The absence of these protocols during the ACT may have hampered participant motivation / confidence to truly engage in home practice, which would naturally have deleterious implications for the potency of the intervention. By extension, reduced, or less effective, home practice would negatively influence the repeated nurturing of attentional stability through mindfulness-based techniques, which may have contributed to the limited attentional and arousal-based effects observed in Study 4. As such, the central limitations relating to the nature of the mindfulness-based intervention in Study 4 are explicitly addressed in Study 5, whereby an intervention containing *guided* practice more closely related to MBCT in terms of structure and content was administered.

Another methodological limitation may reside within one of its primary strengths. The pre-post design allowed for a robust analytic exploration of the neurocognitive changes resulting from ACT participation. However, practice effects were observed for both behavioural and psychophysiological outcomes, implying that administering an identical hour-long attention task battery with eye-tracking more than once may have reduced the impact of stimuli on participant responses, thus narrowing the scope of observable intervention-based change. I address this in my successive pilot study (Study 5) by examining similar attentional and psychophysiological outcomes at the post-intervention timepoint only.

Additionally, the original ANT employed in Study 4 was inherently problematic in terms of distinguishing between alerting and orienting networks and between endogenous / exogenous orienting process (Roca et al., 2011), which may have hampered an ability to detect specific alerting and orienting network differences between treatment conditions. Moreover, relying on a two-task paradigm to separately assess attention networks during the ANT, and vigilance outcomes during SARTp Go/NoGo performance, may be less effective than incorporating a Go/NoGo-type task *into* the ANT. Accordingly, these considerations were addressed in Study 5 by utilising a novel version of the ANT – the ANTI-V – which assesses alerting and orienting networks using different sensory modalities, distinguishes endogenous and exogenouis orienting with different visual cues and incorporated a vigilance component in the form of rare stimuli requiring NoGo responses (Roca et al., 2011).

Finally, although randomisation procedures and equivalence tests were utilised to ensure there were no significant differences in age and levels of self-reported mindfulness between ACT and WL groups, utilising a matched approach during the allocation process would have afforded greater confidence in baseline equivalence. Moreover, data around participants' previous experiences of meditation, yoga and other mindfulness-related practices was not collected, introducing the possibility that one group may have harboured more mindfulness experience than the other, thus limiting confidence in the conclusions drawn from the present study.

Conclusion. Overall, present findings do not support broader expectations of the current thesis that mindfulness training can be conceptualised as nurturing greater wakefulness / alertness and LC-NA arousal (Aston-Jones and Cohen, 2005; Britton et al., 2014; Tang et al., 2015). However, ACT-induced changes in subjectively assessed attentional states and obersved links between specific sub-species of off-task thought and distinct levels of tonic arousal offer limited contributions to the conceptual and neurocognitive literature on relationships between intervention, arousal, and cognitive content.

Study 5: Mindfulness-Based Cognitive Attention Training (MBCAT) Exerts Limited Influence on Vigilance and Arousal, with No Impact on Alerting, Orienting or Executive Function

Self-Report Outcomes. The utility of MBCAT at enhancing levels of self-reported mindfulness (H1a) was evident in the present study**,** with MBCAT participants exhibiting significantly larger pre-post change scores for the non-reactivity facet of the FFMQ relative to HEP control group participants. These findings are consistent with prior research evidencing increased Non-Reactivity as a result of eight-week MBCT / MBSR (Baer et al., 2019; Schanche et al., 2020), indicating that participants became less reactive as a result of participating in the MBCAT programme. The fact that Non-Reactivity was receptive to both MBCAT and more established MBCT / MBSR programmes highlights potential mechanistic similarities between the approaches, further validating my decision to create a shorter, more condensed version of MBCT for the benefit of students, who may not have adhered to an eight-month programme. The unusually low rate of attrition in the present study (10%) compared to MBCT (16.5%, Khoury et al., 2013) would appear to support this contention.

In relation to psychological wellbeing, MBCAT participation exerted improvements in general psychological health compared to active controls (H1b), consistent with prior observations that MBCT / MBSR participation improves general mental wellbeing (Solati et al., 2017). These results provide preliminary evidence that a novel four-week programme induces psychological effects comparable to those elicited by traditional eight-week interventions and more established four-week interventions (Demarzo et al., 2017). However, MBCAT exerted no impact on depression or anxiety scores, inconsistent with repeatedly observed effects of MBCT / MBSR on anxious and depression symptoms (Gahari et al., 2020; Kuyken et al., 2019). When developing the MBCAT programme, I deliberately emphasised inclusion of the attentional components of MBCT / MBSR frameworks and omitted much of the cognitive-behavioural exercises tailored to anxious and depressive responding (Segal et al., 2002). Although rendering the programme more suitable for testing my primary attentional hypotheses, this decision likely eliminated potential cognitive training mechanisms underlying previously observed beneficial effects of MBIs on anxiety and depression. In this respect, my research illuminates new research questions about the nature of MBIs in relation to wellbeing, insofar as teasing apart which cognitive elements of MBIs are most conducive to the alleviation anxiety and depression remains open to debate and offers clear opportunities for future research.

Behavioural / Performance Outcomes. There were distinct attention network effects utilising the ANTI-V - participants exhibited clear alerting, orienting and executive effects on RT and accuracy, consistent with those observed in the ACT study. Moreover, there was a clear interaction between alerting and orienting components, insofar as participants benefitted more from an auditory alerting signal in the absence of additional visual orienting information about the expected spatial attributes of the target. These findings justify the extension of my ACT study in utilising an extended version of the ANT (ANTI-V) to distinguish between alerting and orienting networks through distinct network-specific sensory modalities (Roca et al., 2011), thus increasing confidence that any effects of mindfulness training within these networks can be more directly linked to specific changes in alerting and orienting processes. Further grounds for utilising the ANTI-V in the present study were demonstrated by the fact that *d'* scores, which are derived from the vigilance component of the ANTI-V, were negatively related to no tone, no cue (NTNC) errors and alerting network scores (lower alerting scores emerged from improved NTNC performance in the present study and therefore represent enhanced tonic alerting). Moreover, NTNC errors were positively associated with false alarms and negatively related to hits, both of which represent ANT-V vigilance outcomes. The observed relationships between NTNC accuracy (representing enhanced endogenous / tonic alerting) and *d'* scores (representing increased signal sensitivity / vigilance) meaningfully connects the tonic component of the alerting network with the vigilance component of the ANTI-V, lending credence to conclusions that ANTI-V vigilance outcomes represent a reliable additional assessment of sustained tonic alertness (Roca et al., 2011). Resultantly, the ANTI-V in the present study provides a richer and more varied assessment of vigilance and alertness than the original ANT, subsequently allowing for a more sensitive exploration of the effects of mindfulness-based training on behavioural inferences of tonic attentional states.

However, MBCAT participation did not reduce NTNC error rates relative to the HEP group (H2a), suggesting that MBCAT participation exerted no beneficial effects on performance in relation to the tonic component of the alerting network (e.g., during trials where participants had to rely on their own internal alertness / vigilance). Indeed, much of the surveyed literature exploring the effects of MBIs on performance-based tests of attention contains relatively few studies demonstrating reliable effects of MBIs in relation to the ANT (Casedas et al., 2020; Gallant, 2016). The findings of Study 5 appear to corrorborate these null results, despite endeavour to include an independent measure of tonic and phasic alerting for a more sensitive way to detect MBI-induced effects on internally maintained tonic alerting outcomes (Roca et al., 2011). Considering the limited agreement within the literature about the utility of MBIs in enhancing alerting processes, demonstrating such sensitivity seemed important for the benefit of future MBI research.

MBCAT resulted in improved accuracy across all cue types relative to HEP (H2b), suggesting that the nature of the cues did not interact with MBCAT-augmented performance during the orienting component of the ANTI-V. These findings are inconsistent with previous research evidencing enhanced cue-specific orienting capabilities following MBI participation during the ANT (Yakobi, Smilek and Danckert, 2021), which is perhaps reflective of the methodological differences between the original ANT and the ANTI-V. For example, the spatial cue in prior ANT studies is typically 100% predictive of incoming target location, which confounds endogenous and exogenous elements of attention, whereas the ANTI-V spatial cues are 50% predictive, and therefore should only involve exogenous attention (Roca et al., 2011). Indeed, it’s been demonstrated that ANT and ANTI tap different aspects of attentional orienting in relation to accuracy (Ishigami & Klein, 2009; Roca et al., 2011), which may explain the difference between present and prior results, insofar as cues that are 100% predictive likely recruit endogenous and exogenous attentional resources, potentially increasing the likelihood of observing an MBI-related difference in accuracy between spatial and central cues. Future MBI research should explicitly test these predictions by comparing orienting network outcomes across ANT derivatives.

Turning to the executive attention portion of the experiment, there were no improvements in RT or accuracy performance to congruent / incongruent targets for the MBCAT condition relative to the HEP condition (H2c), contrary to research evidencing improved executive function following MBI participation in relation to response inhibition, Stroop interference effects and ANT executive network outcomes (Gallant, 2016; Lao et al., 2016; Verhoeven et al., 2014). In terms of attention network scores, there were no observed benefits of MBCAT participation in relation to network efficiency relative to HEP controls. (H2a/c). In relation to the vigilance component of the ANTI-V, MBCAT participation enhanced signal sensitivity (H2e), suggesting increased tonic vigilance throughout the task for the MBCAT group relative to the HEP group. To my knowledge, these findings are the first to evidence beneficial MBI effects on signal discriminability within the ANTI-V, providing support for existing literature demonstrating enhanced signal detection / discriminability as a result of mindfulness training in the domains of visual (MacClean et al., 2010) and somatic perception (Miram et al., 2013).

Contrary to expectations (H2f), dispositional mindfulness was not associated with any of the ANTI-V performance outcomes, contrasting with prior work demonstrating beneficial associations between Observing and alerting efficiency, and, curiously, detrimental associations between Awareness and orienting efficiency (Di Francesco, 2017). Moreover, there were no interactive effects of training condition and mindfulness on ANTI-V outcomes. These results imply that dispositional capacities to adopt mindful stances toward a variety of experiential stimuli in the present moment (Baer et al., 2004) did not translate into behavioural indices of alertness, orienting or executive function efficiency.

Taken together, present results may be explained by the fact that the ANTI-V, like many tasks of this nature, gauges attentional capacity through an assessment of motor responses. However, prior research has demonstrated that response modality interacts with performance outcomes (e.g., verbal responses have been shown to produce better outcomes than motor responses) (Lao et al., 2016). Given that the most frequently employed measures of cognitive performance in mindfulness-based research rely on motor responses to assess visual / sustained attention and executive control (ANT, CPT, SART and Stroop), it is not unreasonable to assume that such instruments may not harbour a sufficient sensitivity to detect the subtle attentional benefits of mindful dispositions / mindfulness-based training regimes. Future MBI research should actively pursue this line of reasoning by employing attention tasks of various response modalities to more finely examine the cognitive benefits associated with trait mindfulness. Moreover, the absence of associations between mindfulness and ANTI-V performance may have been because facets of the FFMQ, and mindfulness scales in general, may not capture the attentional aspects of mindfulness. Therefore, present null results contribute to a growing body of literature calling for a more thorough examination of the links between how mindfulness is conceptualised and how it is measured (Quickel et al., 2014).

Baseline Pupil Diameter (bPD). RT and accuracy during the vigilance and ANT components of the ANTI-V exhibited no relationship with baseline (pretrial) pupil diameter (bPD), implying that performance was not associated with distinct levels of tonic arousal in the present study. These results contrast with those of Study 4 evidencing differential bPD depending on the type of SARTp error, although this was assessed in a conceptually distinct attention task from the ANTI-V. No differences in bPD were observed between MBCAT and HEP participants (H3). These results (and those of Study 4 in relation to ANT bPD outcomes) are surprising, namely because bPD has been reliably associated with distinct performance outcomes during a variety of attention tasks (Gilzenrat et al., 2010; Murphy et al., 2011; Unsworth & Robison, 2016) and MBIs have been demonstrated to activate brain regions associated with tonic alerting and arousal (Tang et al., 2015), capacities which can be reliably gauged through pupillometry (Gilzenrat et al., 2010). However, these findings are congruent with prior research demonstrating that bPD is not always reliably associated with accuracy within the timeframe of one attention test, instead exhibiting state-level effects that fluctuate more gradually over time and reflect generalised states of arousal (Hoffing et al., 2020). Such an interpretation would imply that utilising a one-task study may not have been the most appropriate way to assess MBI-induced changes in tonic arousal. Nonetheless, as outlined in Study 3, bPD changes have been shown to fluctuate according to intra-task demands (Gilzenrat et al., 2010; Unsworth and Robison, 2018; van den Brink, 2016), nurturing reasonable conclusions that bPD can be considered a reliable proxy of attentional and psychophysiological fluctuation during a single task, and by extension, potentially receptive to MBI participation. Therefore, the fact that MBI-related changes in tonic arousal were not observed in Study 5 may reflect the discussed limitations around the potency of the intervention (e.g., length and duration, See Study 4 discussion) rather than any inherent issues in measuring bPD during a single task**.**

Overall, present findings suggest that my efforts to develop MBCAT as a direct improvement to the ACT intervention (e.g., by enhancing in-session discourse / guidance and increasing motivation / accessibility to engage in home mindfulness practice) did not result in a training programme that was sufficiently potent enough to induce observable changes in tonic arousal states. Future studies might extend the duration of the MBCAT to six or even eight weeks in order to explore whether enhancing temporal potency of the programme exerts stronger effects on bPD.

TEPR Network Outcomes. In terms of task-evoked pupillary responses (TEPR), evaluating TEPR as a function of the ANTI-V alerting network (H4a) revealed an augmented phasic response to alerting stimuli with a remarkably similar temporal and magnitudinal trajectory as those observed in my ACT study and in previous research (Geva et al., 2013), representing the first demonstration of TEPR trajectories in response to *auditory* alerting stimuli within the ANTI-V, thus evidencing the detection of physiological alerting responses within a more independent assessment of the alerting network (Roca et al., 2011). Evidencing similarities in behavioural and psychophysiological responding across sensory modalities is important, as reconciling outcomes emerging from disparate methods in attentional and neurocognitive research offers robustness to overarching accounts of the human attention system (Posner 2008).

Exploring alerting TEPR as a function of training condition (H4b) revealed no differences in TEPR responses to alerting trials between MBCAT and HEP groups, suggesting that MBCAT participation did not augment a pupillary response in *anticipation* of incoming stimuli, thus implying no presence of a potential psychophysiological mechanism underlying an increased readiness to respond accurately to targets (Posner, 2008; Roca et al., 2011). Through the lens of AGT, and in the context of previous insights from pupillometry (Aston-Jones and Cohen, 2005; Geva et al., 2013), it would appear that MBCAT participation did not enhance a form of preparatory tonic alertness / arousal for an increased exploratory readiness to detect incoming signals, thus not supporting contentions that there could be a physiological explanatory variable for the beneficial effects of mindfulness training on attentional outcomes observed in previous research (Yakobi, Smilek and Dankart., 2020). As such, these results do not support central predictions proposed within the current thesis, namely that mindfulness would be associated with improved performance during trials / tasks requiring ongoing endogenous vigilance and that this would be accompanied by enhanced levels of pupillary-inferred LC-NA arousal.

More generally, it is important to note that larger alerting 'scores' (no tone minus tone RT / errors) and greater TEPR differences (tone minus no tone TEPR) represent an enhanced ability to utilise a warning signal for improved responding, which was indeed the case for the whole sample. However, MBCAT results evidence that smaller difference scores, both in terms of errors and TEPR, don’t necessarily reflect diminished alerting, as it’s possible to exhibit augmented preparedness in the absence of such signals, which in turn reduces the difference scores between alerting conditions. This is important because larger alerting scores have been summarised in the literature as representing improved alerting efficiency, yet studies often do not provide information about the specific tonic and phasic components contributing to these scores. For example, an individual exhibiting a high alerting score may indeed harbour improved abilities for utilising phasic alerting signals to augment target responses. However, they may also be particularly poor at maintaining tonic alertness to respond to targets in the absence of phasic signals, which would also contribute to a higher network score. Similarly, an individual with a low alerting network score may actually exhibit improved abilities to utilise phasic alerting signals, but if they also exhibit improved capacities for tonic alertness, this would result in a low network score and an erroneous conclusion of reduced alerting efficiency. In other words, in both of these cases, the tonic and phasic interaction would not be picked up by assessing the network score alone. In the context of MBI research, exploring the benefits of mindfulness training on both tonic *and* phasic components of alerting is crucial, necessitating a thorough assessment of the drivers behind network scores before drawing conclusions about the benefits of MBIs on alerting processes.

Orienting. In relation to the orienting network, specific cues did not induce differences in TEPR (H5a). Contrasting these findings with the fact that spatially valid / informative cues initiated greater *whole-trial* arousal than neutral / central cues in the original ANT (as was observed in Study 4 and in Geva et al., 2013) indicates that orienting cue type was not a sufficient factor in terms of influencing arousal during the ANTI-V. As discussed previously, during the original ANT, spatially informative cues are 100% predictive of target location, therefore recruiting endogenous (certainty that all non-central cues will locate the target) and exogenous (selective attention) orienting resources to respond to targets, resulting in larger TEPR for spatially informative cues. In Study 5, only exogenous resources were recruited due to the inherent uncertainty of spatial cue location (e.g., only 50% of spatial cues were valid). The absence of an enhanced pattern of arousal for spatial cues in the present study may therefore reflect the fact that isolating exogenous orienting responses serves to diminish the potency of orienting cue effects on arousal relative to cues that do not differentiate between between the recruitment of endogenous and exogenous resources (Geva et al., 2013). These results harbour important implications about the nature of ANT-based assessments of the orienting network, namely by highlighting the granularity required when attempting to make accurate conclusions arising from specific ANT methodologies.

MBCAT participation augmented TEPR across cue types (H5b), bearing marked similarities to observed performance, insofar as the MBCAT group exhibited enhanced accuracy across cue conditions relative to the HEP group. However, although mindfulness training enhanced accuracy and TEPR overall, the lack of sensitivity of these outcomes to orienting cues as a function of MBCAT participation implies that the intervention did not specifically improve efficiency of the orienting network, which contrasts with prior findings from studies using the original ANT (Yakobi, Smilek & Danckert (2021). These results may be explained by the mentioned differences in methodology regarding the predictive utility of the cues, insofar as they relate to only exogenous orienting processes. Cue-specific TEPR patterns may have indeed been observed had spatial cues been confounded with the recruitment of endogenous attentional resources (Ishigami & Klein, 2009; Roca et al., 2011).

Executive Function. Evaluating TEPR as a function of the ANTI-V executive network (H6a) revealed an augmented phasic response to incongruent targets, displaying similar trajectory characteristics as those observed in my ACT study and in previous research (Geva et al., 2013). Interestingly, exploring executive TEPR as a function of training condition (H6b) revealed that post-response executive network effects were only evident for the HEP group, whereas the MBCAT group exhibited remarkably similar pupillary trajectories for both congruent and incongruent targets. Directly addressing recommendations arising from Study 4 in relation to the observed descriptive patterns implying such effects, these results suggest that the HEP group exhibited increased recruitment of mental resources to monitor performance in response to incongruent / inconsistent information relative to congruent information, whereas the MBCAT group allocated similar amounts of resources / cognitive effort across target types. Considering that MBCAT participants were more accurate than HEP participants in their responses to incongruent targets, these results suggest that the HEP group allocated more physiological resources to post-response executive monitoring because they presumably found it harder to suppress the influence of incongruent distractors, as reflected by increased error rates. The fact that MBCAT exhibited the same magnitude of Pe and similar rates of accuracy across target types suggests that incongruent flankers were no more demanding of attentional resources to filter out distracting information than congruent flankers for MBCAT participants.

At first glance, these results would appear to contradict prior research demonstrating enhanced activity in brain regions responsible for monitoring and resolving conflict and increased EEG activity in response to incongruent / rare targets as a result of mindfulness training (Allen et al., 2012; Fox et al., 2016; Gotnik et al., 2016; Holzel et al., 2011; Lutz et al., 2008; Norris et al., 2018; Schoenberg et al., 2014; Tang et al., 2015). However, considering that the MBCAT group exhibited significantly larger *overall* post-response TEPR relative to the HEP group, present findings simultaneously support literature illustrating enhanced physiological activity in response to targets as a result of increased awareness of stimuli, whilst remaining consistent with conceptualisations of mindfulness practice as nurturing an ‘effortless’, receptive acceptance toward *all* experiential and environmental information, regardless of congruency (Slutsky et al., 2017; Teper and Inzlicht, 2013). That is, the active monitoring of incongruent stimuli is likely to become increasingly less effortful as MBIs progress (Lutz et al., 2008; Segal et al., 2008; Wolkin, 2015), which is supported by the fact that long-term meditators, who are presumably less effortful due to the length of their experience, have been shown to exhibit *less* brain activation than non-meditators whilst maintaining optimal performance (Kozasa et al., 2017). These conclusions are consistent with the structure and content of MBCAT, namely that the employed FA and OM techniques explicitly nurtured the ability to train attentional focus and become aware of internal and external events and to accept them without reacting to them, which may have augmented effortless attentional control in the face of incongruent ANTI-V target distractors, thus requiring less post-response resource allocation. Indeed, participants without such training did not exhibit an overall increase in arousal but did display *relative* increases in arousal in order to manage the cognitive load of incongruent information and performance monitoring.

Limitations. The main limitations of the present study encompass several methodological issues, the most prominent of which being the absence of pre-intervention cognitive and pupillary data collection. Due to observations arising from Study 4 (ACT) that practice effects may have confounded the ability to detect ACT-induced attentional / psychophysiological changes during the ANT, the ANTI-V was not administered pre-intervention in the present study, especially given that this was intended as a pilot study to test feasibility of MBCAT delivery in relation to addressing structural and content-based issues prior to a wider rollout of the programme. Following necessary refinements of study protocol based on practitioner and participant feedback, such a rollout would have occurred in waves throughout 2020, all of which utilising pre-post assessments of attentional and psychophysiological outcomes. Naturally these were stalled due to the pandemic. As such, although randomisation was utilised effectively in the presented study, it cannot be discounted that those in the MBCAT group were naturally more attentive and harboured enhanced capacities for tonic alertness / executive control from the outset than HEP group participants. The particularly small sample size of the study compounds this issue. Therefore, in absence of crucial planned follow-ups, the presented experiment suffers from profound limitations pertaining to the fact that observed patterns of attentional and pupillary-based findings may simply be due to individual differences in attentional capacities within the sample, and nothing to do with the type of intervention administered. Pending continuation of MBCAT protocol aims to address these issues through planned pre-post delivery.

