Examining the Efficacy of Mindfulness Training to Enhance Attention in Normal Aging

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

By

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Abstract

The ability to sustain attention by inhibiting competing distracting processes represents a core attentional function that underpins complex cognitive operations which are known to slow and become increasingly susceptible to interference with age. Mindfulness has emerged as a training technique purportedly capable of enhancing attentional control and may provide protective benefits for older adults against age-related cognitive decline (ARCD). Although evidence of the attentional benefits arising from mindfulness practice continues to grow, studies examining aging cohorts are lacking. This thesis examines the efficacy of mindfulness to enhance attention and affect in healthy older adults, as indexed by both behavioural and electrophysiological measures of performance.

In order to accurately assess mindfulness by means of testable hypotheses, a comprehensive theoretical model of mindfulness capable of describing the attentional processes activated by this practice together with the pathways through which attentional and affective outcomes are achieved is required. In addition, a standardised set of instructions translated from this model is required to assess outcomes arising from this practice. Chapter 2 of this thesis presents a detailed cognitive model of mindfulness along with a standardised technique capable of activating the core processes of mindfulness in isolation from additional factors. Mindfulness-based interventions commonly used to date combine mindfulness with ancillary techniques such as psychoeducation or relaxation techniques, limiting their ability to draw causal inferences regarding observed outcomes. Here a standardised technique translated from a theoretical model is presented for use in longitudinal RCTs.

The N2 and P3 event-related potential (ERP) components are of primary importance in the study of attentional processes, where N2 is thought to reflect early controlled attentional processing and P3 represents further cognitive processing of this information. To assess the efficacy of mindfulness to enhance attention in healthy older adults, a longitudinal active controlled RCT was conducted to examine attentional and affective outcomes. Chapter 3 presents the results of a two-tone auditory oddball task,
while Chapter 4 presents the results from a visual go/no-go task. Participants in the mindfulness group displayed enhanced sustained attention and inhibitory control performance together with reduced N2 and P3 latency at frontal sites, suggesting that the speed of attentional processes had improved. In addition, the mindfulness group displayed reductions in N2 amplitude at frontal and central regions, suggesting enhanced efficiency of attention resource allocation after training. These results indicate that mindfulness may enhance attentional processes known to decline in aging. Affective outcomes arising from mindfulness, as indexed by anterior alpha asymmetry, are presented in Chapter 5. Alpha asymmetry provides a measure of relative left or right-sided cortical activity in anterior regions at rest, and is considered a neurophysiological biomarker of dispositional affective style, where greater left-sided activity is associated with positive affective states and approach-related behaviour, while greater right-sided activity is associated with negative affective states and withdrawal-related behaviours. Participants who achieved a high level of mindfulness proficiency demonstrated a significant shift toward greater relative left-sided anterior cortical activity at rest, which was accompanied by higher levels of positive affect. These results suggest that 8 weeks of mindfulness training is sufficient to induce neurobiological changes reflective of a change in dispositional affect.

The results presented in this thesis make a substantial contribution to the limited literature examining the effectiveness of mindfulness to enhance attention in older adults. These results suggest that mindfulness is capable of enhancing attentional processes known to decline in aging by improving the speed and efficiency of anterior neural networks of attention, and these improvements may be accompanied by a dispositional change in affective style. Accordingly, mindfulness interventions may have a role in providing protective benefits against age-related cognitive declines.
Declaration of Originality

To the best of my knowledge, this thesis contains no material previously published or written by another person, except where duly acknowledged in the text. This thesis contains no material which has been presented for a degree or diploma at the University of the Sunshine Coast or any other university.

Ben Isbel                                      Date: 12\textsuperscript{th} December 2018
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List of Papers and Presentations

Peer-reviewed papers

   - This paper is presented as Chapter 2 of this thesis.

   - This paper is presented as Chapter 3 of this thesis.

   - This paper is presented as Chapter 5 of this thesis.

Papers currently accepted for publication pending revisions

   - This paper is presented as Chapter 4 of this thesis.
Additional relevant peer-reviewed publications

The following paper was written for the journal *Frontiers for Young Minds* to present mindfulness to young researchers, and has been accepted for publication.

  • This paper is presented as Appendix A of this thesis.

The following paper informed the theoretical framework of the present thesis.

doi:10.1016/j.concog.2015.10.005
  • This paper is presented as Appendix B of this thesis.

Conference presentations

1. Happiness and its Causes Conference, 21st-24th June, 2017 at the International Convention Centre, Sydney, Australia. Invited speaker – topic:
   *The Mechanics of Mindfulness: How Training the Mind Leads to Happiness*

2. Society for Mental Health Research (SMHR) Conference on 28-30th November, 2018 at the Sofitel Noosa Pacific Resort, Noosa, Australia. Poster presentation titled:
   *Mindfulness induces prefrontal cortical changes reflective of enhanced dispositional affect*

   *How Mindfulness Can Help Improve Mental Health*
Chapter 1:

Introduction and Aims
1.1 Introduction

**Attention and Aging**

The ability to sustain attention is a fundamental attentional process thought to determine the efficacy of cognitive capacity in general (Sarter, Givens, & Bruno, 2001). Sustained attention refers to the ability to endogenously and purposely maintain an object in awareness using top-down executive control to inhibit competing distracting processes (Sturm & Willmes, 2001). This type of inhibition forms a common executive function underlying other forms of attentional control, such as updating and shifting, and thus represents a core process upon which much of controlled cognitive processing is based (Miyake & Friedman, 2012). Deficits in inhibitory control and sustained attention are amongst the most pervasive of cognitive impairments, leading to a reduced ability to control attention together with a deterioration in working memory and learning capacity.

It has been well established that normal aging is accompanied by declining cognitive performance (Hedden & Gabrieli, 2004). While non-pathological age-related cognitive decline (ARCD) has been observed across a wide range of cognitive domains, it has been suggested that a deterioration of inhibitory control during controlled cognitive processing may represent a common underlying mechanism contributing to ARCD (Andrés, Guerrini, Phillips, & Perfect, 2008; Weeks & Hasher, 2015). Supporting evidence for this is provided by studies reporting age-related declines in both sustained attention (Fortenbaugh et al., 2015) and inhibitory control (Smittenaar et al., 2015). The relationship between sustained attention and inhibitory control, together with their concurrent declines in normal aging, are well demonstrated in behavioural tasks of attention where variability of responding is examined. Response variability during a sustained attention task is inversely related to successful inhibitory control activation, where greater variability is associated with attentional lapses and a loss of executive goal maintenance (Bellgrove, Hester, & Garavan, 2004; Unsworth, Redick, Lakey, & Young, 2010). Healthy aging (> 60yrs) has been shown to be accompanied by increased reaction time (RT) variability, and this variability is negatively correlated with measures of executive attentional processing (Hultsch, MacDonald, & Dixon, 2002; Vasquez, Binns, & Anderson, 2016). Furthermore, reaction time variability in older adults is a useful predictor of executive control performance and cognitive ability in general (West,
Murphy, Armilio, Craik, & Stuss, 2002). Lapses in sustained attention represent a failure of inhibitory control to inhibit prepotent secondary processes, and may involve a loss of goal maintenance together with a redirection of attention to distracting stimuli (Weissman, Roberts, Visscher, & Woldorff, 2006). Increasing susceptibility of attentional processes to interference in this manner is a characteristic feature of ARCD, contributing to greater response variability and reductions in sustained attention performance (Aurtenetxe et al., 2016; Healey, Campbell, & Hasher, 2008; Solesio-Jofre et al., 2011).

**Aging and Event-Related Potentials**

Further evidence of attentional decline with age is found from event-related potential (ERP) studies. Event-related potentials are electroencephalographic (EEG) waveforms representing the summed post-synaptic potentials of spatially aligned cortical pyramidal cells which are simultaneously activated in response to a stimulus (Luck & Kappenman, 2011). This activity is reflected in an ERP waveform consisting of a succession of positive and negative voltage fluctuations known as components which reflect underlying neural processes. Short latency components reflect predominantly pre-attentional neural responses, whereas longer latency components reflect attentional processing of information. Two long latency ERP components of particular interest in the study of cognition are the N2 and P3 components. During tasks of sustained attention that do not involve response conflict, a fronto-central N2 has been shown to index discrimination of stimuli as either congruent or deviant to a perceptual template (Folstein & van Petten, 2008). Tasks that involve either stimulus or response conflict elicit an N2 response reflecting inhibitory control and response selection, with this response appearing to be generated in the anterior cingulate cortex (Gajewski, Ferdinand, Kray, & Falkenstein, 2018; van Veen & Cameron, 2002). The P3 component has generally been thought to index firstly a frontally oriented response related to stimulus evaluation, followed by a temporoparietal response related to context updating and memory storage (Gaeta, Friedman, & Hunt, 2003; Polich, 2007). While there is evidence suggesting that this parietal P3 component may represent the completion of a stimulus-response event (Verleger, Jaśkowski, & Wascher, 2005), it is clear that both the N2 and P3 components reflect underlying neural processes involved in information processing.
The N2 and P3 event-related potentials provide high temporal resolution of brain resource allocation in response to a cognitive task, and thus represent sensitive measures with which to investigate attentional changes in aging. Along with slowing response times during behavioural tasks of attention, the latency of both the N2 and P3 components demonstrate continuous increases with advancing age (Patel & Azzam, 2005; Staub, Doignon-Camus, Bacon, & Bonnefond, 2014). The latency with which an ERP component is produced in response to a stimulus provides useful information regarding the speed of attentional processes (van Dinteren, Arns, Jongsma, & Kessels, 2014). Age-related increases in ERP latency are thought to reflect declining efficiency of the neural mechanisms underlying these attentional processes, and is consistent with a general slowing of controlled cognitive processes in aging (West, 2004). Shorter P3 latencies have generally been associated with superior cognitive performance, further suggesting that increasing P3 latency in aging may be an indicator of declining cognitive performance (Muscoso et al., 2006; Pelosi et al., 1992). In addition to longer latencies, aging is associated with reductions in the amplitude of the N2 and P3 components (Luck & Kappenman, 2011). Component amplitude is thought to reflect brain resource allocation during cognitive processing of stimuli, such that greater amplitudes indicate greater attentional allocation to task demands (Polich, 2007; van Dinteren et al., 2014). In contrast to automatic attentional processes (as indexed by the auditory mismatch negativity) which show little change in both latency and amplitude with age, controlled attentional processes (as indexed by N2 and P3) demonstrate continuous increases in latency and decreases in amplitude with advancing age (Amenedo & Diaz, 1998). These age-related changes to ERP components provide further evidence of a general decline of controlled attentional processes with age.

In addition to changes in latency and amplitude, the N2 and P3 components become more frontally oriented with age, suggesting an increased reliance upon controlled attentional processing during task performance with age (Anderer, Semlitsch, & Saletu, 1996; Mullis, Holcomb, Diner, & Dykman, 1985). Neural networks located in the prefrontal cortex (PFC) are known to play important roles in attention and executive functions, with evidence now suggesting that inhibitory control processes in particular may be differentially lateralised in the dorso-lateral PFC (Ambrosini & Vallesi, 2016; Pessoa, 2008; Posner & Petersen, 1990). Older adults demonstrate greater recruitment of top-down executive control during tasks of sustained attention compared to younger
controls, observed as greater activation of inhibitory control networks located in the PFC (Bellgrove et al., 2004; Staub et al., 2014). Increasing reliance in aging upon top-down inhibitory control is required to compensate for declining stability of attentional processes due to increasing susceptibility to interference (Adam, Mance, Keisuke, & Vogel, 2015; Weissman et al., 2006). Therefore, the profile of changes observed in aging is one in which the stability of attention declines, necessitating greater activation of frontal control networks, observed as more frontally oriented N2 and P3 responses, which themselves show longer latency and reduced amplitude.

**Cognitive Training in Older Adults**

While ARCD has been considered part of normal aging, evidence now suggests that ARCD may be reversible with cognitive training interventions (Gajewski & Falkenstein, 2012; Kelly et al., 2014). In a seminal study using older adults both with and without cognitive decline, Schaie and Willis (1986) demonstrated that between 40-60% of participants with age-related cognitive decline spanning 14 years showed a return to pre-decline levels of performance following a brief cognitive training intervention. Furthermore, of those who had stable cognitive performance over the preceding 14 year period, 40-50% showed significant improvements in attentional performance. These results suggest that cognitive training programs may be effective in not only improving attention in older adults without cognitive decline, but that they may also be effective in reversing some features of ARCD.

More recent studies support the thesis that both the behavioural and neural changes associated with ARCD may be reversible with cognitive training interventions. In a comparison of training interventions to improve cognitive function in healthy older adults, cognitive training was found to improve attentional performance, reduce RT variability, and increase fronto-central N2 and P3 amplitudes (Gajewski & Falkenstein 2012). No such changes were observed in either a physical training or relaxation condition, suggesting that cognitive training in this study was capable of producing both behavioural and neural changes indicative of improved attentional performance in healthy older adults. Further, enhancements in behavioural measures of cognition such as working memory, executive function, and processing speed have been widely reported (for reviews, see Mewborn, Lindbergh, & Miller, 2017; Reijnders, van Heugten, & van Boxtel, 2013). Increases in N2 and P3 amplitudes have also been
shown to accompany these improvements in healthy older adults following cognitive interventions, indicating an enhanced ability to deploy attentional resources to meet task demands after training (Küper, Gajewski, Frieg, & Falkenstein, 2017; O’Brien et al., 2013; Zendel, de Boissyson, Mellah, Démonet, & Belleville, 2016). While changes in ERP amplitudes are widely reported following cognitive training interventions in older adults, these studies report no change in component latency after training (Falkenstein & Gajewski, 2016). Limited evidence for reductions in ERP latency following physical exercise has been demonstrated after nine weeks of strength and endurance training in healthy older adults (Özkaya et al., 2005), suggesting that while cognitive programs may be effective at improving attentional resource allocation, physical exercise programs may be more effective at improving attentional processing speeds.

Cognitive Reserve

Improved attentional performance following cognitive training in older adults is thought to result from increased cognitive reserve. Cognitive reserve is a hypothetical construct referring to the neural mechanisms underlying cognitive processing which permit the maintenance of function while accommodating abnormal neuropathology associated with injury, lesion, or neurodegenerative disease that would otherwise impair cognitive performance (Stern, 2012). Higher levels of cognitive reserve provide protective benefits to cognitive function against age-related neuropathological changes such as those that occur in Alzheimer’s disease (Valenzuela & Sachdev, 2005). Rather than being a fixed quantity determined by measures of brain volume or neural mass, cognitive reserve is the result of the cumulative exposure at any point in one’s lifetime to intellectual enrichment that contributes to the ability of neural networks to accommodate pathological impairment (Stern, 2009). Two differing mechanisms may contribute to the accumulation of cognitive reserve. The first, known as neural reserve, refers to the efficiency, capacity, and flexibility of existing neural networks activated during task performance. The second, known as neural compensation, refers to the activation of alternate neural networks to maintain task performance in the presence of impairment or damage to networks previously activated to perform a task.

Since the efficiency of neural networks is known to decline with age (Stern et al., 2012), greater neural reserve in the form of enhanced neural capacity and efficiency should provide protective benefits against this type of age-related decline. Functional magnetic
resonance imaging (fMRI) studies report enhanced PFC cortical activation patterns reflective of improved neural capacity and efficiency following cognitive training interventions in healthy older adults. In a group of older adults at risk of cognitive impairment, a 6-month cognitive training intervention resulted in improved executive function together with increased neural activation in the left PFC during an Eriksen flanker task (Carlson et al., 2009). Greater activation in regions associated with executive control reflect an improved ability to mobilise attentional resources to meet task demands in this group, indicating greater neural capacity. Furthermore, a 5-week working memory training program in older adults was shown to increase neural efficiency, and these increases were positively associated with training-related performance improvements during the intervention (Brehmer et al., 2011). This study reported decreased cortical activity under high working memory load conditions corresponding with improved task performance, indicating that fewer attentional resources were required to perform the task to a higher level following the training intervention, suggesting greater neural efficiency. Additionally, studies in participants with multiple sclerosis have revealed that higher levels of cognitive reserve (measured through a battery of neuropsychological tests) act to attenuate brain atrophy-induced decline in information processing efficiency and cognitive performance over a four and a half year period (Sumowski et al., 2014; Sumowski et al., 2013).

While fMRI studies provide preliminary evidence of the efficacy of cognitive training programs to enhance neural reserve in aging, a more sensitive measure of neural efficiency may be obtained using ERP measures. Since ERPs provide high temporal resolution regarding the capacity and efficiency of the neural networks underlying attentional processes, they are ideally suited to the investigation of the efficacy of cognitive training to enhance cognitive reserve and improve attention in aging.

**Age-Related Cognitive Decline and Affect**

The cognitive declines associated with aging represent a significant risk factor for mood disorders such as depression and anxiety, which may then exacerbate and accelerate further cognitive decline (Alexopoulos, 2005; Djernes, 2006; Gualtieri & Johnson, 2008). Prevalence rates of symptoms of depression and anxiety remain high in late life, with increasing levels of comorbidity of depression and anxiety in older adults (Beekman et al., 2000; Teachman, 2006). Depression itself is considered one of the
most frequent causes of emotional suffering and decline in quality of life in the elderly, and has been identified as a significant risk factor for the later development of Alzheimer’s disease (Blazer, 2003; Ownby, Crocco, Acevedo, John, & Loewenstein, 2006). Mood disorders in the elderly contribute to accelerated declines in cognitive function and physical health that may persist for many years after remission of symptoms, especially for both executive function and memory performance (Köhler, Thomas, Barnett, & O’Brien, 2010; Yaka, Keskinoglu, Ucku, Yener, & Tunca, 2014).

**Emotion, Affect, and Attention**

The field of study into emotion regulation and affect is still in its infancy, hence while cognitive decline associated with advancing age has been well established, research examining the relationship between ARCD and changes in mood and affect are only emerging. Evidence from brain imaging studies confirm that cognition and affect are not processed separately in the brain, but demonstrate a high level of integration and interdependence, with PFC regions including the dorso-lateral PFC (dlPFC) playing a prominent role in both cognitive, emotional, and behavioural response inhibition (Banich et al., 2009; Damasio, 1994; Goldstein et al., 2007; Pessoa, 2008). Regions of the PFC cortex associated with executive inhibitory control and attention regulation such as the dlPFC, anterior cingulate cortex (ACC), and orbitofrontal PFC are activated during emotion regulation and exert a regulatory influence over amygdala responses (Banks, Eddy, Angstadt, Nathan, & Phan, 2007). The ability to exert inhibitory control over negative affective responses via these prefrontal-limbic networks contributes to individual differences in trait emotional control, such that greater functional connectivity in these networks is associated with improved inhibitory control performance and lower levels of negative affect (Rohr et al., 2015; Rosenkranz, Moore, & Grace, 2003; Urry et al., 2006).

The integrated nature of attentional and emotional control processes is further illustrated by studies examining the efficacy of cognitive training programs to enhance affective regulation. Reduced amygdala activation during an emotional response task has been demonstrated after six days of high-frequency executive control training using a simple flanker task (Cohen et al., 2016). Participants who engaged in low-frequency executive control training did not display similar increases in prefrontal-amygdala connectivity and regulatory capacity. These results clearly demonstrate that training cognitive
inhibitory control can enhance prefrontal-amygdala connectivity resulting in decreased amygdala reactivity in response to emotional challenge. Working memory training has also been shown to enhance the efficiency of frontoparietal networks associated with emotion control (Schweizer, Grahn, Hampshire, Mobbs, & Dalgleish, 2013). Compared to a placebo control group, participants who engaged in a 20 day n-back working memory training program displayed greater activity in frontoparietal networks including the medial and lateral PFC, as well as in networks recruited during affective regulation such as the subgenual ACC, and these outcomes were accompanied by improved working memory performance and emotion regulation. Working memory training has also been shown to enhance cognitive performance and reduce symptoms of trait anxiety (Sari, Koster, Pourtois, & Derakshan, 2016). Taken together, these results demonstrate that enhanced attentional control achieved through cognitive training is capable of providing far transfer effects on affective and emotion regulation, suggesting a shared neurobiological mechanism between cognitive and emotional information processing.

If cognitive and affective processes are regulated through integrated neural networks located in the PFC, then it may be possible that deteriorations in cognition observed in aging might be linked to changes in mood and affect. Executive dysfunction in aging may result from a deterioration of PFC networks involved in emotion regulation through frontostriatal pathways, leading to increasing risk of affective disorder (Alexopoulos, 2005). As discussed, interventions capable of improving cognitive performance by enhancing the efficiency of the neural networks upon which these functions rely may have a unique role to play in combating both cognitive and affective changes that occur in aging. The evidence presented thus far indicates that cognitive training programs may be effective in combating both ARCD and the accompanying increased risk of affective disorder by enhancing the efficiency and capacity of PFC neural networks underlying executive attention and emotion regulation.
1.2 Mindfulness

What is Mindfulness?
The processes involved in the generation and maintenance of mindfulness are examined in Chapter 2 where a comprehensive integrated cognitive model of mindfulness is presented, together with a standardised set of instructions designed to activate these cognitive processes. There currently exists a wide variety of interventions designed to train mindfulness, ranging from contemporary therapeutic mindfulness-based interventions (MBIs) such as mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) and mindfulness-based cognitive therapy (MBCT; Segal, Williams, & Teasdale, 2002), to traditional Buddhist techniques such as those found in Theravadin Vipassana practices and Mahayana Zen, Mahamudra, and Mahasandhi practices. The heterogeneity of these various techniques limits cross-study comparisons when differing practices have been used. Furthermore, since each cultivates mindfulness in conjunction with ancillary techniques, from therapeutic psychoeducation to religious contextualisation, they are not suitable for use in longitudinal randomised control trials (RCTs) seeking to draw clear causative conclusions regarding observed outcomes. For this reason, a standardised mindfulness technique capable of activating the cognitive processes involved in mindfulness separate to confounding ancillary components is required. To address this need, Chapter 2 presents a standardised set of mindfulness instructions translated from the cognitive model of mindfulness which does not introduce secondary factors to the mindfulness practice.

The cognitive faculty of mindfulness is described as consisting of two components: (1) an attentional component which maintains an object in awareness without loss, which is conjoined with (2) equanimity, which involves a non-elaborative orientation toward experience free from both cognitive and emotional reactivity. These two components describe the cognitive faculty of mindfulness as it attends to an object. Mindfulness practice, in which one intentionally generates and seeks to maintain this cognitive faculty, involves the activation of metacognitive monitoring and control functions to regulate attentional stability and clarity, as well as inhibit cognitive and emotional reactivity toward the contents of experience. As proficiency in this practice develops, a transition from analytically contrived states of mindful awareness involving effortful
application toward non-elaborative uncontrived states of equanimous attention begins to slowly take place. This development is accompanied by increasingly efficient allocation of attentional resources as these cognitive processes become progressively automated, culminating in an effortless deployment of vivid attention which is unperturbed by cognitive or emotional reactivity to experience.

Executive inhibitory control is a core process trained in mindfulness practice. During mindfulness training inhibitory control is activated in relation to both cognitive and affective responses in increasingly subtle and sophisticated ways as mindfulness proficiency develops. During early stages of training, inhibition prevents episodes of gross mind wandering in which goal-directed attention is lost. As proficiency improves inhibition attenuates affective responses towards experience, thereby assisting the development of sustained attention. With increased proficiency inhibition prevents a decline in attentional clarity and stability by regulating attentional effort to maintain optimal arousal. Finally, inhibition prevents cognitive elaboration upon experience, allowing for the development of a non-elaborative mode of attentional deployment. As previously discussed, inhibitory control represents a common executive function underlying other forms of attention regulation. Furthermore, this type of inhibitory control is common to emotional and affective regulation. Since the training of inhibitory control is central to mindfulness practice, it should be expected that mindfulness training would result in improved attentional and affective outcomes through enhanced inhibitory control performance.

**Mindfulness and Attention**

Improvements to attentional performance have been widely reported following mindfulness training. Previous studies have demonstrated that mindfulness is capable of enhancing performance on measures of sustained attention (Jha et al., 2015; MacLean et al., 2010; Valentine & Sweet, 1999), orienting attention (Jha, Krompinger, & Baime, 2007; Van den Hurk, Giommi, Gielen, Speckens, & Barendregt, 2009), processing speed (Slagter et al., 2007; van Leeuwen, Singer, & Melloni, 2012), and visuo-spatial attention (Geng, Zhang, & Zhang, 2011). Mindfulness-induced improvements to attentional performance are also associated with reductions in RT variability, indicating improved attentional stability (Lutz et al., 2009; Morrison, Goolsarran, Rogers, & Jha, 2014). Benefits to inhibitory control performance have also been reported (Fan, Tang,
Evidence of improved performance on behavioural measures of attention are further supported by ERP studies reporting faster and more efficient attention resource allocation following mindfulness training. Increased speed of attentional deployment during an attentional blink task following mindfulness training has been shown to be accompanied by reductions in P3 amplitude to the first of two stimuli presented in quick succession, indicating more efficient attentional processing of the first stimulus which allows for faster processing of subsequent stimuli (Slagter et al., 2007). The attentional blink task is designed to determine the shortest period in which two successive stimuli are discriminable, and thus during this task attention is allocated to a stream of rapidly presented stimuli. During tasks requiring focused attentional deployment to target stimuli, such as the Stroop task and auditory oddball task, greater attentional resource deployment as evidenced by increased N2 and P3 amplitudes to target stimuli has been demonstrated after mindfulness training, suggesting an enhanced ability to mobilize neural resources to meet task demands (Atchley et al., 2016; Delgado-Pastor, Perakakis, Subramanya, Telles, & Vila, 2013; Norris, Creem, Hendler, & Kober, 2018).

Cross-sectional studies in older adults suggest that mindfulness practice may provide protective benefits against age-related cognitive decline and deteriorations in brain structures. Long-term mindfulness practitioners have been shown to have faster and more efficient attentional resource allocation during an attentional blink task compared to age-matched controls (van Leeuwen, Muller, & Melloni, 2009), greater resting state functional network connectivity indicating increased resilience to age-related deteriorations in these networks (Gard et al., 2014), greater cortical thickness in anterior regions including the medial and superior PFC indicating resilience to age-related grey matter atrophy (Fox et al., 2014; Luders, Cherbuin, & Kurth, 2015), and greater structural white matter connectivity between the PFC and other brain regions including the thalamus and amygdala (Kang et al., 2013; Laneri et al., 2016). While these results suggest a long-term protective benefit of mindfulness practice to older adults at risk of
ARCD, there exists a paucity of studies examining the short-term efficacy of mindfulness to enhance attention and provide these kinds of protective benefits in older adults.

One longitudinal RCT examining the effect of short-term training in older adults offers preliminary support for mindfulness’s role in combating ARCD. Improved speed of responding during a Stroop task in healthy older adults (mean age 65 years) who completed an 8-week mindfulness intervention was accompanied by increases in N2 amplitude, suggesting that this practice is capable of enhancing attention in those at risk of ARCD (Malinowski, Moore, Mead, & Gruber, 2017). A longitudinal study on middle-aged adults (mean age 48 years) showed improvements to inhibitory control after a 3-month intensive mindfulness retreat, and these gains were partially maintained seven years after the conclusion of training, suggesting that attentional gains from mindfulness may have enduring protective benefits into later life (Zanesco, King, MacLean, & Saron, 2018). Beyond these two studies, there has been little investigation into the efficacy of mindfulness to enhance attention resource allocation in aging. In order to address this gap in the literature, Chapters 3 and 4 present the findings from a longitudinal RCT conducted using an active control condition to examine the effects of an 8-week mindfulness intervention to enhance attention in healthy older adults.

**Mindfulness and Affect**

Emotion regulation in mindfulness practice is not the result of suppression or reappraisal techniques, but rather involves equanimous observation without modification of emotional responses. Neuroimaging studies are beginning to confirm that emotion regulation in mindfulness involves increased prefrontal-amygdala functional connectivity resulting in amygdala activation patterns in response to emotional challenge that differ from those seen in emotional suppression or reappraisal (Doll et al., 2016; Murakami et al., 2015). These findings further support the view that frontally oriented cognitive control processes play a role in emotional and affective regulation. Reductions in negative affect and symptoms of anxiety, stress, and depression, along with enhanced positive affect and well-being, have been commonly reported following mindfulness training. Mindfulness training has been shown to lower symptoms of anxiety and depression (Goldin & Gross, 2010; Hofmann, Sawyer, Witt, & Oh, 2010; Orzech, Shapiro, Brown, & McKay, 2009), reduce expressions of fear and
anger (Robins, Keng, Ekblad, & Brantley, 2012), and decrease levels of negative affect (Chambers, Lo, & Allen, 2008; Jha et al., 2010). In addition to reducing negative affective states, evidence suggests that mindfulness is also capable of enhancing positive affective states (Garland, Geschwind, Peeters, & Wichers, 2015; Jain et al., 2007; Jha et al., 2010) and improving overall well-being (Brown & Ryan, 2003; Goyal et al., 2014; Orzech et al., 2009).

Dispositional affective style has been widely studied using an EEG measure known as anterior alpha asymmetry, which provides a measure of relative left or right-sided anterior cortical activity. Greater relative left-sided anterior activity has been associated with approach-related or behaviourally activating trait styles of motivation, including positive affective states, whereas greater relative right-sided anterior activity is associated with withdrawal-related or behaviourally inhibiting styles of motivation, including negative affective states such as depression (Coan & Allen, 2004; Davidson, 1992; Harmon-Jones & Gable, 2017; Smith, Reznik, Stewart, & Allen, 2017). When recorded during a resting state, anterior alpha asymmetry has demonstrated high test-retest reliability and internal consistency (Towers & Allen, 2009). The relationship between affect and anterior asymmetry has been demonstrated in a study of healthy older adults aged 57-60 years old, where greater left-sided anterior activity at rest was significantly associated with greater levels positive affect and well-being (Urry et al., 2004).

Studies examining the effect of mindfulness on resting anterior alpha asymmetry are scarce. In clinical samples with depressed patients, no change in anterior alpha asymmetry has been reported after eight weeks MBCT training (Barnhofer et al., 2007; Keune, Bostanov, Hautzinger, & Kotchoubey, 2011). In a study using healthy adults (mean age 36 years), eight weeks of MBSR training resulted in reductions in negative affect together with greater left-sided activation at central electrode locations, but not anterior sites (Davidson et al., 2003). Lastly, in a study of older adults (mean age 73 years) who completed eight weeks of MBSR training, no change in affect or anterior alpha asymmetry was reported over the course of the intervention (Moynihan et al., 2013). In order to address the paucity of literature regarding affective change and anterior alpha asymmetry in older adults resulting from mindfulness training, Chapter 5
presents affective and EEG anterior alpha asymmetry findings arising from eight weeks of mindfulness training in healthy older adults compared to an active control condition.

**Measuring Mindfulness**

Studies seeking to measure mindfulness have predominantly relied upon self-report instruments such as the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003) or the Five-Facet Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). While there is some evidence to support the sensitivity of self-report scales to detect changes in mindfulness (Gu et al., 2016), there remain significant shortcomings with these measures ranging from response bias, differing semantic interpretation of scale items between samples, and a reliance on participants’ ability to accurately assess their own level of internal awareness, which may vary greatly according to mindfulness proficiency (Grossman, 2011). Significantly, self-report measures of mindfulness have previously been shown incapable of accurately distinguishing between participants who completed an MBSR course and those who completed an active control condition specifically designed not to include mindfulness training (Goldberg et al., 2016).

An alternative to measuring mindfulness by self-report is to record the amount of time participants spend engaging in formal mindfulness practice as an index of mindfulness experience, and then correlate this metric with observed outcomes (Crane et al., 2014; Parsons, Crane, Parsons, Fjorback, & Kuyken, 2017). However, since mindfulness training is aimed at transforming how participants attend to their experience both during and after formal sessions of training, a simple measure of time spent in formal practice will be incapable of capturing informal practice during activities of daily living (Davidson & Kaszniak, 2015). In addition, participants engaged in a mindfulness intervention will learn the technique at varying speeds and to varying degrees (Eliassen & Høifødt, 2016). As a result, simple practice time may not provide an accurate measure of mindfulness proficiency.

Breath-counting tasks which require mindful attention to the breath have been shown to reliably measure mindfulness proficiency and distinguish between novice and experienced practitioners (Levinson, Stoll, Kindy, Merry, & Davidson, 2014; Wong, Massar, Chee, & Lim, 2018). Measuring mindfulness proficiency is important since it
has been well demonstrated that the benefits of mindfulness training are proportional to
the depth of proficiency achieved. Higher levels of mindfulness proficiency have been
associated with improved performance on tasks of attention (Van den Hurk et al., 2009),
inhibitory control (Chan & Woollacott, 2007), and working memory (Jha et al., 2010),
together with increased functional connectivity within attentional networks (Hasenkamp
& Barsalou, 2012). Furthermore, a behavioural measure of mindfulness such as a
breath-counting task provides a reliable test to assess the effectiveness of an MBI to
enhance mindfulness, and to identify intervention responders from non-responders.
Rather than assume that completion of an MBI assures mindfulness proficiency, the use
of behavioural measures allows the quantification of any increase in mindfulness
proficiency over the course of the intervention. In line with these considerations, Study
3 and Study 4 of this thesis report differential outcomes on measures of both attention
and affect in relation to mindfulness proficiency as determined by the use of a breath-
counting task.
1.3 Aims and objectives

There were three main aims of this thesis.

1. The development of a comprehensive explanatory model of mindfulness together with a standardised set of practical instructions translated from this model for use in longitudinal RCTs.

Of critical importance is the ability of such a model to permit the formulation of testable hypotheses regarding outcomes arising from mindfulness practice through a clear elucidation of the cognitive and affective processes involved. As such, the model should be capable of describing three components:

   a. The core attentional processes activated during mindfulness practice.
   b. The pathways through which attentional and affective outcomes are achieved.
   c. Developmental changes that occur with increasing proficiency in mindfulness practice.

2. An examination of the efficacy of mindfulness training to enhance attention according to the pathways described in the cognitive model of mindfulness.

Of central importance is determining whether or not mindfulness can enhance attentional performance in older adults at risk of age-related cognitive decline. If it is shown that mindfulness is capable of enhancing attentional performance, then such interventions may be capable of providing protective benefits that reduce the risk of later cognitive decline and dementia in healthy older adults.

This aim will be achieved through an RCT evaluating both behavioural and ERP markers of attentional performance following 8-weeks of mindfulness training compared to an active control condition in:

   a. An auditory discrimination task (auditory oddball task).
   b. A visual go/no-go task (sustained attention to response task).
3. Assessing the efficacy of mindfulness to induce dispositional changes in affective style according to the pathways described in the cognitive model of mindfulness.