The present research comprises the first study to directly compare a novel MBI with an active HEP control condition in relation to attentional and pupillary outcomes. As such, it addresses recommendations from existing systematic reviews that the utilisation of active control conditions are crucial for furthering MBI research and for reliable conclusions to be made about exclusively mindfulness-based attentional and psychophysiological effects (Casedas, 2020; Lao et al., 2016). However, although efforts were made to utilise one of the most robust active control groups currently available for MBI research (Lutz et al., 2011), which was matched with the MBCAT as closely as possible in terms of length, duration of sessions and home practice commitment, there remains the possibility that the effects of MBCAT were not exclusively due to mindfulness practice. For example, the practitioner's motivation and experience of guiding MBCT-based practice relative to their lack of experience delivering HEP-based programmes may have resulted in participants simply becoming more engaged with the MBCAT programme than the HEP programme, subsequently aiding motivation during the attention tasks. Moreover, the fact that HEP was reduced in length to match MBCAT potentially eliminated some important components contributing its effectiveness as an active control condition. Compounding this issue, although randomisation procedures and equivalence tests were utilised to ensure there were no significant differences in age and levels of self-reported mindfulness / psychological distress between ACT and WL groups, matching participants in terms of these factors at the point of allocation would have enhanced robustness of baseline equivalence procedures. Moreover, previous experience of meditation or other mindfulness-related practices was not collected, introducing the possibility that one group may have harboured more mindfulness experience than the other, thus limiting confidence in the conclusions drawn from the present study. Future replications should explicitly account for these factors through matching processes to ensure that intervention groups are equal in terms of mindfulness experience and mental wellbeing, thus nurturing confidence that any self-reported increases in psychological or attentional outcomes are a result of mindfulness intervention.

Conclusion. Taken together, the behavioural and psychophysiological findings of Study 5 provide limited support to key attentional and arousal-based expectations, namely that mindfulness training, provided it is sufficiently delivered according to FA and OM-related principles of established interventions, enhances limited tonic and executive components of attention and arousal during a novel expansion of a classic test of attention. These findings are consistent with – and serve to extend – crucial insights from the currently available literature and provide limited support for some of the central hypotheses driving the overall present body of research. Moreover, the results of Study 5 introduce a novel, accessible and conveniently structured MBI into the current landscape that has been demonstrated at the pilot level to enhance general mental health and increase specific indices of mindfulness.

Future Directions. One of the pertinent recommendations emerging from Chapter 5 is that the chosen MBIs may have lacked the potency to initiate substantial attentional and psychophysiological change, thus raising questions about the optimal ‘dosage’ of mindfulness that is necessary to observe such effects. One way to address this question is to examine the broader time course of pertinent neurocognitive change through an examination of different temporal magnitudes of mindfulness-based engagement, including historical experience and current levels of practice. A practical way to do this would be to explore some of the attentional and psychophysiological outcomes discussed in Chapter 5 among cohorts of experienced and consistent meditators. Accordingly, in Chapter 6 I implemented a study utilising meditators and non-meditators and assessed their levels of meditative experience / practice to predict these outcomes.

Study 6: No Evidence that Long-Term / Consistent Vipassana Meditation Enhances Attentional Performance or Improves Task Focus

Mindfulness (H1a/b). As expected, experienced and frequent meditators exhibited higher mindfulness than non-meditators, specifically for MAAS, Observing, Non-Judging, Non-Reactivity and Total FFMQ scores. These findings are consistent with prior observations that MAAS, Non-Judging and Non-Reactivity are receptive to longer-term meditation engagement among experienced meditators (Baer et al., 2008; Josefsson et al., 2011; Soler et al., 2014; Vinchurkar et al., 2014). Present findings bolster these conclusions by demonstrating that Observing and Total FFMQ scores are also receptive to experienced and frequent meditation practice. However, no differences between groups were observed for Describe scores, an unsurprising result considering that the ability to describe thoughts and feelings is not explicitly cultivated during Vipassana / mindfulness meditation practice, which instead focuses on noticing and attending to experiences as they arise in the field of awareness (Britton et al., 2014; Josefsson et al., 2011).

Meditation and ANT Performance (H2a/b). Turning to the ANT outcomes, participants exhibited clear alerting, orienting and executive network effects on RT, validating the online ANT as a method to differentiate between the three attention networks. However, contrary to predictions (H2a), there were no significant differences between meditator groups on any of the network-specific RT or accuracy outcomes. Moreover, length of meditation experience and duration of frequent practice were not associated with alerting, orienting or executive network scores (H2b). These results contrast with prior findings demonstrating that experienced meditators exhibit enhanced overall accuracy during the ANT relative to non-meditators (Jo et al., 2016), which may be explained by the fact that participants in the latter study harboured greater average meditation experience than those in the presented research (13 years vs. 7 years, respectively). It is possible that increased meditation experience in that study was more strongly augmentative of specific components of mindfulness known to be associated with improved ANT responding (Sorensen et al., 2018). However, due to self-reported mindfulness not having been measured in Jo et al.'s study, such inferences represent candidates for future research, namely by directly comparing strengths of association between different magnitudes of meditation experience and specific mindfulness outcomes.

In summary, an augmentative effect of meditation experience was observed in relation to attentive awareness, non-judging and non-reactivity (e.g., increased MAAS and FFMQ facets) but no effects of meditation were observed in terms of ANT performance.

Meditation and CPT Performance (H3a/b). Contrary to predictions, there were no differences between meditators and non-meditators on any indices of CPT performance (RT-inferred attentional lapses, false alarms, errors of omission), suggesting that meditation experience and frequency had no impact on sustained attention / inhibitory control during the CPT. These results contrast with prior work demonstrating that experienced meditators exhibit reduced errors of commission (false alarms) during a Go/NoGo task (Andreu et al., 2019) and improved overall accuracy during the SART (Badart et al., 2018) relative to non-meditators. However, findings are congruent with extant research reporting no beneficial effects of meditation experience / frequency on overall CPT accuracy (Lykins et al., 2012) or on false alarms and errors of omission (misses) during the SART (Josefsson and Broberg, 2011). In terms of the school of meditation (Vedic / Vipassana / mindfulness), length of meditation experience (~6.5 years), frequency / duration of practice (~5 sessions per week, ~30-mins per session) and the tasks utilised to assess sustained attention / inhibitory control (SART, CPT, Go/NoGo), both sets of studies were similarly variable, rendering the identification of methodological differences that may account for the contrasting results difficult. There were also strong sample-based and task-related similarities between both sets of studies and the present research, potentially reducing the likelihood that observed empirical contrasts can be attributed to the experience of the meditative sample or the sensitivity of the chosen assessment technique, although such assertions are, of course, constrained by the relative paucity of research in the domain.

Additional explanations for the discrepancies in the reviewed literature may reside among variables that were not controlled for in the present study, or indeed in prior endeavour. For example, some meditators may have engaged in their meditation practice prior to task completion, whereas others may have meditated after the tasks, or not meditated at all that day. The importance of standardising this process for all participating meditators is heightened by the fact that certain attentional abilities have been shown to temporarily increase after meditation (Rani and Rao, 2000), a fact further exemplified by the emergence of specific attentional benefits as a result of brief mindfulness meditation inductions (Mrazek, Smallwood & Schooler, 2012; Norris et al., 2018). As such, it remains possible that studies demonstrating beneficial attentional effects among experienced / frequent meditators consisted of a higher proportion of same-day, pre-task meditators than studies reporting null effects. Future research should address this confound by asking all meditators to practice one hour prior to the tasks, or by including instructions asking participants to enter a mindful state / adopt a mindful approach to the attention tasks (Valentine and Sweet, 1999; Lykins et al., 2012). Additionally, building upon the present experiment by examining the impact of brief mindfulness inductions on identical attentional outcomes would provide insights into the importance of same day / pre-task meditative activity for attentional augmentation. Indeed, the final study of my thesis addresses this recommendation through the utilisation of a brief mindfulness induction based on my MBCAT programme.

Meditation and Thought Probes (H4a/b). The present study obtained evidence that participants spent much of their time focused on the task relative to other species of thought, consistent with prior findings utilising similar probes during a comparable test of sustained attention (Unsworth and Robison, 2016). As such, the presented research is the first to validate the use of this experience sampling technique within the CPT to assess cognitive content. Moreover, the deployment of an *online* version of this amended CPT for such purposes was justified.

However, contrary to predictions (H4a), experienced and frequent meditators did not report more on-task thoughts or less off-task thoughts than non-meditators, suggesting that historical and current magnitudes of meditative practice did not enhance task focus or reduced distractibility. Similarly (H5b), length of meditation experience and duration of meditation practice were not associated with increased on-task thoughts or reduced task-related interference.

Limitations. Although the decision was made to recruit only experienced Vipassana /

mindfulness meditators, no detailed information about what meditators did during their meditation practice was obtained. For example, meditators were not asked whether they used recorded guidance or which techniques were utilised in the face of mind wandering or difficult internal states. A consideration of these variables would have enhanced the ability to examine the effects of different meditative strategies and may have helped distinguish between FA and OM-specific attentional outcomes. However, the decision to recruit meditators from one of the most recognised mediation centres in the UK potentially minimised variability in certain aspects of practice, thus addressing calls to this effect emerging from comparable research (Lykins et al., 2012).

The online nature of the study naturally introduces a myriad of potential confounds, including the inherent variability in the level of environmental distraction, computer processing speed, visual display differences, internet connectivity issues and time of day completed, to the point any pertinent differences in these domains may have contributed to the mixed results of the present study. However, at least in relation to the deployed attention tasks, online tests of continuous performance have been demonstrated as valid and reliable ways to replicate laboratory-based outcomes in naturalistic settings (Raz et al., 2014), thus conferring confidence in the utility of the online ANT and CPT for measuring sustained and executive attention. Indeed, the fact that attention network effects and expected performance norms / probe frequencies were observed during these well documented and widely used measures of attention suggests that the online tasks were appropriate for the detection of any meditation-induced attentional effects.

The meditation cohort was older than the non-meditating cohort. Despite controlling for age in all analyses (Josefsson and Broberg, 2011), future research might seek to match meditators and non-meditators in relation to age, education level, socio-economic status and a variety of additional demographic variables as closely as possible at the recruitment stage.

Indeed, utilising a matched approach during the recruitment process and collecting additional data around lifestyle factors, such as alcohol consumption, smoking, sleep hygiene, diet, yoga practices and exercise would have afforded greater confidence in current assessments of the impact of meditation on attentional outcomes, as participants' lifestyle confounds would have been accounted for. Without these practices, confidence in the conclusions drawn from the present study is limited. Moreover, the association between age and meditation experience in present analyses emphasises the importance of controlling for demographic variables in future investigations utilising meditator and non-meditator cohorts.

It should be noted that participation in psychotherapy or specific psychological interventions (e.g., CBT), avenues that are effective in diminishing depressive and anxious symptoms (Andersson et al., 2012; Newman et al., 2008; Pybis et al., 2017), were also not controlled for in analyses. Consequently, the possibility remains that personal therapeutic development independent of meditation engagement could have impacted outcomes, specifically those pertaining to wellbeing. Future research might explicitly control for participation in regular psycho-therapeutic discourse or indeed any form of 1:1 practitioner-based inquiry.

The nature of the design impacts causal inferences that can be drawn from the mediation models. An alternative interpretation of the data could be that increased depressive and anxious symptoms or less attentive dispositions negatively impact the motivation to meditate for longer periods and substantially diminish the ability to be mindful. Individuals with longer meditation experience / consistent daily practice may therefore represent a subset of the population who are innately patient, mindful and attentive enough to initiate consistent meditation practice without experiencing adverse effects earlier on in their meditative journey. Indeed, the relationship between quantity of meditation and psychological wellbeing may represent an inverted non-monotonic U-shaped trend, insofar as "too much" meditation can also result in null or negative psychological effects (Britton, 2019). As such, perhaps the present study did not examine the benefits of greater meditation activity, but rather the benefits of being the kind of person who can engage in longer meditation without experiencing null or adverse mental health consequences associated with extensive practice. These are important considerations to bear in mind when conducting and evaluating future investigations into the effects of meditation on attention and wellbeing.

Finally, the nature of the recruitment methods utilised in the current experiment made it inescapably clear that the study was about the effects of meditation on various outcomes. As such, participants may have been primed to embody a mindful perspective throughout the task, which may have confounded the limited effects pointing to the impact of meditation *experience* on present outcomes.

Conclusion. A central goal of the present research was to explore behavioural indices of vigilance and executive control as a function of different magnitudes of meditative engagement. Overall, present findings pertaining to the effects of meditation on mindfulness and cognitive content supported expectations that experienced and frequent meditators would exhibit enhanced mindful responding. However, the limited findings in relation to objectively assessed attentional outcomes warrant additional efforts to examine the utility of widely used and adapted visual tests of sustained / executive attention at detecting meditation-induced change. Moreover, exploring differences between meditation experience and meditation frequency / duration in relation to attentional outcomes prompts more granular inquiry into the temporally specific effects of meditative practice. Addressing pertinent recommendations, namely that *proximal* meditative practice relative to task completion may represent a salient factor contributing to the mixed attentional effects in the meditation literature, my final study employs a brief MBCAT induction to examine whether immediately-predecessive mindfulness practice exerts influence over identical attentional outcomes.

Study 7: Brief Online Mindfulness Meditation (MBCAT) Exerts No Influence on Coronavirus Anxiety, Vaccine Hesitancy, Sustained Attention or Executive Control

My first prediction (H1a) that MBCAT induction would reduce coronavirus-related distress and vaccine hesitancy relative to educational controls was not supported, suggesting that my brief MM did not influence levels of COVID-specific anxiety or vaccine apprehension. Moreover, I observed no associations between dispositional mindfulness and COVID-specific anxiety or vaccine hesitancy (H1b). These findings are inconsistent with extant research evidencing ameliorative effects of brief MMs on symptoms of depression, anxiety and stress (Howarth et al., 2019) and inverse associations between dispositional mindfulness and COVID-specific worry and negative affect (Dillard & Meier, 2021). Considering that the present study utilised comparable single-session audio recordings and mindfulness instructions as those employed in similar prior research, one possible explanation for the discrepancy in results could be a combination of the coronavirus-specificity of presently used measures and the timing of administration. My sample displayed a minimal degree of anxiety response to the viral pandemic, and minimal apprehension towards the vaccination programme, below agreed thresholds of a ‘mild’ anxiety reaction (Chung et al., 2021) or negligible vaccine hesitancy (Freeman et al., 2020). This could be because the vaccine rollout was well underway when the study was conducted, rendering the fear of contracting / passing on the virus significantly less pronounced than at most other points during the pandemic. Moreover, the low hesitancy findings may be attributed to the fact that the vaccine rollout had been progressing for several months at the point of experimental administration, whereby vaccine knowledge may have increased and initial concerns about efficacy and risk may have subsided. Additionally, many of the respondents had achieved at least an undergraduate level of education, which has been demonstrated to significantly contribute to the likelihood of receiving the COVID-19 vaccination (Center for Economic and Social Research, 2021). As such, my ability to detect differences between induction groups on COVID-specific anxiety and vaccine hesitancy outcomes, and to observe dispositional mindfulness associations with these measures, were confined to the narrow minimal spread of overall scores. Future studies should explore the impact of brief MMs on more temporally relevant COVID-related issues, such as specific anxieties around societal reintegration (e.g., returning to communal working environments, visiting restaurants, going to gigs, etc.) and fears around chronic effects of contracting coronavirus (e.g., long-COVID), which unlike acute illnesses, hospitalisations and deaths, the current vaccine efficacy data does not provide assurance about.

Contrary to expectations (H2a), I observed no significant differences between MBCAT and control group participants in relation to overall ANT RTs and accuracy, or in terms of aggregate ANT network RT / network accuracy scores. That is, MBCAT and control groups exhibited similar attentional capacities in relation to alerting, orienting and executive function scores during the online ANT when assessed in combination. These results are not consistent with prior research demonstrating enhanced efficiency of the ANT executive network (Norris et al., 2018) and reduced interference effects in a Stroop task (Wenk-Sormaz, 2005) but do align with research finding no differences between a 14-minute MM and an educational control condition in relation to executive scores (Larson et al., 2013).

Present results harbour interesting implications for the promotion and uptake of brief mindfulness techniques among meditation-naive individuals for the purpose of improving psychological wellbeing and attention. For example, several studies have evidenced associations between diminished executive function, namely in relation to inhibition control and cognitive flexibility, and increased levels of depression (Brooks et al., 2010; Wagner et al., 2014; Warren et al., 2021), anxiety (Ajilchi & Nejati, 2017; Ursache & Raver, 2014;

Warren et al., 2021) and poorer health outcomes in the presence of stress (Shields, Moons & Slavich, 2017). Such findings have invited conclusions that poorer executive function is likely a contributory factor to the maintenance of affective disorders and stress-related health problems, and that efforts to improve capacities for executive attention may also improve depressive, anxious and stress-related health concerns (Shields, Moons & Slavich, 2017; Warren et al., 2021). I found no effects of MM on wellbeing or executive network scores, thus raising important questions about the identification and promotion of brief mindfulness meditation as a potentially effective way to ameliorate psychological distress through enhanced executive control (Teper and Inzlicht, 2013).

Consistent with present results, brief MMs have been shown to be ineffective at inducing improvements in response inhibition during a flanker task (Larson et al., 2013) or in cognitive flexibility during an attentional switch task (Jankowski & Holas, 2020) during studies employing comparable induction and control methodologies. However, research in this respect is in its infancy, and future studies should continue to utilise brief MM paradigms incorporating flanker, Stroop, attention-switching and ANT outcomes in order to expand present knowledge around the specific conditions and sub-categories of executive control that may be sensitive to brief MM inductions.

There were no associations between dispositional mindfulness and executive network scores during the ANT (H2b) and no moderative effects of trait mindfulness on the effect of MBCAT induction on executive function (H2c), contrasting with prior research demonstrating interactions between brief MMs and dispositional mindfulness on Stroop interference (Watier & Dubois, 2016). However, specific components of trait mindfulness did moderate effects of MBCAT on alerting network RT scores, insofar as greater capacities for Observing and Non-Reactivity were associated with improved alerting network efficiency for

MBCAT participants relative to control group participants. Driving these interactions appeared to be two distinct processes: Firstly, Observing was associated with slower double cue RT and no cue RT for the whole sample, yet exhibited no relationship with alerting network RT scores (no cue RT - double cue RT). This suggests that, overall, the capacity to observe internal and external events during the ANT resulted in slower RT both in response to, and in the absence of, alerting stimuli. Interestingly, the relationship between Observing and double cue RT persisted among the MBCAT group, but not the control group, whereas the association between Observing and no cue RT was not evident in the MBCAT group. As such, the difference in RT between alerting and non-alerting cue types for high-Observing individuals was smaller for the MBCAT group versus the control group, suggesting that MBCAT induction ameliorated no cue RT for those higher in dispositional Observing, thus enhancing the efficiency of the alerting network for high-Observing individuals.

Secondly, Non-Reactivity was unrelated to double cue RT, no cue RT, and alerting network scores for the MBCAT group and for the whole sample. However, within the control group, Non-Reactivity was associated with slower no cue RT, suggesting that the capacity to remain non-reactive to internal and external events manifested in slower RT in the absence of any alerting stimuli for control group participants. Considering that slower RT to no cue trials, but not to double cue trials, increases alerting network scores (e.g., diminishes alerting efficiency), as was the case in the control group, it would appear that MBCAT induction ameliorated a potential performance deficit for those higher in Non-Reactivity who may have exhibited slower RT to no cue trials had MBCAT induction not been administered, thus enhancing the efficiency of the alerting network. These results are consistent with prior observations that trait mindfulness can moderate the effects of brief MM induction on specific attentional outcomes (Watier & Dubois, 2016), and suggest that brief MM enhanced alerting network efficiency for those harbouring higher dispositional levels of observing and non-reactivity.

I detected no differences between MBCAT and control conditions in relation to RT-inferred attentional lapses, false alarms or omission errors during the CPT (H3a), suggesting that MBCAT induction did not reduce the likelihood of performance-based interruptions to sustained attention. These findings are inconsistent with prior work evidencing reduced false alarms, omission errors and RTCV as a result of 8 minutes of mindful breathing (Mrazek, Smallwood & Schooler, 2012), but are congruent with more recent studies demonstrating no such effects (Asli et al., 2021; Banks et al., 2019; Johnson et al., 2015; Somaraju et al., 2021). As such, brief MMs may be of insufficient potency to alter sustained attention performance, even during less demanding and more sensitive sustained attention tasks like the SART and CPT (Johnson et al., 2015). Indeed, multi-session MMs and more extensive MIs have been demonstrated to influence these outcomes (Jha et al., 2007; Tang et al., 2007), consistent with an emphasis among Buddhist traditions and models of mindfulness that the benefits of meditative training on attentional stability rely on a more consistent and longer duration of practice over many weeks, months and years (Lutz et al., 2008; Rapgay & Bystrisky, 2009).

Additionally, it was hoped that by building on existing studies (Banks et al., 2019 & Somaraju et al., 2021) through the utilisation of a richer experience-sampling method that I would enhance the sensitivity of specific off-task thought reports to the effects of brief MM induction. However, my MM had no effect on tendencies to engage in different sub-species of off-task thought (H4a), contrary to prior studies demonstrating effects of longer MBIs on task-related and task-unrelated thought processes (Jha et al., 2016; Morrison et al., 2014). This raises the question of whether the “dose” of my single-session MM was enough to influence probe-caught instances of mind wandering, especially within the current paradigm whereby the CPT was separated from the induction by two questionnaires and the 25-minute ANT. Indeed, brief MMs have been demonstrated to influence objective assessments of mind wandering during comparable attention tasks, but only when these tasks immediately follow MM induction (Mrazek, Smallwood & Schooler, 2012). Therefore, any impact of my MM on subjective and objective indices of mind wandering during the CPT may have been because the "dose" of the induction was not sufficient for a two-task study. This contention would appear to be supported by the fact that the MM marginally influenced executive network scores and exhibited interactive effects with trait mindfulness on alerting network scores during the immediately successive ANT.

Finally, consistent with expectations (H4b), greater levels of trait mindfulness were associated with reduced instances of mind wandering, but exerted no impact on any other subtype of off-task thought or aggregated off-task thought reports. These results echo those of extant research (Mrazek, Smallwood & Schooler, 2012) and support the contention that mindfulness and mind wandering can reasonably by viewed as qualitatively different expressions of similar capacities. Importantly, these findings justify my decision to employ a more sensitive measure of off-task thought (Unsworth & Robison, 2016), insofar as the effects of my MM essentially differentiated between non-alertness, external distraction, task-related interference, and mind wandering in terms of their sensitivity to induction. Evidently, such segregation was necessary in order to observe aforementioned associations, thus providing a plausible explanation as to why prior studies may have failed to demonstrate effects on off-task thoughts when treated as a singular variable (Banks et al., 2019; Somaraju et al., 2021). Enhancing the sensitivity of experience-sampling methods would therefore appear to offer a potentially fruitful opportunity for further examinations of the effects of brief MMs on on-task and off-task thought processes. Contrary to predictions (**H4c**), there were no interactive effects of trait mindfulness and brief MM on on-task or off-task thought processes during the CPT.

Limitations. The results of the present study are confined to several limitations related to its execution. Firstly, at the recruitment stage, I excluded participants with prior mindfulness / meditative experience to eliminate this confound from primary analyses. However, as is the case with trait mindfulness, previous meditation experience represents an interesting moderator in terms of revealing which individuals are most likely to benefit from a brief mindfulness induction in relation to cognitive processes (Heppner & Shirk, 2018). For example, meditation-naive audiences may have difficulty settling into a brief practice, at least from the outset, whereas those who've meditated before will be well-versed in following guidance and initiating meditative states more quickly, thus enhancing the potential effects of induction. As such, future MM studies should recruit meditation-naive individuals and participants with varying levels of meditation experience for the assessment of independent and interactive effects of trait mindfulness, meditation experience and brief MM induction on attentional outcomes.

Secondly, although the MM induction utilised in the current study was drawn directly from my MBCAT programme, and harboured largely the same temporal, structural and instructional characteristics as comparable prior research, it is possible that a longer MM induction or multi-session intervention may have resulted in significant effects and larger effect sizes on my outcomes of interest. Indeed, I previously demonstrated behavioural and psychophysiological effects of the 4-week MBCAT intervention on executive network efficiency, which resulted in large effect sizes for the small pilot sample. The fact that participants listened to a series of brief MMs as a daily commitment to home tasks, and were guided through each MM in person, likely enhanced the effect of the programme on ANT outcomes, implying that the present online MBCAT MM was of insufficient potency to initiate similar independent changes to the alerting and orienting networks or to subsequent sustained attention outcomes.

Thirdly, and consistent with prior research (Johnson et al., 2015; Larson et al., 2013; Norris et al., 2018), I utilised a non-arousing educational extract instead of an explicit, instructional mind wandering control, as it is a more ecologically valid way of comparing mindfulness training / inductions with scenarios whereby general levels of attention are required but natural tendencies to mind wander will occur. However, the lack of explicit instructions to allow the mind to wander may have been required in order to detect more salient attentional differences between inductions of mindfulness and mind wandering (Wenk-Sormaz, 2005). Nonetheless, some have criticised the use of mind wandering instruction as a true control condition, as it represents an active induction-like experience rather than a neutral attentional control condition (Heppner & Shirk, 2018). Moreover, unlike some studies (Banks et al., 2019; Johnson et al., 2015; Mrazek, Smallwood & Schooler, 2012), I did not include an active relaxation / sham meditation (SM) control condition (whereby participants are offered identical instructions to sit and breathe deeply without the presence of specific mindfulness instructions), so the limited effects observed in the present research may have simply been due to an MM-induced relaxation state rather than an increase in mindfulness. Additionally, it's been suggested that active relaxation and SM conditions control for participant expectancy, which is critical for any study examining cognitive benefits of mindfulness meditation (Banks et al., 2019). The inclusion of additional control conditions and a post-induction manipulation check in the form of a state measure of mindfulness (e.g., the State Mindfulness Scale) to compare across experimental and control conditions in future research would address these points. Although it remains a challenge to develop appropriate control conditions in mindfulness research, future studies may particularly benefit from developing a brief induction based on the Health Enhancement Plan, an innovative and comprehensive active control condition utilised in an increasing amount of MBI research (Ainsworth et al., 2013), and one that I employed as an active control condition for my more extensive MBCAT study.

Finally, as is often the case with online experimental research of this nature, there were a myriad of confounds that were impossible to control for. Perhaps the most important of these in the present research was that there was no way of ensuring that participants were fully present throughout the MBCAT instructions and educational extract. Although an attempt was made to ensure adherence to audio instruction by withholding the option for experimental progression until a 15-minute period had passed, there was no performance outcome / attention check associated with this stage of the experiment. As such, participants could have essentially disengaged fully from the experiment whilst the audio was playing, rendering my manipulation redundant. However, the fact that I observed a limited effect of MM on executive function would appear to dispute this suggestion.

Conclusion

Study 7 demonstrates that attentional components in the present study were not receptive to brief mindfulness induction, implying that longer meditative engagement is required for most attentional effects to be identified at an appropriate level of significance and clinical relevance (Somajaru et al., 2021). As such, identifying the optimal 'dosage' of brief mindfulness meditation through which specific cognitive benefits begin to manifest, particularly in relation to sustained attention and cognitive processes, remains fertile ground for future research. Such insights will facilitate a more informed picture of the mindfulness-based practices individuals are often recommended to utilise for the purpose of becoming more attentive in daily life, which is especially important during these uncertain times.

Final Conclusions

The primary aims of my thesis involved examining mindfulness through the lens of AGT-predicted LC-NA activity across a range of attentional modalities to endow a deeper understanding of mindfulness as a human capacity for wakefulness and vigilance. Specifically, I converged the use of pupillometry – a reliable index of LC-NA activity – with a range of attentional stimuli to conceptualise mindfulness as an AGT-predicted mode of elevated LC-NA arousal and augmented attention. Across seven experiments, I revealed variegated and limited behavioural evidence that mindfulness was related to subjective and objective indices of attentiveness, awareness and attentional control. Moreover, there was little evidence that mindfulness was associated with distinct patterns of pupillary activity inferring AGT-predicted fluctuations in LC-NA arousal in response to inconsistency and specific task demands. As such, contrary to general predictions that mindfulness would be widely conducive to attentional augmentation and psychophysiological change, the majority of outcomes remained non-receptive to mindfulness, both as a trait and nurtured state. Nonetheless, the research attempted to reveal some interesting insights into dispositional and interventional mindfulness qualities in relation to a diverse range of attentional, cognitive, and arousal-based outcomes, providing potentially fruitful opportunities for elaboration in future research.

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Appendix X: Mindfulness Mediates the Impact of Meditation on Depression, Anxiety and COVID-Related Distress

Wellbeing in The Age of COVID-19.

Considering the timing of the present study, I decided to enhance the broader relevance of my research in relation to the unfolding pandemic. Accordingly, utilising aforementioned methodological combinations, I examined distinct measures of wellbeing and COVID-related distress as a function of meditation experience and self-reported mindfulness.

The “new normal” of mass quarantine regulations, self-isolation and social distancing as a result of the COVID-19 outbreak has changed the way we live, substantially limiting the ability to interact socially and engage in activities associated with the maintenance of optimal psychological health. Combined with the economic and interpersonal impact of these regulations, we face a decidedly abnormal psychological existence, characterized by increased loneliness, heightened vigilance, vocational instability, financial worries, uncertainty about the future and elevated concerns about one’s own physical health and the well-being of loved ones. These factors can initiate a “perfect storm” of depressive and anxious thoughts, substantially increasing the risk of serious mental distress (Green et al., 2020; Serafini et al., 2020; Thakur & Jain, 2020; Wang et al., 2020). Indeed, increased rates of depression, anxiety, intolerance of uncertainty and symptoms consistent with post-traumatic stress disorder (PTSD) have been observed in studies exploring psychological responses to the pandemic among children and adolescents (Saurabh & Ranjan, 2020), university students (Liu et al., 2020), healthcare workers (Greenberg et al., 2021; Temsah et al., 2020), the elderly (Banerjee, 2020) and pregnant mothers (Davenport et al., 2020). Such is the extent of the unfolding “psychological pandemic” (Thakur & Jain, 2020) that the effects on mental wellbeing are extremely likely to remain long after the crisis is over. This highlights a need for strategies to help individuals cope in more adaptive ways. Self-management strategies offer the advantages of facilitating convenient, flexible and home-based autonomous support in a way that fosters a sense of empowerment among service users by affording them opportunities to take an active role in their healthcare (Green et al., 2020). One such strategy enjoying universal promotion from mental health services worldwide is meditation practice, which, in various forms, has been consistently demonstrated to improve mental health outcomes (Chen et al., 2012; Goyal et al., 2014), but has remained relatively understudied in terms of the direct and indirect effects of historical and current levels of meditative engagement on mental wellbeing during the current crisis. It is therefore vital to assess whether, and indeed how, mindfulness and meditative practice can target psychological discomfort resulting from the pandemic. Moreover, isolating the effects of historical and current meditation practice seems especially important for justifying the promotion of new meditative regimes to practice-naïve audiences.

The Mindfulness Mechanism

Researchers have proposed that the beneficial changes in mental health outcomes as a result of meditation are contingent on the ability to respond more mindfully in daily life. Support for this contention emerges from observations of negative associations between self-reported mindfulness - whether defined as a trait or a cultivated skill - and symptoms of stress, anxiety, and depression (Carpenter et al., 2019; Nekić & Mamić, 2019; Solem et al., 2015). Consequently, eliciting increases in mindfulness can plausibly be assumed to be associated with concurrent reductions in psychological distress. Historical meditation experience and regular meditative engagement have been linked to enhanced dispositional mindfulness, as assessed by the MAAS and specific facets of the

FFMQ, namely, Observing, Describing and Non-Reactivity (Brown and Ryan, 2003; Campos et al., 2019; Chambers et al., 2008; Josefsson and Broberg, 2011). Moreover, meditation experience has been reliably associated with improved wellbeing outcomes, as measured by the Psychological Wellbeing Scale (PWB, Ryff, 1989) (Baer et al., 2008; Josefsson et al., 2011). Crucially, within combined samples of meditators and non-meditators, meditation practice has been demonstrated to alleviate various generalised forms of psychological distress (e.g., PWB, stress, mood and negative effect) by enhancing specific elements of self-reported mindfulness, as assessed by the FFMQ and measures of mindful responding (Baer et al., 2008; Joesefsson et al., 2011; Lacaille et al., 2017; Soler et al., 2014). Such is the moderating effect of mindfulness that some research has reported the dissolution of beneficial meditative effects when associated changes in mindfulness were accounted for (Lacaille et al., 2017).

However, although examined extensively within the context of MBI / brief mindfulness training facilitation (Gu et al., 2015; Hoge et al., 2013; Tickell, 2020), exploring the impact of longer-term / higher-frequency meditation practice on disorder-specific symptomologies, such as those associated with depression and anxiety, remains understudied. Moreover, examining potential prodromal and maintaining transdiagnostic factors underlying the development of common and persistent mental health issues is especially pertinent during the current climate. One such factor shown to underlie the maintenance of disorder-specific distress and the deterioration of mental wellbeing is intolerance of uncertainty (Carleton et al., 2012). Considering that the pandemic has become synonymous with a level of uncertainty that pervades many aspects of daily existence (e.g., around physical health, distancing rules and the lack of a timebound resolution), the inability to tolerate such uncertainty represents a troublesome and self-perpetuating characteristic. Finally, the pandemic presents a unique opportunity to examine outcomes explicitly tailored for the detection of COVID-specific distress.

With accumulating support for the role of mindfulness in mediating the effects of meditation on general wellbeing, it is also reasonable to assume that any benefits of meditation on uncertainty intolerance, depressive and anxious symptoms and COVID-specific distress within the context of the pandemic are largely reliant on the ability to respond more mindfully to internal and external events. In Study 3, I demonstrated that mindfulness facilitated greater arousal (bPD) to utility-based inconsistency without the need for behavioural reactivity to this arousal (e.g., escape behaviours). Moreover, in Study 5, I evidenced the impact of a unique MBI on diminished post-response arousal (TEPR), typically indicative of reduced cognitive effort in the face of motor responses to inconsistency (incongruent targets). I concluded that such findings likely emerged from an increased capacity for mindful acceptance in the face of cognitive / arousal-based reactivity to inconsistent information (Teper and Inzlicht, 2013). It is possible that this capacity also nurtures an acceptance of the uncertainty associated with the myriad of aversive components associated with the pandemic, which may be evidenced through examinations of meditation-mindfulness-wellbeing relationships in the present study.

Hypotheses

It was predicted that meditators would exhibit reduced signs of disorder-specific psychological discomfort (e.g., depression and anxiety), transdiagnostic indices of aversion (intolerance of uncertainty) and COVID-related distress (H1a), thus extending previous findings evidencing increases in general wellbeing among meditators (Baer et al., 2008; Josefsson et al., 2011). Further, it was hypothesised that meditation experience and frequency would be negatively associated with these outcomes (H1b), thus addressing the limited available literature exploring meditation "dosage" in relation to wellbeing (Zeng et al., 2017) and building upon recommendations to concurrently examine historical *and* current duration of meditation on wellbeing (Josefsson et al., 2011). In an effort to examine psychological mechanisms underlying expected positive outcomes, it was predicted that meditation-induced increases in mindfulness would augment the positive effects of meditation experience / frequency on depression, anxiety, intolerance of uncertainty and COVID-related distress (H1c), thus extending prior endeavour examining mediatory effects of mindfulness on general wellbeing (Baer et al., 2008; Carpenter et al., 2019; Joesefsson et al., 2011; Lacaille et al., 2017; Nekić & Mamić, 2019; Solem et al., 2015; Soler et al., 2014).

Materials

MAAS (Brown & Ryan, 2003). The scale showed excellent reliability (α=.91).

FFMQ (Baer et al. 2008). Reliability of the Observe subscale was limited (α = .52). Removing the most problematic item resulted in only a marginally improvement (α = .61). Nonetheless, the Observe scale was included in all analyses. Reliability of total FFMQ scores was good (all α = .83).

Intolerance of Uncertainty Scale, Short Form (IUS-12 McEvoy & Mahoney, 2011). The IUS-12 was utilised to assess prospective and inhibitory intolerance of uncertainty (IUS-P/IUS-I). Higher scores indicate greater uncertainty intolerance. Reliability for total IUS-12 scores was good (α = .83).

PHQ-9 (Kroenke et al., 2009). To test hypotheses pertaining to the effects meditation experience / frequency on depressive symptoms, the PHQ-9 was utilised. The scale showed strong reliability in the current sample (α = .89).

GAD-7 (Spitzer et al., 2006). The GAD-7 was employed to assess participants' anxiety levels during the previous two weeks. Higher scores represent greater anxiety. The scale showed strong reliability (α = .90).

Coronavirus Anxiety Scale (CAS, Lee 2020a). To test hypotheses pertaining to the effects of meditation experience / frequency on COVID-specific distress, the CAS was employed. The CAS is a 5-item mental health screener to identify anxiety associated with the COVID-19 crisis. Higher CAS scores represent greater coronavirus-related distress. The scale showed strong reliability (α=.88).

Mediation Analyses

To investigate whether the relationship between meditation and wellbeing / attentional performance was mediated by mindfulness, I implemented multiple mediation analyses utilising the *Lavaan* package (version 0.6) for *R* (Rosseel, 2012), controlling for age and gender, to examine path models estimating direct (direct influence of one variable on another), specific indirect (indirect pathway via one mediator), total indirect (sum of specific indirect effects in multiple models) and total effects (sum of direct and total indirect effects) using regression coefficients to define each pathway. The procedure is explained in detail in Appendix 0ii: 'Overview of Procedures; Study 6 Mediation Analyses'.

Results

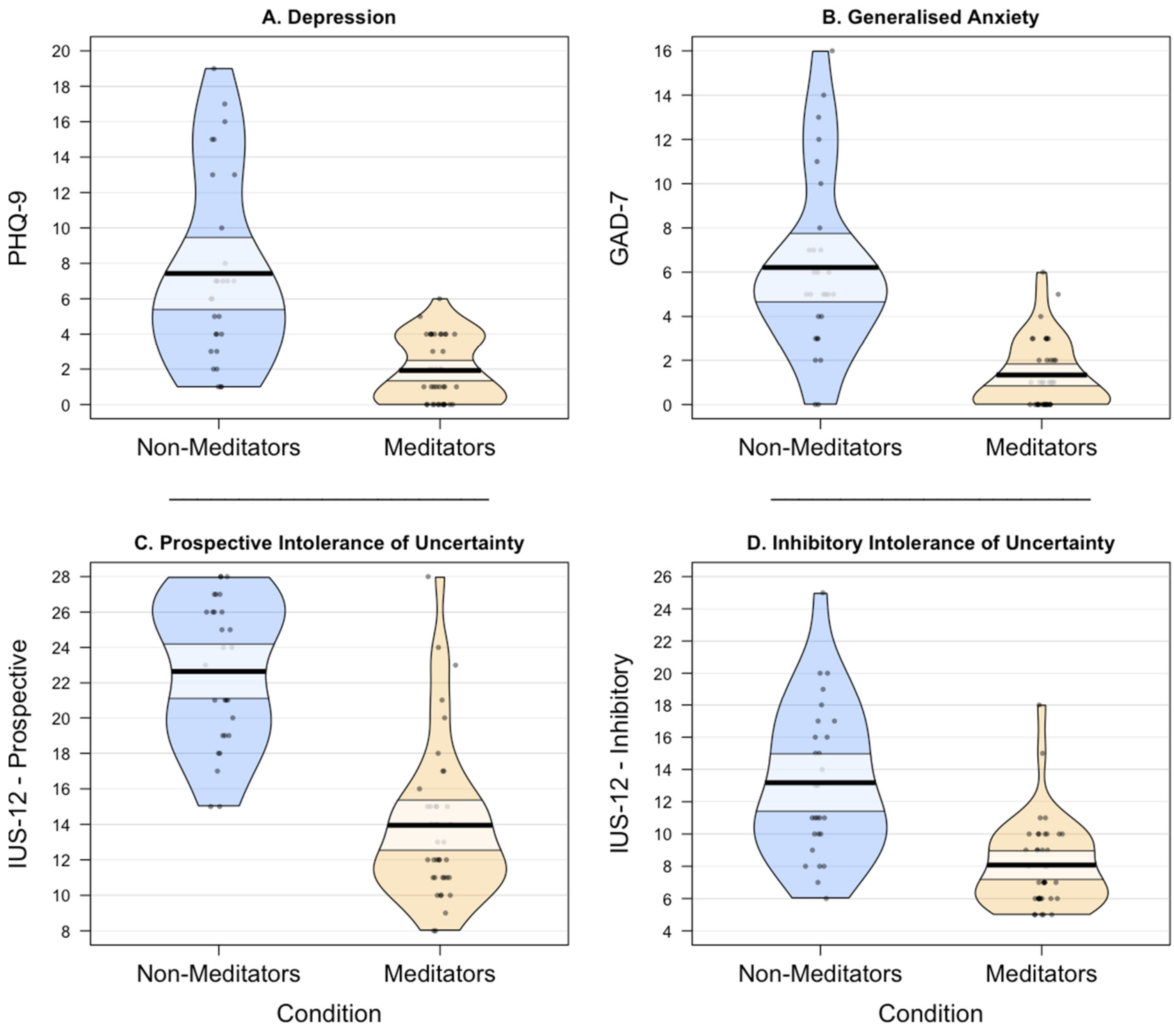
Mindfulness and Psychological Wellbeing

Demographic Characteristics. MANCOVAs revealed no interactions between overall meditation condition and gender for composite mindfulness (p = .28) and psychological distress outcomes (p = .69). Nonetheless, gender was controlled for in all further analyses, in line with comparable meditation studies (Josefsson et al., 2011). As expected, age was significantly positively correlated with meditation experience (r[65] = 0.73, p < .001) and daily meditation duration (r[65] = 0.50, p < .001). Partial correlations also revealed significant associations between age and self-reported mindfulness and psychological distress, controlling for meditation experience (Appendix 6.3). Accordingly, I controlled for age in all analyses exploring effects of meditation on mindfulness and mental wellbeing.

Psychological Distress (Cohorts, H1a). MANCOVA modelling all wellbeing outcomes as a function of meditation condition revealed significant differences between experienced meditators and non-meditators (Figure 61). As expected (H1a), there was a significant overall effect of meditation condition on composite distress scores (V = 0.36, F(5, 59) = 6.60, p < .0001). Follow-up univariate ANCOVAS (Table 6) revealed significant effects of meditation experience on depression, anxiety, prospective anxiety to uncertainty and inhibitory anxiety to uncertainty, Figure 61A:61D). Similarly, there were significant differences between long-frequent meditators and matched non-meditators (Appendix 6.5). As predicted (H1a), there was a significant overall effect of current meditation practice on composite distress scores (V = 0.51, F(5, 27) = 5.60, p < .01). Follow-up univariate ANCOVAS (Table 6) revealed significant effects of daily meditation practice on depression, anxiety, prospective anxiety to uncertainty and inhibitory anxiety to uncertainty (Appendix 6.5). These results are the first to demonstrate that cohorts defined by increased meditation experience / practice frequency report reduced intolerance of uncertainty, both in terms of the desire for future predictability and the discomfort associated with a perceived lack of information. In relation to the uncertainties of the pandemic, these findings harbour important implications (see Discussion).

Figure 61.

Differences in Indices of Psychological Distress Between Experienced Meditators and Non-Meditators.



Note. A) Depression, (B) Generalised Anxiety, (C) Prospective Intolerance of Uncertainty and (D) Inhibitory Intolerance of Uncertainty, controlling for age and gender. Inference bands reflect 95% confidence intervals. Total FFMQ comparisons not displayed. See Appendix 6A.5 for results pertaining to similar differences between long-frequent meditators and matched non-meditators

Table 6.

Meditator Cohorts and Psychological Distress.

Meditators vs. Non-Meditators	*F*	*p*	*Cohen's d*	LCI - UCI
1. PHQ-9	10.94	<.01	.83	.32 – 1.35
2. GAD-7	19.10	<.001	1.10	.57 – 1.63
3. IUS-P	19.60	<.001	1.11	.58 – 1.64
4. IUS-I	10.14	<.01	.80	.29 – 1.31
Long-Frequent Meditators vs. Matched Non-Meditators	*F*	*p*	*Cohen's d*	LCI - UCI
1. PHQ-9	4.62	.04	.77	.04 – 1.50
2. GAD-7	7.60	.01	.99	.24 – 1.73
3. IUS-P	15.85	<.001	1.43	.63 – 2.21
4. IUS-I	4.06	.05	.72	-.01 – 1.45

Note. Follow-up ANCOVAs illustrating significant effects of meditation experience and frequency / duration of meditation practice on psychological distress. Effect sizes displayed as *Cohen's d* with associated confidence intervals. PHQ-9 = depression, GAD-7 = generalised anxiety, IUS-P = prospective intolerance to uncertainty, IUS-I = inhibitory intolerance of anxiety.