This aim will be achieved through an RCT evaluating self-report and anterior alpha asymmetry measures of dispositional affective style following 8-weeks of mindfulness training compared to an active control condition to determine the long-term stability of affective outcomes arising from mindfulness training.

By undertaking these studies, this thesis will make a major contribution to the scientific understanding of the cognitive processes of mindfulness by subjecting a comprehensive theoretical model of mindfulness to rigorous empirical investigation. Through demonstrating the efficacy of this practice to enhance attention in healthy older adults at risk of ARCD, the findings of these studies may indicate that mindfulness interventions have a role to play in reducing the risk of developing cognitive impairment and dementia in later life.
Chapter 2:

Distinguishing the cognitive processes of mindfulness: Developing a standardised mindfulness technique for use in longitudinal randomised control trials
Distinguishing the cognitive processes of mindfulness: Developing a standardised mindfulness technique for use in longitudinal randomised control trials

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ABSTRACT

A capacity model of mindfulness is adopted to differentiate the cognitive faculty of mindfulness from the metacognitive processes required to cultivate this faculty in mindfulness training. The model provides an explanatory framework incorporating both the developmental progression from focussed attention to open monitoring styles of mindfulness practice, along with the development of equanimity and insight. A standardised technique for activating these processes without the addition of secondary components is then introduced. Mindfulness-based interventions currently available for use in randomised control trials introduce components ancillary to the cognitive processes of mindfulness, limiting their ability to draw clear causative inferences. The standardised technique presented here does not introduce such ancillary factors, rendering it a valuable tool with which to investigate the processes activated in mindfulness practice.

1. Introduction

Empirical studies to date have produced a large corpus of evidence supporting the beneficial effect of mindfulness-based interventions (MBIs) in the treatment of psychological disorders (see Gotink et al., 2015; Goyal et al., 2014; Khoury et al., 2013). At the same time, the mechanisms underlying these beneficial outcomes have yet to be clearly identified (Gu, Strauss, Bond, & Cavanagh, 2015). Investigation into these mechanisms has produced support for mindfulness-induced changes to sustained attention (Jha et al., 2015; Semple, 2010), executive function (Heeren, Van Broeck, & Philippot, 2009), working memory (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013), mood and affect (Eberth & Sedlmeier, 2012; Garland, Geschwind, Peeters, & Wichers, 2015), and emotion regulation (Chambers, Gullone, & Allen, 2009; Teper, Segal, & Inzlicht, 2013). For a wide-ranging review of the effects of mindfulness training on psychological outcomes, see Sedlmeier et al. (2012). While studies to date have contributed greatly to our understanding of mindfulness and its effects, many authors have raised significant concerns regarding the methodological rigour of much of this evidence, citing a lack of randomisation, the use of cross-sectional rather than longitudinal designs, absence of active control conditions, the use of mindfulness interventions with varying components, together with the lack of an accepted integrated theoretical model of mindfulness (see Dahl, Lutz, & Davidson, 2015; Davidson & Kaszniak, 2015; Tang, Hölzel, & Posner, 2015). These issues are reflective of a field of research still in its infancy (Tang & Posner, 2013).

In response to these concerns, the use of longitudinal randomised controlled trials (RCTs) has begun to increase as the field now matures toward more rigorous methodological designs. Well-designed RCTs enable researchers to directly examine the influence of...
mindfulness on cognitive processes while reducing the influence of confounding factors (Jensen, Vangkilde, Frokjaer, & Hasselbalch, 2012). However, the move toward the use of longitudinal RCTs itself raises two further challenges. Firstly, in the absence of an integrated theoretical model of mindfulness, accurate hypothesis formulation and experimental design is impeded. Secondly, as long as the interventions utilised contain factors ancillary to the core practice of cultivating mindfulness, precise causal inferences between the various elements of the intervention and observed outcomes remain limited, even in the presence of rigorous methodological design. For example, in a recent longitudinal RCT studying the effects of a short-term mindfulness intervention, the authors reported that they were unable to determine which of the elements of the intervention was responsible for the observed attentional improvements in the mindfulness group since the intervention utilised mindfulness training together with several ancillary factors, including body relaxation and mental imagery (Tang et al., 2007). Reviews of the field have highlighted the need for a mindfulness technique that does not include confounding factors that can be used to make both accurate causal inferences regarding experimental outcomes and meaningful cross-study comparisons (Chiesa, Calati, & Serretti, 2011; Chiesa & Malinowski, 2011; Gallant, 2016). The use of such an intervention would allow greater understanding of the cognitive processes underlying mindfulness practice, thereby enabling the refinement of therapeutic MBIs to maximise beneficial outcomes (Gu et al., 2015).

This paper aims to address these issues by firstly introducing a theoretical model describing the cognitive processes recruited through mindfulness practice, and secondly, using this theoretical framework to develop a mindfulness technique for use in longitudinal RCTs that does not include confounding ancillary factors. While a range of views regarding what constitutes mindfulness exists amongst clinical and theoretical frameworks, the commonality across the range of MBIs is an emphasis on paying attention to the present-moment in a non-judgemental manner (Kabat-Zinn, 2004; Malinowski, 2013; Tang et al., 2015). The generation and maintenance of non-judgemental attention to the present-moment represents the core mindfulness practice (Bishop et al., 2004; Lutz, Jha, Dunne, & Saron, 2015; Shapiro, Carlson, Astin, & Freedman, 2006), and it is this process that warrants further investigation in order to identify the cognitive mechanisms cultivated in mindfulness-based applications.

The development of an evidence-based effective mindfulness technique relies upon a close analysis of the cognitive mechanisms involved in mindfulness practice (Chiesa & Malinowski, 2011). This requires precisely identifying and separating those faculties required to establish and maintain mindfulness from those that either derive from this process or are ancillary to it (Bishop et al., 2004; Brown, Ryan, & Creswell, 2007). The following analysis demonstrates how a fine-grained investigation of mindfulness can serve to elucidate these cognitive components.

2. Developing specificity in describing mindfulness

The term mindfulness has been variously used to refer to: (a) a trait quality; (b) a broad path constituting either a spiritual or lifestyle approach; (c) a therapeutic approach utilising an array of factors; or, (d) a cognitive process (Lutz et al., 2015; Vago & Silbersweig, 2012). It is important to note that the following discussion regarding the components and processes of mindfulness sits within the last usage of the term described above, of mindfulness as a cognitive process.

In order to precisely examine the cognitive processes recruited during mindfulness it is essential to distinguish between (a) the cognitive faculty of mindfulness, and (b) the process of cultivating the cognitive faculty of mindfulness. The cognitive faculty of mindfulness refers to non-judgemental attention, the cognitive faculty to be aroused and maintained in mindfulness practice. The process of cultivating and maintaining this cognitive faculty is known as mindfulness practice. This distinction between the faculty and practice of mindfulness corresponds to traditional accounts describing the mental factors of mindfulness and introspection as fundamental components of this practice (Bodhi, 2011; Purser & Milillo, 2015; Wallace, 2006). While such a distinction has its roots in traditional Buddhist psychological models, this division allows the components of mindfulness to be mapped on to contemporary psychological concepts while retaining their unique and distinguishing features (Kuan, 2012; Thera, 1962). Mindfulness has recently become the subject of increased debate as both clinicians and researchers attempt to interpret a practice whose origins lie in traditional Buddhist sources (Chiesa & Malinowski, 2011; Dreyfus, 2011; Monteiro, Musten, & Compson, 2015). This debate is due in part to the fact that when mindfulness was initially adopted into therapeutic applications it lacked reference to contemporary cognitive psychological theory. Accordingly, the terminology used here in making the distinction between the faculty and the practice of mindfulness permits modern conceptualisations of attention to be directly linked to the underlying cognitive processes of mindfulness.

2.1. The cognitive faculty of mindfulness

The cognitive faculty of mindfulness (a) retains an object in awareness such that it is continuously present as the object of attentional processes in (b) a non-elaborative manner free of affective and cognitive reactivity (Bishop et al., 2004). As such, the cognitive faculty of mindfulness comprises two sub-components: (1) an attentional component; and (2) equanimity, a quality of even-minded stability such that attention is unperturbed and balanced, and captures the ‘non-judgemental’, ‘non-elaborative,’ and ‘non-reactive’ elements found in many definitions of mindfulness (Desbordes et al., 2015). In advanced stages of practice these sub-components describe two qualities of the awareness that pays attention rather than discrete processes operating independently. However, in a novice practitioner the quality of equanimity is not fully developed, and is present as a mentally adopted similitude of actual equanimity (Bishop et al., 2004; Shapiro et al., 2006).

2.1.1. The attentional component of the cognitive faculty of mindfulness

The attentional component of the cognitive faculty of mindfulness is the quality of mind that continuously attends to an object...
without its loss from awareness. Cognitive psychological theories of attention (Kahneman, 1973; Posner & Boies, 1971; Sturm & Willmes, 2001; Zomeren & Brouwer, 1994) describe this quality of mind as having two aspects, one that relates to its intensity, and another that relates to its selectivity. Intensity manifests as alertness and sustained attention. Alertness corresponds to arousal, either as a general state (tonic alertness) or momentary change (phasic alertness), whereas sustained attention is a product of endogenously and purposefully maintaining arousal through mental effort and top-down control (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Tang et al., 2015). The selective aspect of attention refers to the object taken by awareness, which in mindfulness practice is present-moment experience. Following this theoretical framework, the attentional component of the cognitive faculty of mindfulness can be described as sustained attention to present-moment experience, which is the result of intentional mental effort and executive attentional process.

This conceptualisation accords with a capacity model of attention (Kahneman, 1973), in which a limited capacity of attention is available to perform tasks, and this capacity varies from moment to moment with arousal. The modulation of mental effort via the use of metacognitive introspection is considered a key instruction in traditional mindfulness practices, where both an excess and an insufficiency of arousal lead to impaired performance of attention (Goldstein, 2013; Tsongkhapa, 2002; Wallace, 2011). This concordance between traditional mindfulness and contemporary cognitive theories of attention provides an elegant framework for discussing the cognitive mechanisms recruited in mindfulness practice.

In a capacity model approach to the cognitive faculty of mindfulness, attentional performance is a product of the demands on a limited supply of attentional capacity, the evaluation of those demands, and the resulting allocation of capacity to those demands (Kahneman, 1973). Mental effort is required for the primary task of sustaining attention towards present-moment experience, and this effort places demands on capacity. Interference with performance on this primary task occurs when other processes directly compete for available capacity. A lapse of sustained attention may occur when there is insufficient capacity, or where capacity has been allocated to competing tasks. For instance, when a distracting stimulus captures attentional capacity a failure of the primary task occurs. Additionally, deterioration of performance on the primary task may result from a state of low arousal, which diminishes available capacity below the threshold required by task demands (Kahneman, 1973). Thus, the performance of the attentional component of the cognitive faculty of mindfulness is reliant on available capacity at any given moment. Available capacity is affected by arousal, which determines the total capacity available, and interference from competing processes, which determines the amount available for primary task demands.

Arousal and interference are the main determinants of attentional performance in mindfulness practice. Modulation of arousal is required to ensure that sufficient capacity is available for the primary task of sustaining attention towards present-moment experience, as well as for processes monitoring and controlling attention (Vago & Silbersweig, 2012). Hyper-arousal leads to increased lability of attention, mental scattering, and distraction, while hypo-arousal leads to insufficient capacity for primary task demands, mental lethargy, and a lack of perceptual clarity (Kahneman, 1973). During early stages, when practitioners are learning the technique, sustained attention to present-moment experience operates as a controlled process demanding high attentional capacity and is susceptible to interference (Lutz et al., 2015; Schneider & Shiffrin, 1977; Tang et al., 2015). The susceptibility of sustained attention to interference requires the novice practitioner to closely monitor and control attention to prevent task failures, however these metacognitive processes directly compete for attentional capacity resulting in further interference (Parasuraman, 1979). Thus a novice is faced with maintaining high levels of mental effort to maintain a primary task that is susceptible to interference, resulting in a marked vigilance decrement over time (Warm, Parasuraman, & Matthews, 2008). As a result, the early stages of practice are characterised by frequent failures of sustained attention as arousal fluctuates and mind-wandering, attentional control and monitoring processes, sensations of discomfort, and distraction all compete for limited capacity and cause task interference.

The primary task becomes increasingly automated as proficiency improves, leaving greater residual attentional capacity available (Bargh & Chartrand, 1999; Schneider & Shiffrin, 1977). Advancing stages of practice are characterised by increasing attentional efficiency and stability, as less mental effort is required to maintain attentional processes (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; Slagter, Lutz, Greischar, Nieuwenhuis, & Davidson, 2009; Slagter et al., 2007). By attending with greater capacity, objects are apprehended in greater detail, leading to enhanced interpretation by later stages of perceptual processing (Kahneman, 1973). At advanced stages of practice this quality of awareness is present as vivid clarity and a high degree of perceptual acuity (Lutz et al., 2015; Vago & Silbersweig, 2012; Wallace, 2006; Zanesco, King, Maclean, & Saron, 2013), which not only permits greater interpretation of objects by later stages of perceptual processing but also facilitates insight (Dreyfus, 2011; Holzel, Lazar, et al., 2011). According to this framework, failures of sustained attention reduce with proficiency and attention becomes stabilised, while the vividness and clarity of awareness is enhanced due to greater capacity applied at early stages of perceptual processing.

The importance of sustained attention to present-moment experience in mindfulness practice is reflected by its primary role in theoretical models of mindfulness (Bishop et al., 2004; Dahl et al., 2015; Shapiro et al., 2006). In a therapeutic context, Segal, Williams, and Teasdale (2002) state that sustained and focussed attention is the central component to all other aspects of mindfulness-based cognitive therapy. This role is supported by empirical evidence reporting enhanced performance of sustained attention as a frequent outcome of mindfulness practice (Chambers, Lo, & Allen, 2008; Chiesa et al., 2011; Jha, Krompinger, & Bai, 2007; Lutz et al., 2009; MacLean et al., 2010; Moore & Malinowski, 2009; Valentine & Sweet, 1999). Sustained attention itself is foundational to higher cognitive processes such as executive forms of attention, working memory, learning capacity, and more broadly to cognitive capacity in general (Bishop et al., 2004; Sarter, Givens, & Bruno, 2001). Therefore, enhancements to sustained attention with mindfulness practice may provide a pathway for transferable benefit to other cognitive functions. Evidence for such a pathway is found in studies reporting mindfulness-related improvements to executive function (Moore & Malinowski, 2009; Tang et al., 2007; Van den Hurk, Giommi, Gielen, Speckens, & Barendregt, 2009), working memory (Chambers et al., 2008; Jha, Stanley,
accompanying the breath in order to develop the strength of mindfulness before turning awareness towards the entire on-going focused upon in the present-moment varies. Mindfulness practices often begin by directing attention to a localised set of sensations present-moment awareness and equanimity to bring about bene

Rosenkranz et al., 2013; Tomfohr, Pung, Mills, & Edwards, 2014

psychological health bene

physiological and psychological outcomes, whereas attending with a non-judgemental and accepting attitude provides physical and uncontrived equanimity found in advanced stages of practice, a beginner

Jankowski & Holas, 2014

strategy of no-response when either reactivity to experience or mind-wandering occurs (Johnson, Diamond, David, & Goolkasian, 2010) and visuo-spatial processing (Geng, Zhang, & Zhang, 2011).

2.1.2. The equanimity component of the cognitive faculty of mindfulness

The attentional component of the cognitive faculty of mindfulness is coupled with equanimity to facilitate a non-elaborative mode of paying attention. Equanimity is a quality of mind characterised by a non-reactive orientation toward the contents of experience and experience itself, involving cognitive and affective impartiality free of bias and evaluative discrimination (Desbordes et al., 2015). Equanimity supports the development of sustained attention by reducing cognitive and emotional proliferation upon the contents of awareness, thereby reducing mind-wandering (Vago & Silbersweig, 2012). Empirical studies reporting reductions in mind-wandering with mindfulness practice provide support for the role of equanimity to diminish task-unrelated processes (Levinson, Stoll, Kindy, Merry, & Davidson, 2014; Mrazek, Smallwood, & Schooler, 2012; Mrazek et al., 2013). Reduced mind-wandering results in reduced capture of attentional capacity by task-unrelated processes, as well a reduction in the activation of attentional control mechanisms required to redirect attention back to the primary task (Lutz, Slagter, Dunne, & Davidson, 2008). In this way, equanimity acts to reduce interference to, and thus increase available capacity for, a non-elaborative mode of paying attention by reducing reactivity to experience.

Equanimity further ensures optimal capacity for sustained attention by manifesting as a balanced level of mental effort. Optimal levels of attentional performance are achieved when arousal is neither too high, which causes increased liability of attention and an inability to precisely control the allocation of capacity, nor too low, which interferes with the ability to accurately monitor ongoing performance and may prevent the adoption of the primary task (Kahneman, 1973; Yerkes & Dodson, 1908). Traditional sources indicate that at advanced stages of practice equanimity balances mental effort so that attention is neither too tight nor too lax, allowing for monitoring and control processes themselves to be de-emphasised as attention stabilises and remains continuously upon its object (Tsongkhapa, 2002; Vago & Silbersweig, 2012). The avoidance of extremes of arousal by endogenously modulating mental effort maintains attentional performance at optimal levels (Yerkes & Dodson, 1908).

During the early stages of practice, both components of the cognitive faculty of mindfulness are weak, and a novice suffers from frequent failures of sustained attention, reactive and evaluative responses to the contents of experience, and mental lethargy and excitement (Lutz et al., 2015; Thera, 1962). In this case, a similitude of actual equanimity is cultivated by adopting a non-judgemental and accepting attitude toward experience that helps stabilise the attentional component by reducing cognitive and affective proliferation (Bishop et al., 2004; Shapiro et al., 2006). This attitude manifests as an implicational intention, an ‘if-then’ strategy of no-response when either reactivity to experience or mind-wandering occurs (Gollwitzer & Bargh, 2005; Jankowski & Holas, 2014). This strategy is proposed to diminish cognitive and emotional responding, reducing processes that interfere with the primary task, leaving greater capacity available for non-elaborative attending. Although this attitude is not the uncontrived equanimity found in advanced stages of practice, a beginner’s adoption of a similitude of equanimity acts to stabilise attention and cultivate increasing levels of even-minded stability as experience grows (Gu et al., 2016; Wallace, 2006). As practitioners are increasingly able to adopt an orientation towards experience free of evaluation, judgement, and action, equanimity itself is proposed to be the foundation from which higher insights regarding the relational quality of experience are gained (Hopkins, 2014; Salzberg, 2011; Wallace, 2006).

In the absence of equanimity, present-moment awareness may trigger reactive responses to experience resulting in adverse physiological and psychological outcomes, whereas attending with a non-judgemental and accepting attitude provides physical and psychological health benefits (Desrosiers, Vine, Curtiss, & Klemanski, 2014; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Rosenkrantz et al., 2013; Tomfohr, Pung, Mills, & Edwards, 2014). This relationship highlights the importance of conjoining present-moment awareness and equanimity to bring about beneficial outcomes in MBIs.

While the selective aspect of attention in most mindfulness applications is directed toward present-moment experience, the object focused upon in the present-moment varies. Mindfulness practices often begin by directing attention to a localised set of sensations accompanying the breath in order to develop the strength of mindfulness before turning awareness towards the entire on-going field of present-moment experience, or even awareness itself (Kabat-Zinn, 1990; Lutz et al., 2008; Malinowski, 2008; Segal et al., 2002). Practitioners spend considerable time cultivating stability of attention through practices focussed upon the sensations accompanying the breath as this technique provides a comprehensive training ground for gaining proficiency in all of the essential cognitive processes required in later stages of mindfulness practice (Lutz et al., 2015; Wallace, 2006). Only after gaining proficiency in sustained focused attention do practitioners begin to slowly transition to more non-referential forms of mindfulness (Lutz et al., 2008). Thus, although there are differing techniques, the fundamental process operating is a common one (Dahl et al., 2015), a non-judgemental attention to present-moment experience. This is the cognitive faculty of mindfulness.

2.2. Mindfulness as a process of training

Traditional Buddhist sources provide a rich description of the way in which the cognitive faculty of mindfulness can be enhanced through training (Bodhi, 1993; Buddhaghosa, 2010; Tsongkhapa, 2002). Despite some methodological shortcomings, empirical evidence is beginning to support this premise, and there now exists broad agreement in contemporary mindfulness research that mindfulness can be enhanced through structured training (for commentary and reviews see Chiesa & Malinowski, 2011; Lutz et al., 2009, 2015; Posner, Rothbart, & Tang, 2015; Tang et al., 2015). This process of training requires the cognitive faculty of mindfulness to be coupled with metacognitive processes to monitor and control attention (Vago & Silbersweig, 2012).

Metacognition has been defined as the process of re-representing the contents of consciousness in awareness, taking cognition
itself as an object of attention (Flavell, 1979; Schooler, 2002). In mindfulness practice, metacognition may operate in a manner concordant with this description, where attention is directed toward cognition itself via explicit introspection, or in a broader manner in which off-object features of experience are brought into awareness while simultaneously maintaining a continuity of attention towards the primary object (Dahl et al., 2015; Lutz et al., 2015). It should be noted that the term metacognition is often used interchangeably with meta-awareness when describing these processes (Grabovac, Lau, & Willett, 2011; Schooler et al., 2011). To maintain clarity, here metacognition is used to refer to all monitoring and control processes, both explicit conceptual types and distributed non-conceptual types (Holzel, Lazar, et al., 2011). Distributed non-conceptual forms of metacognition accord with the model of ‘background awareness’ described by Lutz et al. (2015), which always operates in relation to the maintenance of a specific task-set held in working memory, and is considered a precursor to explicit forms of metacognition. As discussed below, both explicit and non-explicit types are subsumed within a threefold division of metacognition. In both cases, cognition and metacognition interact with each other through the functions of monitoring and control.

Three facets of metacognition are recruited to monitor and control cognition: (1) metacognitive knowledge, which is knowledge of task relevant instructions, strategies, and goals stored in memory; (2) metacognitive experience, which includes both elaborative and non-elaborative monitoring of cognitive processes, experience, and awareness; and (3) metacognitive skills, which relate to the application of strategies for controlling cognition and are identified with executive attentional control (Efklides, 2008; Flavell, 1979; Nelson, Stuart, Howard, & Crowley, 1999). Metacognition may operate as an analytical process, as in the case of a judgement of one’s current cognitive performance, or as a non-analytical process, as in the case of ‘background awareness’ of the broader contextual experience and environment in which cognition occurs (Jankowski & Holas, 2014). Metacognition encompasses strategies and instructional guidelines for task completion as well as processes for the monitoring and control of attention. As a result, metacognition is of central importance in mindfulness practice (Dahl et al., 2015; Lutz et al., 2015).

Metacognition functions by comparing attentional processes with the task-set instructions defined in metacognitive knowledge and stored in working memory (see Fig. 1). The guidelines for attentional application are executed as metacognitive skills modulating the components of the cognitive faculty of mindfulness. Metacognitive experience provides feedback on the phenomenal clarity and stability of attention, whether attention has wandered from its object, and whether mental effort is too high or low. When task-set instructions are lost from working memory, the operating instructions and standards to which attention is compared are also lost and metacognitive monitoring fails. This leads to either a degradation in the quality of attention or a total loss of attentional focus resulting in mind-wandering (see Fig. 2). This type of failure represents a temporal dissociation between the contents of experience and metacognition characterised by a lack of awareness that one’s mind has wandered (Schooler, 2002). As proficiency in mindfulness practice increases, temporal dissociations become less frequent and mind-wandering is reduced (Levinson et al., 2014; Mrazek et al., 2012). Translational dissociations may also occur when the re-representation by metacognition misrepresents the actual contents of experience (Schooler, 2002). Mindfulness practice aims to reduce both types of dissociations so that the contents of experience are continually available to awareness in a form that accurately reflects reality.

As illustrated in Fig. 1, working memory is central to the processes required to generate and maintain the cognitive faculty of mindfulness (Dreyfus, 2011; Jha et al., 2010). Working memory refers to a limited capacity set of processes capable of temporarily

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**Fig. 1.** Metacognitive regulation of attention in mindfulness practice. Metacognitive monitoring and control is executed through (1) retrieval of task instructions and strategies by metacognitive knowledge; (2) adoption of task instructions and strategies in working memory; (3) execution of task instructions and strategies as metacognitive skills to control attention; (4) generation of sustained non-judgemental attention to present-moment experience; (5) monitoring of attention by metacognitive experience providing feedback on attentional application; (6) updating of strategy adoption by metacognitive knowledge. As long as these processes remain active, the cognitive faculty of mindfulness can be maintained upon the primary object. If secondary objects capture attention, metacognitive experience detects the shift in attentional focus, and this discrepancy with task-set instructions held in working memory results in the execution of metacognitive skills to redirect attention back to the primary object.
storing and manipulating information in order to carry out complex cognitive activities (Baddeley & Hitch, 1974). In mindfulness practice, working memory retrieves and retains the task-set instructions held in long term memory as metacognitive knowledge, initiates these strategies as cognitive operations in the form of metacognitive skills, and continually evaluates on-going attentional processes through metacognitive experiences, enabling the updating and modification of task strategies in response to current task performance. The episodic buffer component of working memory in particular allows these various cognitive processes to be integrated by binding together multiple sources of information into unified episodes, and this function is considered to represent a core feature of conscious awareness (Baars, 2005; Baddeley, 2007; Baddeley, Allen, & Hitch, 2011). The centrality of working memory in the cognitive processes of mindfulness corresponds to traditional meanings of the term that has come to be known as mindfulness in English. In traditional usage, sati (Pali) describes the process of calling something to mind, of recollection, non-forgetfulness, and remembrance (Chiesa & Malinowski, 2011; Gethin, 2011; Purser & Milillo, 2015). Thus, working memory as the central process allows metacognitive monitoring and control of attentional processes in mindfulness practice. The centrality of working memory in this model leads to the testable prediction that mindfulness training should result in improved working memory performance as the processes involved in updating, shifting and inhibition are repeatedly engaged (Lutz et al., 2009; Malinowski, 2013). This prediction is supported by studies reporting improvements in working memory capacity after mindfulness training (Chambers et al., 2008; Jha et al., 2010; Mrazek et al., 2013; Quach et al., 2016).

Metacognitive processes determine the allocation of attentional resources in a capacity model of mindfulness. In mindfulness practice, distraction may degrade attentional performance through interference, or it may cause a failure of attention by capturing available capacity, leading to mind-wandering (Kahneman, 1973). A common instruction in mindfulness practice is to notice when attention has wandered and then gently redirect attention back to the primary object, repeating this process each time distraction arises (Kabat-Zinn, 1990; Segal et al., 2002). This process describes the metacognitive skill of inhibitory control, in which one deliberately inhibits prepotent and automatic responses that interfere with the primary task of mindfulness practice (Miyake et al., 2000). Only by inhibiting competing processes can sustained attention remain upon the primary object (Stuss et al., 1995). Thus, inhibition is proposed to provide the foundation for the development of sustained attention to present-moment experience in mindfulness practice. By preventing the allocation of attentional capacity to secondary processes, inhibition preserves capacity for sustained attention. The training of metacognitive processes to allocate capacity to sustained attention and inhibit allocation to interfering processes constitutes the core of mindfulness practice.

A recent review reporting consistent improvements to inhibition as opposed to other executive functions with mindfulness practice supports the centrality of this metacognitive skill (Gallant, 2016). That inhibition training should be the primary process in mindfulness practice is further supported by Miyake and Friedman (2012), who report that inhibition represents a common attentional control factor underlying other forms of executive function. Inhibition in this context is described as the process of maintaining task goals, instructions, and strategies in order to control attention. This formulation corresponds to the use of metacognitive skills to maintain attention to present-moment experience while overriding competing processes such as distraction. Skill in metacognitive inhibition results in sustained attention (Stuss et al., 1995). There is mounting evidence that the cognitive benefits of mindfulness practice can be traced back to enhancements in metacognitive monitoring and control of attention, specifically to inhibitory control (Chiesa et al., 2011; Gallant, 2016; Moore, Gruber, Derose, & Malinowski, 2012; Slagter et al., 2007).

Since mental effort is necessary to sustain attention, accurately modulating mental effort is an essential metacognitive skill (Broadhurst, 1959; Kahneman, 1973). Metacognitive experience and knowledge operate in parallel with attentional processes to
monitor the clarity and stability of awareness while metacognitive skills modulate mental effort (Bodhi, 2011; Lutz, Dunne, & Davidson, 2007; Smallwood & Schooler, 2015). In contrast to semantic or episodic knowledge, metacognitive knowledge is informed by a contextual awareness of attentional performance as well as an awareness of available strategies acquired through metacognitive experience, enabling appropriate selection and application of metacognitive skills to modulate effort. In mindfulness practice, rather than modulating effort in response to task difficulty, mental effort is modulated to provide optimum attentional clarity and balance. Insufficient arousal results in an inadequate supply of capacity for the primary task and a loss of perceptual acuity and clarity. Low levels of arousal also result in insufficient activation of the capacity required to meet metacognitive demands, leading to an impaired ability to monitor ongoing attentional performance, maintain task-set instructions in working memory, and execute metacognitive skills. Hyper-arousal disrupts the allocation of attentional capacity by metacognitive skills, with dominant stimuli being preferentially allocated capacity, leading to increased lability and scattering of attention (Kahneman, 1973).

Metacognitive skills represent procedural knowledge gained through task familiarity (Efklides, 2008). During the early stages of mindfulness practice, metacognitive skills are applied in an analytical manner based upon newly acquired metacognitive knowledge. In the absence of familiarity, these processes operate in a controlled manner, demanding high levels of attentional capacity and interfering with the performance of the primary task. Advanced stages of practice are characterised by the development of effortless non-elaborative metacognitive skills and experience capable of detecting task-incongruent movements of attention before they manifest as distraction (Bishop et al., 2004; Wallace, 2006). In addition, metacognitive knowledge is continually updated as practitioners acquire greater understanding of the instructions, gain more metacognitive experience, and learn how to select and apply different metacognitive skills according to their ability (Flavell, 1979).

The development of metacognition is closely related to effective self-regulation (Efklides, 2008), and the functions of monitoring and control have been highlighted as a possible mechanism for emotion regulation in mindfulness practice (see Chambers et al., 2009; Teper et al., 2013; Wadlinger & Isaacowitz, 2011). In particular, evidence suggests that improved inhibition may enhance emotional control through a shared neurological basis, thus providing a potential pathway for enhancements in cognitive control to transfer to enhanced emotional control (Chiesa, Serretti, & Jakobsen, 2013; Fernandez-Duque, Baird, & Posner, 2000; Jha et al., 2010; Malinowski, 2013; Tang et al., 2015). In mindfulness practice, a culmination of metacognitive development occurs when the processes of metacognition themselves are taken as objects of awareness, resulting in an expansive cognition of both the contents of awareness and awareness itself, leading to the arising of insight (Bishop et al., 2004; Efklides, 2008). The proposed pathways through which improved attentional control in mindfulness practice leads to improved emotional control, psychological well-being, and insight are presented in Fig. 3. The scientific study of emotion regulation is in its early stages, and studies investigating the mechanisms of emotion regulation are limited (Chambers et al., 2009). It is hoped that this model, developed from available theoretical and empirical evidence, will stimulate further well-designed empirical studies to investigate these proposed mechanisms.

According to the model, the ability to sustain present-moment experience is influenced by both positive and negative factors. As outlined earlier, equanimity enhances a practitioner’s ability to sustain attention by reducing cognitive and emotional proliferation and ensuring mental exertion is neither too high nor too low. Equanimity is thought to assist in weakening automated cognitive and

![Fig. 3. The cognitive processes of mindfulness. Distraction and disruptive emotions have a negative influence on attention in mindfulness practice, while equanimity and enhancing emotions exert a positive influence on attention. Metacognitive processes apply a negative control influence on disruptive emotions and mind wandering, while exerting a positive influence on enhancing emotions and equanimity. In this way, emotion regulation is achieved through attentional monitoring and control functions. Insight represents a culmination of mindfulness practice, and is capable of trait changes to both disruptive and enhancing emotions.](image-url)
emotional processes through its non-reactive stance to experience (Desbordes et al., 2015). As a practitioner progresses from mentally contrived forms of equanimity to uncontrived authentic states characterised by stable, sustained attention it is proposed that they will experience increasing levels of positive emotional states along with a corresponding absence of disruptive cognitive and emotional events (Desrosiers et al., 2014). This manifests as a state of subjective well-being. Such an outcome is supported by Chambers et al. (2009) and Wadlinger and Isacowitz (2011) who also propose increased positive emotions as a result of mindfulness-based attention training. A growing body of research reporting increased positive affect and well-being after mindfulness training is beginning to add further support to this thesis (Carmody & Baer, 2008; Davidson et al., 2003; Garland et al., 2015; Tang et al., 2007). The model proposes that increases in positive emotion and well-being reinforce equanimity, thereby enhancing sustained attention to present-moment experience. Enhancing emotions are so termed due to their positive influence upon the stability of attention in mindfulness practice.

Distraction has a negative influence on the performance of sustained attention since it involves the allocation of attentional capacity to task-unrelated processes, a failure of metacognitive monitoring and control, and the arising of mind wandering. In accord with traditional Buddhist psychological models (Engle, 2009; Gyeltsen, 2006; Tsering, 2010), the current model proposes that distracting thoughts, mind wandering, and rumination are all positively influenced by disruptive emotions, described elsewhere as disturbing emotions (see Chambers et al., 2009). Increasing levels of disruptive emotion lead to increasing levels of distraction and mind wandering, which may further increase disturbing emotional states. This reciprocal relationship has already been observed in studies examining anxiety and depression (Jose, Wilkins, & Spendelow, 2012; Nolen-Hoeksema, 2000; Nolen-Hoeksema et al., 2008; Starr & Davila, 2012). The result is a negative influence on attentional stability, and thus the emotional states underlying distraction, mind wandering, and rumination are termed disruptive.

During mindfulness practice, metacognitive processes continually monitor the arising of distraction and disruptive emotions and prevent their further proliferation through inhibition, thereby exerting a negative control influence upon factors disruptive to attentional stability. Metacognitive processes also ensure equanimity and enhancing states of mind are maintained, thereby exerting a positive control influence upon factors supportive to attentional stability. Through the functions of monitoring and control, metacognitive processes regulating attention exert state changes to both disruptive and enhancing emotions, resulting in emotion regulation (Teper et al., 2013; Wolkin, 2015). Mindful emotion regulation is thought to be achieved through training non-elaborative attention in conjunction with equanimity, leading to the gradual unlearning of automatized and habitual cognitive and emotional responses (Desbordes et al., 2015; Holzel, Lazar, et al., 2011). Studies reporting improved attentional and executive functioning together with enhanced affect and well-being after mindfulness training are beginning to support the role of attention training in emotion regulation (Doll et al., 2016; Sahdra et al., 2011).

The model predicts that stable, trait changes to emotions can be achieved through the development of insight. While studies have previously investigated insight as a suddenly arising phenomenon in the context of problem-solving (Kounios & Beeman, 2014), the scientific study of insight arising from sustained mindfulness practice has yet to be taken up and the concept remains poorly defined. The present model describes insight as an unmediated perceptual ascertainment of the nature of phenomena arising from the cultivation of stable and penetrative attentional processes. Since insight arises on the basis of non-elaborative sustained attention rather than analytical modes of investigation, it is an unmediated perceptual ascertainment of reality that is experiential in nature rather than intellectual (Grabovac, 2015). In contemporary theoretical models of mindfulness, insight results from enhanced metacognitive monitoring of the contents of experience, resulting in decentering (Bishop et al., 2004; Holas & Jankowski, 2013; Kang, Gruber, & Gray, 2012; Shapiro et al., 2006). Decentering is described as a changed relationship with experience characterised by the capacity to adopt a detached perspective towards one’s thoughts and emotions based upon understanding the transitory nature of experience and a weakening of fixation upon a solid, unchanging sense of self (Holzel, Lazar, et al., 2011; Vago & Silbersweig, 2012). This form of metacognitive decentering provides an important mechanism for emotion regulation and self-change in therapeutic MBIs (Hayes-Skelton & Graham, 2013; Safran & Segal, 1990; Teasdale, Segal, & Williams, 1995).

Since insight in this model arises upon the basis of stable sustained attention, the model proposes a developmental progression of insight with increasing levels of sustained attention. Metacognitively derived insights such as decentering therefore represent the beginning of the development of insight. As outlined previously, with advancing proficiency the capacity of attention applied at early stages of perceptual processing increases, which manifests as a high degree of perceptual acuity characterised by vivid clarity of awareness. As a result, objects are apprehended in greater detail, leading to heightened interpretation by later stages of perceptual processing. This heightened perceptual interpretation of the characteristics of phenomena gives rise to the development of insight. According to traditional sources this development includes insight into the relational nature of cognition and its objects, direct cognition of the transitory nature of phenomena, and an unmediated perceptual ascertainment of the insubstantiality of a personal sense of self. See Grabovac (2015) for a detailed discussion of the developmental stages and types of insight in mindfulness practice.

Insight here is an unmistaken apprehension of the contents of experience. Brown et al. (2007) suggest that this type of unmediated, clear perceptual awareness may directly improve well-being by clearing obstacles to correctly understanding the reality of one’s actual experience, which is often distorted and interpreted through varying mental superimpositions that influence our perception of the world. Such is the value of this quality that an accurate view of reality is considered indicative of psychological well-being, whereas psychological disorders frequently have an underlying component of a distorted view of reality (Leary, 2004). The model predicts that insight directly counteracts distorted and erroneous apprehensions of reality, exerting a negative influence on disruptive emotions by undermining and weakening the misapprehension upon which they are based. Similarly, increasing engagement with the world through insight is predicted to exert a positive influence on emotional states enhancing well-being, as improved understanding of the nature of one’s experience arises (Bishop et al., 2004; Grossman, 2013; Shapiro et al., 2006).

Empirical studies reporting increased positive affect and reduced negative affect after mindfulness practice, with the degree of
benefit correlated to the amount of practice support the role of this accurate apprehension of experience in improving psychological well-being (Brown & Ryan, 2003; Davidson et al., 2003; Garland et al., 2015; Hofmann, Sawyer, Witt, & Oh, 2010; Jain et al., 2007, Jha et al., 2010; Schroevers & Brandsma, 2010; Sedlmeier et al., 2012). Furthermore, studies reporting reductions in behavioural measures of mind wandering after mindfulness training lend support to the model’s prediction of reduced distraction and mind wandering with mindfulness practice (Levinson et al., 2014; Mrazek et al., 2012). While self-report and behavioural measures of equanimity have yet to be developed, studies utilising self-report measures corresponding to the construct of equanimity, such as non-attachment, are also beginning to support mindfulness-related improvements in this domain (Sahdra, Ciarrochi, & Parker, 2016; Sahdra, Shaver, & Brown, 2010).

Of particular note is the model’s ability to explain the role of factors other than mindfulness that are often incorporated into MBIs to elicit therapeutic outcomes. According to the model presented here, explicit techniques such as the cultivation of patience, acceptance, loving-kindness, and compassion can be applied to develop enhancing emotions. Through the development of these positive states, equanimity is enhanced, increasing practitioners’ ability to successfully engage in the core practice of sustaining attention to present-moment experience. Likewise, explicit techniques such as cognitive behavioural therapy (CBT) or psychoeducation can act to reduce disruptive emotions, thereby assisting practitioners’ through the dampening of mind wandering and distraction. Thus, the model provides an explanatory framework through which both the core cognitive processes of mindfulness together with ancillary practices can be shown to effect attentional, emotional, and metacognitive outcomes.

A practical intervention capable of recruiting the attentional and metacognitive processes of mindfulness without the addition of these types of ancillary components is required to accurately investigate their ability to modify mood and cognition. Such an intervention would also enable an assessment of the influence of these secondary factors when conjoined to the core components, thereby informing future therapeutic applications to maximise desired outcomes. The following brief review of MBIs currently used in longitudinal RCTs highlights the need for an intervention that recruits the cognitive components of mindfulness practice without ancillary components.

3. Empirical investigation of mindfulness practice

Empirical longitudinal studies of mindfulness practice have commonly recruited either Buddhist meditators or practitioners of contemporary MBIs (Chiesa & Malinowski, 2011; Tang et al., 2015; Thomas & Cohen, 2014).

Traditional Buddhist practices are immersed within a religious context that confounds the effect of mindfulness. Mindfulness practice in this context is always accompanied by a constellation of additional factors such as devotion, religious belief, and lifestyle factors that render these practices unsuitable for use in studies aiming to assess the efficacy of mindfulness alone. Furthermore, studies utilising these practices in retreat settings where participants are secluded in quiet surrounds with controlled activities and stimulation are not amenable to conclusive findings, since environmental and social factors may contribute to the observed findings. Community-based interventions that do not require participants to drastically alter their normal daily life or adopt particular philosophical or religious attitudes will be those that allow robust conclusions.

Mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) uses mindfulness together with yoga and psychoeducation for the purpose of alleviating stress. In addition, participants develop specific goal expectations and cultivate a personal vision of themselves. This type of expectancy effect can undermine the use of MBSR-type interventions in empirical studies due to its confounding effect on observed outcomes (Jensen et al., 2012). Since the components of mindfulness are presented within a framework of additional methods and attitudes, MBSR is unsuitable for use in studies designed to test the ability of mindfulness to enhance cognitive function and psychological well-being. Mindfulness-based cognitive therapy (MBCT; Segal et al., 2002) was developed to treat depression and utilises mindfulness together with techniques derived from CBT. Since MBCT shares much of the attitudinal orientation of MBSR in conjunction with an emphasis on CBT methods, it is subject to similar confounds.

Dialectical behaviour therapy (DBT; Linehan, 1993) and acceptance and commitment therapy (ACT; Hayes, Strosahl, & Wilson, 1999) are similarly unsuitable since they incorporate a wide range of CBT methods, psychoeducation, and exposure training to change thoughts, behaviours, and emotions. Integrative body-mind training (IBMT; Tang, Rothbart, & Posner, 2012; Tang et al., 2007) teaches mindfulness accompanied by music, relaxation techniques, and mental imagery. Since these elements are ancillary to the cognitive processes of mindfulness, IBMT also cannot be considered a suitable intervention for assessing the cognitive mechanisms of mindfulness.

The wide range of MBIs currently used in empirical studies often precludes cross-study comparisons. Even amongst studies utilising the same intervention, precise causative inferences are not permitted since the cognitive processes of mindfulness are accompanied by additional factors that may influence outcomes. A standardised mindfulness intervention free of additional components is therefore required in order to allow accurate cross-study comparisons of the cognitive processes of mindfulness.

4. Developing a standard experimental mindfulness technique

The standardised technique developed here is not intended for use as a therapeutic intervention to treat psychological disorder, or to be adopted as a complete path of transformation. Rather it is designed for use in empirical longitudinal RCTs seeking to investigate the cognitive processes activated by mindfulness practice. In fact, one of the values of such a standardised technique is that it permits quantification of the benefits of additional therapeutic components when conjoined to the cognitive processes of mindfulness in comparison studies.

Table 1 describes the technique applied to a sitting practice in which the cognitive faculty of mindfulness is directed toward the
### Table 1

<table>
<thead>
<tr>
<th>Instruction phase</th>
<th>Key instruction</th>
<th>Instructions to participants</th>
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<tbody>
<tr>
<td>Preparation</td>
<td>Assume a comfortable, erect posture</td>
<td>Sit cross-legged on a cushion placed on the floor, or if this is uncomfortable, in a straight-backed chair with your feet placed flat on the floor. Sit in a relaxed, erect posture, with your hands resting either in your lap or resting on your knees. Your eyes can be either closed, or slightly open with the gaze cast slightly downward. Adopt a comfortable and alert posture you are capable of maintaining for the duration of the session.</td>
</tr>
<tr>
<td>Basic technique</td>
<td>Be attentive to the sensations arising with the breath at the abdomen</td>
<td>Direct your attention to the sensations occurring at the abdomen with each breath. Do not intentionally breathe faster or slower, deeper or shallower, but let the breath remain natural. Observe the sensations of movement or tightness that arise with the rising and falling of the abdomen. As you breathe in, try to notice the beginning, the middle, and the end of the rising movement. As you breathe out, try to notice the beginning, the middle, and the end of the falling movement. Notice these physical sensations without thinking about them in any way. Note the rising and falling with mental labelling. Make a soft mental note of ‘rising’ while attending to the sensations of the rising abdomen, and ‘falling’ while attending to the falling sensations. Without thinking about these sensations or the fact that you are attending to them, simply be aware of the sensations of rising and falling as closely as possible while gently noting ‘rising, falling.’ Return again and again to the breath. At the beginning, you will find it difficult to remain attentive to each successive rising and falling movement as it occurs. Remember that this is a learning process, and that the movements of the breath are always present. Simply return your attention with accuracy and clarity to these sensations whenever the mind wanders.</td>
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<tr>
<td>Dealing with distraction</td>
<td>Note thoughts as soon as they arise</td>
<td>Mindfulness is not the absence of thought. Distracting thoughts will naturally arise. Simply try to be mindful of thoughts when they arise. When a thought occurs, without getting caught up in or following the thought, simply be aware of the thought. Use the mental label ‘thinking’ to note it, and return your attention to the sensations of rising and falling. Do not follow thoughts, feelings, or emotions when they arise. Do not think about your thoughts. Do not worry if your thoughts are good or bad. Simply note ‘thinking’ and return to the rising and falling of the abdomen. You may not be aware for some time that your mind has wandered, but as soon as you become aware of distraction, note ‘thinking,’ and return to the rising and falling of the abdomen. If you notice many thoughts, this is mindfulness. Being aware of thoughts is mindfulness. Being lost in thoughts is distraction. Do not be concerned with other objects. Remain attentive to the rising and falling. Only notice other objects when they draw your attention away from the rising and falling. For example, if a loud sound occurs, be aware of the experience of hearing, without thinking about what caused the sound. Mentally note ‘hearing’ and once the sound has passed, return to the rising and falling. Do not seek out or be concerned with other objects.</td>
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<tr>
<td>Stay relaxed and balanced</td>
<td>Do not worry about pleasant or unpleasant experiences</td>
<td>Do not be concerned whether your experience is pleasant or unpleasant. You will experience both pleasant and unpleasant sensations while paying attention to your body and mind. Both types of feeling will arise and pass away, so try not to hold onto pleasant feelings or push unpleasant ones away. Simply remain mindful and mentally note everything that occurs.</td>
</tr>
<tr>
<td>Stay relaxed</td>
<td>Keep the mental label simple, calm, and natural. While we may experience a bewildering range of thoughts, hopes, concerns, doubts and mental images, simply label them ‘thinking’ as they arise, and return to the rising and falling movements of the abdomen.</td>
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<tr>
<td>Dealing with difficulties</td>
<td>Direct your attention to discomfort when it arises</td>
<td>After sitting for a while, you may experience persistent feelings of tiredness, discomfort, itching, and pain. At this time, direct your attention to these feelings, maintaining awareness of the sensations by noting ‘pain,’ ‘aching,’ or ‘itching.’ Remain mindful of such sensations without worry or concern. If the sensations fade away, return to the rising and falling. If the sensations continue to increase and you wish to move, change your position mindfully in the following manner.</td>
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<td>Move slowly and mindfully</td>
<td>If you intend to scratch an itch on your leg, make a mental note ‘intending.’ When lifting the hand, note ‘lifting.’ When moving the hand, note ‘moving.’ In extending a finger, note ‘moving.’ When touching the leg, ‘touching,’ when scratching, ‘scratching.’ When intending to withdraw one’s hand, note ‘intending.’ When withdrawing the hand back, ‘moving,’ and in resting the hand in your lap, ‘touching.’ Do so slowly, directing your attention to the mere sensations that arise with each act. Apply the same mindful attention to other actions, such as adjusting your posture, or swallowing saliva.</td>
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<td>Developing proficiency</td>
<td>Continue to note everything that occurs</td>
<td>During the sitting session, simply remain continuously attentive to the sensations of rising and falling as they occur, trying to notice them closer and closer. As thoughts, sounds, feelings, doubts, wishes, and bodily sensations arise, simply note them by (continued on next page)</td>
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bodily sensations arising at the abdomen with the inhalation and exhalation of the breath. These sensations arise effortlessly and are continuously available to return to when attention wanders, providing a foundation for the development of non-elaborative forms of sustained attention (Lutz et al., 2015). Importantly, the sensations accompanying the breath arise in the present-moment, and by fixing attention upon them awareness is prevented from elaborative discursions into the past or future. For further details regarding the significance of using the breath as the object of mindfulness, see Grossman (2010). Table 1 contains detailed Instructions to Participants explaining how to apply and develop the technique, together with Key Instruction points that can be adopted as guidelines during the practice. Table 2 describes the application of the technique to a walking practice, while Table 3 describes how this technique can be extended to any activity.

The Basic Technique instructions found in Table 1 outline the technique for generating and maintaining non-judgemental attention to present-moment experience in a sitting practice. Focussed attention is activated by instructing participants to direct their attention accurately to the sensations accompanying the rising and falling of the abdomen. Sustained attention is activated as participants are

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<tr>
<td>Preparation</td>
<td>Adopt a relaxed posture</td>
<td>Choose a level path to walk on, about 20-30 paces long, where there are no obstacles and you can walk up and down without interruption. Your arms can be loosely hanging in front or behind, with one hand clasping the wrist of the other arm. Adopt an upright posture that is comfortable</td>
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<tr>
<td>Basic technique</td>
<td>Note intentions preceding actions</td>
<td>To start, be aware of the intention to begin walking and mentally note ‘intending.’</td>
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<td>Note lifting, moving, and placing</td>
<td>In raising your foot, direct your attention to the sensations that accompany the lifting of your foot from the ground. As soon as the lifting begins, note ‘lifting,’ and be aware of the sensations that arise.</td>
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<td>Be aware only of sensations</td>
<td>When the forward movement of the foot begins, note ‘moving’ while attending to the sensations of movement. When you begin to place the foot, note ‘placing,’ and be aware of the sensations of placing.</td>
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<td>Stop and turn mindfully</td>
<td>With each step, be aware of the three movements of ‘lifting,’ ‘moving,’ and ‘placing’</td>
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<td>Remain mindful of lifting, moving, placing</td>
<td>It is important not to hold an image or concept of your foot in mind during this practice. Instead, be attentive only to the physical sensations that arise as you move your foot</td>
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<td>Use 1- or 2-part noting when walking faster</td>
<td>Attend to the sensations of movement, lightness, or heaviness without thinking or imagining anything. When lifting your foot you may feel a sense of lightness, or sensations of movement. At this time, note ‘lifting.’ Try to be aware of the beginning of each movement, directing your attention accurately to the sensations as they arise</td>
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Table 2
Walking exercise instructions.

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<th>Instruction phase</th>
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<tr>
<td>Balance your effort</td>
<td>Practice in a relaxed but alert manner. Avoid becoming tense through excessive striving, or lethargic and dull by relaxing too much. Seek to balance your effort, calmly remaining attentive to the rising and falling movements while noting when your attention wanders or is drawn away</td>
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</tr>
<tr>
<td>Relax the use of labelling</td>
<td>Mental labelling helps direct your attention to the sensations you are noting. With practice attention begins to rest evenly upon the rising and falling, so the label can be slowly relaxed. Eventually you may continue without the need for noting</td>
<td></td>
</tr>
<tr>
<td>Relax in Awareness</td>
<td>After developing proficiency through sustained practice, gradually relax your focus on the sensations accompanying the breath and open your awareness to all of your experience</td>
<td></td>
</tr>
<tr>
<td>Ending the session</td>
<td>End your session mindfully</td>
<td>When you wish to end your session, be mindful of this intention, noting ‘intending.’</td>
</tr>
<tr>
<td></td>
<td>When you wish to end your session, be mindful of this intention, noting ‘intending.’</td>
<td>Then be mindful of the actions of body and mind as you arise from your sitting posture</td>
</tr>
</tbody>
</table>

When you intend to turn around, note ‘standing.’ When turning to turn around, note ‘intending.’ When turning, note each movement of lifting, moving, and placing the feet. When you are finished turning, note ‘standing.’ When you intend to begin walking again, note ‘intending.’ When you begin walking, direct your attention to the ‘lifting’, ‘moving’, and ‘placing’ movements again. When distracting thoughts and sensations arise, note them and return to the sensations of lifting, moving, and placing. Use the technique for dealing with distraction and discomfort that was described in the sitting practice. Mindful walking can be adopted throughout the day by noting each step as you walk. If you are walking quickly, note ‘left, right, left, right,’ while directing your attention to the sensations arising at the foot with each step. If you are walking slower, note ‘lifting, placing, lifting, placing,’ using a 2-part labelling process. During other times, you may use the 3-part process of ‘lifting, moving, placing.’
Table 3
Instructions for practicing in daily activities.

<table>
<thead>
<tr>
<th>Instruction phase</th>
<th>Key instruction</th>
<th>Instructions to participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Instruction</td>
<td>Note intentions that precede all actions</td>
<td>Mindfulness can be applied throughout the day by directing your attention to all of the mental and physical processes that arise in carrying out your activities. Notice the intention that precedes all actions, noting ‘intending.’ If this involves planning and thinking, note ‘thinking.’</td>
</tr>
<tr>
<td>Basic technique</td>
<td>Note the sensations that arise with all of your actions</td>
<td>As you perform any action, direct your attention accurately to the mere sensory experience that arises, without thinking about yourself as being the performer of the action, or the object you are engaged with. When dressing, opening and closing doors, washing, and eating, try to remain attentive to every detail as it occurs, noting all of the mental and physical processes that arise.</td>
</tr>
<tr>
<td>Practice in a relaxed and patient manner</td>
<td>Act slowly so you can be aware of the details of your experience</td>
<td>For example, when eating, firstly be mindful of all of the actions in preparing the food. Then, when you sit down to your meal, do so mindfully, noting ‘sitting.’ When looking at the food, note ‘seeing.’ In intending to take a fork, ‘intending.’ In taking the fork, note the ‘moving’ of the hand, ‘reaching,’ ‘touching,’ and ‘lifting’ of the fork. Notice the intention to take some food, followed by all of the movements of the hand in doing so, mentally labelling each of them in order. In bringing the food to the mouth, ‘moving,’ when opening the mouth, ‘opening,’ when the food touches the mouth, ‘touching,’ When you place the food in your mouth, ‘placing,’ withdrawing the fork, ‘moving,’ and in tasting the food, ‘tasting.’ Use mental noting to help direct your attention to all of the processes of chewing, tasting, and swallowing. Each mouthful of your meal can be attended to in this way. In the beginning, you will be unable to remain attentive to all of these processes as they occur, and there will be many lapses of attention. As you become mindful you will notice more and more. Without becoming discouraged or weary, continue to apply your attention closely and accurately. When thoughts of discouragement, doubt, or wishes to stop the practice arise, simply be aware of them, noting ‘thinking,’ and continue to persevere. In this way, apply mindful attention to all of your actions throughout the day, no matter how small.</td>
</tr>
</tbody>
</table>

Instructed to continuously attend to these sensations. Participants are instructed to notice all of the details of the rising and falling process by paying close attention to the beginning, middle, and end of each movement. These instructions serve to enhance the accuracy of orienting attention and increase sustained attention by uninterruptedly maintaining awareness throughout each movement. Further refinement of these processes is introduced through the Developing Proficiency instruction to pay closer and closer attention to rising and falling movements, eventually noting pauses between these movements if they occur.

The use of mental labelling as part of the Basic Technique is designed to support accurate attentional orientation and the dampening of cognitive and affective reactivity to the contents of experience (Wallace, 2006). Mental labelling has been presented in both traditional Buddhist systems of mindfulness practice (Mahasi, 1980; Pandita, 1995) and contemporary models of mindfulness (Vago & Silbersweig, 2012) as an effective technique to control attention and limit mind wandering. Mentally noting all objects of experience also ensures continuous rather than intermittent engagement of attentional processes, supporting the further development of sustained attention. The repeated instruction to note the whole range of mental and physical experience followed by non-reactively redirecting attention back to the breath reinforces the repetitive nature of this training. As the practice will involve alternating periods of sustained attention, distraction, identification of distraction, disengaging awareness from distraction, and reorienting attention back to the sensations of the breath, each process will be engaged numerous times in a single session (Lutz et al., 2009; Malinowski, 2013).

Equanimity is introduced as a mental attitude of non-elaborative acceptance of experience. The Basic Technique encourages acceptance of task difficulty while encouraging non-elaborative attention together with non-reactive responding to mind-wandering. Dealing with Distractions expands upon this mental attitude by instructing participants not to be concerned by distractions, thoughts, or feelings that arise during the practice. This instruction provides a crucial guideline to be retained as metacognitive task knowledge. Practitioners may mistakenly believe that mindfulness has failed if thoughts arise and attention wanders from the breath (Segal et al., 2002). The arising of thought does not signal task failure if noticed and attended to, since no temporal dissociation between cognition and metacognition has occurred. Even the act of noticing mind-wandering after a temporal dissociation is an instance of correct mindful attention. Adopting this task knowledge supports a non-reactive and accepting stance toward the proliferation of thought during mindfulness practice, protecting against discouragement and developing the mental attitude of equanimity. The Stay Relaxed and Balanced instructions encourage disregarding whether such experiences are good or bad. Participants are instructed to merely observe their thoughts, feelings, and emotions without following them, elaborating on them, or worrying about them. In this way participants are instructed to openly observe their experience without bias or preference, thereby engendering an equanimous mental attitude. Furthermore, participants are instructed not to grasp on to pleasant experiences or reject unpleasant ones. These instructions aim to reduce cognitive and affective reactivity to ongoing experience by generating an attitude of equanimity.

Mental labelling is thought to protect against cognitive and emotional reactivity by interrupting conditioned responses and automatic processing, leading toward the development of unbiased, non-elaborative acceptance of experience (Vago & Silbersweig, 2012). Enhanced functional connectivity between prefrontal cortical regions and the amygdala and limbic regions has been proposed as the neurobiological pathway underpinning the efficacy of mental labelling to diminish emotional reactivity (Lieberman et al., 2007). The Stay Relaxed and Balanced instructions indicate that the mental noting employed in this technique should be free from
evaluation, assessment, or judgement. Through the use of mental labelling, practitioners slowly become acquainted with the experience of directly observing the contents of awareness without reactivity or elaboration, leading to diminished translational dissociations between the contents of experience and metacognition. In this way, practitioners begin to develop increasingly accurate representations of the contents of experience in metacognition, leading to a greater concordance with reality, and eventually insight.

Novice practitioners may have difficulty maintaining equanimous attention in the face of frequent mind-wandering and physical discomfort, and thus effective metacognitive strategies for monitoring and controlling the cognitive faculty of mindfulness are required (Bishop et al., 2004; Gunaratana, 2011). The Key Instructions are designed to be retained as operating guidelines in metacognitive task knowledge and represent task-set instructions for the execution of metacognitive skills. The Key Instruction statements advise participants to attend to the sensations accompanying the breath, note thoughts as they arise, return attention back to the breath, and not be concerned with other objects. These phrases provide task strategy summaries to be stored in metacognitive knowledge. Strategies for use in response to specific circumstances are also found in the Key Instructions, such as those relating to Dealing with Difficulties. Important Key Instructions are Stay relaxed and Balance your effort, which assist the metacognitive modulation of mental effort to maintain attentional clarity. Once participants have thoroughly understood the Instructions to Participants, the Key Instructions provide a complete set of task guidelines for monitoring and controlling the cognitive faculty of mindfulness.

The primary metacognitive skill to be trained is inhibitory control. Inhibition is trained through repeatedly engaging metacognitive processes to detect distraction, disengage from it, and redirect attention back to the sensations of rising and falling, thereby maintaining task goals. This process is described in the Basic Technique and elaborated upon in the Dealing with Distraction and Stay Relaxed and Balanced sections, where the importance of discontinuing processes that interfere with sustained attention to the breath is repeated again and again. For novice practitioners attention frequently wanders from the breath, requiring these metacognitive control processes to be continuously activated throughout a session (Malinowski, 2013).

As metacognitive skills improve and attention is able to remain with stability upon the sensations accompanying the breath, the Developing Proficiency instructions advise participants to progressively deemphasise the use of mental labelling. In this way, participants transition from elaborative to non-elaborative styles of focussed attention before eventually transitioning to an open monitoring style of practice. The instructions establish a foundation of focused attention in meditation-naive participants since focussed attention is a preliminary to later stages of open monitoring. The noting of objects in all modalities while sustaining attention to the sensations accompanying the breath lays the foundation for open monitoring by allowing practitioners to remain attentive to other objects as they arise. Practitioners are instructed to gradually expand the focus of their sustained attention to allow awareness of all objects of experience. This instruction describes an open monitoring style of practice (Lutz et al., 2008). Finally, the instruction to gently recognise the knowing quality of awareness itself introduces a non-referential form of open monitoring practice. For further discussion on the progression from focused attention styles of mindfulness practice to open monitoring styles, see Lutz et al. (2008), Slagter, Davidson, and Lutz (2011) and Vago and Silbersweig (2012).

The primary focus of the cognitive faculty of mindfulness shifts as the individual progresses, from a discrete subset of tactile sensations accompanying the breath to eventually open awareness free from reference or fixation. The cognitive faculty operating throughout is non-judgemental attention to present-moment experience. It is only the object taken in the present moment that changes, not the cognitive processes underlying that attention. Thus, even though the emphasis on individual processes may alter during the course of training, the set of cognitive processes themselves are common. It must be noted that the intervention presented here is intended for use with mindfulness-naive participants, and that the level of proficiency required to transition from focussed attention to open monitoring practice is expected to only arise with prolonged and dedicated practice (Lutz et al., 2008).

The instructions for the walking practice and daily activities follow the same framework as the instructions for the sitting practice. During the walking practice participants direct the cognitive faculty of mindfulness towards the sensations accompanying the motions of the foot while walking rather than the sensations accompanying the breath. Just as in the sitting practice, participants are instructed to generate close attention to each movement in order to develop continuous and accurate sustained attention to present-moment experience. The walking instructions prescribe taking all of the movements involved in stopping and turning around as well as the mental intentions controlling these actions as objects to be attended to, thereby extending the mindfulness practice to active and intentional bodily movements. This extension is further progressed in the daily activities practice where the cognitive faculty of mindfulness is applied to all physical and mental activities that arise throughout the day.

Significantly, the standardised technique does not introduce additional factors or techniques beyond the cognitive processes of mindfulness. The standardised technique does not rely upon the acceptance of any philosophical, religious, theoretical, or therapeutic framework. In addition, secondary techniques such as CBT, yoga, psychoeducation, relaxation, or mental imagery are absent, making the standardised approach a powerful tool for studying the cognitive processes of mindfulness in isolation from secondary factors. The absence of ancillary techniques, attitudes, and therapies renders the standardised technique suitable for use in longitudinal RCTs designed to draw causal links between mindfulness practice and cognitive functions.

4.1. Implementation guidelines

The standardised technique is developed through the instructions found in Tables 1–3. The length, frequency, and format of sessions used in RCTs utilising the standardised technique will be determined by the specific research question posed by each study. In studies of community-based participants assessing the efficacy of the standardised technique to improve cognitive function and psychological well-being, we suggest an 8-week program based upon an MBSR course structure, consisting of weekly two-hour group sessions with practical instruction, group practice, and discussion sessions, together with home assigned sitting practice of between
30 and 60 min per day during the training period. Mindfulness practice can be extended beyond the sitting practice using the walking and daily activities exercises as required. An eight-week training program provides sufficient time for participants to become familiar with this new mental technique, and a large body of research on 8-week mindfulness programs supports the effectiveness of this training period (Creswell, 2017; Gu et al., 2015). In addition, neuroimaging studies are beginning to demonstrate that eight weeks of mindfulness training is sufficient to induce functional and structural brain changes similar to those observed in long-term mindfulness practitioners (Fox et al., 2014; Gotink, Meijboom, Vernooy, Smits, & Hunink, 2016; Hasenkamp & Barsalou, 2012; Holzel, Carmody, et al., 2011; Pickut et al., 2013).

Knowledgeable, experienced mindfulness practitioners and instructors should give the instructions without reliance on philosophical or therapeutic frameworks. In clarifying the standardised technique, discussing difficulties, and assisting participants through the challenges that arise during mindfulness practice, instructors should adhere to the principles detailed throughout this paper without adding therapeutic or religious contexts to experience. A key point in applying these instructions is the balancing of mental effort with concentration. Instructors should be capable of drawing from their own experience to emphasise the importance of practicing in a relaxed manner while striving to maintain attentional stability and agility.

4.2. Measuring mindfulness

The cognitive faculty of mindfulness is thought to be present in all individuals to some degree, but becomes fully qualified and manifest through intentional cultivation (Grossman & Van Dam, 2011). This assumption underpins the development of self-report measures designed to quantify trait mindfulness, such as the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), and the Five-Facet Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). Individual differences on these measures have been linked to differences in psychological well-being (Brown & Ryan, 2003), attentional performance (Josefsson & Broberg, 2011), task-unrelated thought production (Fountain-Zaragoza, Londerée, Whitmoyer, & Prakash, 2016), and default-mode network connectivity (Prakash, De Leon, Klatt, Malarkey, & Patterson, 2013). While it is possible that these individual difference factors may explain varying response outcomes to mindfulness training, significant concerns regarding the ability of self-report scales to measure mindfulness have been raised (Grossman, 2008, 2011), and this area remains an active field of investigation (Quaglia, Braun, Freeman, McDaniel, & Brown, 2016). In light of the model presented here, any assessment of individual differences in dispositional mindfulness would rely on instruments capable of measuring the cognitive faculty of mindfulness without confounding measures of either the metacognitive processes involved in the process of mindfulness training or their outcomes, such as decentering. See Park, Reilly-Spong, and Gross (2013) for a discussion of construct validity in existing self-report measures of mindfulness.

Behavioural measures assessing attentional outcomes after mindfulness training are frequently reported in studies examining the effect of mindfulness. While measures of sustained attention, selective attention, working memory, and response inhibition may provide indirect and inferential evidence of improvements in mindfulness, they cannot be used to determine if participants have successfully generated the cognitive faculty of mindfulness. Furthermore, timed tasks such as the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002), continuous performance tasks (Ballard, 2001), go no-go tasks such as the Sustained Attention to Response Task (SART; Robertson et al., 1997), the Stroop task (Stroop, 1935), and the d2 Test of Attention (Brickenkamp & Zillmer, 1998) are all susceptible to a range of confounding factors such as incentive and motor-response time that may adversely influence performance outcomes (Jensen et al., 2012). Of particular concern is the assumption that mindfulness training will result in reaction time response improvements on these tasks. It is not yet certain if proficiency in internally regulating attention with equanimity in mindfulness practice should result in enhanced reaction times to external stimuli involving a motor response (Isbel & Mahar, 2015).

Levinson et al. (2014) present a breath counting task as a behavioural measure of mindfulness that does not involve a timed response. The task requires participants to repeatedly count their breath to a predetermined number while reporting their count via key press. This computerised task has been shown to reflect increases in mindfulness following training, discriminate experienced from novice practitioners, and be separable from measures of sustained attention, mind-wandering, or working memory. Experiments in our laboratory indicate that the use of physiological breath tracking to confirm participants’ reported count during this task improves test reliability. In the absence of neuroimaging and electroencephalographic measures capable of detecting a proxy or signature of mindfulness (Davidson & Kasznia, 2015), the breath-counting task represents a valuable objective measure for use in assessing the effectiveness of mindfulness interventions.

5. Future directions

The purpose in developing a standardised technique is to facilitate the investigation of the cognitive processes of mindfulness and assess their ability to produce salient therapeutic change. It is hoped that a clearer understanding of the processes underlying this practice may arise from longitudinal RCTs utilising the standardised technique. The repeated application of the standardised technique across studies will address the possibility that differences in mindfulness technique could be responsible for significantly varying neurobiological findings (Chiesa et al., 2011; Davidson, 2010). Comparative studies using the standardised technique with additional therapeutic components will open the door to investigating the role and outcome of each therapeutic factor when added to the standardised technique. A rich field of research awaits the investigation of the effect of attitudes, expectations, therapies, values, and other factors in mediating the benefits resulting from mindfulness practice. Clearly understanding the role of each element within existing MBIs in producing beneficial outcomes is essential in effectively targeting therapeutic applications. The technique presented
here is designed to facilitate an investigation into these factors.

6. Conclusion

While the study of mindfulness has grown exponentially over the last two decades, consensus as to exactly what constitutes mindfulness has yet to be achieved (Chiesa & Malinowski, 2011; Sun, 2014). A first step in clarifying this issue is to distinguish the cognitive faculty of mindfulness from the practices designed to cultivate it. In this way, the cognitive processes of mindfulness can be separated from ancillary factors. As the field moves toward the use of rigorously designed longitudinal RCTs there is a need for a standardised mindfulness technique for use in such studies. The standardised technique presented here is suitable for advancing the scientific investigation of mindfulness since it provides a method for generating the cognitive processes underlying mindfulness practice without the addition of secondary factors.