Psychological Distress (Associations, H1b). Contrary to expectations, there were no significant negative associations between meditation experience and any index of psychological distress. However, daily meditation practice duration was negatively related to PHQ-9 ($r[72] = -0.29$, $p = 0.01$), GAD-7 ($r[72] = -0.34$, $p < 0.01$), IUS-12-Prospective ($r[72] = -0.34$, $p < 0.01$) and IUS-12-Inhibitory scores ($r[72] = -0.34$, $p < 0.01$) (H2b). Meditation experience and daily meditation duration were not directly associated with CAS. These findings imply that frequency and duration of current practice was more salient for the reduction of psychological distress than historical experience.

Self-Reported Mindfulness and Wellbeing (H1c). Intercorrelations among self-report measures are illustrated in Appendix 6.6. As expected, there were negative associations between most measures of mindfulness and psychological distress. However, mindfulness was not related to CAS scores.

Mediation Analyses

Meditation Experience (H1c). Due to observed associations between meditation experience / duration and self-reported mindfulness, and inverse associations between mindfulness and psychological distress, mediation analyses were utilised to explore whether expected effects of meditation on wellbeing manifested themselves indirectly through mediatory mindfulness pathways (H1c). Initially, simple mediation analyses were conducted to explore the indirect effects of meditation experience on each of the wellbeing measures via mindfulness, controlling for age and gender (Appendix 6.7A). As hypothesised (H2c), there was a significant direct effect of meditation experience on MAAS scores, with trending effects on Non-Judging (p = 0.07) and Non-Reactivity scores (p = 0.08). Direct effects of MAAS and Non-Judging, and a marginal effect of Non-Reactivity (p = 0.06) on PHQ-9 were observed. There were also direct effects of MAAS, Non-Judging and Non-Reactivity on GAD-7 and IUS-I scores, with the direct effect of Non-Reactivity on IUS-I marginal (p = 0.06), consistent with expectations (H2c). However, there were no direct effects of meditation on Observe, Describe, Awareness or Total FFMQ scores, and no direct effects of Observe, Describe or Awareness on any well-being outcome.

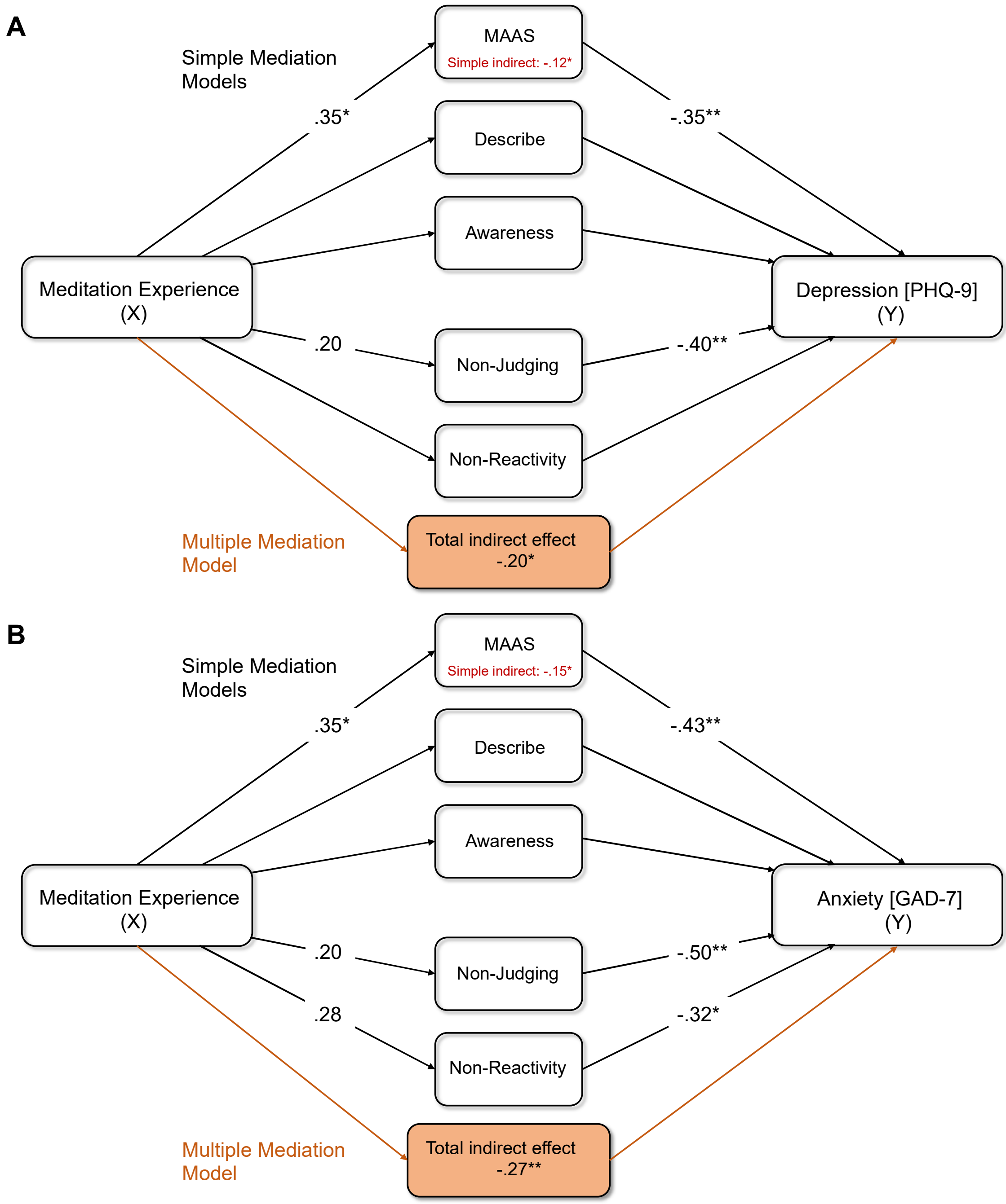
In terms of the simple indirect effects (Appendix 6.7A) and partly in line with expectations (H1c), MAAS was the only mindfulness measure to significantly mediate the relationship between meditation experience and distress, with indirect effects on PHQ-9 (p = 0.05, 95% CI [-0.109, -0.013]), GAD-7 (p < 0.05, 95% CI [-0.103 -0.016]) and a marginal effect on IUS-12-I scores (p = 0.06, 95% CI [-0.11, -0.012]). These simple indirect effects are instances of *indirect-only mediation* (Zhao et al. 2010), as the direct effects of meditation experience in each model (c' pathways) were non-significant.

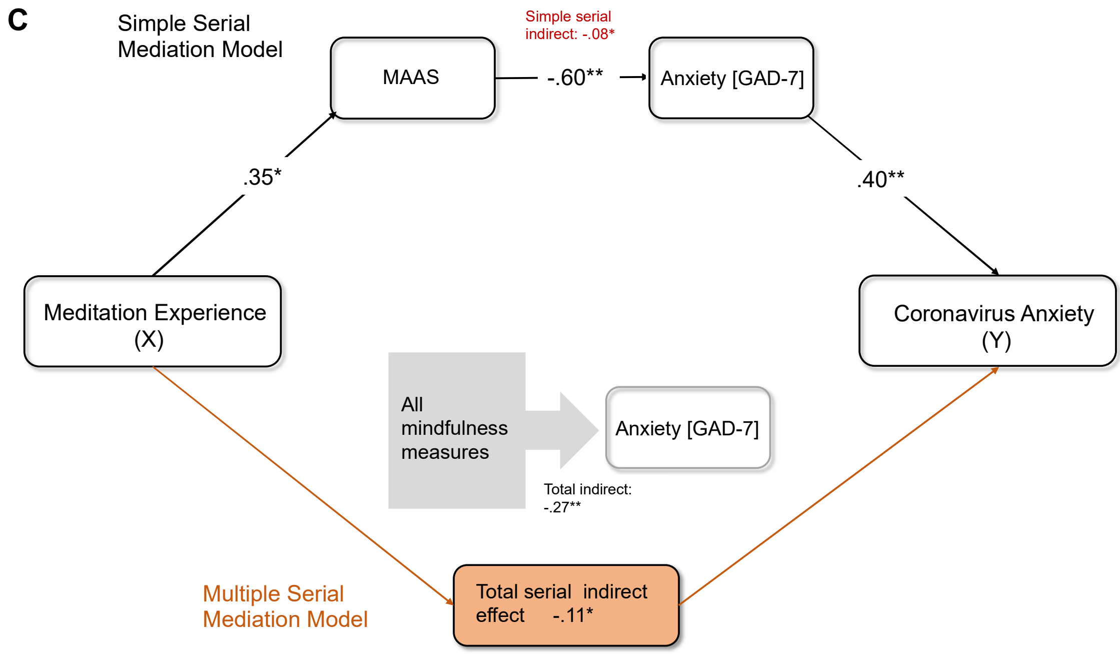
Multiple mediation models including all mindfulness mediators simultaneously for each well-being outcome (Appendix 6.7B) revealed significant total indirect-only effects on PHQ-9 (p = 0.03, 95% CI [-0.147, -0.015], Figure 62A) and GAD-7 scores (p < 0.01, 95% CI [-0.161, -0.034], Figure 62B), further supporting my predictions (H1c). The specific indirect effects for each mindfulness measure were non-significant in the multiple models. Substituting FFMQ subscales with total FFMQ scores in the multiple model resulted in marginal indirect-only effects on PHQ-9 (β = -0.12 (0.03), p = 0.07, 95% CI [-0.11, -0.01]) and GAD-7 (*β* = -0.15 (0.03), *p* = 0.06, 95% CI [-0.11, -0.01]).

As there were no observed direct or indirect effects of meditation experience on CAS via self-reported mindfulness, I constructed serial mediation models to explore whether the effects of meditation experience on wellbeing through mindfulness mediated a change in CAS scores. Like multiple mediation, serial mediation constructs indirect effects for each mediator considering all other mediators in the model. Crucially, serial mediation allows for an evaluation of the indirect effect passing through both mediators in a serial chain (Hayes, 2013; Van Jaarsveld et al., 2010). Simple serial mediations revealed a significant indirect-only effect of meditation experience on CAS through MAAS and GAD-7 (*p* = 0.05, 95% CI [-0.032, -0.004], Appendix 6.7C). Multiple serial mediations also revealed a significant indirect-only effect of meditation experience on CAS through all mindfulness measures and GAD-7 (*p* = 0.04, 95% CI [-0.041, -0.004], Figure 62C). The specific indirect effects for each mindfulness measure and GAD-7 in the multiple serial mediation models were non-significant. Substituting FFMQ subscales with total FFMQ scores in the multiple model resulted in a trending serial effect on CAS via GAD-7 (*β* = -0.08 (0.01), *p* = 0.09, 95% CI [-0.03, -0.002]).

Figure 62.

Simple, Multiple and Serial Mediation Pathways Illustrating Indirect Effects of Meditation Experience on Psychological Distress.





Note. Simple, multiple and serial mediation pathways illustrating indirect effects of meditation experience on PHQ-9, GAD-7 and CAS scores. Black lines represent direct effects in simple mediation models (only relevant coefficients displayed, including non-significant but notable direct effects), orange lines represent total indirect effects in multiple mediation models. Simple indirect effects from singular mediation models are reported in red text. All specific indirect pathways in multiple models were non-significant and are not reported. **(A)** Simple and total (multiple) indirect effects of meditation experience on depression [PHQ-9] via self-reported mindfulness, **(B)** simple and total (multiple) indirect effects of meditation experience on generalised anxiety [GAD-7] via self-reported mindfulness, and **(C)** simple serial and total (multiple) serial indirect effects of meditation experience on coronavirus-related anxiety via self-report mindfulness and GAD-7. Standardised coefficients displayed. 95% CIs for all indirect pathways did not include 0, indicating significant indirect effects of meditation experience on PHQ-9, GAD-7 and CAS scores. *p <= 0.05, **p < 0.01.

Meditation Duration (H1c). Mediation analyses for duration of frequent meditation practice followed identical steps as those examining meditation experience, but a simplified summary is provided here. Full details can be found in Appendix 0ii; ‘Overview of Procedures and Data Preparation’, pg. 16 and Appendix 6.8.

Simple mediation analyses revealed significant direct effects of meditation duration on MAAS scores, Non-Judging, Non-Reactivity and total FFMQ scores, in line with expectations (H1b). There were no direct effects of daily meditation on remaining mindfulness measures and no direct effects these measures on wellbeing outcomes.

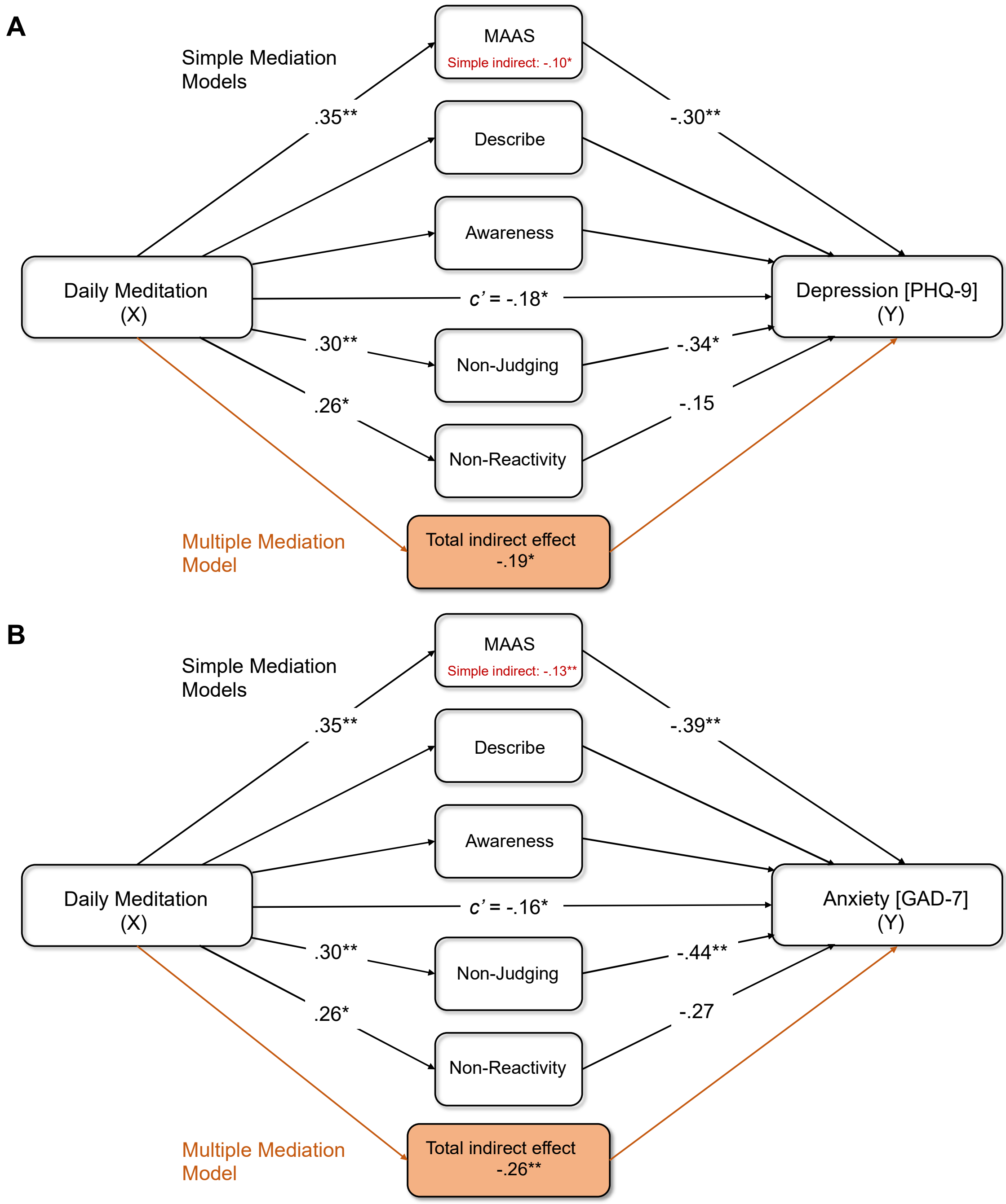
Partly in line with my predictions (H1c), simple indirect effects revealed that MAAS, Non-Judging and total FFMQ scores significantly mediated the relationship between daily meditation duration and wellbeing, with an indirect effect of MAAS on PHQ-9 scores (p = 0.02, 95% CI [-0.184, -0.027]), and indirect effects of MAAS (p = 0.04, 95% CI [-0.176, -0.038]), Non-Judging (p = 0.03, 95% CI [-0.191, -0.023]) and total FFMQ scores (p < 0.01, 95% CI [-1.41, -0.14]) on GAD-7.

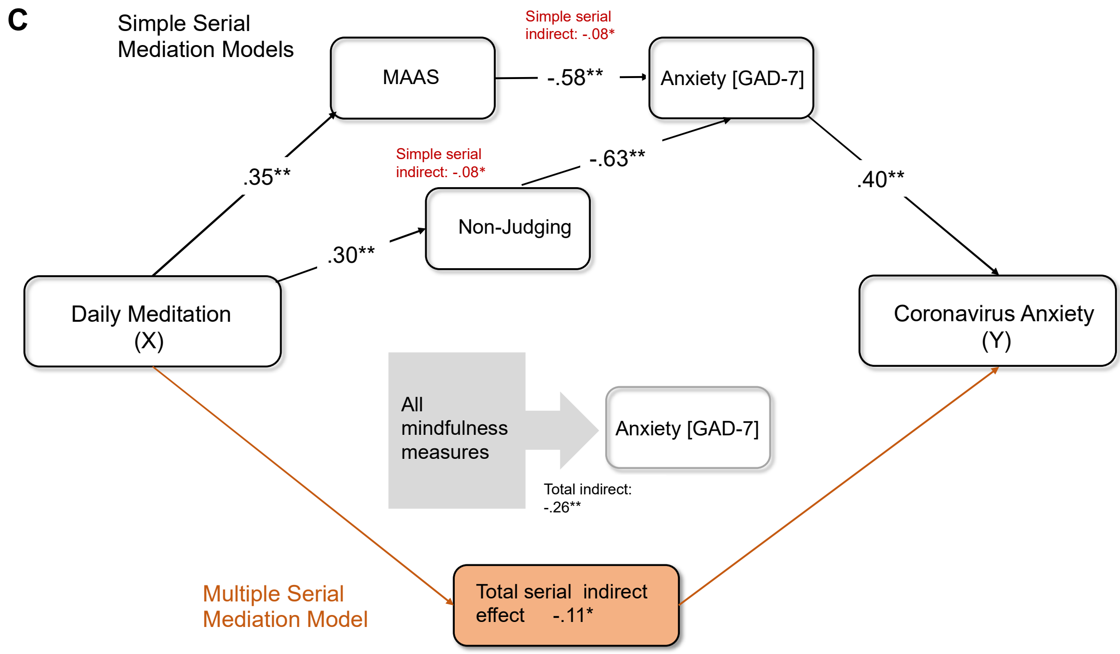
As expected (H1c), multiple mediation models revealed significant total *indirect-only* effects of daily duration on PHQ-9 (p = 0.04, 95% CI [-0.36, -0.01], Figure 63A) and GAD-7 scores (p = 0.01, 95% CI [-0.35, -0.06], Figure 63B).

Simple serial mediation models to explore whether the effects of meditation experience on wellbeing through mindfulness mediated a change in CAS scores revealed marginal indirect-only effects of daily duration on CAS via MAAS and PHQ-9 (p = 0.06, 95% CI [-0.057, -0.005]), via Non-Judging and PHQ-9 (p = 0.06, 95% CI [-0.058, -0.007]) and via total FFMQ scores and PHQ-9 (p = 0.05, 95% CI [-0.06, -0.008]). There were significant simple indirect-only effects of daily duration on CAS via MAAS and GAD-7 (p = 0.02, 95% CI [-0.062, -0.011]), via Non-Judging and GAD-7 (p = 0.04 [-0.065, -0.009) and via total FFMQ scores and GAD-7 (p = 0.03, 95% CI [-0.07, -0.01]. Multiple serial mediations also revealed a significant indirect-only effect of daily meditation duration on CAS through all mindfulness measures and GAD-7 (p = 0.04, 95% CI [-0.085, -0.006], Figure 63C).

Figure 63.

Simple, Multiple and Serial Mediation Pathways Illustrating Indirect Effects of Frequent Meditation Duration on Psychological Distress.





Note. Simple, multiple and serial mediation pathways illustrating indirect effects of daily meditation duration on PHQ-9, GAD-7 and CAS scores. Black lines represent direct effects in simple mediation models only relevant coefficients displayed, including non-significant but notable direct effects), orange lines represent total indirect effects in multiple mediation models. Simple indirect effects from singular mediation models are reported in red text. Specific indirect pathways in multiple models remained significant. (**A)** Simple and total (multiple) indirect effects of daily meditation duration on depression [PHQ-9] via self-reported mindfulness, **(B)** simple and total (multiple) indirect effects of daily meditation duration on generalised anxiety [GAD-7] via self-reported mindfulness, and **(C)** simple serial and total (multiple) serial indirect effects of daily meditation duration on coronavirus-related anxiety via self-report mindfulness and GAD-7. Standardised coefficients displayed. 95% CIs for all indirect pathways did not include 0, indicating significant indirect effects of meditation experience on PHQ-9, GAD-7 and CAS scores. $*p < 0.05$, $**p < 0.01$.

Attentional Performance, Probe Responses (see Study 5) and Psychological Distress. I conducted exploratory analyses to assess whether attentional performance and thought probe responses were associated with indices of psychological distress. There were no notable associations between GAD-7 / PHQ-9 / IUS-12 / CAS scores and attention network scores (all *ps* > .60) or CPT performance outcomes (all *ps* > .35).

Given that duration of meditative practice was associated with increased on-task thought and reduced TRI, I examined whether the ability to maintain task-focused thought during the CPT represented a potential mediatory mechanism underlying improved wellbeing. Interestingly, on-task thoughts were negatively associated with PHQ-9 and GAD-7 scores, whereas TRI was positively related to these outcomes (**Table 13).** As such, I entered on-task thoughts and TRI into separate mediation models exploring indirect effects of frequent meditation duration on these wellbeing outcomes.

Although the indirect-only effect of daily meditation on PHQ-9 scores via on-task thought was non-significant (B = -.03, SE = .20, p = .43, 95% CI [-0.65, 0.16]), there was a significant total effect (B = -.28, SE = .42, p < .001, 95% CI [-2.54, -0.87]), mainly comprised of the significant direct effect of daily meditation on PHQ-9 scores. Within the non-significant indirect effect, there was a significant effect of daily meditation on on-task thoughts (B = .28, SE = .40, p < .01, 95% CI [0.18, 1.80]), and a non-significant effect of on-task thoughts on PHQ-9 (B = -.10, SE = .17, p = .34, 95% CI [-0.47, 0.19]). Moreover, the indirect-only effect of daily meditation on PHQ-9 scores via TRI was non-significant (B = -.03, SE = .20, p = .43, 95% CI [-0.68, 0.10]) but there was a significant total effect (B = -.28, SE = .42, p < .001, 95% CI [-2.54, -0.87]), mainly comprised of the direct effect of daily meditation practice duration on PHQ-9. Within the non-significant indirect effect, there was a significant effect of daily meditation on TRI (B = -.22, SE = .30, p < .05, 95% CI [-1.20, -0.01]) and a non-significant *effect* of TRI on PHQ-9 (B = .12, SE = .23, p = .36, 95% CI [-0.24, 0.68]). Similar relationships were observed for GAD-7 scores, insofar as there were significant total effects but no significant indirect effects of daily meditation in on-task and TRI mediation models.