Conflict of interest

The authors declare no conflicts of interest.

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References


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Chapter 3:
Mental Training Affects Electrophysiological
Markers of Attention Resource Allocation in
Healthy Older Adults
Research article

Mental training affects electrophysiological markers of attention resource allocation in healthy older adults

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ABSTRACT

Aging is associated with a decline in performance and speed of attentional processing. Mindfulness has been shown to enhance attentional performance, however evidence of this is lacking in aging cohorts. A longitudinal RCT was conducted to examine the effect of mindfulness training on attentional performance in healthy older adults (n = 49) together with an active control computer-based attention training group (n = 30). While both groups displayed decreased N2 amplitudes at frontal and central regions during an auditory oddball task after training, only the mindfulness group showed reductions in frontal N2 and P3 latency. These results suggest that programs targeting sustained attention may result in efficient allocation of attentional resources in older adults. In particular, mindfulness may enhance the speed of attentional processes which are known to decline in aging, thereby providing benefits against age-related cognitive decline.

1. Introduction

Healthy aging is associated with declining performance of sustained attention, observed as increased reaction time variability [1] during task performance. Declining speed and efficiency of neural networks underpinning attentional control are thought to be responsible for these changes in aging [2]. Sensitive measures of neural activation in the deployment of attentional resources are found in event-related potential (ERP) components. Whereas short-latency components such as P1 and N1 largely index automatic attentional processes, longer latency components such as the N2 and P3 components reflect neural activation during controlled processing of information [3]. While the N2 indexes response inhibition during tasks involving response conflict [4], during tasks of sustained attention that do not involve response conflict a frontocentral N2 has been shown to index discrimination of stimuli as either congruent or deviant to a perceptual template [3]. The P3 component has generally been thought to index firstly a frontally oriented response related to stimulus evaluation, followed by a temporoparietal response related to context updating and memory storage [6,7]. While there is evidence suggesting that this parietal P3 component may represent the completion of a stimulus-response event [8], it is clear that both the P3 and N2 components index underlying neural processes involved in information processing. The deterioration of these neural networks in aging is reflected in longer latencies and reduced amplitudes of both the N2 and P3 components with age, and these changes are accompanied by increased variability of attentional performance [9].

Mindfulness has emerged as a training technique purportedly capable of enhancing sustained attention [10] and may have benefit in older adults experiencing age-related cognitive decline (ARCD). Mindfulness involves the cultivation of sustained attention toward the breath along with equanimity, which is an unbiased and non-reactive orientation toward the contents of experience [11]. This type of attention training requires the continuous activation of attentional control processes to prevent attentional interference across sensory modalities, and thus repeatedly activates the neural networks associated with these functions [12]. Accordingly, mindfulness training has been shown effective at improving the speed and stability of attention [13], and enhancing ERP amplitudes [14]. However, evidence of its efficacy in older adults is lacking. One longitudinal study used a Stroop task to demonstrate increased N2 amplitude following eight weeks of mindfulness training in older adults [15]. Given the importance of sustained attention to general cognitive function, there is a need to examine the efficacy of mindfulness to enhance this kind of attention in older adults at risk of ARCD. Sustained attention is best assessed using simple, monotonous tasks that do not require shifting attentional focus, suppressing distractors, or resolving stimulus or response conflicts [16]. Accordingly, the auditory oddball task is well suited to investigate ERP.

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changes during sustained attention resulting from mindfulness training in older adults.

We conducted an RCT to assess ERP changes resulting from an 8-week mindfulness intervention (MT) in a group of healthy older adults. An auditory oddball task was used to elicit ERP components. A computer-based training program (CT) was utilised as an active control condition to determine if the previously reported benefits of mindfulness to attention related to the attention-training component of this practice, or rather were the result of mindfulness-specific factors. Cognitive training has previously been shown to improve attentional performance in older adults [17]. Accordingly, performance on the auditory oddball was expected to improve in both groups, since both engaged in attention training. However, we hypothesised that the MT group would show increases in N2 and P3 amplitude after training due to enhanced attention resource mobilisation resulting from this practice. No change in N2 or P3 amplitude was predicted for the active control CT group.

2. Materials and methods

2.1. Participants

Healthy older adults (≥60 years age; n = 120) were randomly assigned to the interventions (MT: n = 77; CT: n = 43). All participants were screened prior to acceptance into the study for conditions and medications known to adversely impact cognitive performance, as well as prior exposure to either mindfulness or computerised brain-training programs. No remuneration for participation was provided to participants. After attrition, data from 79 participants (MT: n = 49; CT: n = 30) was eligible for analysis (see Table 1 for participant demographic information).

2.2. Interventions

Each program consisted of eight weekly teacher-guided group training sessions together with a daily home practice requirement of 20 min/day in week one, increasing to 45 min/day in week eight. Participants recorded their daily training, and ten participants were excluded from analysis (MT: n = 8; CT: n = 2) for failing to meet the minimum training requirement. Inspection of mean daily practice time showed that the CT group (M = 36.0 min/day (SD = 6.0)) spent approximately three minutes longer per day engaged in the training program than the MT group (MT: M = 33.1 min/day (SD = 4.0)).

2.2.1. Mindfulness-based attention training program

A standardised mindfulness technique designed for use in longitudinal RCTs was used in the MT program [18]. This technique develops mindfulness toward the sensations accompanying the breath as the primary focus of attention. Practiced in this way, mindfulness activates the attentional processes of selective attention, task switching, inhibitory control, and working memory (see [18] for a detailed description of the cognitive processes activated during mindfulness).

2.2.2. Computer-based attention training program

A computerised game format was used to deliver exercises designed to activate similar attentional processes to those activated in mindfulness practice. The CT program was specifically developed for the current study, and included modified versions of the Eriksen flanker task, a visual search task, task switching task, Stroop task, divided attention task, a Corsi block task, and a card matching working memory task. In order to target the cultivation of sustained attention, participants were instructed to continuously perform the same task for the duration of their training session. Tasks were changed weekly. The CT program was available to access online on participants’ own device to enable the training to be done in a way most suitable for each participant.

2.3. Auditory oddball task

Prior to testing, all participants underwent a hearing test to assess hearing loss in the frequency range used in the auditory oddball task. No participant was found to have hearing impairments in frequency range used. Standard tones (1000 Hz; n = 293) and target tones (1500 Hz; n = 48) were presented binaurally in a pseudorandom order at 70 dB SPL for a duration of 75 ms (5 ms rise/fall) with a variable inter-stimulus interval (1000–1500 ms). Participants were instructed to respond as accurately and quickly as possible to target tones by pressing a keypad. A full-feedback practice block consisting of 60 stimuli including nine target tones was completed prior to the experimental block. Total task time including practice block was approximately nine minutes.

Performance measures included total errors (%), reaction time (RT), and reaction time coefficient of variation (RT CV). Variability in RT indexes sustained attention, whereby greater fluctuations in sustained attention are observed as increasing variability (CV) of responding (RT) to stimuli [19].

2.4. Procedures

Testing was conducted at both pre (T1) and post-intervention (T2). Sleep quality, along with symptoms of anxiety and depression [20] were reported before each session as they are known to adversely impact EEG measures. No participant reported reduced sleep or elevated symptoms of anxiety or depression. A breath-counting task requiring participants to mentally count their breath cycles to 21 for 15 min served as a behavioural measure of mindfulness [21]. Counting accuracy was physiologically confirmed using an effort sensor placed around the chest. Breath-counting accuracy was calculated as a percentage of correct counts to total cycles completed. The auditory oddball task was then completed.

All procedures were performed in accordance with the ethical standards of the University of the Sunshine Coast Human Research Ethics Committee (approval: HREC A-15-748), the Australian National Statement on Ethical Conduct in Human Research, and the Code of Ethics of the World Medical Association (Declaration of Helsinki). In accordance with the latter two ethical statements which proscribe the use of no-treatment or placebo controls when existing effective treatment conditions exist, an active control condition consisting of a program of cognitive training was used as a comparison condition to assess the benefits of mindfulness training. Informed consent was obtained from participants to participate in the research.

Table 1

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Participant demographic information.</th>
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<td>Mindfulness-based training group</td>
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</tbody>
</table>
| Gender balance | (% female) | 55% | 75% | $X^2_{1, n = 79} = 3.10, p = .08$
| Age | M (SD) | 71.6 (4.8) | 69.5 (5.9) | \(t_{77} = 1.71, p = .09\)
|       | Range | 60–83 | 60–86 | \(t_{79} = 0.66, p = .51\)
| Predicted FSIQ | M (SD) | 112.5 (7.0) | 111.5 (6.97) | \(X^2_{1, n = 79} = 0.399, p = .53\)
| Handedness | (% RH) | 93.8% | 90.0% | \(t_{77} = 0.53, p = .58\)

* FSIQ = Full Scale IQ (as estimated by the Wechsler test of adult reading).
all individual participants included in the study.

2.5. EEG data acquisition and processing

EEG was acquired by ActiveTwo system using Ag/AgCl active electrodes (Biosemi, Amsterdam, Netherlands) with vertical and horizontal electrooculogram to monitor eye movements. Data was sampled at 1024 Hz and processed offline using BrainVision Analyzer2 software (Brain Products, GmbH, Gilching, Germany).

EEG data from F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4 sites were used for ERP analysis. Data was referenced offline to an average mastoid, then filtered using a Butterworth filter (0.1–30 Hz, 12 dB/octave) with a 50 Hz notch filter. Ocular artefacts were corrected [22] and correct target trials segmented ~200 ms before to 800 ms after stimulus onset. Trials containing voltages exceeding an absolute change of 50 μV/ms or an absolute min-max difference of 100 μV/200 ms on any channel were rejected from analysis. Remaining trials were baseline corrected using the 200 ms pre-stimulus period as a reference and averaged. An a priori decision to reject participants with fewer than 50% artefact-free trials resulted in seven participants being excluded due to insufficient artefact-free trials (MT: n = 5; CT: n = 2). There were no significant differences in the number of artefact-free trials between the groups at both pre [MT: M = 44.4 (SD = 5.0); CT: M = 43.8 (SD = 6.2)] and post-intervention [MT: M = 44.0 (SD = 6.1); CT: M = 45.6 (SD = 5.3)].

Latency windows for N2 and P3 components on target trials were determined using grand average ERP waveforms at T1. Similar grand average waveforms for standard tones revealed no N2 or P3 response to standards, and thus they were not analysed. Peak amplitude and latency for N2 (180–280 ms) and P3 (280–480 ms) to target tones were determined for frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) sites. ERP component amplitude was calculated using peak-to-peak measures to control for positive or negative drift across multiple components, where N2 amplitude was calculated as the change in voltage from P2 to N2 peaks, and P3 amplitude as the change in voltage from N2 to P3 peaks.

2.6. Statistical analysis

Behavioural measures were analysed using mixed design ANOVA with group (MT, CT) as a between-subjects factor and time (T1, T2) as a within-subjects factor. Mixed design ANOVAs for N2 and P3 latency and amplitude were conducted for each region (frontal, central, parietal) with electrode (3 levels) and time (T1, T2) as within-subjects factors with group (MT, CT) as a between-subjects factor. Significant effects were investigated with follow-up pairwise comparisons. All statistical analysis was performed using SPSS version 24 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Behavioural performance data

Variability of responding reduced over time [RT CV (F(1,77) = 5.852, p = .018, partial η2 = 0.071)], however no group x time interaction was observed. Thus, both groups displayed an improved ability to sustain attention during the task. Participants performed at near-ceiling levels at T1, and no significant change in total errors or RT was observed (see Table 2).

A significant group x time interaction was observed for breath-counting accuracy scores (F(1,77) = 5.485, p = .022, partial η2 = .066). Follow-up pairwise comparisons indicated the MT group showed significant improvement (M(CT) = 14.146, SE = 4.632, p = .003), while the CT group showed no significant change (M(CT) = -3.459, SE = 5.920, p = .561).

Behavioural data indicates that the MT intervention was effective in improving both attentional performance and mindfulness, while the CT intervention was successful at training attention without improving mindfulness.

3.2. ERP data

3.2.1. N2 results

Mean N2 latency and amplitude values for each group at T1 and T2 are represented in Fig. 1.

Mixed ANOVA for N2 latency revealed a significant group x time interaction for frontal region (F(1,77) = 12.259, p = .001, partial η2 = .137). Follow-up pairwise comparisons revealed that the MT group displayed significant reductions in N2 latency at F3 (M(CT) = -12.039, SE = 3.130, p < .001), Fz (M(CT) = -10.283, SE = 3.376, p = .003), and F4 (M(CT) = -7.494, SE = 3.227, p = .023) not observed in the CT group. No significant changes were observed at central or parietal regions.

Mixed ANOVA results for N2 amplitude revealed a main effect of time at frontal (F(1,77) = 5.291, p = .024, partial η2 = .064), central (F(1,77) = 9.497, p = .003, partial η2 = .110) and parietal (F(1,77) = 16.021, p < .001, partial η2 = .172) regions. No group x time interaction effect was observed at frontal (F(1,77) = 1.114, p = .294, partial η2 = .014) or central (F(1,77) = 0.564, p = .455, partial η2 = .007) regions, indicating that both groups showed reductions in N2 amplitudes in these regions. A significant group x time interaction for N2 amplitude was observed for parietal region (F(1,77) = 5.236, p = .025, partial η2 = .064). Follow-up pairwise comparisons revealed that the CT group displayed reductions in N2 amplitude at P3 (M(CT) = -1.691, SE = 0.527, p = .002), Pz (M(CT) = -2.391, SE = 0.546, p < .001), and P4 (M(CT) = -1.665, SE = 0.521, p = .002) not observed in the MT group.

3.2.2. P3 results

Mean P3 latency and amplitude values for each group at T1 and T2 are represented in Fig. 2.

Mixed ANOVA for P3 latency revealed a significant group x time interaction for frontal region (F(1,77) = 5.849, p = .018, partial η2 = 0.071). Follow-up pairwise comparisons revealed significant reductions in P3 latency for the MT group at F3 (M(CT) = -11.541, SE = 5.772, p = .049) and Fz (M(CT) = -12.556, SE = 5.665, p = .030), but not F4 (M(CT) = -4.287, SE = 5.850, p = .466). No significant changes were observed at central or parietal regions.

Mixed ANOVAs for P3 amplitude revealed no significant main or interaction effects.

4. Discussion

The present study reports reduced frontal N2 and P3 latency resulting from mindfulness training in healthy older adults, suggesting that the speed of neural processes reflected by these components had
increased in this group compared to an active control group. Since aging is associated with declining efficiency of attentional networks and a slowing of information processing, these results suggest mindfulness may have a role in combating ARCD.

Faster information processing during an attentional blink task has previously been reported after mindfulness training, and these improvements were accompanied by reductions in P3 amplitude [23]. Reductions in ERP amplitude in this study were interpreted as indicating enhanced efficiency of attentional resource allocation, enabling faster processing of rapid stimuli. In the current study, a reduction in N2 amplitude to target tones was observed at frontal and central regions in both groups. This decrease in attentional allocation was accompanied by improved stability of attentional performance as measured by RT CV, together with non-significant reductions in both error rates and RTs. This combination of results suggest that the efficiency of neural processes underlying the N2 response had increased, since fewer neural resources were required to be activated to achieve similar or higher task performance after training.

Two studies reporting increases in N2 amplitude after mindfulness training used a Stroop task to elicit ERP components [15,24]. As noted earlier, tasks requiring response conflict elicit an N2 response thought to index inhibition, whereas tasks of sustained attention that do not involve conflict are thought to elicit a frontocentral N2 response reflective of discrimination of stimuli as either congruent or deviant to a perceptual template. It is therefore likely that the N2 elicited by the Stroop task is not identical to that elicited by tasks which do not involve conflict resolution, such as the auditory oddball and attentional blink task. Thus, while enhanced N2 amplitude during inhibition has been reported following mindfulness, our results are in line with the reductions in ERP amplitude reported during the attentional blink task, which shares similar characteristics to the auditory oddball, and therefore support the conclusion that the N2 elicited by these different tasks reflect differing processes.

The presence of reduced N2 amplitude in the CT group suggests that the training undertaken by this group accurately replicated the attention training engaged by mindfulness practice, and was also effective at improving neural efficiency. However, the presence of this effect in parietal regions in the CT group not observed in the MT group suggests further mechanisms were activated by the computer-based intervention not present in the mindfulness intervention. Previous studies reporting increased N2 amplitude following cognitive training in older adults support the view that cognitive training in this age group can impact neural processes of attention, although these studies have again used tasks involving stimulus and response conflict, such as a task switching paradigm, rather than tasks of sustained attention [25,26].

Taken together, evidence suggests an ability to modify attention resource mobilisation after cognitive training, and indicates that further research is required to examine the differential effects of cognitive training on attention in older adults. Furthermore, the results presented here indicate that mindfulness in particular may have a role in combating ARCD, which is characterised by increases in N2 and P3 latency.
4.1. Limitations

The absence of an additional control group not engaged in any training limits our ability to determine if the benefits observed are a product of non-specific intervention effects, such as social engagement and mental stimulation. Previous research [15] utilising a brain training control group reported no change in ERP component amplitude or latency, suggesting the findings reported here were not due to non-specific intervention factors.

The contribution of practice effects cannot be entirely ruled out. While frequent task repetition has been shown to lead to reductions in RT and error rates when retest times are short [27,28], RT CV during tasks of sustained attention has been shown to be virtually unaffected by practice effects [29]. Therefore, it is unlikely that reductions in RT CV observed resulted from practice effects. Additionally, while high frequency practice effects on ERP component amplitude and latency have previously been examined, there is little evidence of long-term infrequent task effects on ERP components [30].

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References

Chapter 4

Mental Training Improves Attention Resource Allocation during Response Inhibition in Older Adults
Mental Training Improves Attention Resource Allocation during Response Inhibition in Older Adults

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Abstract

Mindfulness has been shown to improve attentional control, however studies examining aging cohorts are lacking. A core process trained during mindfulness is inhibitory control. Deteriorations in inhibitory control are thought to underlie cognitive declines observed in aging. The N2 and P3 event-related brain potentials index both the speed and allocation of attentional resources, making them useful in assessing attentional changes in aging. We conducted a longitudinal RCT to examine the effect of mindfulness training (MT) on attention in healthy older adults ($n = 48$) together with an active control computer-based attention training group (CT; $n = 27$). The MT group showed reductions in frontal P3 latency during a Sustained Attention to Response Task, and these reductions were accompanied by improvements to sustained attention not observed in the CT group. Exploratory analyses revealed shorter reaction times and P3 latencies during response inhibition in those who achieved a high level of proficiency in mindfulness (MT-HIGH; $n = 24$) but not in those who achieved a low level of proficiency (MT-LOW; $n = 24$). The mindfulness group also showed reductions in N2 amplitude compared to increases in the control group, suggesting enhanced efficiency of attentional resource allocation during the task. The results suggest that mindfulness may enhance the speed and efficiency of attentional processes, thus providing protective benefits against age-related cognitive decline.

KEYWORDS: mindfulness, attention, ERP, cognitive training, aging, inhibition.
1. Introduction

The ability to sustain attention by inhibiting competing distracting processes represents a core attentional function that underpins complex cognitive operations which are known to slow and become increasingly susceptible to interference with age (Hedden & Gabrieli, 2004; Sarter, Givens, & Bruno, 2001). Deteriorations in inhibitory control during controlled cognitive processing are thought to underlie these age-related declines in cognitive performance (Andrés, Guerrini, Phillips, & Perfect, 2008; Weeks & Hasher, 2015). This type of age-related cognitive decline (ARCD) has been shown to be reversible with cognitive training (Gajewski & Falkenstein, 2012; Kelly et al., 2014). Mindfulness has emerged as a training technique shown to enhance attentional control (Van den Hurk, Giommi, Gielen, Speckens, & Barendregt, 2009), and may provide protective benefits for older adults against ARCD.

Event-related potentials (ERPs) offer sensitive temporal measures of attentional processes. During a go/no-go task such as the Sustained Attention to Response task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), the N2-P3 ERP complex has been consistently demonstrated across brain regions when response inhibition is required. The no-go N2 elicited in this way is thought to index controlled attentional processes including response inhibition (Näätänen & Picton, 1986), while the P3 reflects attentional resource allocation (Polich, 2007). Both N2 and P3 components are known to increase in latency with aging, suggesting a slowing of attentional processing (Anderer, Semlitsch, & Saletu, 1996; Enoki, Sanada, Yoshinaga, Oka, & Ohtahara, 1993). While studies reporting attentional benefits arising from mindfulness training in younger cohorts continue to grow, there is little evidence of its effectiveness to improve attention in aging.

In order to investigate the efficacy of mindfulness to enhance attention in normal aging, we conducted an RCT with an active control to assess both behavioural and ERP outcomes resulting from an 8-week mindfulness intervention (MT) in a group of healthy older adults. The SART, a widely used measure of sustained attention and inhibition, was used to assess the effectiveness of the intervention in improving attentional control. A breath-counting task was employed to assess the development of proficiency in mindfulness practice. An active control computer-based training program (CT) designed to activate similar attentional processes to mindfulness was utilised to determine if the reported benefits of mindfulness to attention resulted from its attention-training component or from additional mindfulness-
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Specific factors beyond attention training. Cognitive training has previously been shown to improve attentional performance in older adults (Kelly et al., 2014) and reverse ARCD (Willis & Schaie, 1986). Accordingly, performance on the SART was expected to improve in both groups, since both engaged in attention training. However, in line with previous findings we hypothesised that the MT group would show increases in N2 and P3 amplitude and decreases in N2 and P3 latency after training due to enhanced attention resource mobilisation resulting from this practice. Based upon evidence suggesting that outcomes from mindfulness are proportional to proficiency (Jha, Stanley, Kiyonaga, Wong, & Gelfand 2010), it was hypothesised that participants who gained high proficiency in mindfulness (MT-HIGH) would demonstrate greater change than those who gained low proficiency (MT-LOW). No change in N2 or P3 amplitude or latency was predicted for the active control CT group.

2. Materials and Methods

2.1. Participants

Healthy older adults (≥ 60 years age; \(n = 120\)) recruited from the general community to participate in an attention training program were randomly assigned to the interventions (MT: \(n = 77\); CT: \(n = 43\)). Participants were randomly allocated at a rate of 2:1 to MT to enable this group to be divided post-hoc into high and low proficiency groups following MT training. Prior to acceptance into the study, all participants were screened for conditions known to adversely impact cognitive performance, as well as prior exposure to either mindfulness or computerised brain-training (see Supplementary Table 4.1 for eligibility criteria). The interventions were described to participants as equivalent attention training programs differing only in delivery format, and thus participants were blinded to experimental and control conditions. After participant attrition, artefact-free data from 75 participants (MT: \(n = 48\); CT: \(n = 27\)) was available for final analysis (see Figure 4.1 for flowchart of participant retention and reason for dropout). A priori power calculations indicated that to achieve power > 0.80 with an effect size of \(r = 0.32\) (expected effect size as reported by Sedlmeier et al., 2012) at a significance level of \(p = .05\), a sample size of \(n = 27\) would be required for a three-group mixed ANOVA design. Participant demographic information for the reported data is presented in Table 4.1.
Table 4.1: Study 3 participant demographic information

<table>
<thead>
<tr>
<th></th>
<th>Mindfulness-based training group</th>
<th>Active control group</th>
<th>Statistical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender balance (% female)</td>
<td>55%</td>
<td>75%</td>
<td>$X^2(1, N = 71) = 3.00, p = .08$</td>
</tr>
<tr>
<td>Age $M$ $(SD)$</td>
<td>71 (4.5)</td>
<td>70 (5.9)</td>
<td>$t_{(73)} = 1.61, p = .11$</td>
</tr>
<tr>
<td>Range</td>
<td>60-83</td>
<td>60-86</td>
<td></td>
</tr>
<tr>
<td>Predicted FSIQ* $M$ $(SD)$</td>
<td>112.6 (7.0)</td>
<td>112.5 (5.7)</td>
<td>$t_{(73)} = 0.10 , p = .92$</td>
</tr>
</tbody>
</table>

* FSIQ = Full Scale IQ (as estimated by the Wechsler test of adult reading).

Figure 4.1: Study 3 CONSORT flowchart of participant retention with reason for dropout
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2.2. Interventions

The interventions were structurally equivalent, consisting of eight weekly group training sessions together with a home practice requirement of 20 min/day in week one increasing to 45 min/day in week eight. Program content for each week of the interventions is outlined in Supplementary Table 4.2. Daily home practice was recorded, and ten participants were excluded from analysis for failing to meet the minimum training requirement for the program (MT: \( n = 8 \); CT: \( n = 2 \)). Participants in both groups were instructed to perform the home training in a quiet environment where the training exercise could be carried out uninterruptedly.

**Mindfulness-based attention training program**

A standardised mindfulness technique developed for use in longitudinal RCTs was used in the MT program (for details see: Isbel & Summers, 2017). The practice of mindfulness primarily involves the cultivation of two components: (1) an attentional component involving inhibitory control, and (2) equanimity, which is an unbiased and non-reactive orientation toward the contents of experience. During this practice participants are required to inhibit distracting processes as well as cognitive and emotional reactivity in order to sustain attention upon the breath in an equanimous manner. When attention wanders from this primary task participants are instructed to inhibit and disengage from distracting processes and redirect attention back to the primary task. Working memory is thought to be central to this training as participants are required to retain the task instructions and continually update and monitor ongoing attentional performance. The core process trained in this practice is therefore executive inhibitory control, through which sustained attention and equanimity are gradually developed.

**Computer-based attention training program**

A series of computer-based training exercises delivered in game format were used to activate similar attentional processes to those engaged during mindfulness practice. Each game emphasised a specific aspect of attention, such as sustained attention, selective attention, inhibitory control, or a combination of these to replicate attentional deployment during mindfulness practice (see Supplementary Table 4.3 for a description of the primary attentional components trained in each task). The training of inhibitory control was emphasised during the CT program since inhibitory control is considered central to
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attentional deployment during mindfulness practice. Participants were instructed to perform the same task repeatedly during each session to replicate the continuous application to a single task that occurs in mindfulness practice, with tasks being changed weekly.

2.3. Measures

*Wechsler test of adult reading*

The Wechsler Test of Adult Reading is a widely used word reading list used to estimate full scale intelligence quotient (FSIQ) in adults. The WTAR is co-normed against the Wechsler Adult Intelligence Scale, 3rd edition and is a reliable and valid estimate of intellectual capacity.

*Hospital anxiety and depression scale*

The Hospital Anxiety and Depression scale (HADS; Zigmond & Snaith, 1983) is designed to detect clinically significant states of anxiety and depression, and was utilised to screen for psychological states which may adversely impact EEG measures. The HADS is a cut-off criterion instrument consisting of two 7-item subscales for anxiety (HADS-A) and depression (HADS-D) on which participants indicate the frequency with which they experience symptoms on a Likert-type scale. The HADS has been shown to have high validity and reliability (HADS-A: Cronbach’s α .83; HADS-D: Cronbach’s α .82).

*Breath-counting task*

Breath-counting has previously been validated as a behavioural measure capable of distinguishing proficient from non-proficient mindfulness practitioners (Levinson, Stoll, Kindy, Merry, & Davidson, 2014). Participants were required to count 21 in-and-out breath cycles repeatedly for 15 minutes, reporting each successfully completed 21 count-cycle with a right-arrow key-press. Self-caught counting errors were indicated by a left-arrow key press. Breath-counting accuracy was physiologically confirmed using a piezo-electric crystal effort sensor placed around the chest to record respiration movement. A breath-counting accuracy score was calculated as a percentage of correct count cycles to total cycles completed during the task (correct count/total cycles x 100).
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Sustained Attention to Response Task

The SART consisted of a serial presentation of digits (1-9) to which participants respond via keypress to go stimuli (digits 1-2, and 4-9) while withholding a response to no-go stimuli (digit 3). For each block of nine trials a single digit (1-9) was randomly chosen without replacement. The experimental block consisted of 540 trials (60 blocks of 9 trials) containing 60 no-go stimuli (11% of total trials). Digits were presented in black font in randomly allocated sizes (100, 120, 140, 160, or 180 points) in the centre of a grey background for 200ms. After stimulus offset, a yellow fixation cross was presented in the middle of the grey background for a variable inter-stimulus interval between 1000-2000ms. Participants were instructed to respond as quickly and accurately as possible during the task. Participants completed a practice block with performance feedback prior to task commencement to ensure the task was correctly understood. The two groups demonstrated equivalent performance during completion of the practice block.

Performance measures for the SART included errors of commission (percentage of errors on no-go), reaction time (RT), and reaction time coefficient of variation (RT CV). Errors of commission index failures of inhibitory control while variability in RT indexes sustained attention, wherein greater fluctuations in sustained attention are observed as increasing variability (CV) of responding (RT) to stimuli (Mrazek, Smallwood, & Schooler, 2012; Robertson et al., 1997). All measures were calculated for each half of the task to assess attentional performance over time-on-task.

EEG Measures

EEG was acquired using an ActiveTwo system with Ag/AgCl electrodes (Biosemi, Amsterdam, Netherlands) with vertical and horizontal EOG electrodes to monitor eye movements. Data was sampled at 1024Hz with additional offline processing conducted using BrainVision Analyzer2 (Brain Products, GmbH, Gilching, Germany).

Data was referenced offline to average mastoid, then filtered using a zero phase-shift Butterworth filter (0.1-30Hz, 12 dB/octave) with a 50Hz notch filter. Ocular artefacts were corrected using the technique of Gratton, Coles, and Donchin (1983) and correct trials segmented -200ms before to 800ms after stimulus onset. Trials containing voltages exceeding an absolute change of 50µV/ms or an absolute min-max difference of 100µV/200ms were rejected from analysis. Remaining trials were baseline corrected and averaged. An a priori
decision to reject participants with fewer than 50% artefact-free trials resulted in 11 participants being excluded due to insufficient artefact-free data (MT: \( n = 6 \); CT: \( n = 5 \)). Remaining number of artefact-free trials for each group were similar at both pre [MT: \( M = 46.6 \ (SD = 7.3) \); CT: \( M = 45.5 \ (SD = 7.7) \)] and post-intervention [MT: \( M = 48.0 \ (SD = 6.8) \); CT: \( M = 48.0 \ (SD = 6.0) \)].

Latency windows for N2 and P3 components were determined using grand average ERP waveforms at T1. Peak amplitude and latency for N2 (180-380ms) and P3 (380-580ms) were determined for frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) sites. ERP component amplitude was calculated using peak-to-peak measures to control for positive or negative drift across multiple components, where N2 amplitude was calculated as the change in voltage from P2 to N2 peaks, and P3 amplitude as the change in voltage from N2 to P3 peaks.

2.4. Procedures

All assessments except the WTAR were performed at pre (T1) and post-intervention (T2). Sleep quality together with symptoms of anxiety and depression (HADS) were reported before each session as they are known to adversely impact EEG measures. No participant reported reduced sleep or elevated anxiety or depression. The WTAR was performed once only at baseline testing. Participants were fitted with the EEG equipment and instructed to minimise eye and muscle movements during the recording. Participants first completed the breath counting task, followed by the SART. Task instructions were presented on a monitor screen placed 65cm from the participant. Stimuli were presented using E-Prime 2.0.10 software (Psychology Software Tools, Pittsburgh, PA, USA).

All procedures were performed in accordance with the ethical standards of the University of the Sunshine Coast Human Research Ethics Committee (approval: HREC A-15-748), the Australian National Statement on Ethical Conduct in Human Research, and the Code of Ethics of the World Medical Association (Declaration of Helsinki). In accordance with the latter two ethical statements which proscribe the use of no-treatment or placebo controls when existing effective treatment conditions exist, an active control condition consisting of a program of cognitive training was used as a comparison condition to assess the benefits of mindfulness training. Informed consent was obtained from all individual participants included in the study.
2.5. Statistical Analysis

Independent groups $t$ tests were performed to examine pre-intervention between-group differences in age, FSIQ, SART measures, and N2 and P3 amplitudes and latencies. Between groups gender balance was examined using Chi square analysis.

To assess change in mindfulness, breath-counting accuracy scores were entered into a mixed design ANOVA with group (MT, CT) as a between-subjects factor and time (T1, T2) as a within-subjects factor. Breath-counting scores at T2 were used to provide a median split of the MT group into top and bottom 50th percentile groups, corresponding to mindfulness high performers (MT-HIGH) and mindfulness low performers (MT-LOW). This enabled exploratory analysis of the differential effects of mindfulness proficiency on test measures.

Behavioural measures for the SART were analysed using mixed design ANOVA of total commission errors, RT, and RT CV with group (MT, CT) as a between-subjects factor and time (T1, T2) and period (1st half, 2nd half) as a within-subjects factors. Significant effects were investigated with follow-up pairwise comparisons. To examine the effect of mindfulness proficiency on SART measures, exploratory mixed design ANOVA with three-level (MT-LOW, MT-HIGH, CT) between-groups factor was also performed.

Mixed design ANOVAs for N2 and P3 latency and amplitude were conducted for each region (frontal, central, parietal) with electrode (3 levels) and time (T1, T2) as within-subjects factors with group (MT, CT) as a between-subjects factor. Significant effects were investigated with follow-up pairwise comparisons. To examine the effect of mindfulness proficiency on N2 and P3 measures, exploratory mixed design ANOVA with three-level (MT-LOW, MT-HIGH, CT) between-groups factor was also performed.

In order to demonstrate the relationship between electrophysiological markers of brain resource allocation and behavioural performance, partial correlations controlling for group (MT-LOW, MT-HIGH, CT) were calculated between N2 and P3 latency and RT. Where a breach of the assumption of sphericity occurred in the ANOVA, Greenhouse-Geisser corrected $p$ values are reported. All statistical analysis was performed using SPSS version 24 (SPSS Inc., Chicago, IL, USA).
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3. Results

3.1. Pre-Intervention Between-Group Comparisons

There were no significant pre-intervention differences between the MT and CT groups in age, gender balance, FSIQ (see Table 1), errors of commission, reaction time, or RT CV (see Table 4.2). No significant pre-intervention difference in N2 or P3 amplitude or latency was observed (see Table 4.3).

Table 4.2: Study 3 pre-intervention scores on Sustained Attention to Response Task by group

<table>
<thead>
<tr>
<th></th>
<th>Mindfulness-based training group</th>
<th>Active control group</th>
<th>Statistical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Errors of commission (%)</td>
<td>M (SD) 16.4 (9.9)</td>
<td>21.3 (12.3)</td>
<td>( t_{(73)} = -1.887, p = .06 )</td>
</tr>
<tr>
<td>RT (ms)</td>
<td>M (SD) 500.8 (56.7)</td>
<td>480.0 (53.3)</td>
<td>( t_{(73)} = 1.557, p = .12 )</td>
</tr>
<tr>
<td>RT CV</td>
<td>M (SD) 0.228 (0.05)</td>
<td>0.218 (0.04)</td>
<td>( t_{(73)} = 0.843, p = .40 )</td>
</tr>
</tbody>
</table>

* FSIQ = Full Scale IQ (as estimated by the Wechsler test of adult reading).

3.2. Behavioural Performance Data

*Breath-counting Task*

Repeated measures ANOVA revealed a significant group x time interaction (\( F_{(1,73)} = 5.186, p = .026, \text{partial } \eta^2 = .066 \)). Follow-up Bonferroni-corrected pairwise comparisons indicated that the MT group showed significant pre to post-intervention improvement on the breath-counting task (\( M_{I-J} = 14.94, \ SE = 4.76, p = .002 \)), while the CT group showed no significant change (\( M_{I-J} = -3.13, \ SE = 6.35, p = .623 \)). These results indicate that the MT program was effective at improving mindfulness while the CT program was successful at training attention without improving mindfulness.
Table 4.3: Study 3 pre-intervention difference in ERP component latency and amplitude at midline electrode sites.

<table>
<thead>
<tr>
<th></th>
<th>Mindfulness-based training group</th>
<th>Active control group</th>
<th>Statistical values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latency (ms) (M {SD})</td>
<td>Latency (ms) (M {SD})</td>
<td>(t_{73})</td>
</tr>
<tr>
<td>Fz</td>
<td>331.7 (33.7)</td>
<td>318.7 (41.0)</td>
<td>1.487, (p = .14)</td>
</tr>
<tr>
<td>Amplitude (uV) (M {SD})</td>
<td>-9.06 (5.7)</td>
<td>-9.13 (5.6)</td>
<td>0.053, (p = .96)</td>
</tr>
<tr>
<td></td>
<td>Latency (ms) (M {SD})</td>
<td>Latency (ms) (M {SD})</td>
<td>(t_{73})</td>
</tr>
<tr>
<td>Cz</td>
<td>325.2 (35.3)</td>
<td>312.8 (40.7)</td>
<td>1.380, (p = .17)</td>
</tr>
<tr>
<td>Amplitude (uV) (M {SD})</td>
<td>-11.75 (6.1)</td>
<td>-10.91 (5.8)</td>
<td>-0.584, (p = .56)</td>
</tr>
<tr>
<td></td>
<td>Latency (ms) (M {SD})</td>
<td>Latency (ms) (M {SD})</td>
<td>(t_{73})</td>
</tr>
<tr>
<td>Pz</td>
<td>319.1 (42.2)</td>
<td>306.2 (49.7)</td>
<td>1.196, (p = .23)</td>
</tr>
<tr>
<td>Amplitude (uV) (M {SD})</td>
<td>-7.89 (5.8)</td>
<td>-6.80 (5.0)</td>
<td>-0.816, (p = .42)</td>
</tr>
<tr>
<td></td>
<td>Latency (ms) (M {SD})</td>
<td>Latency (ms) (M {SD})</td>
<td>(t_{73})</td>
</tr>
<tr>
<td>Fz</td>
<td>492.6 (49.9)</td>
<td>484.5 (41.9)</td>
<td>0.714, (p = .48)</td>
</tr>
<tr>
<td>Amplitude (uV) (M {SD})</td>
<td>15.6 (5.1)</td>
<td>16.9 (4.6)</td>
<td>-1.078, (p = .28)</td>
</tr>
<tr>
<td></td>
<td>Latency (ms) (M {SD})</td>
<td>Latency (ms) (M {SD})</td>
<td>(t_{73})</td>
</tr>
<tr>
<td>Cz</td>
<td>500.0 (47.8)</td>
<td>495.8 (39.6)</td>
<td>0.391, (p = .70)</td>
</tr>
<tr>
<td>Amplitude (uV) (M {SD})</td>
<td>20.0 (6.3)</td>
<td>21.5 (5.8)</td>
<td>-1.006, (p = .32)</td>
</tr>
<tr>
<td></td>
<td>Latency (ms) (M {SD})</td>
<td>Latency (ms) (M {SD})</td>
<td>(t_{73})</td>
</tr>
<tr>
<td>Pz</td>
<td>496.3 (50.8)</td>
<td>488.8 (35.5)</td>
<td>0.675, (p = .50)</td>
</tr>
<tr>
<td>Amplitude (uV) (M {SD})</td>
<td>16.9 (6.1)</td>
<td>17.5 (5.5)</td>
<td>-0.403, (p = .69)</td>
</tr>
</tbody>
</table>

3.2. Behavioural Performance Data

The median score on the breath-counting task at T2 within the MT group was 71.4%. Using this score, we were able to median split the MT group into top (> 71.4% accuracy = MT-HIGH; \(n = 24\)) and bottom (≤ 71.4% accuracy = MT-LOW; \(n = 24\)) 50th percentile groups based on T2 breath-counting accuracy scores.

**Sustained Attention to Response Task**

Mixed ANOVA (between-subjects: MT, CT) revealed a main effect of time for total errors of commission \(F_{(1,73)} = 16.533, p < .001\), partial \(\eta^2 = .185\) and RT CV \(F_{(1,73)} = 26.354, p < .001\), partial \(\eta^2 = .265\), together with a significant group x time x period interaction for RT
significant group x time x period interaction was observed for RT (\(F_{(1,73)} = 3.808, p = .055\), partial \(\eta^2 = .050\)). No interaction effects were observed for total errors of commission, indicating that both groups made fewer errors (MT: \(M_{t,j} = -2.604, SE = 1.148, p = .026\); CT: \(M_{t,j} = -5.185, SE = 1.531, p = .001\)) following the interventions, suggesting improved inhibitory control. Follow-up pairwise comparisons revealed that while the MT group showed significant reductions in RT CV in both the first half (\(M_{t,j} = -0.014, SE = 0.005, p = .005\)) and second half (\(M_{t,j} = -0.020, SE = 0.006, p = .001\)) of the task, the CT group showed reduced RT CV in only the first half (\(M_{t,j} = -0.025, SE = 0.006, p < .001\)) but not the second half (\(M_{t,j} = -0.008, SE = 0.007, p = .306\)), as shown in Figure 4.2. Pairwise comparisons for RT revealed non-significant changes in both groups that differed according to period, such that the MT group showed longer reactions times during the first half (\(M_{t,j} = 7.723, SE = 6.267, p = .222\)), but shorter RT during the second half of the task (\(M_{t,j} = -1.858, SE = 6.538, p = .777\)), while the CT group showed reduced RT in the first half (\(M_{t,j} = -5.604, SE = 8.356, p = .505\)) but longer RT during the second half of the task (\(M_{t,j} = 7.934, SE = 8.717, p = .366\)).

Exploratory mixed ANOVA with three-level between-groups factor (MT-LOW, MT-HIGH, CT) revealed significant group x time x period interactions for both RT (\(F_{(1,72)} = 3.786, p = .027, \text{partial } \eta^2 = .095\)) and errors of commission (\(F_{(1,72)} = 3.146, p = .049, \text{partial } \eta^2 = .080\)). Follow-up pairwise comparisons revealed that while the MT-HIGH group showed reductions in RT during the second half of the task (\(M_{t,j} = -7.412, SE = 9.26, p = .426\)), both the MT-LOW (\(M_{t,j} = 3.695, SE = 9.26, p = .691\)) and CT (\(M_{t,j} = 7.934, SE = 8.734, p = .367\)) groups displayed increases in RT during the second half. Pairwise comparisons for errors of commission showed that while the MT-HIGH group showed no change in error rate during either the first (\(M_{t,j} = -2.361, SE = 1.820, p = .199\)) or second (\(M_{t,j} = 0.833, SE = 1.851, p = .654\)) halves of the task, the MT-LOW group showed significant reductions during the second half (\(M_{t,j} = -5.833, SE = 1.851, p = .002\)) but not the first half (\(M_{t,j} = -3.054, SE = 1.820, p = .098\)), while the CT group showed significant reductions across both the first (\(M_{t,j} = -4.816, SE = 1.716, p = .006\)) and second halves (\(M_{t,j} = -5.679, SE = 1.745, p = .002\)). No significant group x time x period interaction was observed for RT CV for proficiency groups.
These results suggest that the MT group showed improved sustained attention throughout the whole task, whereas the CT group did so only for the first half of the task. Thus, the MT group displayed enhanced sustained attention compared to the CT group following training. In addition, the MT-HIGH group showed reductions in RT during the task, whereas both the MT-LOW and CT groups showed increases in RT. While both groups as a whole displayed improved inhibitory control as indexed by errors of commission, improvements in the MT group were greatest in the MT-LOW group who showed significantly fewer errors during the second half of the task.
3.3. ERP Data

Figure 4.3 displays ERP grand averages for correct no-go stimuli at Fz, Cz, and Pz at T1 and T2 for both groups.

*Figure 4.3*: Study 3 ERP grand average waveforms to no-go stimuli for the mindfulness-based attention training group and the computer-based attention training group at midline electrode sites at pre (T1) and post-intervention (T2).
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3.3.1. N2 Results

Mixed ANOVA (between-subjects: MT, CT) for N2 amplitude revealed a marginally significant group x time interaction for central region ($F_{(1,73)} = 3.988, p = .050$, partial $\eta^2 = .052$), together with a marginally significant group x time x electrode interaction ($F_{(1,72,125.78)} = 3.063, p = .058$, partial $\eta^2 = .040$). Inspection of mean amplitude values revealed that while the CT group showed increases in N2 amplitude at central sites (C3: $M_{I-J} = 0.716$, SE = 0.616, $p = .249$; Cz: $M_{I-J} = 1.457$, SE = 0.638, $p = .025$; C4: $M_{I-J} = 0.660$, SE = 0.605, $p = .279$), the MT group showed decreases (C3: $M_{I-J} = -0.533$, SE = 0.462, $p = .252$; Cz: $M_{I-J} = -0.702$, SE = 0.479, $p = .147$; C4: $M_{I-J} = -0.165$, SE = 0.454, $p = .717$). A similar non-significant group x time interaction was observed at frontal ($F_{(1,73)} = 2.956, p = .090$, partial $\eta^2 = .090$) and parietal ($F_{(1,73)} = 2.516, p = .117$, partial $\eta^2 = .033$) regions, where again the CT group showed increases in N2 amplitude while MT group showed reductions (see Figure 4.4). No main or interaction effects were observed for N2 latency at either region.

Exploratory mixed ANOVA with three-level between-groups factor (MT-LOW, MT-HIGH, CT) revealed no significant group x time interactions for N2 amplitude or latency at frontal, central or parietal regions.

3.3.2. P3 Results

Mixed ANOVA (between-subjects: MT, CT) for P3 latency revealed a significant group x time interaction for frontal region ($F_{(1,73)} = 7.111, p = .009$, partial $\eta^2 = .089$). Follow-up pairwise comparisons revealed significant reductions in P3 latency for the MT group at F3 ($M_{I-J} = -11.230$, SE = 4.413, $p = .013$), Fz ($M_{I-J} = -11.779$, SE = 4.261, $p = .007$), and F4 ($M_{I-J} = -12.165$, SE = 4.399, $p = .007$). No significant change in P3 latency was observed at frontal sites in the CT group. A similar but non-significant interaction was observed at both central ($F_{(1,73)} = 0.996, p = .322$, partial $\eta^2 = .013$) and parietal regions ($F_{(1,73)} = 1.931, p = .169$, partial $\eta^2 = .026$), where the MT group displayed reductions in P3 latency not observed in the CT group (see Figure 4.5). No main or interaction effects were observed for P3 amplitude at either region.
Figure 4.4: Study 3 mean N2 amplitudes at midline electrode sites at pre (T1) and post-intervention (T2) for the mindfulness-based attention training group (MT) and the computer-based attention training group (CT). Error bars show standard error of the mean.

Exploratory mixed ANOVA with three-level between-groups factor (MT-LOW, MT-HIGH, CT) revealed a significant group x time interaction for frontal P3 latency ($F_{1(1,72)} = 3.699, p = .030$, partial $\eta^2 = .093$). Follow-up pairwise comparisons showed that the MT-HIGH group displayed significant reductions in P3 latency across all frontal electrode sites (F3: $M_{t,j} = -13.468$, SE = 6.273, $p = .035$; Fz: $M_{t,j} = -14.323$, SE = 6.052, $p = .021$; F4: $M_{t,j} = -14.647$, $p = .001$).
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SE = 6.251, \( p = .022 \)), while the MT-LOW (F3: \( M_{I,J} = -8.992 \), SE = 6.273, \( p = .156 \); Fz: \( M_{I,J} = -9.236 \), SE = 6.052, \( p = .131 \); F4: \( M_{I,J} = -9.683 \), SE = 6.251, \( p = .126 \)) and the CT groups (F3: \( M_{I,J} = 8.536 \), SE = 5.914, \( p = .153 \); Fz: \( M_{I,J} = 7.198 \), SE = 5.706, \( p = .211 \); F4: \( M_{I,J} = 3.328 \), SE = 5.894, \( p = .574 \)) showed no significant change in P3 latency. As demonstrated by these pairwise comparisons, the trend was once again that of reductions in P3 latency in both MT groups and increases in P3 latency in the CT group.

These results indicate that where the MT group showed reductions in central N2 amplitudes, the CT group showed increases. No differential effect of proficiency was evident upon N2 amplitude. However, frontal P3 latency was significantly reduced in the MT-HIGH group, but not the MT-LOW or CT groups.

Figure 4.5: Study 3 mean P3 latency at midline electrode sites at pre (T1) and post-intervention (T2) for the mindfulness-based attention training group (MT) and the computer-based attention training group (CT). Error bars show standard error of the mean.
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3.4. Correlations

Significant moderate partial correlations between P3 latency and RT were observed at all electrodes for each time point, while N2 latency was significantly correlated at central sites at post-intervention only (see Table 4.4).

Table 4.4: Study 3 partial correlations of reaction time (RT) at T1 and T2 with N2 and P3 latency controlling for proficiency group.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>T1 RT</th>
<th>T2 RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2 latency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>.091</td>
<td>.211</td>
</tr>
<tr>
<td>Fz</td>
<td>.082</td>
<td>.223</td>
</tr>
<tr>
<td>F4</td>
<td>.081</td>
<td>.203</td>
</tr>
<tr>
<td>C3</td>
<td>.133</td>
<td>.238*</td>
</tr>
<tr>
<td>Cz</td>
<td>.115</td>
<td>.248*</td>
</tr>
<tr>
<td>C4</td>
<td>.141</td>
<td>.275*</td>
</tr>
<tr>
<td>P3</td>
<td>.046</td>
<td>.177</td>
</tr>
<tr>
<td>Pz</td>
<td>.089</td>
<td>.179</td>
</tr>
<tr>
<td>P4</td>
<td>.073</td>
<td>.130</td>
</tr>
<tr>
<td>P3 latency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>.314**</td>
<td>.352**</td>
</tr>
<tr>
<td>Fz</td>
<td>.309**</td>
<td>.350**</td>
</tr>
<tr>
<td>F4</td>
<td>.298**</td>
<td>.347**</td>
</tr>
<tr>
<td>C3</td>
<td>.344**</td>
<td>.305**</td>
</tr>
<tr>
<td>Cz</td>
<td>.340**</td>
<td>.365**</td>
</tr>
<tr>
<td>C4</td>
<td>.307**</td>
<td>.359**</td>
</tr>
<tr>
<td>P3</td>
<td>.289*</td>
<td>.264*</td>
</tr>
<tr>
<td>Pz</td>
<td>.271*</td>
<td>.314**</td>
</tr>
<tr>
<td>P4</td>
<td>.277*</td>
<td>.339**</td>
</tr>
</tbody>
</table>

Note: df = 72.
*significant at p = 0.05; **significant at p = 0.01.
4. Discussion

The present study reports reduced frontal P3 latency during an inhibitory control task after eight weeks of mindfulness training, suggesting that the speed of attention resource allocation during this task had improved compared to an active control group. Reduced frontal P3 latency in the MT group was accompanied by improvements to sustained attention not observed in the CT group. Exploratory analyses revealed that significant reductions in P3 latency were observed only in those who achieved a high level of proficiency in mindfulness practice, and these reductions were accompanied by shorter reaction times.

Reductions in P3 latency reported here suggest that eight weeks of mindfulness training may be associated with faster deployment of attentional resources during tasks requiring inhibitory control. Inhibitory control represents the primary component trained during mindfulness practice, which requires the continuous rapid detection and inhibition of distracting processes while sustaining attention toward the breath, ensuring the neural networks related to these attentional processes are repeatedly activated (Isbel & Summers, 2017). Faster attention resource allocation has previously been reported after mindfulness during an attentional blink task which requires the identification of two numbers presented in short succession amongst a stream of rapidly appearing letters (Slagter et al., 2007). Mindfulness has been shown to result in faster processing times during this task, and these benefits were accompanied by reduced P3 amplitude, indicating enhanced efficiency of attentional resource allocation. In the current study, P3 latency was significantly correlated with reaction time, and reductions in P3 latency in the MT-HIGH group were accompanied by reductions in RT during the second half of the task compared to increases observed in both the MT-LOW and CT groups. The observation of reduced P3 latency and RT in the MT-HIGH group and not the other groups suggests that these outcomes were not merely the result of non-specific intervention effects.

While it was hypothesised that the MT group would show increases in ERP amplitude after training, greater N2 amplitudes were observed in the CT group while the MT group showed reductions in N2 amplitude. Thus, while both groups demonstrated improved inhibitory control performance as indexed by errors of commission, the neural processes underlying these improvements appear to differ between the groups. Enhanced N2 amplitude in the CT group suggests greater attention resource allocation to response inhibition after training in this group, whereas reductions in N2 amplitude in the MT group suggest a reduced
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requirement of attentional resources for inhibitory processing after training. This interpretation is in line with previously reported reductions in P3 amplitude after mindfulness training indicating improved efficiency of attentional resource allocation during an attentional blink task (Slagter et al., 2007). Of note, central N2 latency in the current study was significantly correlated with RT after training, suggesting that changes to the N2 ERP component induced by the interventions enhanced its relation to behavioural response.

Two previous studies reporting increases in N2 amplitude after mindfulness training used a Stroop task to elicit ERP components (Malinowski, Moore, Mead, & Gruber, 2017; Moore, Gruber, Derose, & Malinowski, 2012). The Stroop task requires inhibitory control to override the automatic response to read a word rather than name its colour. Whereas the Stroop task requires inhibitory control to override automatic semantic processing of stimuli, the SART requires inhibitory control to prevent the execution of a prepotent motor response after sensory discrimination of a no-go stimuli (Seli, 2016). Differences in the complexity of these processes may contribute to differing N2 amplitude results reported from these two tasks and suggest that further research is warranted to delineate the effects of mindfulness on attention.

Aging is known to be associated with reductions in attentional efficiency together with a decline in both the speed and performance of attentional processes (West, 2004). Deterioration of inhibitory control is thought to underpin many of the declines in cognitive function observed in ARCD (Sarter et al., 2001). As such, our finding of improved inhibitory control performance in the present study suggests that cognitive training programs may have a role in combating ARCD, with mindfulness in particular providing protective benefits against the slowing of attentional processes that occurs during normal aging.

4.1. Limitations

Due to the total number of artefact-free trials available for ERP analysis, component amplitude and latency analyses over time-on-task (first and second half) were not able to be performed. Duncan et al. (2009) suggest a minimum of 36 artefact-free trials for eliciting the P3 component, which is considerably higher than the 22 available for T1 split-half analysis of the SART. This limitation meant that we were not able to mirror our behavioural data analyses to assess changes in ERP component amplitude and latency with time-on-task. Future studies should utilise greater numbers of no-go stimuli in order to assess ERP changes with ongoing attentional performance.
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The present study lacks post-intervention follow-up assessments which limits our ability to determine the long-term stability of the effects reported here. Long-term maintenance of these attentional benefits is crucial if such interventions are to have a role in combating ARCD. The absence of an additional control group not engaged in any training somewhat limits our ability to determine if the benefits observed are a product of non-specific intervention effects, such as social engagement and mental stimulation. However, previous research (Malinowski et al., 2017) utilising a brain training control group reported no change in ERP component amplitude or latency, suggesting the findings reported here were not due to non-specific intervention factors. The presence of unique benefits in the MT group not observed in the CT group in the present study supports this interpretation.

5. Conclusion

Cognitive training programs targeting sustained attention and inhibitory control may be effective at improving attentional performance in healthy older adults, which is known to decline with age. Mindfulness training in particular may enhance the speed of attentional processes which are known to decline in aging, thereby providing protective benefits against age-related cognitive decline.
References


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Supplementary Table 4.1: Study 3 participant acceptance criteria.

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 60 years of age.</td>
</tr>
<tr>
<td>Normal or corrected-to-normal visual acuity.</td>
</tr>
<tr>
<td>Able to sit upright for up to 45 minutes in a straight-backed chair.</td>
</tr>
<tr>
<td>Availability to attend all testing, training, and home practice requirements.</td>
</tr>
<tr>
<td>Access to a computer with the internet at home.</td>
</tr>
<tr>
<td>Able to understand, read, and speak English.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous mindfulness/meditation experience.</td>
</tr>
<tr>
<td>Current regular practice of other mind-body techniques such as yoga or tai-chi.</td>
</tr>
<tr>
<td>Previous use of computerised brain training programs.</td>
</tr>
<tr>
<td>Current diagnosis of Mild Cognitive Impairment or Dementia.</td>
</tr>
<tr>
<td>Multiple sclerosis.</td>
</tr>
<tr>
<td>Prior head injury requiring hospitalization.</td>
</tr>
<tr>
<td>Cerebrovascular complication (eg., stroke, aneurysm, transient ischaemic attack).</td>
</tr>
<tr>
<td>Epilepsy.</td>
</tr>
<tr>
<td>Poorly controlled diabetes.</td>
</tr>
<tr>
<td>Poorly controlled hypertension or hypotension.</td>
</tr>
<tr>
<td>Neurological disorder (eg., cerebral palsy or spina bifida).</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease.</td>
</tr>
<tr>
<td>Heart disease.</td>
</tr>
<tr>
<td>Partial or total blindness.</td>
</tr>
<tr>
<td>Deafness.</td>
</tr>
<tr>
<td>Current psychiatric diagnosis (eg., depression, anxiety).</td>
</tr>
<tr>
<td>Current use of medications affecting CNS function (eg., anti-depressants).</td>
</tr>
<tr>
<td>Medical disorder which would make EEG data interpretation difficult (eg., brain injury).</td>
</tr>
<tr>
<td>Insomnia.</td>
</tr>
<tr>
<td>Engagement in moderate physical or sporting activity lasting at least 20 minutes per occasion more than 5 times a week.</td>
</tr>
<tr>
<td>Engagement in vigorous physical or sporting activity lasting at least 20 minutes per occasion more than 4 times a week.</td>
</tr>
</tbody>
</table>
Supplementary Table 4.2: Study 3 weekly structure for training interventions

<table>
<thead>
<tr>
<th>Week</th>
<th>Mindfulness-based training program</th>
<th>Computer-based training program</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to program</td>
<td>Introduction to program</td>
</tr>
<tr>
<td>2</td>
<td>What is Attention?</td>
<td>What is Attention?</td>
</tr>
<tr>
<td>3</td>
<td>Working Memory</td>
<td>Executive Attentional Functions</td>
</tr>
<tr>
<td>4</td>
<td>Executive Attentional Functions</td>
<td>Working Memory</td>
</tr>
<tr>
<td>5</td>
<td>Age-related Cognitive Decline</td>
<td>Age-related Cognitive Decline</td>
</tr>
<tr>
<td>6</td>
<td>Emotional Regulation</td>
<td>Emotional Regulation and Memory</td>
</tr>
<tr>
<td>7</td>
<td>Metacognition</td>
<td>Controlled vs Automatic Cognitive Processes</td>
</tr>
<tr>
<td>8</td>
<td>Cognitive Flexibility</td>
<td>Metacognition</td>
</tr>
</tbody>
</table>
Supplementary Table 4.3: Study 3 tasks utilised in the active control condition

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Selective Attention</th>
<th>Task Switching</th>
<th>Inhibitory Control</th>
<th>Working Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flanker task based upon Eriksen and Eriksen (1974)</td>
<td>Participants are instructed to indicate the direction of a central arrow flanked on either side by two distractor arrows.</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2. Visual search task based upon Treisman and Gormican (1988)</td>
<td>Participants are instructed to indicate a unique object amongst a field of similar distractor objects. The number of distractors increases with successful performance, while their differences become less obvious.</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3. Task switching paradigm in accord with Kiesel et al. (2010).</td>
<td>This task involves arrows of two different colours moving across a screen. Arrows may point in the direction they are moving, or in a different direction. Participants are instructed to switch between indicating either the direction of movement of the arrow, or the direction that the arrow is pointing, depending on the colour of the arrows.</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4. Task switching paradigm in accord with Kiesel et al. (2010)</td>
<td>Participants are shown a card with a number and a letter on it. Participants are instructed to switch between indicating whether the number is an even number or if the letter is a vowel or not, depending upon the location that the card is presented. Presented at the top of the screen, participants are to indicate if the number is even. Presented at the bottom of the screen, participants are to indicate if the letter is a vowel.</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5. Stroop task based upon Stroop (1935)</td>
<td>Participants are shown two cards with two colour words written on them. The words and the colour of the letters change with each trial. Participants are instructed to indicate if the colour of the letters on the second card matches the meaning of the colour word presented on the first card.</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6. Moving visual divided attention task based upon Treisman (1982)</td>
<td>A number of identical objects move randomly within a fixed field. Participants are required to select one object at a time at three second intervals, without selecting the same object twice, until all objects have been selected. The number of objects</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>increases with successful completion of the task.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>7. Static adaptation of the Corsi block task (Milner, 1971) to assess working memory (Baddeley, 2003)</td>
<td>Participants are presented with a grid of squares of a uniform colour. A small number of squares change colour briefly before changing back to the original uniform colour. Participants are instructed to indicate which squares changed colour after they have switched back to the uniform grid colour. The number of squares in the grid as well as the number of squares changing colour increases with successful performance.</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8. Serial working memory task (Baddeley, 2003)</td>
<td>Participants are presented with cards showing a variety of coloured shapes that appear serially. The new card remains face-up, while the card that appeared previously is turned face-down. Participants are instructed to remember if the card currently face-up matches the card that appeared two cards previous.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 5

Mindfulness Induces Changes in Anterior Alpha Asymmetry in Healthy Older Adults
Mindfulness Induces Changes in Anterior Alpha Asymmetry in Healthy Older Adults

Ben Isbel1 · Jim Lagopoulos1 · Daniel F. Hermens1 · Mathew J. Summers1

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Abstract

Objectives Anterior alpha asymmetry is an EEG measure of relative left- or right-sided prefrontal cortical activity that has been associated with affective style, such that greater relative left-sided activity is associated with positive affect and approach-related behaviours. While mindfulness has been shown to enhance attention and affect, here we investigate the underlying neurobiological changes supporting these outcomes by assessing anterior alpha asymmetry.

Methods A longitudinal RCT was conducted to investigate the effect of an 8-week mindfulness training (MT) intervention on anterior alpha asymmetry and affect in a group of healthy adults aged over 60 years (n = 41). An active control computer-based attention training (CT) program (n = 26) designed to activate similar attentional components to mindfulness was used to determine if outcomes resulted from attention training or mindfulness-specific factors. The Sustained Attention to Response Task was used to assess attentional performance, while a breathing counting task was used to classify mindfulness participants into high (MT-HIGH; n = 19) and low (MT-LOW; n = 22) proficiency groups.

Results While all groups displayed improved attentional performance, only the MT-HIGH and MT-LOW groups showed significant increases in positive affect as measured by the Positive and Negative Affect Schedule. The MT-HIGH group showed significantly increased relative left-sided activity at both Fp1/Fp2 and F3/F4 electrode pairs, while no significant changes were observed in the MT-LOW and CT groups.

Conclusions These results suggest that 8 weeks of mindfulness training is capable of inducing changes in resting anterior alpha asymmetry, but these results are dependent upon the level of proficiency achieved.

Keywords Mindfulness · Alpha asymmetry · Attention · Affect · Ageing

A growing body of evidence suggests that mindfulness-based practices are capable of inducing both structural and functional brain changes, and these changes have been associated with enhanced cognitive and affective outcomes (Fox et al. 2014; Gotink et al. 2016). Notwithstanding critiques regarding some of the methodological shortcomings present in the field of mindfulness research (Coronado-Montoya et al. 2016; Van Dam et al. 2017), findings to date suggest that mindfulness is capable of enhancing attention and executive function (Lutz et al. 2009; Van den Hurk et al. 2009), increasing positive affect (Garland et al. 2015), and reducing negative affect (Brown and Ryan 2003; Davidson et al. 2003). While the mechanisms underlying these outcomes currently remain unclear, an intriguing possibility is the use of anterior EEG alpha asymmetry to assess patterns of neural activation associated with dispositional changes in affect resulting from mindfulness training.

Anterior alpha asymmetry provides a measure of relative left- or right-sided cortical activity by calculating the difference between EEG alpha power at homologous left and right frontal scalp electrodes. Oscillations in the alpha range have long been assumed to exert an inhibitory influence on cortical network activity, leading to the convention of inversely associating alpha power with cortical activity (Klimesch 1999; Pfurtscheller et al. 1996). Accordingly, when calculated as a
measure of right minus left alpha power, higher asymmetry scores reflect greater relative left-sided cortical activity, while lower scores reflect greater relative right-sided activity (Allen et al. 2004). When recorded during a resting state, anterior alpha asymmetry has demonstrated high test-retest reliability and internal consistency (Tomarken et al. 1992b; Towers and Allen 2009).

Greater relative left-sided anterior activity has been associated with approach-related or behaviourally activating trait styles of motivation, including positive dispositional affect, whereas greater relative right-sided anterior activity is associated with withdrawal-related or behaviourally inhibiting styles of motivation, including negative dispositional affect (Coan and Allen 2004; Davidson 1992, 2004; Harmon-Jones and Gable 2017; Reznik and Allen 2018; Smith et al. 2017). Two models have been proposed to describe the lateralisation of anterior cortical activity and its association with affect and behaviour. Tomarken et al. (1992a) have described an affective valence model of anterior asymmetry, where greater relative left-sided anterior cortical activity is associated with positive affect, and greater relative right-sided activity with negative affect. Harmon-Jones (2003) proposed a motivational model, where greater relative left-sided anterior cortical activity is associated with approach motivations, and greater relative right-sided activity with withdrawal motivations. While both of these models are largely descriptive, they offer little specificity as to which neurobiological processes are differentially lateralised, and how these processes impact affect and motivation. Recent evidence from both electrophysiological and brain imaging studies suggest that inhibitory control functions may be differentially lateralised in the prefrontal cortex (Vallesi 2012), such that enhanced inhibitory control has been associated with greater left-sided anterior cortical activity (Allen et al. 2012; Ambrosini and Vallesi 2016; Taren et al. 2017). Grimshaw and Carmel (2014) have integrated these findings with existing models of anterior asymmetry to propose that the lateralisation of attentional inhibitory control processing in anterior cortical regions underlies the observed difference in affective and motivational outcomes.

To date, few studies have investigated the effect of mindfulness training on anterior alpha asymmetry and affect. Studies examining clinical samples (Barnhofer et al. 2007; Keune et al. 2011) report no change toward relative left-sided activity (at Fp1/Fp2, F3/F4, and F7/F8 homologous electrode pairs) after 8 weeks of mindfulness-based cognitive therapy (MBCT; Segal et al. 2002). Two studies examined pre-post mindfulness changes in resting anterior alpha asymmetry in healthy non-clinical samples. Both Moynihan et al. (2013) and Davidson et al. (2003) utilised an 8-week mindfulness-based stress reduction program (MBSR; Kabat-Zinn 1990) together with wait-list control conditions, reporting no significant change anterior alpha asymmetry (at Fp1/Fp2, F3/F4, and F7/F8 homologous electrode pairs) as a result of mindfulness training. Davidson et al. reported evidence of increased relative left-sided cortical activity at central sites (C3/C4 electrode pair), but not at anterior sites. Therefore, while mindfulness has been shown to enhance affect, there is little evidence to date of mindfulness’s ability to produce changes in anterior alpha asymmetry.

The practice of mindfulness primarily involves the cultivation of two components: (1) an attentional component, involving inhibitory control, which continuously attends to an object without its loss from awareness; and (2) equanimity, which is an unbiased and non-reactive orientation toward the contents of experience (Bishop et al. 2004). Each of the studies described above utilised a therapeutic mindfulness-based intervention (either MBCT or MBSR) which cultivate mindfulness together with a range of additional factors, such as cognitive behaviour therapy, psychoeducation, and an array of goal-oriented practices (Chiesa and Malinowski 2011). The heterogeneity of these interventions eliminates the possibility of making clear causal inferences regarding observed outcomes, including affective outcomes. For this reason, studies seeking to clearly investigate the mechanisms underlying mindfulness practice must use an intervention that generates mindfulness without confounding additional components. Isbel and Summers (2017) have introduced such a cognitive model of mindfulness together with a standardised mindfulness technique for use in longitudinal randomised control trials (RCTs). The standardised technique is not a therapeutic mindfulness intervention, but rather permits the study of mindfulness without introducing confounding components, thereby facilitating clearer inferential assessment of observed outcomes.

Attention training as a core feature of mindfulness practice may provide benefits for those at risk of cognitive decline. Normal ageing is associated with a decline in cognitive performance known as age-related cognitive decline (ARCD), which is a non-pathological decline in cognitive performance becoming increasingly evident beyond the age of 60 years (Hedden and Gabrieli 2004; Salthouse 2009), and can be accompanied by a decline in subjective well-being, mood, and affect (Blazer 2003; Gates et al. 2014). The previously reported benefits of mindfulness to attention and cognitive performance may indicate a role for mindfulness interventions in combating ARCD.

The current study sought to examine whether affective outcomes following mindfulness result from attention training or from mindfulness-specific factors, and whether or not affective outcomes are accompanied by changes in anterior alpha asymmetry. In line with previous research, it was hypothesised that 8 weeks of mindfulness training (MT) would result in increases in positive affect and reductions in negative affect, and that these changes would be accompanied by increased relative left-sided anterior alpha activity. Furthermore, it was hypothesised that participants who gained high proficiency in mindfulness (MT-HIGH) would demonstrate greater increases in anterior asymmetry scores and greater affective outcomes.
than those who gain low proficiency (MT-LOW). A computer-based attention training (CT) program designed to activate similar attentional processes to mindfulness was utilised as an active control condition.