Table 13.

Thought Probe Responses and Wellbeing

	On-Task	TRI
PHQ-9	-.33*	.36*
GAD-7	.30*	.35

Note. Bivariate correlations between PHQ-9 (depression) and GAD-7 (generalised anxiety) and proportion of thought probe responses, adjusted for multiple tests. *On-task*; on-task thoughts, *TRI;* task-related interference. N = 75. $*p < 0.05$.

Discussion

Psychological Wellbeing (H1a/b/c). As expected, experienced meditators and long-frequent meditators scored lower than non-meditators on symptoms of depression (PHQ-8), generalised anxiety (GAD-7) and intolerance of uncertainty (IUS-12), compatible with prior findings outlining the effectiveness of meditation experience and regular meditation practice at improving psychological wellbeing (Levin et al., 2014; Smith et al., 2019). However, there were no differences between meditation groups in terms of coronavirus-related anxiety (CAS). Nonetheless, these findings offer novel evidence that meditation experience and frequency of sustained practice impacts upon disorder-specific mental health outcomes, extending prior research evidencing beneficial effects on more general indices of psychological wellbeing. Moreover, during the heightened uncertainty of the pandemic, I demonstrate for the first time that cohorts defined by increased meditation experience and practice frequency report reduced intolerance of uncertainty (IUS), both in terms of the desire for future predictability (prospective IUS) and the paralytical inability to tolerate aversive reactions triggered by a perceived lack of information (inhibitory IUS). Considering that each of these facets represent transdiagnostic components underlying the development and maintenance of more serious psychological disorders (Carleton et al., 2012), combined with the fact that IUS facets can so easily be exacerbated by the myriad of uncertainties associated with the pandemic, highlights the importance of methods to diminish these transdiagnostic indices of distress. As such, present results offer novel and important contributions to the literature pertaining to the maintenance of wellbeing as the world traverses through the constantly changing landscape of the pandemic.

Partly consistent with hypotheses (H1b), daily meditation duration was negatively associated with all symptoms of psychological distress, except CAS scores. Interestingly, meditation experience was not related to any of the mental health outcomes, except for a marginal negative association with GAD-7 scores. The observed discrepancy between meditation experience and daily meditation duration in terms of their zero-order effects on psychological wellbeing are consistent with prior studies demonstrating that frequency and duration of current meditation practice are more important for the maintenance of psychological health than historical meditation experience (Lacaille et al., 2017; Smith et al., 2019). Specifically, the fact that meditation experience was controlled for in all analyses examining associations between daily meditation duration and mental health outcomes, and that all meditators reported practicing for at least 30-minutes per day, 6 days per week, lends credence to proposals that consistent meditation practice for a minimum of 30-45 minutes each day is crucial for the beneficial psychological effects of current meditation practice to manifest, regardless of meditation experience (Green et al., 2020; Lacaille et al., 2017). These findings offer novel empirical support for the notion that frequent and recent practice is more important for wellbeing than historical experience, harbouring important messaging implications around the promotion of mindfulness techniques to meditation-naïve audiences.

In relation to mindfulness and wellbeing (H1c), negative correlations were observed between measures of mindfulness and psychological distress, except for CAS, augmenting prior findings linking increased self-reported mindfulness with reduced psychological distress (Carpenter et al., 2019; Solem et al., 2017). Moreover, simple mediation analyses revealed indirect effects of daily meditation duration on PHQ-9 and GAD-7 via Non-Judging, replicating prior studies demonstrating specific mediatory pathways of Non-Judging (Baer et al., 2008; Lacaille et al., 2017; Joseffson et al., 2011). These results suggest that meditation duration was associated with reduced symptoms of depression and generalised anxiety through an increased capacity to remain non-judgemental toward experiential processes. However, although related to increased meditation experience / longer meditative practice and reduced depression and anxiety, no significant mediatory effects of Non-Reactivity were observed, indicating that non-reactive responding did not play a significantly singular role in mediating the effects of meditation on depressive and anxious symptoms in the present study.

Multiple mediation analyses (H1c) including Non-Judging and Non-Reactivity simultaneously revealed indirect effects of meditation experience and frequent meditation duration on PHQ-8 and GAD-7 scores, emphasising the idea that meditation practice is associated with multi-faceted increases in mindful responding, specifically the ability to remain non-judgemental and non-reactive towards inner and outer experience, which in turn is related to improvements in wellbeing (Josefsson et al. 2011). The majority of specific indirect effects of meditation experience on PHQ-8 and GAD-7 were non-significant in the multiple models, highlighting that indirect effects in simple mediation models are not the same as specific indirect effects in multiple models. The latter reflects the ability of a specific variable to mediate the relationship between X and Y when all other mediators are included in the model simultaneously. If mediators in multiple models are correlated, as they were in the present study, then this could result in non-significant specific indirect effects but significant combined effects (Josefsson et al., 2011; Preacher & Hayes, 2008). However, the specific indirect effect of daily meditation duration on GAD-7 via Non-Judging remained significant in the multiple model, further supporting the assertion that a crucial element of mindfulness nurtured through daily meditation practice is the ability to cultivate a non-judgmental attitude toward inner experiences, which subsequently facilitates reduced symptoms of depression and anxiety. The fact that direct effects on PHQ-8 and GAD-7 were observed in simple mediation models for daily meditation duration, but not for meditation experience, further supports prior proposals that frequency and duration of meditation practice are the most influential parameters in terms of the beneficial meditative effects on psychological wellbeing (Lacaille et al. 2017; Smith et al., 2019).

In contrast to hypotheses (H1b/c), coronavirus-specific anxiety [CAS] was not directly associated with meditation experience, daily meditation duration or any of the mindfulness measures. However, CAS scores were positively related to GAD-7 scores, consistent with prior studies demonstrating that COVID-19 related worries are reliably associated with increased levels of generalised anxiety (Barzilay et al., 2020). This suggests, somewhat intuitively, that addressing general levels of anxiety in daily life during the crisis may influence COVID-specific dysfunctional anxiety. As such, exploratory serial mediation analyses were conducted, modelling extended indirect effects of meditation experience and daily meditation duration on CAS via self-reported mindfulness (M1) and depression / generalised anxiety (M2). Simple serial mediations revealed specific indirect effects of daily meditation duration on CAS via Non-Judging and GAD-7. Moreover, multiple serial mediation analyses revealed indirect effects of daily meditation duration on CAS via all FFMQ facets, via total FFMQ scores and via Non-Judging, and GAD-7. These results extend previous research demonstrating indirect effects of meditation on wellbeing via mindfulness (Josefsson et al., 2011; Lacaille et al., 2017) by offering the first exploration of the indirect impact of meditation practice on pandemic-specific psychological distress, highlighting the importance of mindfulness and wellbeing pathways in facilitating improvements in mental health during the ongoing crisis.

Overall, these results suggest that the ability to attend mindfully in a non-judgmental and non-reactive way in the months following the coronavirus outbreak is reliably nurtured by increased meditation experience and daily meditation duration. The study presents evidence that enhanced capacities for non-judging and non-reactivity mediate beneficial associations between meditation and mental health outcomes. Crucially, the present research demonstrates, for the first time, that beneficial mediatory associations between meditation, mindfulness and psychological wellbeing extend into periods of unprecedented stress and uncertainty and facilitate improvements in pandemic-specific distress, harbouring important implications for the widespread recommendation and utilisation of comparable self-management strategies.

Appendix 0i: Overview of Self-Report Measures

Throughout this thesis, I employ one or more of the following self-report measures in each study to gauge levels of mindfulness. I also incorporate study-specific measures of psychological distress, including COVID-related symptoms, in order to examine the impact of mindfulness-based interventions / meditation on wellbeing. All questionnaires were displayed via the online survey management platform Qualtrics Online Questionnaires (see https://www.qualtrics.com/uk/).

Five Facet Mindfulness Scale-15 (FFMQ, Baer et al., 2008). The 15-item FFMQ is a short form of the 39-item FFMQ (Baer et al., 2006) and one of the most widely used self-report measures of mindfulness, having been employed in hundreds of studies (Teeple et al., 2018). It was designed to measure five aspects of mindfulness, namely: observation, description, awareness, non-judgment and non--reactivity. The 15-item FFMQ shows strong convergent validity and internal consistency (Gu et al., 2016). Each facet is made up of three items. Participants respond to statements representing Observing (e.g., *"When I take a shower or a bath, I stay alert to the sensations of water on my body"*), Describing *("I'm good at finding words to describe my feelings"*), Acting with Awareness (*"I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted" – reverse scored*), Non-Judging (*"I believe some of my thoughts are abnormal or bad and I shouldn't think that way" – reverse scored*) and Non-Reactivity subscales *("When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it"*). Items are answered on a five-point scale (1 = *Never or very rarely true* to 5 = *Very often or always true)*, with higher scores representing enhanced mindful responding. It has been utilised as a dispositional measure of mindfulness and has been demonstrated to be responsive to various forms of mindfulness training with moderate effect sizes reported in MBI-based meta-analyses (Khoury et al. 2013; Quaglia et al., 2016).

It has been demonstrated that specific facets of the FFMQ relate to distinct attentional capabilities; Observing is associated with increased observations of inner experiences, reactions and sensations, Describing refers to efficient articulation of observations of experiences of perceptions, sensations, thoughts and emotions, Awareness relates to the ability to voluntarily focus attention, Non-Judging is associated with an accepting observation of inner experienced without judgment and Non-Reactivity refers to refraining from responding to inner experiences (Sorensen et al., 2018). Empirically, Observing has been related to improved alerting performance during the ANT (Di Francesco et al., 2017) and Observing and Non-Judging have both been shown to predict improved orienting and enhanced conflict detection during the ANT (Sorensen et al., 2018). Moreover, greater Describing and Total FFMQ scores have been reliably associated with improved sustained attention performance during the SART and improved executive performance during the Stroop task (Josefsson and Broberg, 2011). Additionally, Awareness scores have been shown to augment executive function during a flanker task (Lin et al., 2018).

As such, utilising the FFMQ in the present thesis allow for an exploration of the awareness and acceptance dimensions of mindfulness in relation to attentional and neurocognitive processes.

Mindful Attention Awareness Scale (MAAS, Brown and Ryan, 2003). The MAAS is a 15-item self-report survey that measures the tendency to be fully attentive and aware in the present moment without distraction. Questions prompt individuals to consider how mindless rather than how mindful they are (e.g., "*I snack without being aware that I'm eating*" and *"I tend not to notice feelings of physical tension or discomfort until they really grab my* *attention"*). Responses are provided on a six-point scale (1 = *Almost always* to 6 = *Almost never*), with higher scores representing higher dispositional mindfulness. Although reckoned to provide a narrower assessment of mindfulness than the FFMQ, recent evidence provides support for the validity of the MAAS to examine individual differences in trait mindfulness, specifically in relation to increased attentiveness that is informed by a sensitive awareness of what is taking place in the present moment (Brown and Ryan, 2003; Brown, Ryan, Loverich et al., 2011).

Patient Health Questionnaire, Depression Scale-9 (PHQ-9, Kroenke et al., 2009). The PHQ-9 is a valid and reliable 9-item tool to gauge depression severity, based directly on the diagnostic criteria for major depressive disorders in the Diagnostic and Statistical Manual Fourth Edition (DSM-IV). The PHQ-9 assesses participants' mood during the two weeks prior to self-report. Participants indicate how often they are bothered by criteria for depression (e.g., *"Feeling down, depressed, or hopeless"*) using a 4-point (0 = *Not at all* to 3 = *Nearly every day*), with higher total PHQ-9 scores representing increased depressive symptoms. Total PHQ-9 scores of 1-4 represent minimal depression, 5-9; mild depression, 10-14; moderate depression, 15-19; moderately severe depression and 20-27; severe depression (Kroenke et al., 2001).

***Generalised Anxiety Disorder Scale-7* (GAD-7, Spitzer et al., 2006).** The GAD-7 is a 7-item measure designed to gauge severity of generalised anxiety during the previous two weeks of assessment. It has been validated for primary care patients, general population, and adolescents with GAD (Mossman et al., 2018). Participants indicate how frequently they experience each item (e.g., "*Worrying too much about different things"*) on a 4-point scale (0 = *Not at all*, 1 = *Several days,* 2 = *More than half the days,* 3 = *Nearly every day*), with higher scores representing greater anxiety. GAD-7 scores range from 0 to 21. Scores of 5, 10, and 15 represent cut-off points for mild, moderate and severe anxiety, respectively.

The General Health Questionnaire- 12 (GHQ--12: (Goldberg et al. 1997). The GHQ-12 is a widely -used, valid and reliable 12-item measure of general mental health in the general population (Donath 2001; Goldberg et al. 1997), commonly utilised to screen for non-specific psychiatric morbidity. The GHQ-12 assesses symptoms of psychological distress by assessing thoughts, emotions and behaviours. Participants indicate answers to items across several domains of psychological wellbeing, including six positively worded items (e.g., *"Have you recently felt capable of making decisions about things*?") and six negatively worded items (e.g., *"Have you recently felt constantly under strain?"*) using a 4-point ordinal scale (0-3). Positively worded item responses (0 = *"better than usual",* 1 = *"same as usual",* 2 = *"less than usual"* and 3 = *"much less than usual"*) and negatively worded item responses *("not at all," "no more than usual," "rather more than usual" and "much more than usual"*). The GHQ-12 can be scored using two methods; the four-point Likert scale method, with scores ranging from 0 to 36, and the bimodal method, with scores ranging from 0 to 12. Responses were reverse scored, insofar as higher scores represent greater wellbeing.

Intolerance of Uncertainty Scale, Short Form (IUS-12 Carleton, Norton and Asmundson, 2007). The IUS-12 is a valid and reliable 12-item version of the original 27-item Intolerance of Uncertainty Scale (IUS) developed to measure prospective intolerance of uncertainty (IUS-P), concerning the intolerance of future uncertainty, and inhibitory intolerance of uncertainty (IUS-I), which measures aversion paralysis associated with uncertainty (Freeston et al, 1994). Participants indicate how frequently they experience each item (e.g., IUS-P; "*Unforeseen events upset me greatly"* / IUS-I; *"When it's time to act, uncertainty paralyses me"*) on a 5-point scale (1 = "*Not at all characteristic of me", 2 = "A little characteristic of me",* 3 = *"Somewhat characteristic of me"*, 4 = "*Very characteristic of me",* 5 = "*Entirely characteristic of me"*). As such, higher scores indicate greater intolerance of uncertainty.

Coronavirus Anxiety Scale (CAS, Lee 2020a). The CAS is a 5-item mental health screener to identify anxiety associated with the COVID-19 crisis, demonstrating strong reliability and validity (> .90, Lee, 2020a). Participants respond to questions exploring coronavirus anxiety (e.g., *"I had trouble falling or staying asleep because I was thinking about the coronavirus"*) using a 5-point scale (0 = *Not at all* to 4 = *Nearly every day over the last 2 weeks)*. Elevated CAS scores have been found to be associated with substance misuse, hopelessness, negative coping approaches and passive suicidal ideation related to the pandemic (Lee, 2020b).

Stress and Anxiety to Viral Epidemics Scale (SAVE-6, Ahn et al., 2020). The SAVE-6 is derived from the original SAVE-9 designed to assess work-related stress and anxiety responses of healthcare workers to the COVID-19 pandemic. The first factor of the SAVE-9 - '*anxiety response to viral epidemics*' - has been extracted for use in the general population, and termed SAVE-6. Participants respond to six questions regarding health-related concerns as a result of the pandemic (e.g., *"Are you more sensitive toward minor physical symptoms than usual?"*) using a five-point scale (0 = *Never,* 4 = *Always*). Higher scores represent greater stress / anxiety towards the pandemic.

COVID-19 Vaccine Hesitancy Scale (VHS, Freeman et al., 2020). The COVID-19 VHS is a 7-item measure designed to assess hesitancy toward the COVID-19 vaccines. Participants respond to questions regarding vaccine attitudes and motivation to receive COVID-19 vaccines (e.g., *"If a COVID-19 vaccine was available at my local pharmacy, I would…",* and *"I would describe myself as…"*) using a five-point scale (respectively, "*0 = Never get it* - *4 = Get it as soon as possible",* and *"0 = Anti-vaccination for COVID-19* - *4 = Eager to get the COVID-19 vaccine"*). Higher scores represent more favourable attitudes towards - and greater motivation to receive – COVID-19 vaccinations.

Appendix 0ii: Overview of Procedures and Data Preparation

General Laboratory Procedure

All experiments requiring in-person testing (studies two, three, four and five) took place in a quiet laboratory in the School of Psychology at Cardiff University. The researcher remained in the room for all testing procedures in order to answer questions or to address any technical issues. All task-specific instructions were displayed to the participant on-screen.

Each in-person laboratory experiment consisted of information provision, consent forms and questionnaire completion via either Qualtrics Online Questionnaires (XM Version, Qualtrics, Provo, UT, 2021) or E-Prime 2.0 Professional (Psychology Software Tools, Pittsburgh, PA). All study-specific attention / compensation tasks were presented in E-Prime 2.0 Professional. Basic timeline of study-specific events outlined in order of statements below:

Study 2. Presentation of all questionnaires (inc. mindfulness), the Face stimuli and the bond severity measure (compensatory affirmation measure) were utilised in E-Prime.

Study 3. Presentation of all questionnaires (inc. mindfulness), the DUT task and the learning / testing phases of the AGL (compensatory abstraction measure) were utilised in E-Prime.

Study 4. Presentation of all questionnaires (inc. mindfulness), the ANT and the SARTp were utilised in Qualtrics (questionnaires) and E-Prime (attention tasks) prior to ACT intervention. Attention tasks and the mindfulness questionnaire were also administered after the ACT intervention in order to assess pre-post changes in mindfulness and attention.

Study 5. Presentation of all pre-intervention questionnaires (inc. mindfulness and wellbeing), the post-intervention ANTI-V and the post-intervention mindfulness and wellbeing questionnaires were utilised in Qualtrics (questionnaires) and E-Prime (attention tasks).

General Online Procedure

The two experiments employing online testing methods (studies six and seven) harnessed the use of Qualtrics for self-report measures and PsychoPy 3.0 for the design and implementation of the attention tasks (Peirce et al., 2019). The attention tasks were subsequently hosted by the online experiment platform, Pavlovia (https://pavlovia.org). Study one presented all questionnaires, Stroop task and compensatory affirmation measures solely in Qualtrics.

Study 1. Presentation of all questionnaires (inc. mindfulness), the Stroop task and the belief adherence / bond severity measures (compensatory affirmation measures) were utilised in Qualtrics.

Study 6. Presentation of all questionnaires (inc. meditation characteristics, mindfulness and wellbeing), the online ANT and the online CPTp were utilised in Qualtrics (questionnaires) and Psychopy / Pavlovia (attention tasks).

Study 7. Presentation of all questionnaires (inc. mindfulness and wellbeing), the online MBCAT induction, the online ANT and the online CPTp were utilised in Qualtrics (questionnaires and MBCAT induction) and Psychopy / Pavlovia (attention tasks).

Eye Tracker Calibration for Laboratory Experiments

For optimal ongoing pupillary data collection during laboratory experiments, each participant was situated approximately 65cm away from the screen at the height of the task stimuli. PD was continuously recorded during all tasks at 120 Hz using a Tobii X3-120 screen-based non-invasive eye tracker on a 17" computer screen with 1920 x 1080 pixel resolution. The system was calibrated for each participant using a 9-point calibration within Tobii Studio. Tobii software compensates for eye movements and fluctuations in the angle of pupil size recording via an in-built algorithm that corrects pupil size output according to these compensation criteria.

For each study utilising eye-tracking techniques (studies two, three, four and five), a calibration procedure preceded each E-Prime task (e.g., Faces, DUT, ANT, SARTp, ANTI-V), whereby participants were instructed to sit in front of the computer screen and informed that an eye-tracking calibration would commence. During this procedure, the Tobii eye tracker obtains information about the participant's eyes relating to attributes such as position and light refraction and creates an internal 3D model for each eye in order to accurately represent eye movement and pupil size during experimental trials (Tobii Group, 2015). During calibration, participants are instructed to maintain their gaze on a red dot floating around the screen on a grey background, which pauses in position intermittently. The dot moves slowly to all extremities of the screen (top-left/right, bottom-left/right, middle-left/right) and to the centre. If calibration is successful (unsuccessful attempts are repeated), Tobii Studio gauges and displays the quality of calibration, whereby the experimenter can opt for the experiment to proceed (provided the quality is acceptable. If not, calibration is repeated). Subsequently, participants are instructed to progress to the E-Prime tasks.

Data Preparation

Broadly following relevant pupillary data preparation procedures for Tobii software used in prior research (Zarzeczna et al., 2019), missing data points for both eyes due to blinks, off-screen fixations and/or eye tracker malfunction were coded as missing values[48] by E-Prime software and removed. This resulted in an average of 23.4% of pupillary data loss across studies employing pupillometry techniques (*range;* 17.4% - 25.6%), commensurate with prior estimations of useable Tobii eye-tracking data (78%, Funke et al., 2016). Moreover, data loss was approximately equal across blocks and conditions in studies two, three, four and five. Smoothing and filtering pupillary data has garnered multiple approaches (Kelbsch et al., 2019; Lin et al., 2018; Mathot et al., 2017), so techniques were combined to best fit study-specific data in terms of eye tracker speed and signal loss. Following prior procedures implemented to smooth implausible pupillary signal (Proulx, Sleegers and Tritt, 2017; Zarzeczna at al., 2019), pupil values were filtered using a median regression filter[49] using the *robfilter* package in *R* (R Core Team, 2016; Schettlinger, Fried and Gather, 2010). Filtering in this way ascertains the slope of pupil size increase / decrease over time within a specified *inner* window width, which is determined by all samples contributing to slope estimation. Then, the median is calculated for slope estimations for a specific *outer* window. Visual inspection of data for each individual participant and trial informed which inner and outer widths were most appropriate for the data. For my pupillometry studies, an inner width of 15 and an outer width of 25 samples was most appropriate.

[48] The validity indicator ranges from 0 (the eye-tracker is certain that the data belongs to the eye) to 4 (pupillary data is missing or incorrect). Only recordings with a validity score of 0 were used.
[49] Median filters are applied to assess the signal within a specific window of time, replacing data points with the median of entries adjacent to that window.