Method

Participants

Participants were healthy older adults (≥ 60 years age) recruited from the general community to participate in an attention training program. Respondents underwent telephone screening to ensure those recruited met eligibility criteria (see Supplementary Material 1 for eligibility criteria) and had no prior exposure to either mindfulness or computerised brain training (see Fig. 1 for flowchart of participant retention and reason for dropout). As seen in Fig. 1, the most common exclusion criteria were inability to attend all sessions over the study period, followed by health reasons. As the study sought to recruit healthy older adults, it was expected that exclusion rates would be high given the age group targeted and the stringent eligibility criteria adopted to ensure the integrity of any findings. Information sessions were held for eligible participants, from which 120 participants were allocated by random number generator to the interventions (MT, n = 77; CT, n = 43). Participants were randomly allocated at a rate of 2:1 to MT to enable this group to be divided into high and low proficiency groups following MT training. As shown in Fig. 1, data from 67 participants (MT, n = 41; CT, n = 26) was eligible for analysis. Participant demographic information for the reported data is presented in Table 1.

Procedures

Participants were assessed on all measures at both pre-intervention (T1) and post-intervention (T2), with the exception of the Wechsler Test of Adult Reading which was administered only at baseline. The Positive and Negative Affect Schedule (PANAS; Watson et al. 1988) was completed at a group questionnaire session approximately 1 week prior to the EEG testing session. At the commencement of the EEG testing session, participants were required to report their sleep length and quality over the preceding week on a 5-point Likert-type scale (1 = increased to 5 = greatly reduced), as marked reduction in sleep is known to affect cognitive performance (Dinges and Kribbs 1991). The Hospital Anxiety and Depression Scale (HADS; Zigmond and Snaith 1983) was also completed at the commencement of the EEG test to assess for anxiety and depression as a potential confound. No participant reported markedly reduced sleep length or quality (all scores < 4) or elevated anxiety or depression (all scores < 11) immediately prior to the EEG session, and thus no participants were excluded from analysis due to sleep disturbance or significant psychological states of anxiety or depression.

Participants were fitted with the EEG equipment before being given a demonstration of eye and muscle movement effects on EEG recording in order to minimise artefacts during the session. Resting EEG was then collected continuously for 4 min in an eyes open condition. Participants were instructed to “just rest” without intentionally performing any particular task for 4 min. In order to minimise eye movements during the EEG recording, participants were instructed to rest with their eyes fixed in a relaxed manner upon a yellow cross situated in the centre of a grey background presented on a monitor screen placed at a distance of 65 cm. Instructions were presented on the monitor screen prior to the task and participants proceeded at their own pace. An audible tone signalled the commencement of the resting period, which was followed 10 s later by the start of the continuous 4-min EEG recording. Participants then completed the breath counting task followed by the Sustained Attention to Response Task. Stimuli for all tasks were presented using E-Prime 2.0.10 software (Psychology Software Tools, Pittsburgh, PA, USA).

Interventions

The interventions were described to participants as attention training programs, differing only in delivery format. In this way, participants were blinded to experimental and control conditions. The CT program was designed to activate similar attentional components to those trained in mindfulness, but without the inclusion of mindfulness practice. Both programs were structurally equivalent, consisting of weekly 2-h group training sessions for 8 weeks, with topics covering the cognitive processes involved in attention training (see Supplementary Material 2 for weekly structure of the programs). A personal daily home practice requirement was included for both groups, which began at 20 min per day in week 1 and progressed to 45 min per day by week 8. Participants were required to keep a diary record of the amount of time spent engaged in the training intervention. Participants who did not meet the minimum amount of practice assigned during the intervention were excluded from analysis (MT, n = 8; CT, n = 2). All training sessions were conducted by the same trainer in the same room at the same time of day. Participants in both groups were instructed to perform the home training in a quiet environment where the training exercise could be carried out uninterrupted.

Mindfulness-Based Attention Training Program

The MT program utilised the standardised mindfulness technique developed by Isbel and Summers (2017) for use in longitudinal RCTs. The primary task trained in this technique requires participants to direct and sustain their attention upon a
localised set of sensations accompanying the breath at the abdomen in a manner that is nonjudgmental and non-reactive. Participants are required to notice when attention wanders from the primary task to secondary objects, such as mind

**Table 1** Participant demographic information and baseline asymmetry scores by group

<table>
<thead>
<tr>
<th></th>
<th>Mindfulness-based training group</th>
<th>Active control group</th>
<th>Statistical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (% female)</td>
<td>55%</td>
<td>75%</td>
<td>(X^2 (1, N = 67) = 3.00, p = .08 )</td>
</tr>
<tr>
<td>Age (M (SD))</td>
<td>71.9 (4.5)</td>
<td>70 (5.9)</td>
<td>(t_{(65)} = 1.61, p = .11 )</td>
</tr>
<tr>
<td>Range</td>
<td>64–83</td>
<td>60–86</td>
<td></td>
</tr>
<tr>
<td>Handedness (% RH)</td>
<td>97.6%</td>
<td>100%</td>
<td>(X^2 (1, N = 67) = 0.644, p = .42 )</td>
</tr>
<tr>
<td>Predicted FSIQ (M (SD))</td>
<td>112.6 (7.0)</td>
<td>112.5 (5.7)</td>
<td>(t_{(65)} = 0.10, p = .92 )</td>
</tr>
<tr>
<td>Fp1/Fp2 (M (SD))</td>
<td>-0.113 (0.24)</td>
<td>-0.012 (0.15)</td>
<td>(t_{(65)} = 1.943, p = .06 )</td>
</tr>
<tr>
<td>F3/F4 (M (SD))</td>
<td>-0.097 (0.28)</td>
<td>-0.046 (0.19)</td>
<td>(t_{(65)} = 0.811, p = .42 )</td>
</tr>
<tr>
<td>F7/F8 (M (SD))</td>
<td>-0.209 (0.28)</td>
<td>-0.163 (0.22)</td>
<td>(t_{(65)} = -0.708, p = .48 )</td>
</tr>
</tbody>
</table>

*FSIQ* full scale IQ (as estimated by the Wechsler Test of Adult Reading), *RH* right-handed
wandering or distraction. When such an attentional shift occurs, participants were instructed to inhibit and disengage secondary processes, and redirect attention back to the primary task. Working memory is thought to be central to this training, as participants were required to retain the task instructions and continually update and monitor ongoing attentional performance. Thus, the core attentional processes trained in the standardised mindfulness technique include selective attention, task switching, inhibitory control, and working memory. Importantly, the standardised mindfulness technique does not contain non-specific additional components such as relaxation, psychoeducation, or yoga, which are found in MBCT and MBSR.

**Computer-Based Attention Training Program**

The CT program consisted of a series of targeted attention training exercises presented in game format designed to activate similar attentional processes to those activated in mindfulness practice. Each game emphasised a specific aspect of attention, such as sustained attention, selective attention, inhibitory control, or executive function to replicate the attention training occurring in the MT program (see Supplementary Material 3 for a description of the primary attentional components trained in each task). Difficulty increased on some tasks with successful performance to replicate the changing nature of attentional demands that occurs in mindfulness practice with increasing proficiency. Furthermore, participants were required to play an assigned game continuously each day during their home training sessions rather than switching between games in order to replicate the continuous application to a single task that occurs in MT. Assigned tasks were changed each week. The CT program was available to access online on any device to enable the training to be done in a way most suitable for each participant.

**Measures**

**Wechsler Test of Adult Reading**

The Wechsler Test of Adult Reading is a widely used word reading list used to estimate full scale intelligence quotient in adults. The WTAR is co-normed against the Wechsler Adult Intelligence Scale, 3rd edition, and is a reliable and valid estimate of intellectual capacity.

**Positive and Negative Affect Schedule**

Dispositional positive and negative mood was measured using the PANAS which consists of two 10-item subscales that assess positive affect (PA) and negative affect (NA). Participants respond on a Likert-type scale to indicate the frequency with which they experience particular emotions. The PANAS has demonstrated validity and high reliability (PA, Cronbach’s $\alpha$.89; NA, Cronbach’s $\alpha$.85) as a measure of affect in non-clinical samples (Crawford and Henry 2004).

**Hospital Anxiety and Depression Scale**

Symptoms of anxiety and depression were measured using the HADS. The HADS consists of two 7-item subscales for anxiety (HADS-A) and depression (HADS-D) on which participants indicate the frequency with which they experience symptoms on a Likert-type scale. The HADS is a cut-off criterion instrument designed to detect clinically significant states of anxiety and depression, where subscale scores greater than 11 indicate clinical significance. The HADS was utilised to screen for psychological states which may confound EEG findings such that participants with subscale scores greater than 11 would be excluded. The HADS has been shown to have high validity and reliability (HADS-A, Cronbach’s $\alpha$.83; HADS-D, Cronbach’s $\alpha$.82).

**Breath Counting Task**

Breath counting has previously been validated as a behavioural measure capable of distinguishing proficient from non-proficient mindfulness practitioners and has shown good test-retest reliability (Levinson et al. 2014; Wong et al. 2018). The task requires participants to observe their breathing while reporting a count of their in-and-out breath cycles for 15 min. Participants were instructed to breathe naturally while being attentive to the sensations accompanying the rising and falling of the abdomen as they mentally counted the in-out cycles of their breath from one to 21. Participants reported each in-out cycle with a down-arrow key press on counts one to 20, while on count 21 participants were instructed to press the right-arrow key to indicate successful count cycle. Self-caught counting errors were indicated by a left-arrow key press. Breath counting accuracy was physiologically confirmed using a piezo-electric crystal effort sensor placed around the chest to record respiration movement. A breath counting accuracy score was calculated as a percentage of correct count cycles to total cycles completed during the task (correct count × total cycles ÷ 100). Each self-caught error was recorded as an incorrect count cycle.

**Sustained Attention to Response Task**

The Sustained Attention to Response Task (SART; Robertson et al. 1997) consisted of a serial presentation of digits (1–9) to which participants were instructed to respond via keypress to all go stimuli (digits 1–2, and 4–9) while withholding a response to each no-go stimuli (digit 3). For each block of nine trials, a single digit (1–9) was randomly chosen without replacement. Prior to the commencement of the experimental
EEG Measures

Continuous EEG data was recorded from 128 Ag/AgCl active electrodes mounted in an elastic head cap using a Biosemi ActiveTwo amplifier system (Biosemi, Amsterdam, Netherlands). To monitor eye movements, horizontal electro-oculogram (EOG) was recorded using electrodes placed 1 cm lateral to the outer canthus of each eye, while vertical EOG was recorded using supra- and infraorbital electrodes on the left eye. During acquisition data was hardware filtered using a fixed first order analogue anti-aliasing filter (−3 dB at 208 Hz) and digitised at 1024 Hz with a 24-bit analogue-to-digital converter. Further, offline processing was conducted using Brain Vision Analyzer2 software (Brain Products, GmbH, Gilching, Germany).

Continuous EEG data was referenced offline to an average reference in accord with the recommendations of Davidson (1998) and Allen et al. (2004). A zero-phase shift Butterworth infinite response filter (slope 12 dB/octave) was used to low pass (30-Hz cut-off) and high pass (0.5-Hz cut-off) filter the data, while a 50-Hz notch filter was applied to remove electrical line noise. All EEG data was visually inspected to detect noisy electrodes, and electrodes with consistent artefact were interpolated using spherical spines from surrounding sites (0.17% of all electrodes analysed). Ocular artefact correction was then performed to remove eye blink artefacts using the linear regression technique of Gratton et al. (1983). Artefact detection was then performed using a semi-automatic procedure to detect activity that (i) exceeded an absolute change of 50 μV/ms, or (ii) exceeded an absolute min-max difference of 100 μV/200 ms. When artefact was detected in any channel, data 200 ms prior to 200-ms post-event was marked as bad for all channels.

Each 4-min continuous recording was then segmented into overlapping 2-s epochs (50% overlap), with epochs containing artefact excluded from analysis. An a priori decision to reject participants with fewer than 50% artefact-free epochs at both time points from further analysis resulted in 19 participants being excluded due to insufficient artefact-free data (MT, n = 13; CT, n = 6). Spectral power (μV²) was calculated on artefact-free epochs using a fast Fourier transform (FFT) with a Hanning window at a resolution of 0.5 Hz. Epochs were averaged to provide the average power spectrum at each electrode for T1 and T2. Absolute power in the alpha frequency band (8–13 Hz) was then calculated and natural log-transformed to normalise the data distribution (Allen et al. 2004). In accord with previous studies examining anterior alpha asymmetry and mindfulness, an asymmetry score was calculated for homologous anterior electrode pairs Fp1/Fp2, F3/F4, and F7/F8 by subtracting log-transformed power at left location from log-transformed power at right location (i.e., ln(right) − ln(left)). Higher scores calculated in this way indicate increased relative left-sided cortical activity.

Data Analyses

Independent groups t tests were performed to examine pre-intervention between-group differences in age, FSIQ, and anterior alpha asymmetry, between-group difference in amount of training undertaken during the intervention, and between-group difference in artefact-free epochs available for analysis at each time point. Gender balance and handedness differences between the groups were examined using chi-square analysis.

To test the effect of the attention training programs on attention and inhibitory control, a mixed design analysis of variation (ANOVA) of SART commission errors, RT, and RT CV, with group (MT, CT) as a between-subjects factor and time (T1, T2) as a within-subjects factor, was performed.

Change in mindfulness across the intervention was assessed using the breath counting task. Breath counting accuracy scores were entered into a mixed design ANOVA performed with group (MT, CT) as a between-subjects factor and time (T1, T2) as a within-subjects factor. Breath counting scores at T2 were also used to provide a median split of the MT group into top and bottom 50th percentile groups, corresponding to mindfulness high performers (MT-HIGH) and mindfulness low performers (MT-LOW). This enables exploratory analysis of the differential effects of mindfulness proficiency on anterior alpha asymmetry and affect. Differences in reported and physiologically confirmed breath counting scores were assessed using mixed design ANOVA with group (MT, CT) as a between-subjects factor and time (T1, T2) as a within-subjects factor.
To determine the effect of the interventions on affect, a mixed design ANOVA with PANAS (PA, NA) and time (T1, T2) as within-subjects factors and group (MT, CT) as a between-subjects factor was performed. To examine the effect of mindfulness proficiency on affective outcomes, a second mixed design ANOVA with PANAS (PA, NA) and time (T1, T2) as within-subjects factors with group (MT-HIGH, MT-LOW, CT) as a between-subjects factor was performed. A single PANAS factor with two levels was used in order to reduce the risk of spurious type I errors resulting from multiple statistical analyses. Significant main effects were investigated with follow-up pairwise comparisons.

To test the effect of the attention training programs on resting anterior alpha asymmetry, a mixed design ANOVA of electrode (Fp1/Fp2, F3/F4, F7/F8) and time (T1, T2) as within-subjects factors with group (MT, CT) as a between-subjects factor was performed. To examine the effect of mindfulness proficiency on resting anterior alpha asymmetry, a second mixed design ANOVA with electrode (Fp1/Fp2, F3/F4, F7/F8) and time (T1, T2) as within-subjects factors with group (MT-HIGH, MT-LOW, CT) as a between-subjects factor was performed. A single electrode factor with three levels was used in order to reduce the risk of spurious type I errors resulting from multiple electrode analyses. Significant main effects were investigated with follow-up pairwise comparisons.

Intraclass correlation coefficients (ICC) were calculated for each group on breath counting scores over time to assess the test-retest reliability of this measure. To assess the correlation between change in resting anterior alpha asymmetry and change in affect, change scores for each variable were calculated by subtracting T1 scores from T2 scores. Bivariate correlations between change scores were then assessed. All statistical analysis was performed using SPSS version 24 (SPSS Inc., Chicago, IL, USA).

Results

Pre-Intervention Between-Group Comparisons

There were no significant pre-intervention differences between the MT and CT groups in age, gender balance, handedness, FSIQ, or anterior alpha asymmetry at Fp1/Fp2, F3/F4, or F7/F8 homologous electrode sites (see Table 1). Pre-intervention differences between post hoc identified groups are presented in Table 2.

Intervention Training Time

Inspection of mean daily practice time showed that the CT group (M = 36.0 min/day (SD = 6.3)) spent approximately 3 min longer per day engaged in the training program than the MT group (MT, M = 33.4 min/day (SD = 4.0)). An independent groups t test confirmed that the CT group engaged in a significantly greater amount of daily practice than the MT group during the 8-week program (t(65) = 2.07, p = .04).

Sustained Attention to Response Task

Table 3 shows the descriptive statistics and ANOVA results for each SART measure. Both groups showed significant reductions in errors of commission (F(1,63) = 12.84, p = .001, partial η² = .165) and RT CV (F(1,63) = 18.33, p < .001, partial η² = .200) from pre- to post-intervention, with no change in RT (F(1,63) = .051, p = .822, partial η² = .001). No significant group × time interactions were observed. These results demonstrate that both attention training programs were effective in improving sustained attention and executive inhibitory control, and confirm that the CT group was not a sham control, but rather a true active control that effectively trained the attentional components targeted.

Breath Counting Task

Mean breath counting accuracy scores for each group at pre- and post-intervention are shown in Fig. 2. Repeated measures ANOVA revealed a significant group × time interaction (F(1,63) = 4.311, p = .042, partial η² = .062). Follow-up Bonferroni-corrected pairwise comparisons indicated that the MT group showed significant pre- to post-intervention improvement on the breath counting task (M(1,27) = 14.01, SE = 5.06, p = .007), while the CT group showed no significant change (M(1,27) = -2.87, SE = 6.36, p = .653). These results indicate that the MT intervention was effective in improving both attention and mindfulness, while the CT intervention was effective in training attention without improving mindfulness.

In the MT group, the median score on the breath counting task at T2 was 75%. Using this score, we were able to median split the MT group into top (> 75% accuracy = MT-HIGH; n = 19) and bottom (≤ 75% accuracy = MT-LOW; n = 22) 50th percentile groups based on T2 breath counting accuracy scores.

No significant change between reported and physiological confirmed breath counting scores was observed over time (F(1,63) = 2.091, p = .158, partial η² = .060) or within groups (F(1,63) = 0.036, p = .850, partial η² = .001).

Positive and Negative Affect

Mixed design ANOVA (between-subjects: MT, CT) revealed a significant main effect of time (F(1,63) = 9.140, p = .004, partial η² = .123), together with a significant group × time interaction (F(1,63) = 4.909, p = .030, partial η² = .070). Follow-up pairwise comparisons confirmed PA significantly increased over time in the MT group (M(1,27) = 3.24, SE = 0.771, p < .001) but not in the CT group (M(1,27) = 0.500, SE = 0.969, p = .608). These results indicate that the MT program was
effective at increasing positive affect, while no change in positive affect was observed in the CT group.

Exploratory mixed ANOVA with three-level between-groups factor (MT-LOW, MT-HIGH, CT) revealed a significant main effect of time ($F_{(1,64)} = 15.575, p < .001$, partial $\eta^2 = .196$), together with a significant main effect of PANAS ($F_{(1,64)} = 592.355, p < .001$, partial $\eta^2 = .902$) and a marginally significant main effect of time × group × PANAS interaction ($F_{(1,64)} = 3.026, p = .050$, partial $\eta^2 = .086$). Follow-up pairwise comparisons revealed that both the MT-LOW ($M_{t-j} = 3.14$, SE = 1.09, $p = .005$) and MT-HIGH ($M_{t-j} = 3.35$, SE = 1.11, $p = .004$) groups showed significant increases in PA from pre- to post-intervention, while the CT group ($M_{t-j} = 0.500$, SE = 0.976, $p = .610$) showed no significant change in PA. Mean positive affect scores for these groups at pre- and post-intervention are shown in Fig. 3a. Negative affect scores showed no significant change from pre- to post-intervention in the MT-LOW ($M_{t-j} = 0.455$, SE = 1.150, $p = .694$) and MT-HIGH ($M_{t-j} = -1.053$, SE = 1.237, $p = .398$) groups, while the CT groups displayed a marginally significant increase in NA ($M_{t-j} = 2.115$, SE = 1.058, $p = .050$), as seen in Fig. 3b.

**Anterior Alpha Asymmetry Scores**

Mixed design ANOVA with two-level between-groups factor (MT, CT) revealed a significant main effect of time ($F_{(1,65)} = 4.392, p = .040$, partial $\eta^2 = .063$) without any group or electrode interaction effects, indicating that there was a change in asymmetry scores over time disregarding group and electrode location. Exploratory mixed design ANOVA with three-level between-groups factor (MT-LOW, MT-HIGH, CT) showed a significant main effect of time ($F_{(1,64)} = 8.632, p = .005$, partial $\eta^2 = .119$) qualified by a significant time × group interaction ($F_{(1,64)} = 5.009, p = .010$, partial $\eta^2 = .135$) and a significant 3-way time × electrode × group interaction ($F_{(1,64)} = 2.715, p = .033$, partial $\eta^2 = .1078$). Follow-up Bonferroni-corrected pairwise comparisons revealed that the MT-HIGH group showed significant pre- to post-intervention increases in anterior alpha asymmetry scores at both the Fp1/Fp2 ($M_{t-j} = 0.178$, SE = 0.06, $p = .007$) and F3/F4 ($M_{t-j} = 0.280$, SE = 0.07, $p < .001$) homologous electrode pairs (see Fig. 4a and b respectively). The MT-HIGH group showed no significant change in alpha asymmetry at the F7/F8 electrode pair (see Fig. 4c). No significant change in anterior alpha asymmetry at any electrode pair was observed for the MT-LOW or CT group.

These results indicate that participants who gained high proficiency in mindfulness showed significant increases in relative left-sided anterior cortical activity as recorded at Fp1/Fp2 and F3/F4 homologous electrode sites, while those who gained low proficiency in mindfulness or who undertook CT did not demonstrate a change in anterior alpha asymmetry.
Correlations

Breath counting accuracy scores in the MT group demonstrated an 8-week test-retest reliability of ICC = .62, and for the CT group ICC = .68, which were very similar to the ICC = .60 reported by Levinson et al. (2014) in their original validation studies of this task as a measure of mindfulness proficiency.

To examine the relation between changes in anterior asymmetry and affect, change scores were calculated by subtracting T1 scores from T2 scores for Fp1/Fp2, F3/F4, and F7/F8 asymmetry scores, positive affect, and negative affect. Bivariate correlations identified no significant relationship between alpha asymmetry change scores and positive or negative affect or breath counting accuracy change scores in either the MT-HIGH group or the MT-LOW group, or the MT group as a whole or the CT group (see Supplementary Material 5 for correlation tables). Change in alpha asymmetry at Fp1/Fp2 and F3/F4 was significantly correlated in the MT-HIGH group ($r = .678, p = .001$), but not in the MT-LOW or CT groups.

Discussion

The present study found increased relative left-sided resting anterior cortical activity as measured at both the Fp1/Fp2 and F3/F4 electrode pairs in participants who achieved a high level of proficiency in mindfulness after an 8-week mindfulness intervention. No such changes were observed in those who gained low proficiency after the intervention, or in those who undertook an 8-week CT program. These results lend partial support to the hypothesis that 8 weeks of MT is capable of inducing changes in resting anterior alpha asymmetry since these changes were observed only in those who gained high proficiency in the practice.
The training of attention is a core feature of the early stages of mindfulness practice, and thus the CT program was designed to train similar attentional components to those activated in mindfulness practice. Both the MT and CT groups demonstrated improved inhibitory control and sustained attention as measured by SART errors of commission and RT CV respectively, indicating that both programs were effective in improving attention. While the CT group engaged in more training time than the MT group, only the MT group demonstrated improved performance on the breath counting task. This is an important finding, since previous studies comparing mindfulness to active control conditions have failed to show that the active control did not also improve mindfulness (Goldberg et al. 2016). In the present study, we have demonstrated that the CT program was a true active control that was effective at improving attention without enhancing mindfulness. In this way, we can be confident that any differences observed between the MT group and the CT group are the result of MT, since the CT program contained similar attention training and was structurally equivalent to the MT program.

It has been proposed that during mindfulness the prefrontal cortex exerts top-down inhibitory control to effect emotion regulation (Chiesa et al. 2013; Davidson et al. 2000). Orbitofrontal cortical (OFC) regions have been implicated in both the assignment of affective value to stimuli based upon a reward or punishment valence (Davidson 2004; Kringelbach 2005), as well as emotion regulation through amygdala-OFC functional connectivity (Banks et al. 2007). In particular, greater OFC/ventromedial PFC activity has been associated with increased ability to regulate negative affect and lower amygdala activity (Urry et al. 2006), while greater relative left-sided cortical activity has been associated with increased ability to regulate emotional responses to adverse emotional events (Jackson et al. 2003). Dorsolateral PFC (dlPFC) regions have been directly implicated in inhibitory control functions during emotion regulation (Ochsner et al. 2012; Pessoa 2008; Tang et al. 2015), with evidence now suggesting that inhibitory control may be differentially lateralised across the dlPFC such that effective inhibitory control is associated with greater left-sided dlPFC activity (Ambrosini and Vallesi 2016; Vallesi 2012). Increased left-sided activation in resting frontoparietal intrinsic networks has been shown following cognitive training in older adults, suggesting that lateralisation of intrinsic central executive network functions is alterable through targeted training interventions (Luo et al. 2016). In relation to MT, increased left dlPFC activity after a 6-week mindfulness intervention has been associated with greater inhibitory control during an affective Stroop task, with increases proportional to the amount of MT undertaken (Allen et al. 2012). Furthermore, Taren et al. (2017) have reported increased resting state functional connectivity between the left dlPFC and multiple distributed neural regions associated with executive control and emotion processing following a short-term mindfulness intervention. While research into emotion regulation is still in its infancy, evidence to date suggests that OFC and dlPFC regions of the PFC cortex may act via different pathways to enact affective regulation, whereby OFC regions are recruited in the top-down regulation of limbic regions via efferent projections to the amygdala and limbic centres once an emotional response has been generated, whereas the dlPFC acts via inhibitory control and attentional regulation to diminish the initial response itself (Davidson 2004; Nejati et al. 2018; Pessoa 2008; Rule et al. 2002).

Emotion regulation in mindfulness practice does not involve suppression or cognitive reappraisal of affective stimuli, but rather an ability to simply observe with equanimity one’s emotional responses without altering them (Chambers et al. 2009; Vago and Silbersweig 2012). According to the cognitive model proposed by Isbel and Summers (2017), early stages of mindfulness practice involve metacognitive regulation of affective responses
without avoidance, allowing them to be experienced without becoming caught up in them. These control influences produce state-like changes in overall affective composition since metacognitive monitoring and control is effective only when active (Teasdale et al. 1995). This corresponds to the regulation of active emotional responses via the recruitment of OFC regions to regulate active limbic centres. The model of Isbel and Summers further predicts that stable dispositional changes to affective composition are enacted through the development of insight which is capable of inhibiting disruptive cognitive and affective responses in a manner that prevents them from becoming manifest emotional disturbances. Importantly, the model predicts that the development of insight unfolds with enhanced executive attentional control, and these changes are expected only in those who achieve a high level of proficiency in mindfulness. In support of this prediction, evidence from fMRI studies suggests that minimising emotional responses via dLIFC regions through effective inhibitory control of aversive affective stimuli may only be achieved with proficiency in mindfulness practice. Allen et al. (2012) demonstrated that greater mindfulness experience is associated with increased left dLIFC activation and enhanced inhibitory control toward adverse affective content. Brefczynski-Lewis et al. (2007) reported increasing levels of activation in left dLIFC regions as practitioners develop from novice to highly experienced practitioners. In the current study, increased relative left-sided anterior cortical activity was observed only in those who gained high proficiency in mindfulness, supporting the hypothesis that these outcomes are dependent upon proficiency in the practice.

Existing models of anterior asymmetry are yet to clarify the underlying neurobiological mechanisms responsible for observable differences in anterior alpha asymmetry. The findings reported here may offer some support to the asymmetric inhibition model of alpha asymmetry proposed by Grimshaw and Carmel (2014). This model suggests that left-lateralised executive control inhibits negative or withdrawal-related stimuli, while right-lateralised control inhibits positive or approach-related stimuli. Here, we report that increased proficiency in mindfulness, and given its central role in mindfulness practice increased proficiency in inhibitory control, is accompanied by increased relative left-sided anterior cortical activity. Based on these findings, further research is warranted to investigate the role of inhibitory control in affective regulation.

Since anterior alpha asymmetry has been associated with dispositional affective style, the absence of change in asymmetry scores in the MT-LOW group suggests that increases in positive affect in this group may not represent dispositional changes. These findings support the predictions of the cognitive model of mindfulness of Isbel and Summers (2017) regarding state vs trait affective outcomes arising from MT. Since no similar increases in positive affect were observed in the active control group, we are able to conclude that the changes in the MT-LOW group were not the result of attention training or non-specific intervention factors (such as attending weekly training sessions, increased social engagement, and the performance of daily training exercises), but rather were the result of MT. Such a conclusion is supported by the wide body of evidence demonstrating improved affective outcomes resulting from mindfulness practice. Furthermore, since the active control condition was used to partial out the attention training component from mindfulness practice, the lack of change in anterior asymmetry in the CT group suggests that the observed increases in the MT-HIGH group resulted from mindfulness-specific factors such as equanimity, rather than attention training. The results reported here indicate that further research is required to investigate the long-term stability of affective outcomes from mindfulness practice, and whether these outcomes are differentially impacted by mindfulness proficiency.

No significant correlation between change in anterior alpha asymmetry and change in affect was identified in the present study. This accords with the majority of previous mindfulness intervention studies which found no significant correlation between measures of affect and anterior alpha asymmetry (Bamhofer et al. 2007; Davidson et al. 2003). Anterior alpha asymmetry generally correlates with a disposition toward affective experience rather than current mood states (Grimshaw and Carmel 2014). This lack of a simple correlation between anterior asymmetry and affect suggests a more complex relationship between these two variables. Further investigation to determine the possibility that lateralised inhibitory control may serve as a mediator between asymmetry and affect is warranted to uncover the relationship between these variables.

The results reported here have implications for the development of interventions to combat age-related cognitive decline. Cognitive performance is considered to decline beyond the age of 60 years, and may be accompanied by declines in affective well-being (Hedden and Gabrieli 2004). The average age of participants in the current study was approximately 71 years. We have demonstrated that 8-week training interventions are capable of enhancing attentional performance in healthy older adults, suggesting that these programs may have an application in combating age-related cognitive decline. Further studies are required to determine if the cognitive benefits arising from these training programs are maintained beyond the intervention.

Limitations and Future Research

While there were no significant pre-intervention differences in anterior alpha asymmetry between the MT and CT groups, proficiency groups identified post hoc using the breath counting task revealed a marginally significant baseline difference between the MT-HIGH group and the CT group at Fp1/Fp2. Although pre-intervention differences between the MT-HIGH group and other groups did not reach significance at other sites, it is noted that the post hoc median split did appear to create an MT-HIGH group that differed from the other groups. An
intriguing possibility suggested by these results is that future mindfulness proficiency may be predicted by pre-intervention EEG assessment, specifically anterior alpha asymmetry. This finding warrants further investigation into the potential of EEG measures to determine receptiveness to MT.

The absence of follow-up testing for participants after the 8-week program meant that we were unable to assess the stability of these effects beyond the intervention. Ideally, six- or 12-month follow-up assessments would be required to examine if the observed enhancements to attention and affect are maintained. This data would be valuable in determining if the observed improvements to affect in the MT-LOW group represented stable trait-like changes or temporary improvements. This data would be useful in further understanding the relationship between affect and anterior alpha asymmetry. In addition, if the attentional improvements in both the MT and CT groups were maintained over a long period, this would lend support to their use in either slowing age-related cognitive decline.

While two separate studies have provided robust evidence for the use of breath counting tasks as behavioural measures of mindfulness (Levinson et al. 2014; Wong et al. 2018), such tasks remain indirect measures of mindfulness. In the absence of neurobiological markers of mindfulness, the use of breath counting to assess mindfulness is certainly an improvement upon self-report measures. However, as an indirect measure, its sensitivity to discriminate mindfulness proficiency is to some extent confounded by participants’ general cognitive ability which also impacts their ability to successfully control attention during a breath counting task.

Comparison with existing studies of mindfulness and anterior asymmetry are restricted due to the wide range of interventions used, differing study populations, and the heterogeneity of EEG recording and data analysis techniques reported. The adoption of a standardised mindfulness technique would allow accurate cross-study comparisons, rather than the current situation where MBCT, MBSR, and various other MBIs are being utilised. Few studies to date have examined the effects of mindfulness on older adults; however, as the field continues to grow, we expect these numbers to increase, thereby permitting analysis of outcomes in elderly groups compared to younger cohorts. Finally, the field of EEG research has yet to adopt a standardised recording or data analysis procedure, and thus there exists in the literature a wide variety of reported EEG reference choices, electrode sites, and data analysis techniques. The lack of a standardised approach may contribute to the reporting of mixed anterior asymmetry results as evidenced in the field to date.

**Author Contributions** BI designed and conducted the study, delivered the interventions, performed the data analysis, and wrote the paper. JL collaborated in the data analysis, writing, and editing of the final manuscript. DH collaborated in the data analysis, writing, and editing of the final manuscript. MS collaborated in the design, data analysis, writing, and editing of the final manuscript.

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**Compliance with Ethical Standards**

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Ethics Statement** All procedures were performed in accordance with the ethical standards of the University of the Sunshine Coast Human Research Ethics Committee (approval: HREC A-15-748), the Australian National Statement on Ethical Conduct in Human Research, and the Code of Ethics of the World Medical Association (Declaration of Helsinki). In accordance with the latter two ethical statements which proscribe the use of no-treatment or placebo controls when existing effective treatment conditions exist, an active control condition consisting of a program of cognitive training was used as a comparison condition to assess the benefits of mindfulness training.

**Informed Consent** Informed consent was obtained from all individual participants included in the study.

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**References**


Supplementary Table 5.1: Study 4 participant acceptance criteria.

<table>
<thead>
<tr>
<th><strong>Inclusion Criteria</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 60 years of age.</td>
</tr>
<tr>
<td>Normal or corrected-to-normal visual acuity.</td>
</tr>
<tr>
<td>Able to sit upright for up to 45 minutes in a straight-backed chair.</td>
</tr>
<tr>
<td>Availability to attend all testing, training, and home practice requirements.</td>
</tr>
<tr>
<td>Access to a computer with the internet at home.</td>
</tr>
<tr>
<td>Able to understand, read, and speak English.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Exclusion Criteria</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous mindfulness/meditation experience.</td>
</tr>
<tr>
<td>Current regular practice of other mind-body techniques such as yoga or tai-chi.</td>
</tr>
<tr>
<td>Previous use of computerised brain training programs.</td>
</tr>
<tr>
<td>Current diagnosis of Mild Cognitive Impairment or Dementia.</td>
</tr>
<tr>
<td>Multiple sclerosis.</td>
</tr>
<tr>
<td>Prior head injury requiring hospitalization.</td>
</tr>
<tr>
<td>Cerebrovascular complication (eg., stroke, aneurysm, transient ischaemic attack).</td>
</tr>
<tr>
<td>Epilepsy.</td>
</tr>
<tr>
<td>Poorly controlled diabetes.</td>
</tr>
<tr>
<td>Poorly controlled hypertension or hypotension.</td>
</tr>
<tr>
<td>Neurological disorder (eg., cerebral palsy or spina bifida).</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease.</td>
</tr>
<tr>
<td>Heart disease.</td>
</tr>
<tr>
<td>Partial or total blindness.</td>
</tr>
<tr>
<td>Deafness.</td>
</tr>
<tr>
<td>Current psychiatric diagnosis (eg., depression, anxiety).</td>
</tr>
<tr>
<td>Current use of medications affecting CNS function (eg., anti-depressants).</td>
</tr>
<tr>
<td>Medical disorder which would make EEG data interpretation difficult (eg., brain injury).</td>
</tr>
<tr>
<td>Insomnia.</td>
</tr>
<tr>
<td>Engagement in moderate physical or sporting activity lasting at least 20 minutes per occasion more than 5 times a week.</td>
</tr>
<tr>
<td>Engagement in vigorous physical or sporting activity lasting at least 20 minutes per occasion more than 4 times a week.</td>
</tr>
</tbody>
</table>
Supplementary Table 5.2: Study 4 weekly structure for training interventions

<table>
<thead>
<tr>
<th></th>
<th>Mindfulness-based training program</th>
<th>Computer-based training program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>Introduction to program</td>
<td>Introduction to program</td>
</tr>
<tr>
<td>Week 2</td>
<td>What is Attention?</td>
<td>What is Attention?</td>
</tr>
<tr>
<td>Week 3</td>
<td>Working Memory</td>
<td>Executive Attentional Functions</td>
</tr>
<tr>
<td>Week 4</td>
<td>Executive Attentional Functions</td>
<td>Working Memory</td>
</tr>
<tr>
<td>Week 5</td>
<td>Age-related Cognitive Decline</td>
<td>Age-related Cognitive Decline</td>
</tr>
<tr>
<td>Week 6</td>
<td>Emotional Regulation</td>
<td>Emotional Regulation and Memory</td>
</tr>
<tr>
<td>Week 7</td>
<td>Metacognition</td>
<td>Controlled vs Automatic Cognitive Processes</td>
</tr>
<tr>
<td>Week 8</td>
<td>Cognitive Flexibility</td>
<td>Metacognition</td>
</tr>
</tbody>
</table>
### Supplementary Table 5.3: Study 4 tasks utilised in the active control condition

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Selective Attention</th>
<th>Task Switching</th>
<th>Inhibitory Control</th>
<th>Working Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flanker task based upon Eriksen and Eriksen (1974)</td>
<td>Participants are instructed to indicate the direction of a central arrow flanked on either side by two distractor arrows.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Visual search task based upon Treisman and Gormican (1988)</td>
<td>Participants are instructed to indicate a unique object amongst a field of similar distractor objects. The number of distractors increases with successful performance, while their differences become less obvious.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Task switching paradigm in accord with Kiesel et al. (2010).</td>
<td>This task involves arrows of two different colours moving across a screen. Arrows may point in the direction they are moving, or in a different direction. Participants are instructed to switch between indicating either the direction of movement of the arrow, or the direction that the arrow is pointing, depending on the colour of the arrows.</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4. Task switching paradigm in accord with Kiesel et al. (2010)</td>
<td>Participants are shown a card with a number and a letter on it. Participants are instructed to switch between indicating whether the number is an even number or if the letter is a vowel or not, depending upon the location that the card is presented. Presented at the top of the screen, participants are to indicate if the number is even. Presented at the bottom of the screen, participants are to indicate if the letter is a vowel.</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>5. Stroop task based upon Stroop (1935)</td>
<td>Participants are shown two cards with two colour words written on them. The words and the colour of the letters change with each trial. Participants are instructed to indicate if the colour of the letters on the second card matches the meaning of the colour word presented on the first card.</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>6. Moving visual divided attention task based upon Treisman (1982)</td>
<td>A number of identical objects move randomly within a fixed field. Participants are required to select one object at a time at three second intervals, without selecting the same object twice, until all objects have been selected. The number of objects</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>7. Static adaptation of the Corsi block task (Milner, 1971) to assess working memory (Baddeley, 2003)</td>
<td>Participants are presented with a grid of squares of a uniform colour. A small number of squares change colour briefly before changing back to the original uniform colour. Participants are instructed to indicate which squares changed colour after they have switched back to the uniform grid colour. The number of squares in the grid as well as the number of squares changing colour increases with successful performance.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Serial working memory task (Baddeley, 2003)</td>
<td>Participants are presented with cards showing a variety of coloured shapes that appear serially. The new card remains face-up, while the card that appeared previously is turned face-down. Participants are instructed to remember if the card currently face-up matches the card that appeared two cards previous.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Supplementary Figure 5.1: Sustained Attention to Response Task

Participants are required to respond to all frequent non-targets (digits 1-2, 4-9) and to withhold a response to infrequent targets (digit 3).
Supplementary Tables 5.4: Study 4 correlation tables.

Supplementary Table 5.4a: Study 4 bivariate correlations of change scores for alpha asymmetry, affect, and breath-counting accuracy for the mindfulness-training (MT) group.

<table>
<thead>
<tr>
<th></th>
<th>Breath-counting accuracy</th>
<th>Positive affect</th>
<th>Negative affect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive affect</td>
<td>Pearson Correlation</td>
<td>-.149</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.353</td>
<td></td>
</tr>
<tr>
<td>Negative affect</td>
<td>Pearson Correlation</td>
<td>-.068</td>
<td>-.354*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.672</td>
<td>.023</td>
</tr>
<tr>
<td>Fp1/Fp2</td>
<td>Pearson Correlation</td>
<td>-.028</td>
<td>-.254</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.861</td>
<td>.109</td>
</tr>
<tr>
<td>F3/F4</td>
<td>Pearson Correlation</td>
<td>-.100</td>
<td>.072</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.534</td>
<td>.652</td>
</tr>
<tr>
<td>F7/F8</td>
<td>Pearson Correlation</td>
<td>-.028</td>
<td>.256</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.861</td>
<td>.107</td>
</tr>
</tbody>
</table>

Note: n = 41; *Correlation is significant at the 0.05 level (2-tailed).

Supplementary Table 5.4b: Study 4 bivariate correlations of change scores for alpha asymmetry, affect, and breath-counting accuracy for the computer-training (CT) group.

<table>
<thead>
<tr>
<th></th>
<th>Breath-counting accuracy</th>
<th>Positive affect</th>
<th>Negative affect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive affect</td>
<td>Pearson Correlation</td>
<td>.134</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.513</td>
<td></td>
</tr>
<tr>
<td>Negative affect</td>
<td>Pearson Correlation</td>
<td>.029</td>
<td>-.404*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.889</td>
<td>.040</td>
</tr>
<tr>
<td>Fp1/Fp2</td>
<td>Pearson Correlation</td>
<td>-.064</td>
<td>-.184</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.756</td>
<td>.367</td>
</tr>
<tr>
<td>F3/F4</td>
<td>Pearson Correlation</td>
<td>-.034</td>
<td>.131</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.869</td>
<td>.524</td>
</tr>
<tr>
<td>F7/F8</td>
<td>Pearson Correlation</td>
<td>.386</td>
<td>.192</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.052</td>
<td>.349</td>
</tr>
</tbody>
</table>

Note: n = 26; *Correlation is significant at the 0.05 level (2-tailed).
Supplementary Table 5.4c: Study 4 bivariate correlations of change scores for alpha asymmetry, affect, and breath-counting accuracy for the mindfulness-low proficiency (MT-LOW) group.

<table>
<thead>
<tr>
<th></th>
<th>Breath-counting accuracy</th>
<th>Positive affect</th>
<th>Negative affect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positive affect</strong></td>
<td>Pearson Correlation</td>
<td>-.142</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.529</td>
<td></td>
</tr>
<tr>
<td><strong>Negative affect</strong></td>
<td>Pearson Correlation</td>
<td>.013</td>
<td>-.349</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.955</td>
<td>.111</td>
</tr>
<tr>
<td><strong>Fp1/Fp2</strong></td>
<td>Pearson Correlation</td>
<td>-.113</td>
<td>-.302</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.616</td>
<td>.172</td>
</tr>
<tr>
<td><strong>F3/F4</strong></td>
<td>Pearson Correlation</td>
<td>-.220</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.324</td>
<td>.990</td>
</tr>
<tr>
<td><strong>F7/F8</strong></td>
<td>Pearson Correlation</td>
<td>.038</td>
<td>.063</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.868</td>
<td>.782</td>
</tr>
</tbody>
</table>

Note: \( n = 22; ^*\) Correlation is significant at the 0.05 level (2-tailed).

Supplementary Table 5.4d: Study 4 bivariate correlations of change scores for alpha asymmetry, affect, and breath-counting accuracy for the mindfulness-high proficiency (MT-HIGH) group.

<table>
<thead>
<tr>
<th></th>
<th>Breath-counting accuracy</th>
<th>Positive affect</th>
<th>Negative affect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positive affect</strong></td>
<td>Pearson Correlation</td>
<td>-.184</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.450</td>
<td></td>
</tr>
<tr>
<td><strong>Negative affect</strong></td>
<td>Pearson Correlation</td>
<td>-.100</td>
<td>-.361</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.683</td>
<td>.129</td>
</tr>
<tr>
<td><strong>Fp1/Fp2</strong></td>
<td>Pearson Correlation</td>
<td>-.059</td>
<td>-.267</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.812</td>
<td>.269</td>
</tr>
<tr>
<td><strong>F3/F4</strong></td>
<td>Pearson Correlation</td>
<td>-.234</td>
<td>.160</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.335</td>
<td>.513</td>
</tr>
<tr>
<td><strong>F7/F8</strong></td>
<td>Pearson Correlation</td>
<td>-.131</td>
<td>.418</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.592</td>
<td>.075</td>
</tr>
</tbody>
</table>

Note: \( n = 19; ^{**}\) Correlation is significant at the 0.01 level (2-tailed).
Chapter 6

Summary, Discussion, and Future Directions
6.1 Summary of Studies

Study 1

Distinguishing the cognitive processes of mindfulness: Developing a standardised mindfulness technique for use in longitudinal randomised control trials

The model (see Figure 6.1 below) clearly identifies and separates the cognitive faculty of mindfulness from the metacognitive processes required to generate and maintain this cognitive faculty during mindfulness training. In addition, it provides an explanatory framework capable of describing how supportive practices such as the intentional cultivation of loving-kindness and compassion act to stabilise attentional deployment through the enhancement of equanimity. The model highlights the crucial role of executive inhibitory control in mindfulness practice, and through the shared neurobiological basis of this regulatory mechanism in both attentional and affective information processing, the model provides explanatory pathways for the commonly reported benefits to cognition and affect arising from practice. The core attentional components activated during mindfulness are clearly elucidated, permitting the formulation of testable hypotheses that can be assessed in longitudinal RCTs. For instance, the model predicts that sustained attention and inhibitory control performance should improve following mindfulness training. Furthermore, the model also shows how advanced stages of mindfulness lead to the development of insight together with the pathways through which this knowledge acts to undermine negative affective states and enhance positive affective states. The model predicts that a high level of mindfulness proficiency leading to the development of insight should be accompanied by reductions in negative affect and increases in positive affect, and that these changes should represent stable dispositional changes.
Figure 6.1: The cognitive processes of mindfulness.
Study 2
Mental Training Affects Electrophysiological Markers of Attention Resource Allocation in Healthy Older Adults

An active controlled longitudinal RCT was conducted to assess the attentional benefits of an 8-week mindfulness intervention in healthy older adults using the standardised technique developed in Study 1. A computer-based attention training program designed to activate the attentional components predicted by the model as being activated during mindfulness practice was utilised as a comparison condition in order to determine if the previously reported benefits of mindfulness were merely the result of its attention training aspect. Both groups displayed improved sustained attention performance during a two-tone auditory oddball task, together with reductions in N2 amplitudes at frontal sites, indicating that the interventions were successful in enhancing attentional performance and neural efficiency of frontally oriented networks. The mindfulness group displayed additional benefits to the speed of attentional resource allocation, evidenced as reductions in N2 and P3 latencies at frontal sites not observed in the active control condition. The results indicate that mindfulness training may be capable of improving both the speed and efficiency of attention resource allocation in older adults, thereby enhancing cognitive reserve through an increase in neural reserve. Since aging is associated with declining efficiency of attentional networks and a slowing of information processing, the results of this study suggest that mindfulness may have a role in combating age-related cognitive decline and reducing later risk of dementia through its ability to enhance cognitive reserve. The findings of Study 2 support the theoretical model of mindfulness presented in Study 1 by confirming that mindfulness training is associated with enhanced attentional performance, as predicted by the model (see Figure 6.2 below for a simplified representation of these core attentional processes).
Figure 6.2: The maintenance of sustained attention during mindfulness practice.
Study 3
Mental Training Enhances Attention Resource Allocation in Healthy Older Adults

Study 3 further extends our understanding of the attentional benefits of mindfulness training. This study reports the findings from an active controlled longitudinal RCT on the Sustained Attention to Response Task, which is a visual go/no-go task requiring both sustained attention and inhibitory control. Both the mindfulness and computer-training groups showed improved inhibitory control performance, indicating that the control condition was successful at enhancing attention and was therefore not a sham control. However, the mindfulness group displayed greater improvements to sustained attention along with reductions in frontal N2 amplitudes and frontal P3 latencies not observed in the control condition. Exploratory analyses revealed shorter reaction time and reduced P3 latency during response inhibition in those who achieved a high level of mindfulness proficiency and not in those who achieved a low level of proficiency. These findings add further support to the thesis that mindfulness training is capable of enhancing neural reserve in healthy older adults by improving both the speed and efficiency of attention resource allocation. Furthermore, since deteriorations in inhibitory control are thought to underlie age-related declines in attentional performance, improvements to inhibitory control reported in this study suggest that cognitive training interventions targeting sustained attention and inhibitory control may be effective in combating age-related cognitive declines. Increases to neural efficiency in the mindfulness group in particular may represent a mechanism through which mindfulness can exert a protective benefit against age-related declines in attentional performance, however these benefits may be linked to proficiency in the practice. The findings of Study 3 further support the theoretical model of mindfulness by confirming that mindfulness training is associated with improvements to both sustained attention and executive inhibitory control performance, as predicted by the model (see Figure 6.3 below).
Figure 6.3: The core cognitive processes involved in attention regulation during mindfulness practice.
Study 4
Mindfulness Induces Changes in Anterior Alpha Asymmetry in Healthy Older Adults

Affective outcomes arising from eight weeks of mindfulness training were investigated in Study 4. The mindfulness group showed significant increases in positive affect after training while the active control condition showed no change in positive affect. Participants who achieved a high level of proficiency in mindfulness demonstrated significant increases in relative left-sided anterior cortical activity suggestive of a dispositional change in affective style toward more positive affective states. No change in anterior alpha asymmetry was observed in those who achieved a low level of mindfulness proficiency or in the active control condition. These results indicate that mindfulness is capable of inducing a trait change in affective style that is accompanied by greater levels of positive affect, but that this outcome is dependent upon the level of mindfulness proficiency achieved. This finding is in alignment with the theoretical model of mindfulness presented in Study 1 which describes the development of insight, along with its transformational effect on affect, as occurring with advanced proficiency in the practice. Whereas metacognitive regulation of affect provides state-like benefits in mindfulness practice, insight has the ability to exert trait-like changes to affective regulation (see Figure 6.4 below). This relationship is reflected in the finding of increased positive affect in the absence of anterior asymmetry changes in those who achieved a low level of proficiency in mindfulness. In this group, affective changes are likely to represent state-like effects of mindfulness arising from metacognitive regulation of affect rather than trait-like changes resulting from the development of insight such as those observed in the high proficiency group.
Figure 6.4: Affective regulation during mindfulness practice.
6.2 Discussion

Three main aims were identified for this thesis. The first was the development of a cognitive model of mindfulness capable of describing the core processes activated by this practice, together with the pathways through which attentional and affective outcomes are achieved. A standardised mindfulness technique translated from this model was also required for use in longitudinal RCTs seeking to investigate outcomes of this practice. Secondly, an active controlled longitudinal RCT was conducted to examine the efficacy of mindfulness to enhance attention in older adults during a sensory discrimination task (auditory oddball) and an inhibitory go/no-go task (SART). Lastly, the efficacy of mindfulness to induce dispositional changes in affective style according to the pathways described in the model was assessed over the course of an 8-week training intervention.

Explaining Mindfulness

The field of mindfulness research is still in its infancy, and much of the research to date has been performed in the absence of theoretical models capable of providing a clear explanation of the pathways and mechanisms involved in this practice (Van Dam et al., 2017). Early contemporary psychological models of mindfulness emphasised the core components of sustained attention, attention switching, and inhibition together with an attitudinal orientation of acceptance toward the contents of experience (Bishop et al., 2004; Shapiro, Carlson, Astin, & Freedman, 2006). While these models describe the attention regulating components of mindfulness, they offer little specificity regarding the pathways through which outcomes are achieved, the role of attentional clarity and effort in mindfulness practice, or the developmental changes that occur with increasing proficiency. Further models have attempted to incorporate metacognitive processes into a mindfulness framework, but do not provide a comprehensive description of the pathways through which the development of enhanced metacognition leads to beneficial cognitive and affective outcomes, and how these outcomes influence attention (Holas & Jankowski, 2013; Kang, Gruber, & Gray, 2012). In an attempt to provide an explanation of the processes activated across differing styles of mindfulness, Vago and Silbersweig (2012) resort to presenting three different models to describe focused attention, open monitoring, and ethical enhancement styles of mindfulness practice.
The presentation of a comprehensive model of mindfulness in this thesis represents a major contribution to the scientific investigation of mindfulness by incorporating attentional, cognitive, metacognitive, and affective processes within a dynamic developmental framework. The model is capable of explaining the processes activated by novice practitioners, together with the changes and transitions that take place with increasing proficiency. Supportive practices commonly engaged in during MBIs such as generating loving-kindness, compassion, and ethical conduct are also accommodated within the model. Importantly, the model clearly explains the role of introspection in monitoring both the object of attention as well as the subjective qualities of the awareness which holds that object. A key feature often overlooked in existing models of mindfulness is the crucial role of regulating attentional effort to maintain attentional stability and clarity, and the methods through which this regulation is achieved. The model presented here explains the relationship between effort and attentional clarity and stability, and how the adoption of mentally contrived modes of paying attention are required during the early stages of practice, and how these gradually transition to uncontrived effortless states of awareness. The model presented here is novel in providing an overarching framework which captures the range of mindfulness practice, from focussed attention to open monitoring styles.

Empirical scientific investigation is founded upon the testing of hypotheses regarding predicted outcomes. The model presented here permits precise and clear predictions to be made regarding expected outcomes. In relation to attentional outcomes, the model predicts that mindfulness training should increase the stability of attentional deployment through metacognitive monitoring and control mechanisms, primarily through the activation of executive inhibitory control. These predictions relate to fundamental attentional processes activated during mindfulness practice, and as such represent the base level of cognitive training engaged at the outset of mindfulness training. These predictions were tested in Study 2 and Study 3 of this thesis, where enhanced efficiency and speed of attentional deployment was observed following mindfulness training. The findings of these two studies support the hypothesis that mindfulness training can enhance the efficiency and speed of attentional deployment, resulting in improved sustained attention and inhibitory control performance. Predictions regarding working memory and metacognition may also be formulated from the model, however the scope
of this thesis was limited to assessing predictions regarding the foundational attentional processes upon which the model suggests later outcomes are based. In relation to affective outcomes, the model predicts that increasing proficiency in mindfulness should be accompanied by increases in positive affective states and decreases in negative affective states. This prediction was tested in Study 4 of this thesis, where increases in positive affect along with neurobiological changes associated with a trait change of affective style toward greater positive affective states were observed in participants who achieved a high level of proficiency in the practice. These results support the hypothesis that mindfulness training can increase positive affective states, and suggest that these changes may represent stable dispositional alterations to affective style. The studies reported here represent the first steps in testing the pathways detailed in the model. Additional research is required to thoroughly examine further mechanisms of change proposed by the model.

Mindfulness Interventions in Longitudinal RCTs

Previous studies investigating mindfulness have commonly used a standardised MBI such as MBSR or MBCT. Both of these MBIs were developed for therapeutic applications. In the case of MBSR, the intervention was targeted toward the reduction of stress, while MBCT was developed as a psychological therapy to treat depression. Since these interventions use mindfulness in conjunction with secondary techniques such as relaxation, yoga, psychoeducation, or cognitive behaviour therapy (CBT), it is unclear whether or not any outcome regarding cognition or affect observed in scientific studies of their efficacy are due to mindfulness training or some other component of the intervention. Thus, these interventions are unsuitable for use in longitudinal RCTs seeking to examine the cognitive and affective outcomes arising from mindfulness training through causal inference.

The standardised mindfulness technique presented in Study 1 is capable of generating mindfulness without the addition of confounding secondary components, and therefore represents a significant advance in the scientific study of mindfulness since it permits the use of a standardised and reproducible technique. This technique not only permits cross-study comparison through the use of a standardised set of instructions, but it also allows for the first time an empirical assessment of the benefits arising from additional
intervention components when conjoined to mindfulness. For instance, a comparison study using the standardised technique compared to the standardised technique plus CBT would allow for a quantification of the relative contributions of mindfulness and CBT in the therapeutic application of MBCT to treat depression.

**Mindfulness and Attention in Aging**

The efficacy of mindfulness to enhance attention in healthy older adults was assessed in Study 2 and Study 3. The first study utilised a two-tone auditory oddball task while the second utilised the Sustained Attention to Response Task (SART), which is a visual go/no-go task. In this way, the ability of mindfulness to enhance attention across different sensory modalities was assessed. In both studies, improved attentional performance following mindfulness training was observed. The ability to regulate sustained attention, measured by RT CV, improved during both the auditory oddball and the SART. Improved inhibitory control, measured by errors of commission, was also observed during the SART. Improvements to attentional performance in the mindfulness group were accompanied by reductions in frontally oriented N2 and P3 latencies, and reductions in frontally oriented N2 amplitudes, indicating that the speed and efficiency of attention resource allocation had increased after mindfulness training. During the SART, high mindfulness proficiency in particular was associated with shorter reaction times and reduced P3 latency during response inhibition, suggesting that the attentional benefits of mindfulness training may be dependent upon the level of proficiency achieved in the practice. Together, the results from Study 2 and Study 3 support the hypothesis that mindfulness training is capable of enhancing attention in line with the predictions of the model.

Speed of information processing and the efficiency of attentional networks are known to decline with age (West, 2004). A deterioration of inhibitory control is thought to underlie the increased susceptibility of attentional processes to interference with age, resulting in increased variability of attentional deployment, as indexed by RT CV (Andrés et al., 2008; Vasquez et al., 2016; Weeks & Hasher, 2015). Reductions in attentional stability requires the aging adult to exert greater executive regulation of attention to maintain task performance, and this increased reliance upon executive control is thought to be reflected in greater frontally oriented N2 and P3 ERP components (Anderer et al., 1996). These age-related changes to the efficiency and
capacity of attention resource allocation reflect a decline in neural reserve, which underpins cognitive reserve.

The reductions in N2 and P3 latency at frontal sites reported here suggest that mindfulness is capable of increasing the speed of information processing in older adults. Given that the latency of both the N2 and P3 ERP components increase with age, the reductions observed here following mindfulness training suggest that mindfulness may provide protective benefits against this type of age-related deterioration in neural efficiency. It should be noted that while both the mindfulness group (MT) and the active control group (CT) displayed improved performance on behavioural measures of attention such as errors made and RT CV, only the MT group displayed reductions in N2 and P3 latency during the tasks. These results indicate that while both attention training interventions were successful in improving attentional performance, the MT program resulted in unique benefits to the speed of information processing not observed in the CT group. Furthermore, since speed of processing contributes to overall efficiency of information processing, it appears that mindfulness may be successful at enhancing neural reserve through improved neural efficiency.

The current finding of reduced ERP component latency following mindfulness training represents novel evidence that cognitive training interventions are capable of improving speed of information processing in older adults. A reduction in ERP component latency in older adults has previously been reported following physical strength and endurance training, but not after cognitive training, which has been shown to enhance ERP component amplitude (Gajewski & Falkenstein, 2012; O’Brien et al., 2013; Özkaya et al., 2005). An intriguing possibility arises that mindfulness training may share some commonalities with physical training, and as such may be capable of inducing somatic benefits. Supporting evidence is found amongst a growing body of literature reporting improved physiological outcomes arising after mindfulness training, including improved immune system response (Creswell, Myers, Cole, & Irwin, 2009; Davidson et al., 2003), reductions in serological inflammatory markers of disease (Creswell et al., 2016; Tomfohr, Pung, Mills, & Edwards, 2014), increased telomerase activity (Jacobs et al., 2011), improved cerebral blood flow (Newberg et al., 2010; Wang et al., 2011), improved autonomic symptho-vagal balance (Delgado-Pastor et al., 2013; Nijjar et al., 2014), together with reductions in resting respiration rate and blood pressure (Ahani et
Perhaps the most remarkable feature hinted at by these results is that mental training, as embodied by mindfulness, can have such widespread physical benefits not observed from other types of cognitive training interventions. This diverse range of outcomes points toward a shared collection of benefit from both physical exercise and mindfulness training which warrants further investigation.

Faster information processing speeds reported in the current thesis are in line with previous work reporting improved speed of attention resource allocation during an attentional blink task following mindfulness training (Slagter et al., 2007). This study reported reductions in P3 amplitudes to target stimuli, indicating enhanced efficiency of attention resource allocation, but no change in P3 latency. Reductions in ERP amplitudes in this study were accompanied by shorter discrimination times, and were interpreted as permitting faster processing of information through more efficient deployment of attention. This interpretation is consistent with the results of the current thesis where improved attentional performance was accompanied by reductions in N2 amplitudes, reflecting improved efficiency of attention resource allocation. During the auditory oddball task, both the MT and CT groups displayed reduced N2 amplitudes to target tones at both frontal and central sites following the interventions. These reductions were accompanied by improvements to sustained attention, suggesting a reduced requirement to allocate brain resources to perform at a higher level after training, concordant with improved neural efficiency. During the SART, the MT group again showed reductions in N2 amplitude accompanied by improvements in attentional performance. However, the CT group showed increases in N2 amplitude along with a reduced benefit to sustained attention compared to the MT group.

While the auditory oddball task is a very simple sensory discrimination task, the SART is a much more demanding task requiring active response inhibition. This difference is reflected in the performance data for each task at pre-intervention. While participants performed at near ceiling levels on the auditory oddball task at pre-intervention, participants made nearly 20% errors at T1 on the SART, indicating a greater sensitivity of the SART to detect changes in attentional performance. As such, the SART was better able to discriminate attentional changes between groups, as evidenced by the behavioural data which showed greater gains to sustained attention in the MT group.
Furthermore, those who achieved a high level of proficiency in mindfulness demonstrated shorter reaction times during the SART along with reductions in frontal P3 latency not observed in those who achieved a low level of proficiency, suggesting that the SART was more sensitive to attentional changes than the auditory oddball. During the SART, the CT group was required to mobilise greater levels of attentional resources (indexed by increased N2 amplitudes) to perform the task at a higher level following the intervention, while the MT group were able to allocate fewer attentional resources (indexed by reduced N2 amplitudes) to perform the same task to a higher level of performance. Together with the auditory oddball results, these findings support the hypothesis that mindfulness training may enhance neural efficiency, thereby contributing to an increase in overall cognitive reserve.

Aging is associated with an increasingly frontal-oriented topography of ERP responses (Anderer et al., 1996). It is notable that the changes to ERP component latency and amplitude reported here are all found at frontal sites, suggesting that these regions were targeted by the interventions. Greater frontally oriented responses indicate an increased reliance with age on anterior executive control processes to regulate attention in the face of increasing susceptibility to interference. These executive control processes were also hypothesised to be predominantly activated during mindfulness practice. Taken together with improvements to inhibitory control performance on the SART, the frontally oriented ERP changes reported here add further support to the hypothesised primacy of executive attentional processes in mindfulness training.

**Cognitive Training and Sustained Attention**

The CT program was specifically designed to target the attentional processes predicted by the model to be activated during mindfulness practice. Accordingly, the computer-based attention training program emphasised the training of sustained attention and inhibitory control. As demonstrated in Study 2 and Study 3, participants in the CT group displayed improved sustained attention and inhibitory control performance following the 8-week training intervention. These results indicate that the CT condition was an effective attention training intervention rather than a sham control condition. In addition, the CT group displayed changes in N2 amplitudes suggestive of an improved ability to regulate attentional deployment. During the auditory oddball task, the CT group demonstrated reductions in N2 amplitude in line with those observed in the MT
group, suggesting enhanced efficiency of attention resource allocation during sensory discrimination after training. During the SART, the CT group demonstrated increases in N2 amplitudes, suggesting an enhanced ability to deploy attentional resources to meet task demands after training during response inhibition. Increases in N2 amplitude were accompanied by improved task performance, as indexed by reduced RT CV and fewer errors of commission. Together these results indicate that the CT condition was capable of enhancing attention, and therefore served as an effective comparison condition to determine if the benefits of mindfulness practice result from merely its attention training component, or rather were due to mindfulness-specific factors.

The ability to sustain attention is a fundamental process thought to determine the efficacy of cognitive capacity in general (Sarter et al., 2001). The effectiveness of the CT program to enhance sustained attention in healthy older adults suggests that cognitive training programs targeting foundational attentional components may be effective at enhancing cognition in older adults. Cognitive training interventions to combat ARCD and mild cognitive impairment (MCI) commonly train higher cognitive processes such as working memory, problem solving, or executive function, leading only to near-transfer effects (Kelly et al., 2014; Mewborn et al., 2017; Reijnders et al., 2013). Since these higher cognitive abilities are reliant upon sustained attention, it is possible that the improvements to sustained attention demonstrated in the current thesis may lead to greater transfer of benefit to general cognition through improvements to the efficiency of attentional processing in general. Based upon the findings presented here, further investigation of cognitive training techniques for older adults is warranted to examine this hypothesis.

**Mindfulness and Affect in Aging**

The efficacy of mindfulness to enhance affect in healthy older adults was assessed in Study 4. The model predicts that increasing mindfulness proficiency should be accompanied by greater levels of positive affect and lower levels of negative affect. Partial support for this hypothesis was provided by increases in both positive affect and relative left-sided anterior activity observed in those who developed a high level of proficiency in mindfulness practice (MT-HIGH). Those who developed a low level of proficiency in the practice (MT-LOW) also displayed increases in positive affect, but these changes were not accompanied by greater left-sided anterior activity. The
hypothesised decreases in negative affect were not observed in the MT group, who displayed stable levels of negative affect over the intervention. The CT group however displayed a marginally significant increase in negative affect over the course of the intervention with no change in positive affect.

The model predicts that state-like regulatory control over affective states can be achieved in mindfulness practice through metacognitive monitoring and control processes. During mindfulness practice, metacognitive processes exert a negative control influence over disruptive affective states and mind-wandering, and a positive control influence over enhancing affective states and attitudes of equanimity. These control influences produce state-like changes in overall affective composition since metacognitive monitoring and control is effective only when active (Teasdale, Segal, & Williams, 1995). Stable dispositional changes to affective composition are enacted through the development of insight which is capable of undermining the basis upon which many of disruptive affective states arise (Leary, 2004; Mahasi, 1965). In addition, insight enhances equanimity and positive affective states through a removal of erroneous mental superimpositions upon experience and a direct ascertainment of the final mode of existence of phenomena (Pandita, 1995; Tsongkhapa, 2002). The development of insight in mindfulness practice is a gradual process that unfolds proportionate to proficiency, and as such, fully fledged insight is unlikely to be achieved in eight weeks in novice practitioners. However, the preliminary stages of insight, especially metacognitive insight, are accessible to novice practitioners who reach success in the development of mindfulness (Grabovac, 2015).

These predictions are supported by the findings of Study 4, where the MT-HIGH group displayed increases in positive affect together with neurobiological changes reflective of a trait change in affective style. Anterior alpha asymmetry has demonstrated high test-retest reliability and internal consistency as a neurobiological marker of affective style (Tomarken, Davidson, Wheeler, & Kinney, 1992; Towers & Allen, 2009). Given its stability over time, it is significant that eight weeks of mindfulness training was capable of inducing changes in anterior alpha asymmetry reflective of improved affect in the MT-HIGH group, but not in the MT-LOW and CT groups. This result supports the pathways of dispositional affective change proposed by the model, since these pathways are only accessible with high levels of proficiency. The observed increases in positive
affect across both the MT groups suggests that while mindfulness is capable of enhancing affect, this change may only represent a state-like effect in those who achieve low proficiency. Such a conclusion would be in line with the model’s prediction of state-like metacognitive control over affect and mind-wandering which is activated from the very outset of the practice, and thus accessible to those who achieve a low level of mindfulness proficiency.

Metacognitive regulation of affect and cognition is proposed by the model to operate primarily through inhibitory control. Both training interventions were successful at improving inhibitory control as measured by errors of commission during the SART. However, the deployment of inhibitory control differed between the two interventions. In the CT program, inhibitory control was required to inhibit gross instances of mind-wandering which interfered with task performance. However, in mindfulness practice inhibitory control is required to inhibit not only gross mind-wandering, but also subtle mind-wandering together with affective and emotional responses toward the contents of experience. As such, inhibitory control represents the primary process trained during mindfulness practice, spanning both cognitive and emotional domains. The SART is a cognitive task designed to assess gross mind-wandering resulting in a failure to inhibit a prepotent motor response (Seli, 2016). Thus the SART has been designed to specifically assess the type of inhibitory control trained in the CT program rather than the broader type of metacognitive inhibitory control central to mindfulness practice. While the reported improvements observed in both groups confirms that this type of inhibitory control was targeted in both programs, the lack of change in positive affect observed in the CT group suggests that a more limited type of inhibitory control was developed in this group. The MT-LOW group demonstrated similar improvements in inhibitory control to the CT group, but these were accompanied by gains in positive affect, supporting the broader development of metacognitive inhibition in this group which was capable of exerting a state-like increase in positive affect.