Following signal smoothing, linear interpolation was applied to any missing signal not attributable to blinks (gaps of ˜33ms in duration)[50]. Finally, due to artifacts associated with blinks typically occurring approximately 100ms prior (eye tracker fails to record pupil as eyelid closes) and 200ms after a blink (eyelid opens causing constriction of pupil) (Lin et al., 2018), pupil recordings at these time stamps were removed. The resulting gaps in pupil signal were linearly interpolated to a generally agreed maximum blink duration of 500ms (Lin et al., 2018). I then combined data from the left and right eyes to obtain an overall mean pupil size. As a result of pre-processing, useable pupillary data increased by an average of 9.6% across studies (11.6% study 2, 7.7% study 3, 9.2% study 4, and 10% study 5 (MBCAT).

It should be noted that, although only one smoothing / filtering technique was utilised in each study to best fit the respective data, experimenting with different filters and blink corrections resulted in comparable analytic outcomes.

Finally, baseline corrections were administered to ensure baseline equivalence in pupil size between participants relative to subsequent pupillary dilation. Specifically, I calculated the mean pupil diameter during a final time window of each task-specific pre-trial fixation period for each participant and trial and subtracted this mean score from each pupil size measurement during the target trial period, consistent with Mahot et al.'s (2018) recommendations (see specific studies for pre-trial fixation periods and target trial characteristics). As such, pupil sizes closer to 0 represented normal pupil diameters for each participant in relation to subsequent pupil dilation.

[50] During interpolation, missing signal is replaced with the mean of neighbouring valid signal measurements.

Baseline Pupil Diameter (bPD). Consistent with recommendations and comparable research exploring inferred fluctuations in tonic LC-NA activity during tasks of sustained attention and thought probe exploration (Gilzenrat et al., 2010; Mahot et al., 2018; Smallwood et al., 2011; Unsworth and Robison, 2016), baseline (pretrial) pupil diameter (bPD) was calculated for each study that utilised pupillometry during tests of sustained attention / vigilance and thought probe administration (studies three, four and five). Specifically, for sustained attention tasks, bPD was computed as the average period during a task-specific pre-trial fixation period (see specific studies). For examinations of thought probes and arousal, bPD was computed as the average period during the two trials preceding each reported thought (Unsworth and Robison, 2016). All bPD values were *z*-scored normalised for each participant in analyses to correct for individual differences in pupil diameter (Sleegers et al., 2015; Unsworth and Robison, 2018).

Task-Evoked Pupillary Responses (TEPR). In line with existing methods exploring task-evoked pupillary responses (TEPRs) (Granholm et al., 2017; Zarcezna et al., 2019), I analysed fluctuations in participants' pupil diameter across the pupillary time course for Face task trials (study two), ANT trials (study four) and ANTI-V trials (study five), consistent with prior endeavour examining inconsistency-induced TEPR (Proulx et al., 2017) and pre/post-response TEPR (Geva et al., 2013).

Throughout the tasks, I collected 120 samples of pupil size data per second, resulting in 600 samples per Faces trial (5000ms) in study two, 480 samples per ANT trial (4000ms) in study four, and 492 samples per ANTI-V trial (4100ms) in study five. Subsequently, I computed the mean pupil size for each participant, trial and trial type (e.g., alerting, orienting and executive conditions during the ANT/ANTI-V, face type conditions during faces task).

Response Latencies. Across studies, all reaction times (RT) to task-specific stimuli that were faster than 100ms for correct responses were excluded from analyses as these were considered anticipatory responses (van den Hurk, 2012). Thereafter, RTs were range restricted to 3000ms and trimmed utilising the Tukey criterion, which resulted in the removal of RTs that were larger or smaller than the upper or lower quartile, plus or minus 1.5 times the interquartile range for each participant (Clark-Carter, 2018). This method was implemented because RTs outside of this range represent unrealistically slow reaction times beyond those indicated by attentional lapse amid continuous performance (Zarcezna et al., 2019). RTs were subsequently subjected to logarithmic transformations in order to normalise their distribution for analyses. I then calculated mean response times for each specific condition of interest in relation to task-specific conditions. The same procedure was applied to RTs for every attention task and inconsistency-induction task (e.g., DUT) in the present thesis. In-text descriptions and figure displays of RTs are reported as non-transformed data for clarity.

Accuracy and Signal Detection. General accuracy during the attention tasks (ANT, ANTI-V, SARTp and CPTp) was assessed by calculating error rates (%) as a function of stimuli-specific conditions during each task (see specific studies for more details).

In relation to assessments of sustained attention and vigilance, a range of methods were utilised across studies. For example, attentional lapses were calculated as errors of commission / omission and as the slowest RT quintiles. Moreover, signal detection theory (SDT) indices were employed in some studies to assess the vigilance-based capacity to detect signals. Specifically, the signal detection theory (SDT) index of d-prime (*d'*) was calculated, which is a signal sensitivity score reflecting the distance between the two distributions relating to target detection - signal and signal + noise - and corresponds to the *z* -value of the hit rate minus the z-value of false alarm rate. Hits and false alarms correspond to correct and incorrect responses to targets, respectively. When the hit rate matches the false alarm rate, $d' = 0$, indicating no signal sensitivity. Typically, d' values are up to 2.0, but can reach a maximum possible value of 6.93 (Macmillan and Creelman, 1990).

Accordingly, I employed an array of outcomes affording a relatively rich insight into the level of sustained attention and vigilance among different populations during several novel attention tasks (see specific studies for more details).

Mediation Analyses Procedure – Study 6

To investigate whether the relationship between meditation and wellbeing / attentional performance was mediated by mindfulness, I implemented multiple mediation analyses utilising the *Lavaan* package (version 0.6) for *R* (Rosseel, 2012), controlling for age and gender, to examine path models estimating direct (direct influence of one variable on another), specific indirect (indirect pathway via one mediator), total indirect (sum of specific indirect effects in multiple models) and total effects (sum of direct and total indirect effects) using regression coefficients to define each pathway. Meditation (daily duration) (X), self-reported mindfulness (specific and multiple measures) (M) and attention network scores (Y) were linked via *a*-paths (direct effect of X on M), *b*-paths (direct effect of M on Y) and *c'-paths* (direct effect of X on Y), with *c-paths* representing total effects ($c' + a*b$ paths). I utilised multiple mediations to assess the total indirect effect of mindfulness measures on wellbeing / attentional performance, taking into account all other included mediators.

It is important to note that the causal steps approach proposed by Baron and Kenny (1986), although historically popular, has been replaced by more rigorous methods (Hayes, 2013). The causal approach recommends a cessation of analytical exploration in the face of a non-significant zero-order X-Y relationship. However, this relationship is mathematically equivalent to the "total" effect of X on Y in mediation models. As such, ceasing analytical progression in the face of a non-significant X-Y relationship tries to evaluate the presence of mediation without taking into account the indirect pathway(s). This is clearly problematic, as mediation could actually be occurring when the total effect is non-significant, which may be due to factors relating to sample size, lack of power, assumption violation of the test of the total effect, and the potential for two indirect effects in a model cancelling each other out via opposite directions (Selig & Selig, 2008). With this in mind, and considering I was interested in both direct and indirect effects of meditation on wellbeing and attentional performance via mindfulness, I conducted mediation analyses even in the absence of zero-order effects of meditation on psychological distress and attentional outcomes. Specifically, I anticipated *complementary mediation* (direct *and* indirect effects exist) and *indirect-only mediation* (indirect effect but no direct effect exists), consistent with updated mediation typologies designed to avoid treating significant X–Y relationships as "gatekeepers" for further mediatory exploration (see Hayes, 2009; Zhao et al., 2010, Hayes, 2009).

In line with recommended statistical procedures, I utilised bootstrapping methods, resampling the data 5,000 times and generating 95% confidence intervals (CIs) for my indirect/mediation effects (Hayes, 2013, Josefsson et al. 2011, Lacaille et al. 2017). This approach is a powerful and effective alternative method relative to the casual steps approach, as it is less vulnerable to Type I errors and does not assume normal distributions for any variable. Bootstrapped 95% CIs of our indirect effects not straddling zero would be considered statistically significant. These methods were utilised for all simple and multiple mediation analyses.

Behavioural and Pupillary Preparation Techniques - Study 4

Baseline Pupil Diameter (bPD)

Consistent with methodological recommendations and with comparable research exploring inferred fluctuations in tonic LC-NA activity (Gilzenrat et al., 2010; Mahot et al., 2018; Unsworth and Robison, 2018), bPD was computed as the average pupil size during the final 200ms mask period of each SART trial, and during the 200ms fixation period that preceded each ANT trial (cue presentation).

Task-Evoked Pupillary Responses (TEPR)

In line with existing methods exploring task-evoked pupillary responses (TEPR) (Granholm et al., 2017; Zarcezna et al., 2019), fluctuations in participants' pupil diameter were analysed across the pupillary time course for each ANT trial. First, trials with missing responses were removed (participants were not allowed to respond after 4100ms), resulting in 2.6% of omitted data**.** Throughout the ANT, I collected 120 samples of pupil size data per second, resulting in 492 samples per ANT trial. Accordingly, I computed the mean pupil size for each participant, trial and trial type (Alerting; double cue and no cue trials, Orienting; spatial cue and central cue trials, Executive; congruent and incongruent trials). I then calculated the grand mean of reaction time (RT) across all participants for each network (displayed on respective TEPR graphs), allowing for pre-response and post-response time periods to be identified in relation to pupillary reactivity to alerting, orienting and executive network stimuli. Finally, I calculated mean pupil size for each 100ms time bin after trial commencement, allowing me to visually inspect pupillary time course trajectories for each ANT network.

Response Latencies and Accuracy

Mean accuracy (percentage of errors) were inspected for extreme values, as determined by an exclusion threshold of values higher / lower than 3 standard deviations (SD) from the mean. Two participants were excluded from the ACT study based on these criteria. these criteria. Mean reaction time (RT) was averaged as a function of trials relative to ANT and SARTp stimuli (Josefsson and Broberg, 2011; Roca et al., 2011). This resulted in 5.7% of RT data being excluded.

Behavioural and Pupillary Preparation Techniques - Study 5

Baseline Pupil Diameter (bPD).

Consistent with methodological recommendations and with comparable research exploring inferred fluctuations in tonic LC-NA activity (Gilzenrat et al., 2010; Mahot et al., 2018), bPD was computed as the average period during the 200ms fixation period that preceded ANTI-V trial commencement (presence / absence of alerting tone presentation).

Task-Evoked Pupillary Responses (TEPR)

In line with existing methods exploring task-evoked pupillary responses (TEPR) (Granholm et al., 2017; Zarcezna et al., 2019), I analysed fluctuations in participants' pupil diameter across the pupillary time course for each ANTI-V trial. First, trials with missing responses were removed (participants were not allowed to respond after 4100ms), resulting in 1.8% of data omitted. Throughout the ANTI-V, I collected 120 samples of pupil size data per second, resulting in 492 samples per ANTI-V trial. Accordingly, I computed the mean pupil size for each participant, trial and trial type (Alerting; tone trials and no tone trials, Orienting; valid cue, invalid cue and no cue trials, Executive; congruent and incongruent trials, Vigilance; displaced central car trials). I then calculated the grand mean of reaction time (RT) across all participants for each network (displayed on respective TEPR graphs), allowing for pre-response and post-response time periods to be identified in relation to pupillary reactivity to alerting, orienting and executive network stimuli. Finally, I calculated mean pupil size for each 100ms time bin after trial commencement, allowing me to visually inspect pupillary time course trajectories for each ANTI-V network.

Response Latencies and Accuracy

Mean accuracy (percentage of errors) and vigilance data (Signal Detection Theory-based indices) were inspected for extreme values, as determined by an exclusion threshold of values higher / lower than 3 standard deviations (SD) from the mean. No participants were excluded from the MBCAT study based on these criteria. Mean reaction time (RT) was averaged as a function of ANTI-V alerting, cueing and target conditions (van den Hurk, 2012).

Behavioural and Pupillary Preparation Techniques - Study 6

Response Latencies and Accuracy

Mean reaction time for correct trials (RT (ms)) and accuracy (percentage of errors across trials requiring motor commission or omission) were inspected for extreme values, as determined by an exclusion threshold of values higher / lower than 3 standard deviations (SD) from the mean. Mean RT was further filtered to exclude values ±2.5 SD per participant, resulting in 7.4% of RT data being excluded. RTs faster than 100ms for correct responses were excluded from analyses as these were considered anticipatory responses.

Mediation Analyses for Meditation Duration – Study 6

Meditation Duration (H2c). Simple mediation analyses exploring indirect effects of daily meditation duration on each of the well-being measures via self-reported mindfulness, controlling for *meditation experience,* age and gender, revealed significant direct effects of meditation duration on MAAS scores, Non-Judging, Non-Reactivity and total FFMQ scores (Appendix 6.8A), in line with expectations (H1b). There were no direct effects of daily meditation on Observe, Describe or Awareness scores, and no direct effects of Observe, Describe or Awareness on well-being outcomes.

In terms of the simple indirect effects (Appendix 6.8A) and partly in line with my predictions (H2c), MAAS, Non-Judging and total FFMQ scores were the only mindfulness measures to significantly mediate the relationship between current daily meditation duration and well-being, with an indirect effect of MAAS on PHQ-9 scores (p = 0.02, 95% CI [-0.184, -0.027]), and indirect effects of MAAS (p = 0.04, 95% CI [-0.176, -0.038]), Non-Judging (p

= 0.03, 95% CI [-0.191, -0.023]) and total FFMQ scores ($p < 0.01$, 95% CI [-1.41, -0.14]) on GAD-7. These simple indirect effects are instances of *complementary mediation* (Zhao et al. 2010), as the direct effects of daily meditation duration in each model (*c'* pathways) were significant (*ps* < 0.05, $p = 0.07$ in Non-Judging/GAD model), rendering highly significant total effects (*ps* < 0.01).

As expected (H2c), multiple mediation models containing all mindfulness measures for each wellbeing outcome (Appendix 6.8B) revealed significant total *indirect-only* effects (direct *c'* pathways not significant in multiple models) of daily duration on PHQ-9 ($p = 0.04$, 95% CI [-0.36, -0.01], Figure 63A) and GAD-7 scores ($p = 0.01$, 95% CI [-0.35, -0.06], Figure 63B). Moreover, the specific indirect effects via MAAS and Non-Judging were significant in the multiple GAD-7 model (*ps* < 0.05). Direct effects of daily meditation duration on PHQ-9 and GAD-7 were non-significant in the multiple models. Substituting FFMQ subscales with total FFMQ scores in the multiple model resulted in significant indirect-only effects on PHQ-9 ($\beta = -0.11$ (0.04), $p = 0.04$, 95% CI [-0.20, -0.02]) and GAD-7 ($\beta = -0.16$ (0.04), $p = 0.01$, 95% CI [-0.21, -0.04]).

As there were no observed direct or indirect effects of daily meditation duration on coronavirus-related anxiety via self-reported mindfulness, I constructed serial mediation models to explore whether the effects of meditation experience on well-being through mindfulness mediated a change in CAS scores. Simple serial mediations revealed marginal indirect-only effects of daily duration on CAS via MAAS and PHQ-9 ($p = 0.06$, 95% CI [-0.057, -0.005]), via Non-Judging and PHQ-9 ($p = 0.06$, 95% CI [-0.058, -0.007]) and via total FFMQ scores and PHQ-9 ($p = 0.05$, 95% CI [-0.06, -0.008], Appendix 6.8C). As expected (**H2c**), there were significant simple indirect-only effects of daily duration on CAS via MAAS and GAD-7 ($p = 0.02$, 95% CI [-0.062, -0.011]), via Non-Judging and GAD-7 ($p = 0.04$ [-0.065, -0.009) and via total FFMQ scores and GAD-7 ($p = 0.03$, 95% CI [-0.07, -0.01],

Appendix 6A.10c). Multiple serial mediations also revealed a significant indirect-only effect of daily meditation duration on CAS through all mindfulness measures and GAD-7 (p = 0.04, 95% CI [-0.085,-0.006], Figure 63C). The specific indirect effects for each mindfulness measure and GAD-7 in the *multiple* serial mediation models were non-significant, yet trending for MAAS and Non-Judging pathways (ps = 0.08). Substituting FFMQ subscales with total FFMQ scores in the multiple model resulted in a significant serial effect on CAS via GAD-7 (β = -0.10 (0.01), p = 0.01, 95% CI [-0.07, -0.01]).

Appendix 0iii: Procedures for Modelling Effects

In order to establish the random structure for the linear mixed effects models (LMMs) and generalised linear mixed effects models (GLMMs) throughout this thesis, I utilised the *lme4* and *afex* packages for *R* (Bates, et al. 2015) (version 3.3.2), whereby I assessed the appropriate random effects structure that would best fit task-specific data prior to each analysis using random slope comparisons. Subsequently, I estimated a LMM / GLMM to evaluate study-specific fixed effects.

Specifically, minimal and progressively more complex models were compared through Akaike information criterion (AIC), subsequently informing the appropriate random effects structure of the final model. Utilising LMMs in this way harbours the benefits of enhancing power because these models explicitly account for many sources of variation within a single LMM by modelling the variance associated with interactions between participants and the levels of each random variable that would normally be attributed to error. For example, mixed models allowed for controlling the heterogeneity of samples of each category of thought probe in the SART within and between participants, and to control for the dependency caused by repeated sampling of data within participants in the variety of attention tasks employed in the present thesis (Pinheiro & Bates, 2000). LMMs are also superior to mixed ANOVAs in handling unbalanced designs and missing data.

In order to estimate the optimal random effects structure for the final LMMs, a minimal model was first constructed in which intercepts varied across *participants*. Subsequently, further model(s) was estimated that had a similar structure to the minimal model but included a random slope for each task-specific random effect, thereby ascertaining whether the inclusion of random effects associated with each task improved model fit. Comparisons between the minimal model and the random slope model(s) were implemented using the Chi-square difference statistic ($\Delta\chi2$) and AIC criterion. If the model containing the random slope resulted in a better fit of the data (e.g. the loglik value was significantly smaller than that of the minimal model), the random slope was retained in the final model. Comparisons between pertinent minimal and random slope models for each study are presented below.

Study 3.

For study 3, in order to ascertain whether the inclusion of random effects associated with trial epoch improved model fit for effects on baseline pupil diameter (bPD; peri-escape pupils), a model was estimated in which the random slope of *trial epoch* was included. This model was compared to the minimal model, resulting in the inclusion of *trial epoch* in the final analysis. As such, I was able to explicitly model the variance associated with interactions between participants and the levels of trial epoch that would normally be attributed to error. For all other analyses, intercept-only models, that is, those modelling the random intercept of participants only, were implemented. Analyses exploring the effects of arousal on AGL performance and interactive effects of mindfulness / arousal on performance utilised intercept-only models, as these were accepted as a sufficient treatment of the data.

Study 4.

For study 4, model comparisons were utilised for establishing the ANT networks based on RT and accuracy, and for examining RT, accuracy, bPD and TEPR data throughout the ANT as a function of ACT. Random effects of session, cue and target significantly improved model fit for RT, accuracy and TEPR data. A random effect of session significantly improved model fit for bPD data. Minimal models were accepted as sufficient treatments of the SARTp data.

Study 5.

For study 5, model comparisons were utilised for establishing the ANTI-V networks based on RT and accuracy, and for examining RT, accuracy, bPD and TEPR data throughout the ANTI-V as a function of MBCAT. Random effects of tone, cue and target improved model fit for RT but not accuracy or bPD data. Models examining the impact of the MBCAT intervention on pre-response and post-response TEPR activity within the alerting and executive networks necessitated the inclusion of random effects of tone and target respectively. Models examining the impact of the MBCAT programme on the SDT index of *d'* sensitivity necessitated the inclusion of correct response ('Go/No-Go' - ANTI-V vigilance trials) as a random effect in order to improve model fit relative to the minimal model.

Study 6.

For study 6, model comparisons were utilised for establishing the ANT networks based on RT and accuracy, and for examining RT and accuracy throughout the ANT as a function of meditation. Random effects of cue and target significantly improved model fit for RT and accuracy. Minimal models were accepted as sufficient treatments of the CPTp data.

Study 7.

For study 7, model comparisons were utilised for establishing the ANT networks based on RT and accuracy, and for examining RT and accuracy throughout the ANT as a function of meditation. Random effects of cue and target significantly improved model fit for RT and accuracy. Minimal models were accepted as sufficient treatments of the CPTp data.

Appendix 0v: Exploratory DUT Analyses – subjective and objective diminishing utility

Supporting the contention that mindfulness is specifically a capacity for enhanced tonic arousal, the findings of Study 3 reveal an intriguing distinction between arousal states during subjectively-assessed reductions in task utility (escape-trial epochs – *Eteps*) and those observed during epochs of increased absolute task difficulty (identical-trial epochs – *Iteps*), in terms of their respective associations with trait mindfulness and implicit learning. Contrasting with core findings, the absence of an association between bPD during *Iteps* and MAAS scores / AGL performance potentially reflects differential neuromodulatory mechanisms underlying subjective and absolute bPD activity. Specifically, whereas changes in tonic NA are associated with increased bPD during *Eteps*, I propose that *Itep* bPD is reflective of variations in arousal associated with levels of acetylcholine (ACh), and that this NA/ACh distinction likely reflects specific types of uncertainty during the DUT [11]. It could be argued that initial instances of identical-tone presentation following a series of mostly-successful discrimination trials reflect a form of *expected uncertainty* (reward contingencies proceed broadly as expected), insofar as the inherent stochasticity of the DUT - e.g., when tones initially *reach* indiscernible levels - represents a stable probability of increased task difficulty that is known to participants. ACh has been proposed to signal expected uncertainty and is reliably measured using bPD [11, 52], allowing reasonable assumptions to be made that ACh - not NA – is activated during *Iteps*. Conversely, fluctuations in NA reflect a form of *unexpected uncertainty* (difficulty outpaces reward) [11], signalling the detection of unexpected contextual DUT changes - e.g., when tones *remain* indiscernible amid diminishing *Etep* utility - and promoting a move to explore different sources of information. The fact that comparable bPD observations during *Iteps* and *Eteps* manifested such divergent MAAS / AGL relationships supports recent theories proposing distinct roles for ACh and NA amid expected and unexpected uncertainty, respectively [53]. This further promotes the convergence of theoretical perspectives on the psychophysiological similitude between expected/unexpected uncertainty and exploitation/exploration processes [11, 53, 1]. Moreover, present findings linking bPD and inferred NA activation with uncertainty specifically associated with *Eteps* may reflect a proposed role of bPD activation in tracking rapidly updating inference processes in terms of the extent to which predictions are updated in response to unexpected task processes [59].

Appendix 1: AGL Training / Testing Phase Stimuli

Training Phase

PLEASE COPY THE LETTER STRINGS INTO THE SPACES PROVIDED BELOW.

X M X R T V T M

1.____________________________

V V T R T T V T M

2. ____________________________

V T T T T V M

3. ____________________________

X X R T T T V M

4. ____________________________

V T T T V T R V M

5. ____________________________

X X R V T M

6. ____________________________

X M M M M X M

7. ____________________________

X M X R T T T V M

8. ____________________________

X M M X R T V M

9. ____________________________

X M M M X R V T M

10. ____________________________

X X R T V T M

11. ____________________________

V T V T R V T M

12. ____________________________

X M M M X R T V M

13. ____________________________

V V T R V M

14. ____________________________

X M M X M

15. ____________________________

V V T R T T V T M

16. ____________________________

X M X R T T T V M

17. ____________________________

V V T R V M

18. ____________________________

X M M M X R T V M

19. ____________________________

X X R V T M

20. ____________________________

X M M M X R V T M

21. ____________________________

X M M M M X M

22. ____________________________

V T V T R V T M

23. ____________________________

V T T T T V M

24. ____________________________

Testing Phase

THE STRINGS OF LETTERS YOU JUST COPIED CONTAINED A STRICT PATTERN.

SOME OF THE LETTER STRINGS BELOW FOLLOW THE SAME PATTERN.

SOME OF THESE LETTER STRINGS DO NOT.

PLEASE PLACE A CHECKMARK BESIDE THE LETTER STRINGS YOU BELIEVE FOLLOW THE SAME PATTERN AS THE LETTER STRINGS YOU JUST COPIED.

1. **X M X R V M** ____
2. **V T T T V M** ____
3. **X M V R X R M** ____
4. **V V T R X R R R M** ____
5. **X M T R R M** ____
6. **V V R X R R M** ____
7. **X M M M X R V M** ____
8. **X X R T T V T M** ____
9. **V T R R M** ____
10. **X M V T T R X M** ____
11. **V T T V T M** ____
12. **X M V R M V R X M** ____
13. **V V T R V T M** ____
14. **X M M X R V M** ____
15. **X M X R T T V T M** ____
16. **V V T R T T V T M** ____
17. **X M V T R R X R M** ____
18. **V T V T R T V M** ____
19. **X M M M X M** ____
20. **V T T T V T R V M** ____
21. **V V T T R M T M** ____
22. **X M V R X M** ____
23. **V V R M V T R X M** ____
24. **X X R T T V M** ____
25. **V V R M V R X M** ____
26. **X M V R X R R M** ____
27. **V T V T M** ____
28. **X M M X R T T V M** ____
29. **X M V R X R R R M** ____
30. **X X R V T R V M** ____
31. **X M T R R R M** ____
32. **V V T R M T M** ____
33. **X M X R V T R V M** ____
34. **X M X R T T V M** ____
35. **X M T R M** ____
36. **V T T T V T M** ____
37. **V V T R M T R R M** ____
38. **V V T T R M T R M** ____
39. **X M V R M T M** ____
40. **V T T V T R T V M** ____
41. **V T V T R V M** ____
42. **X X R V M** ____
43. **X X R T V T T R V M** ____
44. **V T R R R M** ____
45. **V V T T R X R M** ____
46. **V V R M T R R M** ____
47. **V T T V T R V M** ____
48. **V V T T R X R R M** ____
49. **V V R M T R M** ____
50. **V V R M V R X R M** ____
51. **V T V T R T V T M** ____
52. **V T R R R R R M** ____
53. **X M X R T V M** ____
54. **X X R T T T V T M** ____
55. **V V T R T V T M** ____
56. **V V R M T M** ____
57. **V T V T R T T V M** ____
58. **V T T T T V T M** ____
59. **V V T R M V R X M** ____
60. **X M V T R X R R M** ____

Appendix 2A: ACT Flyers

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYD

RESEARCH PARTICIPANTS NEEDED!

Do you experience stress, anxiety or low mood?
Do you struggle maintaining focus and find you keep getting distracted?
Do you want to take part in a study that could help you cope better?

If so, keep reading!

Cardiff University are offering its' students the opportunity to attend workshops during 2018 which are designed to increase psychological wellbeing and promote the development of psychological coping skills. These workshops will run for 2 hours a week for a 4-week period. Attending these workshops will be **completely FREE** and provide an **opportunity to experience a group delivered psychological therapy.** By attending it is hoped that you will develop psychological coping skills that will be beneficial in everyday life. The workshops will take place in the Cardiff University Centre for Human Developmental Science building in seminar room [INSERT ROOM NUMBER] from [INCLUDE TIMES HERE]

At Cardiff University we are committed to improving the services offered to students and therefore, the workshops will be evaluated to establish their effectiveness at improving the Psychological wellbeing of students. We will also be investigating which aspects of the workshops work best in terms of improving participants' psychological wellbeing. This will hopefully help us understand why these interventions work.

If you are interested in taking part in this exciting study, please email Ben Annear annearb2@cardiff.ac.uk

Study: Learn to cope with stress
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Appendix 2B: Example of ACT Content

In association with
Professor Neil Frude

ACTivate Your Life – At University

ACTivate Your Life is a psychology course that will help you to understand yourself better, and to understand your **Mind**. The course is based on a relatively new approach to therapy – **'Acceptance and Commitment Therapy' (ACT).**
ACT helps people to overcome their suffering using 'Mindfulness' and by helping them understand how to live in accordance with their own important values.
The course is all about you having a better life.

The Course is in 4 sessions – we call these ACT 1, ACT2, ACT 3 and ACT 4

ACT 1 – "You Are Not Your Mind"

Some of our actions are under **OUR OWN** (conscious, deliberate) control, but many of our actions are directly controlled by our **Mind.** Automatic actions such as breathing and walking are sometimes said to be "on autopilot". It is useful if ordinary routine actions are carried out automatically so that we don't have to think about them. But often it is better for us to think carefully about what to do – and to do things 'thoughtfully' or 'Mindfully'. For example, it is often better for us to shop **Mindfully** (or 'wisely') rather than impulsively. It is often a bad idea to allow our **Mind** to decide what we will do and this can lead to a lot of unnecessary suffering. *ACTivate Your Life* will help you to be more thoughtful about what you do – and to suffer less

HOW THE MIND WORKS

1 Your **Mind** does its own thing – you have no control over many of the things that it does
2 You can't direct your **Mind** to **STOP** doing something, but you **CAN** direct it to **DO** something
3 Your **Mind** constantly judges, compares and searches for meaning and patterns
4 Your **Mind** always tries to figure out "what's going on" and often jumps to conclusions
5 Your **Mind** wanders (it travels through time and space)
6 Your **Mind** is very clever (but it often gets things wrong)
7 Your **Mind** is always looking out for threats (and, to avoid danger, it is very cautious)
8 Your **Mind** is often highly critical (and it is likely to be very critical of **YOU**)
9 Your **Mind** always tries to maintain control (and it will resist **YOU** taking control)

The **Mind** ruminates

Through the power of language and the ability to create detailed images, the **Mind** can make past events "happen again" – triggering powerful emotional responses including repeated ("endless") suffering

So the **Mind's** wandering will often take your attention away from what's going at the moment – and it may take you to places and issues that you find worrying and distressing.
What can you do about this? You cannot switch your **Mind** off – and there's little that you can do to divert it. The best thing to do is simply to "let it be" (while noticing what your **Mind** is up to).

ACTivate Your Life – At University - ACT 1 ***© Neil Frude, 2018***

The **Mind constantly compares things** – and it often makes negative comparisons which can bring us down. So even when things are fine, your **Mind** may well suggest that ...
"It won't last"
"It could be a whole lot better"
"It's not as good as your sister's"

The **Mind** often makes mistakes e.g. the Lines Illusion – and it often tells us that things are dangerous when we know that they are not – or that we should check something when we know that there is no real need to do so. So our **Mind** worries us unnecessarily and often holds us back from doing things that could make our life better

The key thing is what we DO
When we know that out **Mind** has got it wrong, the sensible thing to do is to ignore our **Mind's** silly warnings and to do the **WISE** thing. But this may not be easy and it may take a lot of courage

FEEL THE FEAR ...
AND DO IT ANYWAY

It is VERY important for you to recognize that you are not bound to believe everything that your Mind tells you or to go along with its ideas

OUR MIND IS ALWAYS LOOKING OUT FOR DANGER
Our **Mind** evolved to keep us safe, and this means that it is always on the lookout for any possible threat. But **Minds** tend to be over-sensitive – they may become alarmed too easily and may worry us and frighten us when there's no real danger. And because it is very sensitive to any potential threat – now or in the future – the **Mind** tends to be very cautious *("better safe than sorry")* and often tries to hold us back from doing anything different or daring

OUR CRITICAL MIND
Our **Mind** is very critical – and it is often especially critical (and even insulting) towards us. We can't stop this happening but we can learn to live with it so that we are no longer hurt when our **Mind** has a go at us!

THE MIND LIKES TO BE IN CONTROL, BUT ...

Your Mind doesn't have the power to control what you do

We would be better off if we were more thoughtful and took over more control of our actions, so that they became ... less "automatic", less "on autopilot", less **"MINDLESS"** And ... **MORE MINDFUL – this is possible!!**

YOU ARE NOT YOUR MIND

Your **Mind** travels here and there, and back and forth in time

But **YOU** – "the observer" – are always 'here' and in the present – for you it's always 'now'

NOW

YOU are not **YOUR MIND**

Don't Miss ... **Next Week** – ***ACT TWO – "Facing Up to Life"***

ACTivate Your Life – At University - ACT 1 ***© Neil Frude, 2018***

Appendix 3A: MBCAT Flyers

Appendix 3B: Examples of MBCAT Protocol and Recorded Home Practice Guidance

Mindfulness-Based Cognitive Attention Training (MBCAT) Instructor Pack

Session Outlines and In-Session Practice

J. R. J. Hill (2020)

<u>Session 2: The Breath & The Body</u>

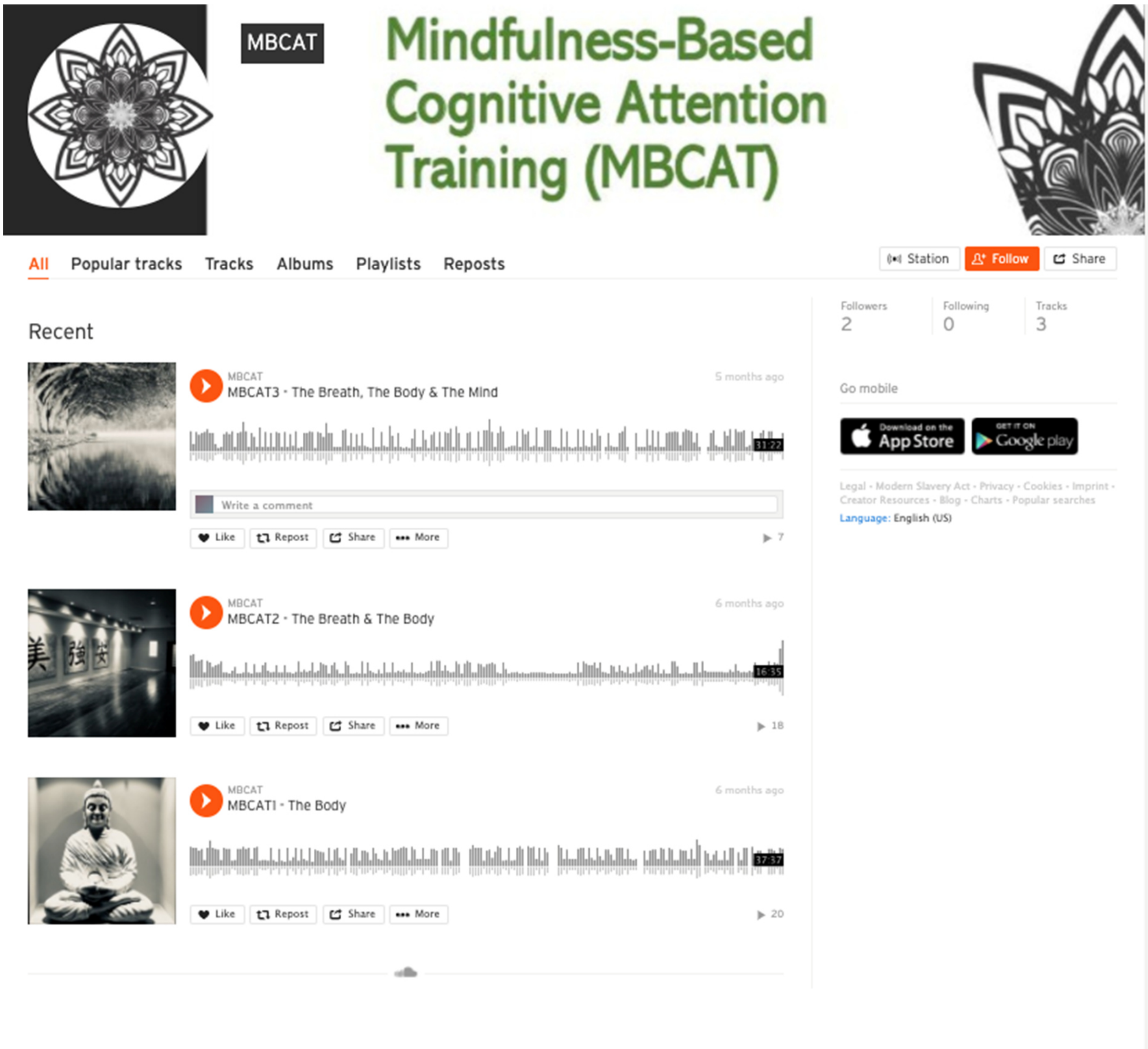
Meditations: the breath & the body, breathing space
Exercises: collect home practice forms, home practice reflection, thoughts & bodily sensations exercise + daily life examples [flipchart], breath & body reflection

Today's Theme
The body scan was designed to move us from "being ushered along by experiences" (i.e. autopilot) to "relating to experiences in the body with awareness." The focus was very much on direct awareness of experience in the body to **step out** of autopilot. Now, we move on to how learning to take awareness more intentionally to the breath offers another opportunity to do so, and offers the possibility of being more focussed and gathered. Moreover, with this as a safe 'base' for exploration, we explore an example of how simple bodily awareness can be extended to relating differently to bodily discomfort, "with openness and curiosity".

Process

- **3-5 min breathing space** Step 1 (Aware of thoughts, emotions etc), Step 2 (Gather to breath), Step 3 (Expand) [hourglass] – Inquiry
- **Recap last week:** Invite feedback
- **Home Practice Review:** *(1) Body Scan, collect in HW; (2) Mindfulness of a daily experience; (3) 5 morning breaths, (4) Eating one meal mindfully.*
- **[FLIP] Theme: Body Scan = step out of AP, Breath can do this too – and can be incorporated in 'bitesize' pieces. We now combine these two techniques, with a more specific focus on bodily discomfort - the core meditation for today.**
- **But first, a thought exercise.** Applies to any part of this course, but introducing now because it's a nice overview of internal states. A useful thing to consider when we're trying to practice any form of mindfulness.
- **"The Street" Exercise:** *"Walking down the street and see someone you know on the other side, perhaps from a university seminar, or from work etc":*
- **[FLIPCHART]** *thoughts, emotions,* ***bodily sensations*** *from group:* ***What do you make of this?***

  [FLIPCHART] Mind-Body Loop: *Our Thoughts, feelings,* ***bodily sensations/discomfort*** *are <u>interlinked</u>. Which influences which? Circle of thoughts, emotions, sensations.*
  - *Our 'natural' reactions to situations are habitual patterns. We've learnt them, and now they're automatic.*
    ASK: Is this an inaccessible loop? If not, why not?
    How does YOUR feedback link to what we've discussed so far in terms of meditation? Can we extrapolate the principles into thoughts etc? Indeed, we can, and will be using what we've learnt here to extend to other experiences first (e.g. sounds, sensations etc.)
  - **DISCUSSION:** *Ask someone, if comfortable, to provide their own example and walk-through of a situation. If none forthcoming, provide your own: 'What would your automatic reaction be?' (in terms of thoughts, feelings, bodily sensations)? How else could you relate to them [i.e. how does body scan approach bodily sensation?] How can we start to relate differently to these thoughts, feelings, sensations?*


MBCAT
Mindfulness-Based Cognitive Attention Training (MBCAT)
All
Popular tracks
Tracks
Albums
Playlists
Reposts
Station
Follow
Share
Recent
Followers 2
Following 0
Tracks 3
MBCAT
MBCAT3 - The Breath, The Body & The Mind
5 months ago
31:22
Write a comment
Like
Repost
Share
More
7
MBCAT
MBCAT2 - The Breath & The Body
6 months ago
16:35
Like
Repost
Share
More
18
MBCAT
MBCAT1 - The Body
6 months ago
37:37
Like
Repost
Share
More
20
Go mobile
Download on the App Store
GET IT ON Google play
Legal - Modern Slavery Act - Privacy - Cookies - Imprint - Creator Resources - Blog - Charts - Popular searches
Language: English (US)

Appendix 4: Study 5 - MBCAT Study, ANTI-V Performance

Table 1: Mean correct RT (ms) for the factorial design; 2 (Warning Tone: Tone/No Tone) x 3 (Cue: Valid/Invalid/No Cue) x 2 (Target: Congruent/Incongruent). Standard deviations in parentheses.

	No tone			Tone		
	Invalid	No cue	Valid	Invalid	No cue	Valid
Congruent	659 (100)	646 (102)	613 (99)	625 (78)	618 (110)	601 (97)
Incongruent	686 (77)	704 (99)	676 (81)	698 (85)	671 (96)	657 (86)

Table 2: Mean accuracy (percentage of errors) for the factorial design; 2 (Warning Tone: Tone/No Tone) x 3 (Cue: Valid/Invalid/No Cue) x 2 (Target: Congruent/Incongruent). Standard deviations in parentheses.

	No tone			Tone		
	Invalid	No cue	Valid	Invalid	No cue	Valid
Congruent	3.0 (5.6)	3.2 (4.9)	2.2 (3.1)	3.1 (4.8)	0.7 (1.9)	1.5 (2.8)
Incongruent	6.1 (7.5)	6.0 (8.3)	6.7 (7.8)	6.0 (6.3)	4.4 (6.3)	4.2 (6.3)

Table 3: A*ttention network scores (alerting, orienting and executive control) for reaction time data (ms) in MBCAT and HEP control conditions. Standard deviations in parentheses.*

	Alerting	Orienting	Executive Control
Control Group	47.6 (42.4)	31.4 (18.1)	76.3 (60.5)
MBCAT Group	26.5 (50.4)	31.7 (29.2)	40.7 (35.1)
Full Cohort	36.4 (46.7)	31.6 (23.9)	57.5 (50.5)

Table 4

A*ttention network scores (alerting, orienting and executive control) for accuracy data (percentage of errors) in MBCAT and HEP control conditions. Standard deviations in parentheses.*

	Alerting	Orienting	Executive Control
Control Group	4.35 (7.56)	1.05 (4.25)	5.33 (5.74)
MBCAT Group	0.01 (3.66)	0.63 (1.96)	1.46 (2.92)
Full Cohort	2.05 (6.06)	0.83 (3.14)	3.28 (4.76)

Appendix 6: Study 6 Supplementary Information

6.1

Length of meditation experience and perceived meditation experience in PA and meditator recruitment cohorts. Values reflect numbers of each cohort within each category.

Meditation by Cohort | Distribution	PA Cohort	Meditator Cohort
Meditation Experience		
None	28	0
Novice (1-6 months)	2	2
Some Experience (> 6 months to 2 years)	4	6
Experienced (>2 years to 5 years)	3	3
Proficient (> 5 years to 10 years)	0	8
Expert (> 10 years)	0	19
Perceived Meditation Experience		
None	25	0
Novice	12	8
Experienced	0	28
Expert	0	2

6.2

Significant differences between cohorts in terms of objective / perceived meditation experience and current meditation practice.

Meditation by Cohort | Tests	Mean	SD	*t*	*p*
Meditation Experience (years)				
PA cohort	0.43	1.03		
Meditator cohort	15.2	13.23	6.86	<.001
Meditation Duration (hours per day)				
PA cohort	0.14	0.25		
Meditator cohort	1.2	0.81	7.62	<.001
	Level		**χ^2**	***p***
Perceived Meditation Experience				
PA cohort	"None"			
Meditator cohort	"Experienced"		55.8	<.001

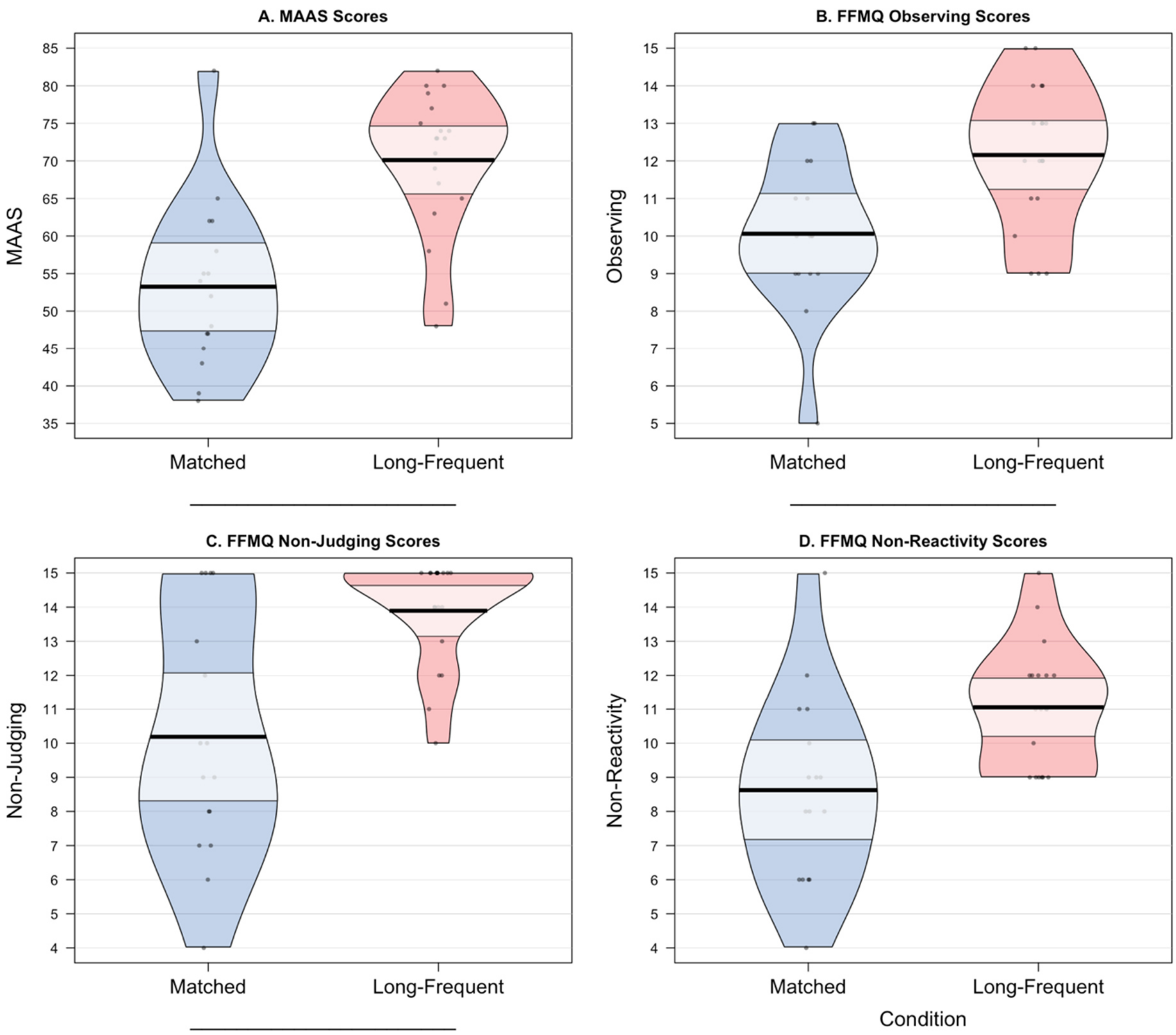
6.3

Partial correlations between age and self-report measures, controlling for meditation experience.

Partial Correlations | Age	*r*	*p*
Mindfulness		
Describe	0.34	<.01
Non-Judging	0.28	0.02
Non-Reactivity	0.28	0.02
Total FFMQ	0.35	<.01
Psychological Distress		
Depression [PHQ-9]	-0.35	<.01
Generalised Anxiety [GAD-7]	-0.26	0.04
Prospective Intolerance [IUS-P]	-0.48	<.001
Inhibitory Intolerance [IUS-I]	-0.29	0.02

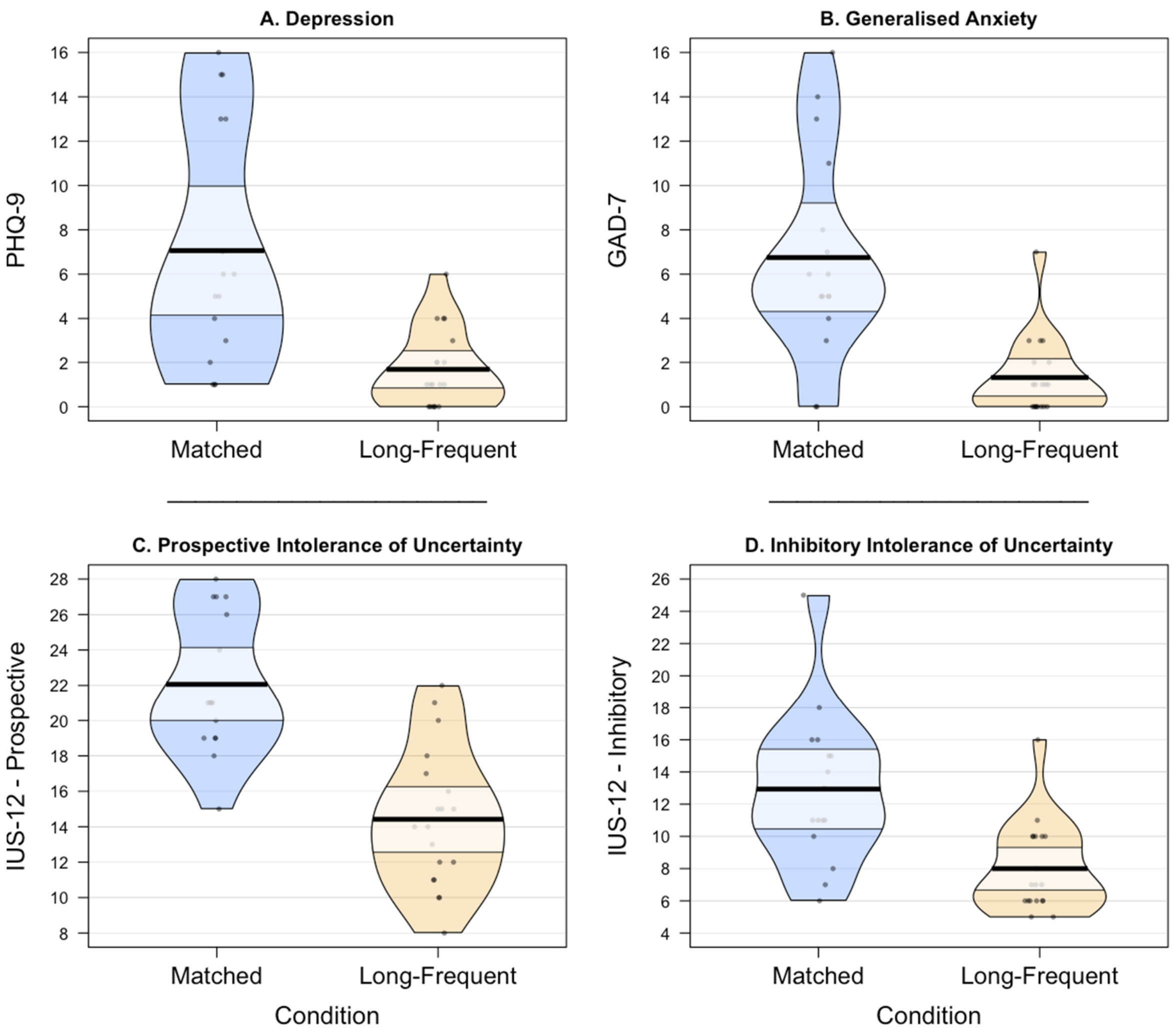
6.4

*Comparisons between long-frequent meditators and matched non-meditators in terms of (**A**) MAAS, (**B**) FFMQ Observe, (**B**) FFMQ Non-Judging and (**C**) FFMQ Non-Reactivity scores, controlling for age and gender. Inference bands reflect 95% confidence intervals. Total FFMQ comparisons not displayed.*



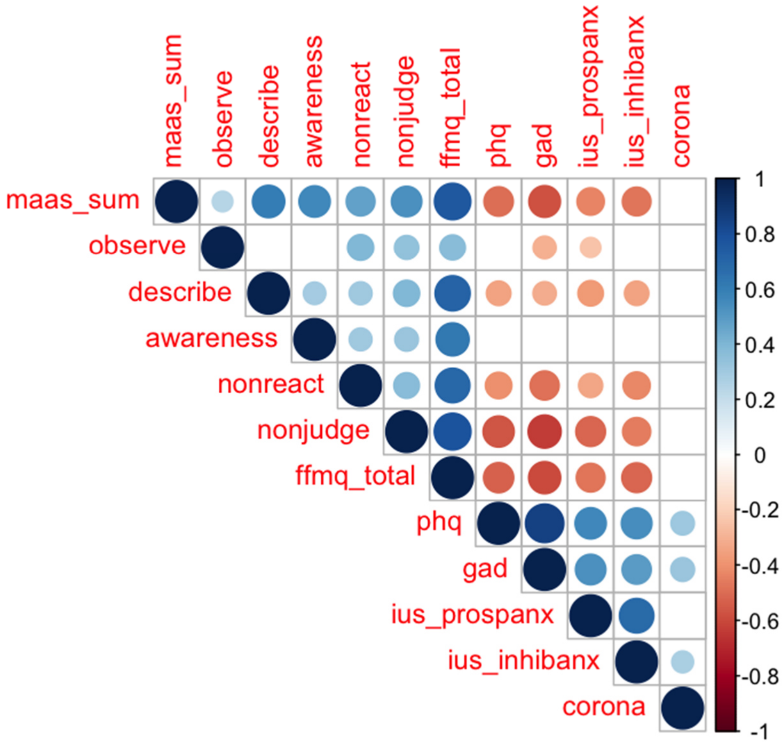
6.5

*Comparisons between long-frequent meditators and matched non-meditators in terms of (**A**) Depression [PHQ-9], (**B**) Generalised Anxiety [GAD-7], (**C**) Prospective Intolerance of Uncertainty [IUS-12], and (**D**) Inhibitory Intolerance of Uncertainty [IUS-12] scores, controlling for age and gender. Lower scores indicate better mental health. Inference bands reflect 95% confidence intervals.*



6.6

Inter-correlation matrix for self-reported mindfulness and distress: Significant correlation coefficients displayed as circles in squares. Darker shades and larger circles represent stronger associations. Blank squares represent non-significant correlations.



6.7

Unstandardised/standardised coefficients are reported with standard errors within brackets. Importantly, bias-corrected confidence intervals (CIs) with 5,000 samples were constructed for all indirect effects. CIs did not contain zero for any of the significant indirect effects.

~p = 0.05

**p < 0.05*

***p < 0.01*

A: Simple mediation analyses illustrating direct and indirect effects of meditation experience on indices of mental health, controlling for age and gender

	MAAS	Non-Judging	Non-Reactivity
Direct effects			
Meditation on mindfulness	0.36/0.35 (0.14)*	0.05/0.20 (0.03)	0.06/0.28 (0.03)
Mindfulness on depression [PHQ-9]	-0.13/-0.35 (0.04)**	-0.60/-0.40 (0.20)**	-0.40/-0.21 (0.21)
Mindfulness on generalised anxiety [GAD-7]	-0.13/-0.43 (0.03)**	-0.06/-0.50 (0.17)**	-0.51/-0.32 (0.22)*
Mindfulness on prospective anxiety [IUS-12-P]	-0.11/-0.22 (0.07)	-0.53/-0.27 (0.25)*	-0.11/-0.05 (0.30)
Mindfulness on inhibitory anxiety [IUS-12-I]	-0.12/-0.33 (0.04)**	-0.47/-0.32 (0.22)*	-0.43/-0.24 (0.23)
Mindfulness on coronavirus anxiety [CAS]	-0.01/-0.08 (0.02)	-0.06/-0.09 (0.06)	-0.08/-0.09 (0.11)
Indirect effects			
Meditation on PHQ-9 through mindfulness	-0.05/-0.12 (0.02)~	-0.03/-0.08 (0.02)	-0.02/-0.06 (0.02)
Meditation on GAD-7 through mindfulness	-0.05/-0.15 (0.02)*	-0.03/-0.10 (0.02)	-0.03/-0.10 (0.02)
Meditation on IUS-12-P through mindfulness	-0.04/-0.08 (0.03)	-0.03/-0.05 (0.02)	-0.01/-0.01 (0.02)
Meditation on IUS-12-I through mindfulness	-0.04/-0.11 (0.02)	-0.02/-0.06 (0.02)	-0.02/-0.07 (0.02)
Meditation on CAS through mindfulness	-0.005/-0.03 (0.01)	-0.003/-0.02 (0.02)	-0.004/-0.03 (0.01)

B: Multiple mediation analyses illustrating specific and total indirect effects of meditation experience on indices of mental health, controlling for age and gender

	Total Indirect Effect
Indirect Effects - Multiple Models	
Meditation on PHQ-9 through mindfulness	-0.07/-0.19 (0.03)*
Meditation on GAD-7 through mindfulness	-0.09/-0.27 (0.03)**
Meditation on IUS-12-P through mindfulness	-0.04/-0.08 (0.04)
Meditation on IUS-12-I through mindfulness	-0.05/-0.14 (0.03)
Meditation on CAS through mindfulness	-0.01/-0.07 (0.01)

C: Simple and multiple serial mediation analyses illustrating effects of meditation experience on coronavirus-related anxiety, controlling for age and gender

	Total Indirect Effect (multiple model)	MAAS (simple model)
Indirect Effects - Serial Models		
Meditation on CAS through mindfulness > PHQ	-0.12/-0.07 (0.01)	-0.01/-0.06 (0.006)
Meditation on CAS through mindfulness > GAD	-0.02/-0.11 (0.01)*	-0.013/-0.08 (0.007)~
Meditation on CAS through mindfulness > IUSP	-0.005/-0.03 (0.005)	-0.005/-0.30 (0.004)
Meditation on CAS through mindfulness > IUSI	-0.008/-0.05 (0.007)	-0.007/-0.04 (0.006)

6.8

Unstandardised/standardised coefficients are reported with standard errors within brackets. Importantly, bias-corrected confidence intervals (CIs) with 5,000 samples were constructed for all indirect effects. CIs did not contain zero for any of the significant indirect effects.

~p = 0.05

**p < 0.05*

***p < 0.01*

A: Simple mediation analyses illustrating direct and indirect effects of daily meditation duration on indices of mental health, controlling for meditation experience, age and gender

	MAAS	Non-Judging	Non-Reactivity	Total FFMQ
Direct effects				
Meditation on mindfulness	0.78/0.35 (0.23)**	0.17/0.30 (0.05)**	0.11/0.26 (0.05)*	3.60/0.34 (0.90)**
Mindfulness on depression [PHQ-9]	-0.11/-0.30 (0.04)**	-0.50/-0.34 (0.21)*	-0.29/-0.15 (0.23)	-0.14/-0.25 (0.07)
Mindfulness on generalised anxiety [GAD-7]	-0.12/-0.39 (0.03)**	-0.54/-0.44 (0.18)**	-0.42/-0.27 (0.23)	-0.17/-0.38 (0.06)**
Mindfulness on prospective anxiety [IUS-12-P]	-0.07/-0.15 (0.07)	-0.38/-0.19 (0.25)	0.09/0.03 (0.27)	-0.07/-0.10 (0.10)
Mindfulness on inhibitory anxiety [IUS-12-I]	-0.10/-0.26 (0.05)~	-0.36/-0.25 (0.23)	-0.30/-0.17 (0.25)	-0.13/-0.25 (0.07)
Mindfulness on coronavirus anxiety [CAS]	-0.01/-0.08 (0.02)	-0.06/-0.09 (0.07)	-0.07/-0.09 (0.11)	0.00/0.00 (0.03)
Indirect effects				
Meditation on PHQ-9 through mindfulness	-0.09/-0.10 (0.04)*	-0.08/-0.10 (0.04)	-0.03/-0.04 (0.03)	-0.50/-0.09 (0.33)
Meditation on GAD-7 through mindfulness	-0.09/-0.13 (0.03)**	-0.09/-0.13 (0.04)*	-0.05/-0.07 (0.04)	-0.62/-0.13 (0.30)*
Meditation on IUS-12-P through mindfulness	-0.06/-0.05 (0.06)	-0.06/-0.06 (0.05)	0.01/0.01 (0.03)	-0.26/-0.03 (0.42)
Meditation on IUS-12-I through mindfulness	-0.07/-0.09 (0.04)	-0.06/-0.07 (0.05)	-0.03/-0.04 (0.04)	-0.47/-0.08 (0.30)
Meditation on CAS through mindfulness	-0.01/-0.03 (0.02)	-0.01/-0.03 (0.01)	-0.01/-0.02 (0.02)	0.00/0.00 (0.11)

B: Multiple mediation analyses illustrating specific and total indirect effects of daily meditation duration on indices of mental health, controlling for meditation experience, age and gender

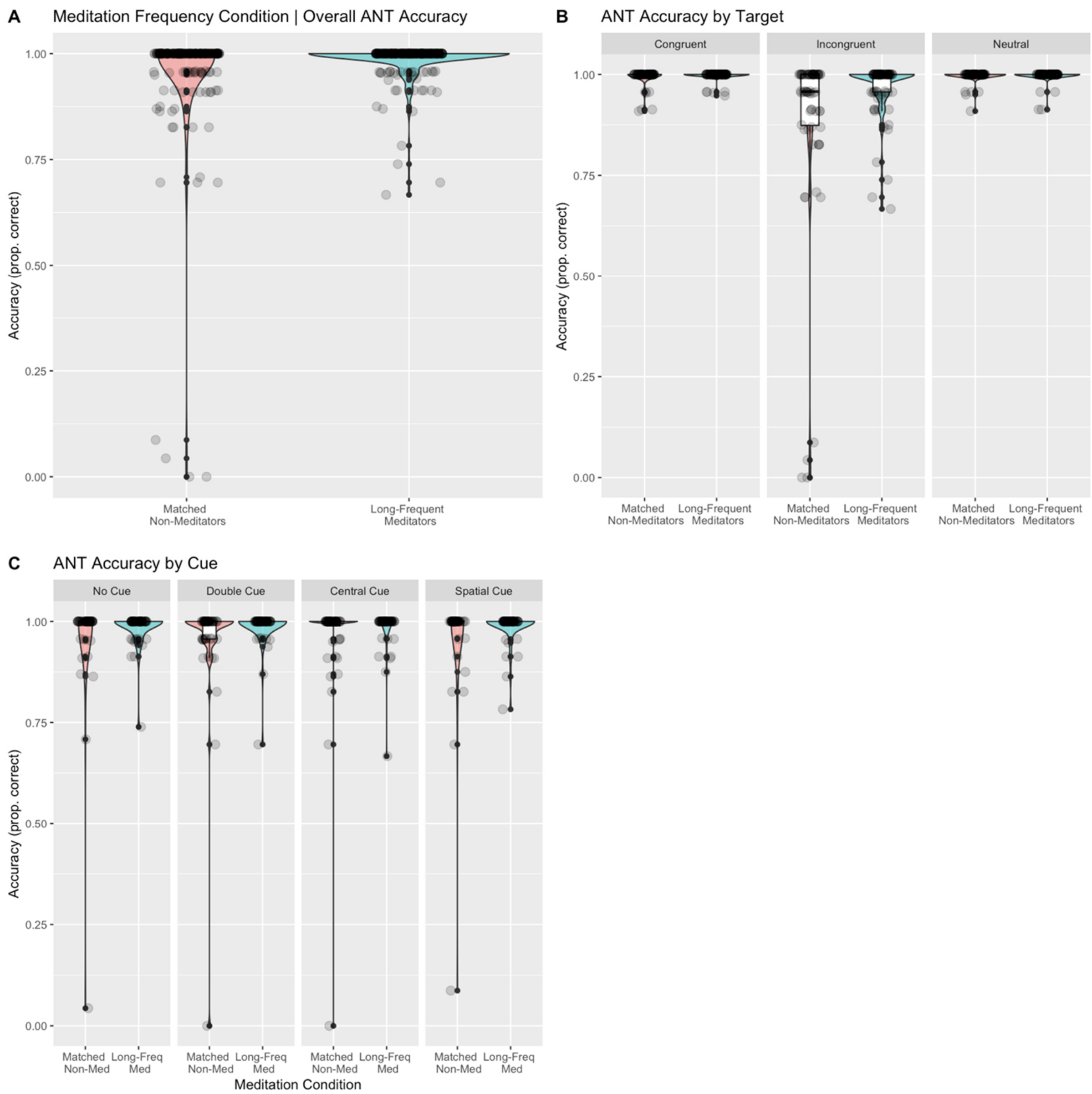
	Total Indirect Effect	MAAS	Non-Judging
Indirect Effects - Multiple Models			
Meditation on PHQ-9 through mindfulness	-0.15/-0.19 (0.07)*	-0.10/-0.13 (0.06)	-0.07/-0.08 (0.04)
Meditation on GAD-7 through mindfulness	-0.17/-0.26 (0.07)*	-0.11/-0.16 (0.05)*	-0.07/-0.11 (0.03)*
Meditation on IUS-12-P through mindfulness	-0.09/-0.08 (0.08)	-0.07/-0.06 (0.07)	-0.06/-0.05 (0.05)
Meditation on IUS-12-I through mindfulness	-0.11/-0.14 (0.07)	-0.05/-0.06 (0.05)	-0.04/-0.05 (0.05)
Meditation on CAS through mindfulness	-0.03/-0.08 (0.03)	-0.02/-0.07 (0.03)	-0.01/0.03 (0.01)

C: Simple and multiple serial mediation analyses illustrating effects of daily meditation duration on coronavirus-related anxiety, controlling for meditation experience, age and gender

	Total Indirect Effect (multiple model)	MAAS (simple model)	Non-Judging (simple model)	Total FFMQ (simple model)
Indirect Effects - Serial Models				
Meditation on CAS through mindfulness > PHQ	-0.03/-0.08 (0.02)	-0.02/-0.06 (0.01)	-0.02/-0.07 (0.01)	-0.02/-0.07 (0.01)*
Meditation on CAS through mindfulness > GAD	-0.04/-0.11 (0.02)*	-0.03/-0.08 (0.01)*	-0.03/-0.08 (0.01)*	-0.03/-0.09 (0.01)*
Meditation on CAS through mindfulness > IUSP	-0.01/-0.03 (0.01)	-0.01/-0.03 (0.01)	-0.01/-0.03 (0.01)	-0.01/-0.03 (0.01)
Meditation on CAS through mindfulness > IUSI	-0.02/-0.06 (0.01)	-0.02/-0.04 (0.01)	-0.01/-0.04 (0.01)	-0.01/-0.04 (0.01)

6.9

ANT accuracy as a function of meditation frequency condition. (A) overall ANT accuracy, (B) target accuracy and (C) cue accuracy. Medians and IQRs displayed in boxplots. Violins represent mirrored density plots and continuous distribution.



6.10

Multiple mediation analyses illustrating specific and multiple indirect effects and total effects of daily meditation duration on CPT performance outcomes, controlling for age, gender and meditation experience. Unstandardised/standardised coefficients are reported with standard errors within brackets.

Effects of Daily Meditation on CPT Outcomes (via FFMQ)	Simple Indirect Effects					Multiple Indirect Effect	Total Effect
	Observe	Describe	Awareness	Non-judging	Non-reactivity		
Mean Response Latency	-.001/-.01 (.004)	-.00/-.001 (.003)	.005/.05 (.005)	-.006/-.06 (.005)	.001/.01 (.005)	-.001/-.01 (.01)	.01/.09 (.01)
Attentional Lapses	-1.96/-.03 (2.98)	-.13/-.002 (1.60)	2.50/.04 (2.60)	-1.04/-.02 (2.20)	3.06/.05 (3.70)	2.42/.04 (5.25)	6.63/.10 (11.2)
False Alarms	-.11/-.02 (.26)	.006/.001 (.20)	.10/.02 (.20)	.26/.04 (.33)	-.27/.04 (.34)	-.02/-.003 (.50)	-.23/-.04 (.85)
Omission Errors	.61/.03 (.72)	-.03/-.002 (.32)	1.10/.05 (1.26)	-1.10/-.05 (1.05)	-1.16/-.06 (1.10)	-.60/-.03 (1.45)	.24/.01 (1.60)

Note: Bias-corrected bootstrapped confidence intervals with 5,000 samples were constructed for all indirect effects.