The presence of equanimity training in the MT group and its absence in the CT group may also have contributed to the affective changes observed in Study 4. Equanimity refers to a non-reactive orientation toward the contents of experience and experience itself, involving cognitive and affective impartiality (Desbordes et al., 2015). This type of approach to dealing with affective stimuli represents a unique approach to emotion
regulation that differs from other techniques such as reappraisal or suppression (Gross, 1998). The model predicts that the development of equanimity should be accompanied by increased enhancing or positive affective states. The relationship between the development of equanimity and positive affect is supported by the increases in positive affect observed in the MT group. It is possible that this pathway may have contributed to the increases in positive affect in the MT-LOW group which were not accompanied by changes in anterior alpha asymmetry. Such a possibility is further suggested by the absence of change in positive affect in the CT group, who also exhibited improvements to inhibitory control, but did not engage in equanimity training. It is likely that affective outcomes in mindfulness practice arise due to a combination of metacognitive inhibitory control and equanimity, as the two are closely linked. In order to develop equanimity, one must inhibit automatic prepotent responses to affective stimuli as well as cognitive elaboration upon experience. Equanimity is supported by and is developed through the broader type of inhibitory control discussed earlier, as described by the pathways outlined in the model. These pathways suggest that greater levels of equanimity would enhance positive affective states, but not directly impact negative affective states. This conclusion is supported by the finding of increased positive affect in the MT group.

While the findings in relation to positive affect were in line with hypothesised improvements, findings regarding negative affect were not so clear. Both MT groups showed no change in negative affect over the intervention, while the CT group showed an increase in levels of negative affect. It is unclear whether the MT program provided a protective benefit against increases in negative affect that would have otherwise occurred over time, as evidenced in the CT group. Such a possibility is suggested by previous work demonstrating a protective benefit of eight weeks of mindfulness training against increases in depressive symptoms observed in a wait-list control group (Keune et al., 2011). This possibility however remains unexamined in the present thesis, and should be the subject of future research in order to investigate the differential effects of mindfulness on positive and negative affective states, and the pathways through which they arise.

**Attentional and Affective Outcomes are Dependent upon Mindfulness Proficiency**
The evidence presented in this thesis suggests that some of the widely reported benefits of mindfulness training may depend upon the level of proficiency achieved in the
practice. In Study 2, improved performance of sustained attention and reduced frontal N2 and P2 latency was observed as a general effect of mindfulness training. Although a general benefit of mindfulness training to sustained attention and inhibitory control was observed in Study 3, when proficiency level was investigated, only participants who achieved a high level of proficiency displayed reductions in frontal P3 latency along with shorter reaction times during the second half of the SART. In Study 4, while increases in positive affect were observed across mindfulness proficiency groups, a significant shift in anterior alpha asymmetry toward greater relative left-sided frontal activity was observed only in the MT-HIGH group. Taken together, these results suggest that while a general effect of mindfulness may be observed on some measures, there clearly exists differential outcomes following mindfulness training that are dependent upon the level of proficiency achieved in the practice.

This conclusion is in line with the theoretical model of mindfulness presented here, where it is predicted that increasing proficiency is accompanied by greater stability and skill in attentional deployment and affective regulation that is not present in novice practitioners. Support for this prediction is found in previous studies reporting improved performance on tasks of attention (Van den Hurk et al., 2009), inhibitory control (Chan & Woollacott, 2007), and working memory (Jha et al., 2010), together with increased functional connectivity within attentional networks (Hasenkamp & Barsalou, 2012) with higher levels of mindfulness experience and proficiency. The effect of proficiency on attentional performance has been well illustrated in a study of practitioners with varying levels of experience compared to novices (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007). In this study, practitioners with a medium level of experience demonstrated greater levels of activation in neural networks associated with sustained attention than both practitioners with high levels of experience and also novices. This pattern of results accords with the predictions of the model, whereby a high level of attentional resources are required during the beginning and middle stages of practice to regulate attentional deployment, until at a high level of proficiency these processes become automated and therefore demand fewer attentional resources.

Future studies investigating the effects of mindfulness on cognition and affect must therefore make an effort to measure the level of proficiency achieved by participants in order to differentiate between general and specific effects of this practice. Only by
examining separately those who truly become proficient in mindfulness from those who merely attend a mindfulness intervention but do not successfully generate mindfulness can we begin to accurately understand the effects of this practice. A differentiation into high and low proficiency groups following mindfulness training will also allow investigation into those characteristics which render participants receptive to this practice. By examining the pre-intervention profiles of participants who go on to achieve high levels of proficiency, we can begin to understand what makes a participant a mindfulness responder rather than a non-responder, and begin to offer tailored interventions to suit individual differences.
6.3 Limitations of the Studies

There are several limitations to the studies reported here that require acknowledging.

**Control Groups**
The lack of a third control group not engaged in any type of training limits the ability to determine the contribution of non-specific intervention effects such as social engagement and increased mental stimulation to observed outcomes. While it can be concluded with some certainty that the ERP changes observed in the MT group but not the CT group are unlikely to have arisen due to non-specific intervention effects, those effects common to both groups however cannot be so excluded. Reductions in N2 amplitudes during the auditory oddball task for instance were shared between the groups, as were performance improvements on the task. While it is possible that reductions in N2 amplitude were the result of a maturation or non-specific intervention effect, such a conclusion is unlikely given the results of existing studies that have used comparison conditions to investigate mindfulness in older adults. Significant changes in N2 amplitudes have previously been reported following mindfulness training, together with no change in N2 amplitude in an active control brain training group (Malinowski et al., 2017). These results suggest that changes to N2 amplitudes are unlikely to result from non-specific intervention effects, since this study used a mental arithmetic program as a comparison condition and found no ERP changes in this group. The lack of an ERP effect in this comparison condition indicates that the mental arithmetic training did not impact the efficiency of neural networks of attention. This may have been due to the fact that mental arithmetic targets higher cognitive functions rather than foundational attentional components such as sustained attention, as was done in the CT group here. The inclusion of a third control group not engaged in any intervention whatsoever would enable a more definitive determination of the origins of the shared N2 effect in the present thesis.

**Practice Effects**
While improvements on the behavioural measures of attention are concluded to result from the intervention training, the contribution of practice effects to performance gains cannot be entirely ruled out. Frequent task repetition has been shown to lead to reaction
time reductions and reduced error rates on behavioural tests of attention when retest times are short (Bartels, Wegrzyn, Wiedl, Ackermann, & Ehrenreich, 2010; Feinstein, Brown, & Ron, 1994). However, reaction time coefficient of variability (RT CV) during tasks of sustained attention has been shown to be virtually unaffected by practice effects, demonstrating stability over multiple assessments (Flehmig, Steinborn, Langner, Scholz, & Westhoff, 2007). Therefore, while it is plausible that reductions in error rates may have resulted from repeated task exposure, it is unlikely that the significant reductions in RT CV observed in each group resulted from practice effects. While high frequency practice effects on ERP component amplitude and latency have previously been examined, there is little evidence of long-term infrequent task effects on ERP components. Short-term repeated task performance has been associated with increases in N2 amplitudes during a visual go/no-go task (Schapkin, Falkenstein, Marks, & Griefahn, 2007), and increases in P3 amplitude during an auditory discrimination task (Shelley et al., 1991). Thus while there is evidence of increased ERP component amplitude following repeated task exposure, such evidence does not support the conclusion that the reductions in ERP amplitudes reported here may have resulted from practice effects.

Test Measures
Additional test measures could have been used to more accurately assess executive attention changes resulting from the interventions, and provide further insight into the pathways outlined in the model of mindfulness. Tasks of sustained attention were utilised in this thesis in order to assess foundational attentional changes resulting from mindfulness practice, as these changes are proposed to provide a basis upon which later developmental progress is based. Therefore, precedence was given to measures of sustained attention. The inclusion of additional cognitive measures such as an emotional Stroop task would have provided insight into the types of inhibitory control developed in each program and their effectiveness in regulating emotion, thereby allowing for a determination of cognitive and affective inhibitory outcomes.

Likewise, more comprehensive affective measures capable of detecting changes in symptoms of stress, anxiety, and depression, such as the DASS 21 (Lovibond & Lovibond, 1995) may have enabled a closer analysis of the effect of mindfulness on mood and affect. The PANAS was selected to accord with previous studies examining
affective outcomes of mindfulness, thereby allowing cross-study comparisons to be made. However, the PANAS is a general affective measure providing no specificity regarding different types of affective symptoms. The use of only the PANAS in the present thesis limits our understanding of the type of affective changes induced by mindfulness, and whether there are differing outcomes regarding symptoms of depression, anxiety, or other disorders.

**Measures of Cognitive Reserve**

The concept of cognitive reserve itself is a hypothetical construct lacking definitive measure (Ward, Summers, Saunders, & Vickers, 2014). Given this nature, it is not possible to quantify either neural reserve, or the neural efficiency and capacity upon which it is based. These constructs are rather inferred from ERP measures related to cortical activation in response to task demands, and thus represent indirect measures. In this way, while reductions in ERP latency and amplitude accompanying improved task performance suggest enhanced neural efficiency, they do not directly assess this construct.

**Follow-up Assessments**

The studies presented in this thesis aimed to determine if mindfulness was capable of enhancing cognitive reserve. Enhanced cognitive reserve is thought to provide protective benefits to neurodegenerative disease and reduce risk of clinical cognitive impairment and dementia in late life (Valenzuela & Sachdev, 2005). While the evidence presented in this thesis supports the hypothesis that mindfulness training is capable to enhancing cognitive reserve through improved neural reserve, the true benefit of these effects is unknown in the absence of post-intervention follow-up testing to determine their long-term stability. Thus, the findings of the present thesis are limited in the absence of follow up testing to demonstrate a protective benefit from these changes, and as such must remain provisional.
6.4 Future Directions

The studies presented in this thesis provide the foundation for the development of future research to investigate mindfulness through empirical RCTs. Through the presentation of a theoretical model of mindfulness it is hoped that a large body of scientific research may be stimulated to examine and test the pathways and predictions proposed by the model. Studies 2, 3, and 4 of this thesis represent the first attempts to assess the model’s predictions. Much more research is required to examine each of the mechanisms suggested by the model. As such, opportunities for future research to extend the work presented here lie in the following areas:

1. While the attentional benefits of mindfulness practice have been relatively well-examined (Sedlmeier et al., 2012), such investigation represents an analysis of only the foundational level of cognitive processes theorised to be activated during mindfulness training. The theoretical model provided here permits the formulation of testable hypotheses regarding higher cognitive outcomes, affective change, as well as the pathways through which these arise. Accordingly, future research is required to examine the metacognitive benefits of mindfulness, the development of insight, and the modes of affective change induced by this practice.

2. Investigations into these processes will be assisted by the use of brain imaging technologies to identify patterns of network activation inaccessible through EEG measures. While EEG provides high temporal resolution regarding the activation of cortical pyramidal neurons, it provides less information regarding structural network activation. The combined use of both EEG and MRI technologies will provide detailed information regarding the neurobiological changes resulting from mindfulness practice by providing high temporal and spatial resolution of neural processes.

3. The use of no-intervention control groups in addition to well-designed active control groups will permit greater clarity of conclusions regarding observed outcomes. It remains critically important in longitudinal RCTs to be able to
accurately identify the contributions of both specific intervention factors along with non-specific intervention factors in order to formulate clear causative inferences. Future studies including multiple comparison conditions can facilitate this process by accurately controlling for confounding influences.

4. The presentation of a standardised mindfulness technique allows for a replicable mindfulness intervention to be used across studies, enabling accurate cross-study comparisons. One area of interest will be the replication of previous studies which used therapeutic MBIs as mindfulness interventions to report beneficial attentional and affective outcomes from mindfulness practice. Using the standardised mindfulness technique to reproduce these findings will confirm that they did indeed arise due to mindfulness and not some combination of ancillary factors included in the MBI. Furthermore, the standardised technique allows the quantification of any therapeutic benefit from the addition of secondary components to mindfulness in MBIs, such as CBT in MCBT. Future research is required to determine the therapeutic contributions of each element of existing psychological MBIs to treat mental disorder. Only by clearly understanding the efficacy of each component in a therapeutic MBI can such interventions be optimally applied.

5. Long-term follow-up testing is required to determine the stability of the changes reported here. The ability of mindfulness to provide protective benefits to older adults against age-related cognitive decline will only be accurately assessed through long-term longitudinal studies over several years. Although practically challenging, longitudinal studies conducted over many years are required to observe the trajectory of changes in cognition following mindfulness training compared to controls. While evidence from cross-sectional studies of long-term practitioners compared to matched controls suggests the existence of protective benefits to brain health from mindfulness in aging (Laneri et al., 2016; Luders et al., 2015), studies with long follow-up periods conducted over many years will have the greatest ability to examine these benefits.

6. While the focus of much of the mindfulness research to date has been on psychological outcomes, evidence is now beginning to point to a range of
somatic benefits arising from mindfulness training (Nijjar et al., 2014; Tomfohr et al., 2014; Wielgosz et al., 2016). Future research is required to examine the mechanism through which mental training in mindfulness induces physiological changes such as improved immune response, lower blood pressure, and reductions in inflammatory markers of disease. It may well be the case that reductions in distressing psychological states and increases in positive affective states underlie these benefits, but this process of change must be thoroughly investigated.
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Appendix A

You probably know that going to the gym to exercise is good for your body. Exercise keeps us fit and healthy. Did you know that you can also exercise your mind to keep it fit and healthy? Mindfulness training is just like taking your brain to the gym for a workout. When we practice mindfulness, we are training our attention to stay in the present moment instead of wandering off with our thoughts into the past or the future. By keeping our attention in the present, and bringing it back each time it wanders, we are training the brain networks that we use to control our attention. This type of training can improve our mental health, just like physical exercise improves our physical health.

**DOES MINDFULNESS MEAN MY MIND IS FULL?**

Have you ever been so deep in thought that you did not hear someone calling your name? At times like these, our minds are full of thoughts
and we are not aware of what is going on around us. Often, we are busy thinking about what is going to happen later, thinking about what happened earlier, or thinking about what is happening now. It can certainly seem like our minds are full of thoughts! But that is not what mindfulness means. Mindfulness means being aware of what is happening now, without getting lost in all of those thoughts. Mindfulness helps us become more aware of what is going on both outside and inside of ourselves, without being distracted by our thoughts. With mindfulness, we can be fully aware of our minds (see Figure 1).

**EXERCISE FOR THE MIND**

Just as we need to exercise our bodies to stay physically healthy, exercising our minds can keep us mentally healthy, too. Mindfulness involves training our attention to stay in the present moment, rather than following our thoughts into the past or future. The same way we do certain exercises to strengthen our body’s muscles, with mindfulness we train the brain’s muscle—attention.

Attention is the brain’s way of selecting one thing to focus on out of the wide range of things in the environment. The brain is constantly receiving information about the world around us from our five senses, as well as interpreting that information using lots of thoughts. There is so much going on in the environment, but we often need to select one thing to focus on, without getting distracted. Attention’s job is to keep that one thing in mind, so we can focus on it. Attention is one of the most important brain functions. When attention does not work well we have lots of difficulties, such as attention deficit hyperactivity disorder (ADHD). In ADHD, people have trouble keeping their minds on one task, which makes it hard to concentrate when trying to solve a math problem at school, for example.

**Figure 1**

When we bring full awareness to what is happening in the mind, we have mindfulness.
When you focus on something, you are using networks made up of brain cells called neurons. When you do physical exercise to strengthen a muscle, you train that muscle by repeating the exercise again and again. In mindfulness, you can target these brain networks by making your attention stay on one thing without getting distracted. And when you do get distracted, you bring your attention back again and again. It is like a gym workout for your brain! Scientists have discovered that this kind of exercise can benefit mental health [1].

**MINDFULNESS**

Let us try a mindfulness exercise right now.

Start by sitting down either on the floor or on a chair with your back nice and straight. As you sit, just relax. Be aware of your body as you sit still. While you are sitting still, notice the rising and falling of your belly as you breathe in and out. Do not try to make your breath deeper or longer, but just let it be. Just feel it. Can you feel the sensations of movement as your belly goes up and down with the breath? Try not to think about these movements. Just pay attention to the sensations of the rising and falling of the belly as you breathe in and out. Without following thoughts as they arise, just stay with the feeling of the rising and falling.

It would not be long before you start thinking of something other than your breath. Your attention will want to follow a thought, since watching the breath can be pretty boring! We usually like to pay attention to things that are exciting. But, by stopping your attention from following thoughts and just returning it to the rising and falling of your breath, you are training several attentional networks in your brain.

- When you focus on the breath, you use a brain network for focused attention.
- When you notice a wandering thought, you use a brain network for detecting distraction.
- When you stop that wandering thought, you use a brain network to prevent your attention from following that thought.
- When you return your attention back to the breath, you use a brain network for redirecting attention.

When we practice mindfulness, we are always getting distracted from the breath, so we have to activate all of these networks over and over again (see Figure 2). This is why mindfulness can seem like hard work. Because it is! We are really giving the brain a workout when we try to keep our attention on the breath.
An important part of mindfulness is paying attention without reacting to what is going on. It is easy to get frustrated by your wandering mind. While you are trying to follow the rising and falling of the breath, just pay attention without reacting to what you are experiencing. Do not worry about whether it is easy or difficult. If you react to what is happening, you are just thinking even more thoughts! Just let your attention rest on the breath. And when it wanders, bring it back each time.

Can you do it for 1 min? Have a try!

**WHAT HAPPENS TO A WANDERING MIND?**

Scientists have discovered that the more our thoughts wander the greater chance we have of being unhappy [2]. When we keep thinking about something bad that happened in the past, we could become depressed. If we keep worrying about something bad that might happen in the future, we could become anxious. Being depressed and anxious occur when our thoughts take us away from what is happening right now, into the past or the future.

**Neuroscientists** (scientists who study the brain and the way it works) have found that depression and anxiety are associated with changes in the brain. Scientists can measure the activity of neurons in the brain using a device called an **electroencephalograph**, or EEG. An EEG measures brain activity by recording the electrical signals produced by the neurons (see Figure 3).

These electrical signals are measured using electrodes placed on the scalp. If electrical activity is measured on both sides of the brain, neuroscientists can see if the activity is the same on both sides. If there is asymmetry (lack of equality) between the two sides of the brain, neuroscientists can see if there is relatively more right-sided or left-sided brain activity.
Studies have shown that greater left-sided brain activity is associated with positive feelings and behavior, while greater right-sided brain activity is associated with more negative feelings and behavior [3]. People with depression and anxiety have been shown to have higher levels of right-sided brain activity than people without these conditions [4].

**PAYING ATTENTION TO THE PRESENT IS GOOD FOR US**

By now, you might be wondering why you have to pay attention to the breath when you are practicing mindfulness. The breath has one very special feature. It only occurs now, in the present moment. If you are paying attention to your breath, you must be paying attention to what is happening right now. When your thoughts wander, you lose the present moment. But you can always come back to the present by remembering the breath.

Scientific studies are beginning to show that mindfulness practice may result in increased left-sided brain activity [5]. This increase in left-sided activity may also be accompanied by more positive feelings and well-being. This is really good news, because it means that we can change our brains just by training the way we pay attention. By training our attention to stay in the present moment, we can keep our minds from running off into the past and the future and worrying about all of those things. And this may change our brains in ways that help us feel better.

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CONFLICT OF INTEREST STATEMENT: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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YOUNG REVIEWERS

MATTHEW FLINDERS ANGLICAN COLLEGE, AGES: 14-15
Matthew Flinders Anglican College young reviewers are keen budding scientists who enjoy taking on challenges. They are a collaborative bunch of young minds, with shared interests in science, music, and sport. This group of young reviewers thoroughly enjoys being part of Frontiers for Young Minds and is excited to be involved in how science is being communicated and shaped.
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Appendix B

Cognitive mechanisms of mindfulness: A test of current models

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Abstract

Existing models of mindfulness describe the self-regulation of attention as primary, leading to enhanced decentering and ability to access and override automatic cognitive processes. This study compared 23 experienced and 21 non-meditators on tests of mindfulness, attention, decentering, and ability to override automatic cognitive processes to test the cognitive mechanisms proposed to underlie mindfulness practice. Experienced meditators had significantly higher mindfulness and decentering than non-meditators. No significant difference between groups was found on measures of attention or ability to override automatic processes. These findings support the prediction that mindfulness leads to enhanced decentering, but do not support the cognitive mechanisms proposed to underlie such enhancement. Since mindfulness practice primarily involves internally directed attention, it may be the case that cognitive tests requiring externally directed attention and timed responses do not accurately assess mindfulness-induced cognitive changes. Implications for the models of mindfulness and future research are discussed.

1. Introduction

The last ten years has seen a surge of interest in the use of mindfulness-based techniques in the treatment of psychological conditions, producing a growing body of empirical evidence for the efficacy of such an approach (Fraser, 2013; Sedlmeier et al., 2012). In spite of this, evidence for the cognitive mechanisms theorised to underlie mindfulness practice is mixed. Contemporary psychological models describe the intentional self-regulation of attention towards present experience as constituting the core of mindfulness practice, with ancillary attitudinal factors variously added (Bishop et al., 2004; Holas & Jankowski, 2013; Kang, Gruber, & Gray, 2012; Shapiro, Carlson, Astin, & Freedman, 2006). Current models describe mindfulness-induced decentering as the primary mechanism for positive therapeutic change, as previously automatic cognitive processes become increasingly consciously attended to. A review of existing models of mindfulness highlights the primacy of attention in mindfulness practice.

1.1. Models of mindfulness

Bishop et al. (2004) propose a two-component model of mindfulness, in which self-regulation of attention towards present experience and adopting an orientation of curiosity, openness and acceptance towards one’s experiences are the main factors. The cultivation of attention towards cognition and its contents in a moment-by-moment, non-elaborative manner is the core component, resulting in enhanced metacognitive monitoring and control of cognitive processes. This process leads to a
changed relationship with the contents of experience, known as decentering, characterised by the capacity to adopt a detached perspective towards one’s thoughts and emotions. Decentering is a result of mindfulness practice, and is described as an important mechanism for positive self-change in cognitive therapy (Safran & Segal, 1990; Teasdale, Segal, & Williams, 1995).

Shapiro et al. (2006) propose a three-component model of mindfulness including the cognitive elements of intention, attention and attitude. Attention is directed towards present-moment experience, leading to a shift in perspective called reperceiving, or decentering. Mindfulness-induced decentering allows for the de-automatisation of cognitive processes that have become automated, by reinvigorating attention towards these processes, allowing cognitive and emotional responses to become more flexible (Deikman, 1983; Sedlmeier et al., 2012).

Kang et al. (2012) outline a four-component model of mindfulness where attention is primary. In this model, attention is cultivated with awareness, present-moment focus, and non-judgemental acceptance of thoughts, experiences and events. The training of attention leads to de-automatisation through reduced automatic inference processing, enhanced cognitive control, and facilitation of metacognitive insight, and decentering (Kang et al., 2012).

Holas and Jankowski (2013) propose a two-component model in which attentional processes are described as fundamental to initiating and maintaining mindfulness. The training of these processes enhances metacognition, leading to decentering. Decentering mediates beneficial psychological outcomes by providing a changed perception of the nature and content of internal experience (Holas & Jankowski, 2013).

The four models of mindfulness reviewed all propose that attention is the core feature of mindfulness practice, and differ only in the formulation of secondary components. Attention must be the core component of mindfulness practice since it is the training of attention that leads to enhanced decentering in these models. The intentional regulation of attention to present-moment experience facilitates metacognitive monitoring of this experience, leading to enhanced decentering, which is a detached perspective upon the contents of this experience (Holas & Jankowski, 2013; Shapiro et al., 2006).

Each of the models describe three subcomponents of attention to be enhanced by mindfulness practice: sustained attention, attention switching, and conflict monitoring and resolution. These subcomponents accord with the elements of attention proposed by Posner and Petersen (1990), who suggest the existence of three functionally distinct neural networks each performing specific operations: alerting, orienting, and executive functions. The alerting network functions to provide a vigilant and alert state of preparedness, resulting in sustained attention. The orienting network regulates attention by prioritising sensorial input to a specific location or modality, resulting in attention switching and selection. Executive attention exercises control over competing thoughts, feelings and responses, providing conflict monitoring and resolution.

While executive attention was further elaborated upon by Miyake et al. (2000), since only the model of Holas and Jankowski (2013) describes these components, it is treated singularly in this study. Importantly, each of the models reviewed predict measurable improvements on cognitive tests of sustained attention, attention switching, and executive attention with increased development of mindfulness.

### 1.2. Mindfulness and the attention network test

The Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) is a combined flanker and cued reaction time task specifically designed to measure the performance of each of the neural networks of attention proposed by Posner and Petersen (1990). This computerised test involves the presentation of a row of five arrows, with participants asked to indicate the direction of the central arrow by means of a key press. Arrows flanking the central arrow may point in congruent or incongruent directions, thereby introducing conflict. Cues in the form of asterisks are sometimes presented prior to the target, indicating where and when the stimulus will appear. No-cue trials offer no spatial or temporal warning of the coming target stimulus. Executive attention is measured by comparing timed responses to the congruent and incongruent arrow conditions. Alerting and orienting attention are assessed through comparing timed responses on trials comprising temporal and spatial visual cues with times on trials with no cue. Lower scores indicate improved attentional performance.

In examining the effects of mindfulness on attention Jha, Krompinger, and Baime (2007) found no significant increases in ANT performance from pre- to post-testing in either experienced meditators who undertook a one-month meditation retreat, or meditation-naïve participants who engaged in an 8-week mindfulness-based stress reduction (MBSR) program. Enhanced ANT executive performance was found at pretesting in experienced meditators compared to non-meditators. Both Ainsworth, Eddershaw, Meron, Baldwin, and Garner (2013) and Tang et al. (2007) used very brief mindfulness-based training to demonstrate improved ANT executive attention from pre- to post-intervention in meditation-naïve participants. No significant improvement in ANT alerting or orienting attention was found in either study. Van den Hurk, Giommi, Gielen, Speckens, and Barendregt (2009) found improved orienting attention, but not alerting or executive attention, in mindfulness practitioners with long-term experience (mean 14.5 years) compared to matched controls. These studies provide mixed evidence to support the models’ predictions of improvement in all three components of attention with mindfulness training.

### 1.3. Mindfulness, decentering, and automatic cognitive processes

Kang et al. (2012, p. 193) define automaticity as an “ability to effortlessly engage in behaviours without paying conscious attention to their operational details.” Such processes are described as being difficult to suppress, and are resistant towards attempts to control them (Norman & Shallice, 1986; Shiffrin & Schneider, 1977, 1984). Automaticity conserves limited attentional resources by freeing conscious attention from tasks in which they are no longer needed, thereby reducing the
self-regulatory burden (Bargh & Chartrand, 1999). The mindfulness models propose that by reinvesting conscious attention towards these cognitive processes through mindfulness practice, enhanced decentering results, together with awareness of cognitive processes that have become automated and an ability to alter them. Evidence that automatic processes are not beyond attentive influence is by provided by Moore and Malinowski (2009), who demonstrated improved Stroop task (Stroop, 1935) performance on a paper version of the test in a cross-sectional comparison of mindfulness mediators with matched controls.

The Stroop task has been widely used to investigate the degree to which automatic processes can be controlled (Lykins, Baer, & Gottlob, 2012; Saling & Phillips, 2007). This task is a measure of participant’s ability to inhibit the automatic response to read a colour word such as ‘blue’ while being asked to name the colour of its letters, which may be incongruent to its semantic meaning. Performance is impaired by the automatic response, which either slows down correct responding or produces an erroneous response, known as Stroop interference. Moore and Malinowski (2009) found that meditators completed more items and made fewer errors compared to controls, and this enhanced performance was significantly correlated with participants’ mindfulness scores. Chan and Woollacott (2007) also used a paper-card version of the Stroop task to demonstrate reduced Stroop interference in experienced meditators compared to non-meditators. Wenk-Sormaz (2005) utilised a computerised single-stimulus version of the test to demonstrate reduced Stroop interference in meditation-naive participants who undertook three 20-min meditation sessions compared to participants who merely rested during the same period. However, neither Chan and Woollacott or Wenk-Sormaz measured mindfulness to assess its link with Stroop performance.

None of the above studies quantified decentering, which can be measured by the decentering subscale of the Experiences Questionnaire (EQ; Fresco et al., 2007). In the absence of measures of both mindfulness and decentering, it is uncertain if any enhanced Stroop performance is linked to mindfulness-induced cognitive flexibility or some other factor. Therefore, in order to determine the cognitive mechanisms underlying mindfulness-induced improvements in Stroop performance, decentering should be measured.

Josefsson, Lindwall, and Broberg (2014) used the Five-Facet Mindfulness Questionnaire (FFMQ; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006), EQ decentering subscale, and Stroop task to compare the effects of a 4-week mindfulness intervention to a relaxation group and a waitlist group. No significant group differences were found in EQ decentering scores or Stroop test performance. FFMQ scores were higher in the mindfulness group compared to the waitlist group, but not the relaxation group. Josefsson et al. report that the non-react sub-scale of the FFMQ was highly correlated with EQ decentering across all groups, suggesting that they are measuring similar phenomena. Therefore, the FFMQ is unable to measure mindfulness separately from decentering. The use of a single factor measure of mindfulness such as the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), which assesses only the present-centered awareness component of mindfulness, would better differentiate mindfulness from decentering as measured by the EQ decentering subscale.

1.4. The current study

The current study first sought to replicate training-related increases in mindfulness, ANT performance, decentering, and Stroop performance previously reported in the literature. Secondly, it sought to clarify the cognitive mechanisms of mindfulness by including both self-report and objective measures in a comparison of experienced mindfulness practitioners with mindfulness-naive participants.

The MAAS was used to measure mindfulness by self-report, while the EQ decentering subscale was used to measure decentering by self-report. The ANT and Stroop task were employed as objective measures. Improved ANT performance in experienced practitioners would provide evidence of mindfulness-induced enhancements of attentional components predicted by the models, as well as support any self-reported increase in mindfulness, ruling out a response shift due to being familiar with the language of mindfulness (Chiesa, 2012). Likewise, since decentering is a higher order metacognitive function, a participant’s perceived ability to separate themselves from their thoughts may not reflect their actual ability to do so (Feldman, Greeson, & Senville, 2010). Thus, the Stroop task was used as an objective measure of participants’ ability to inhibit automatic cognitive processes resulting from enhanced decentering (Lykins et al., 2012).

We are not aware of any study to date that has used both self-report and cognitive measures to investigate the relationship between mindfulness and decentering by comparing experienced mindfulness practitioners with mindfulness-naive participants. The current study compared both mindfulness-naive and experienced participants in order to assess if mindfulness training can significantly increase both mindfulness and decentering above trait levels through the cognitive mechanisms proposed by the models of mindfulness under review.

Based on the models of Bishop et al. (2004), Shapiro et al. (2006), Kang et al. (2012) and Holas and Jankowski (2013), it was hypothesised that the experienced group would have higher MAAS scores than the non-mediator group as a result of mindfulness practice, and higher EQ decentering subscale scores as a result of mindfulness-induced decentering. It was also hypothesised that the experienced group would show better performance than the non-mediator group on the ANT due to mindfulness-related enhancements of the subsystems of attention, and reduced Stroop interference due to greater ability to override automated cognitive processes resulting from enhanced decentering. Furthermore, it was hypothesised that within the experienced group, MAAS scores would be positively correlated with EQ decentering scores, and negatively correlated with ANT scores and Stroop interference as enhanced attentional performance and ability to override automatic cognitive processes improve test performance. It was also predicted that within the experienced group, EQ decentering scores would be negatively correlated with Stroop interference, due to enhanced ability to control automatic processes.
2. Method

2.1. Participants

Twenty-nine experienced mindfulness meditators and 27 non-meditators were recruited using a university promotional website, fliers distributed at local meditation centres, and email to known experienced meditators. Participants in the non-meditator group were required to have no previous meditation, yoga, Tai-chi, or other mindfulness-based therapy or meditation-like experience. Expressed interest in mindfulness practice was a selection criterion for the non-meditator group to exclude between-group differences in disposition. Participants who identified their main practice as mindfulness, Vipassana, insight, or mindfulness-based and were engaged in a minimum of two sessions per week of at least 20 min in length for the last six months were admitted to the experienced group. Participants with a current yoga practice were excluded from both groups.

After application of the exclusion criteria, 23 experienced mindfulness meditators (age \( M = 44.5 \) years, \( SD = 13.9 \) years, range 22–64 years; 10 male) and 21 non-meditators (age \( M = 40.8 \) years, \( SD = 11.3 \) years, range 22–64 years; 10 male) were admitted into the study. Participation was voluntary and no compensation for involvement was given. The mean level of mindfulness meditation experience in the experienced group was 10 years (\( SD = 8.6 \) years), while the level of regular mindfulness practice ranged from one to 21 h each week (\( M = 8.1 \) h/week).

2.2. Design

The study utilised a cross-sectional between-groups design (Experienced vs. Non-mediator). Dependent variables analysed were MAAS score; ANT total error score, alerting score, orienting score, and executive attention score; EQ decentering score; and Stroop total error score, congruent RT, incongruent RT, and interference. Two-tailed independent groups \( t \) tests were used to compare between-group differences, while bivariate correlational analysis was used to determine the relationship between measures.

2.3. Apparatus and procedure

Participants provided consent and demographic information before the commencement of testing. Participants' educational level was recorded to analyse any influence of education on the dependent measures. Previous meditation experience was recorded by self-report of specific technique (months/years of practice), together with current level of continuous regular practice (months or years), frequency (days/week), and length of session (minutes). Participants completed the MAAS, followed by the ANT, the EQ decentering subscale, and the Stroop task. Cyclic counterbalancing of task order was utilised to control for order effects, and all testing was conducted in the University of the Sunshine Coast psychology laboratory. Participants were instructed not to meditate before or during the testing session. The MAAS and EQ decentering subscale were delivered in paper format. The ANT and Stroop task were conducted on a Pentium i7 Lenovo T530 ThinkPad laptop computer with 15-in. display, running E-prime (version 2.0.10.242) software for Windows. Participants were seated 65 cm from the screen and permitted to use eyeglasses if required.

2.3.1. Mindful attention awareness scale

Mindfulness was measured using the MAAS (Brown & Ryan, 2003), a 15-item instrument designed to measure a single-factor construct of trait mindfulness. Participants responded on a 6-point Likert scale from 1 (almost always) to 6 (almost never) to items assessing present-moment attention such as “I find it difficult to stay focused on what’s happening in the present.” Brown and Ryan (2003) demonstrated good internal consistency for the scale, with alpha values of .82 and .87 in validation studies performed on two samples. The mean for the 15 items was calculated to achieve a participant’s MAAS score, with higher scores representing higher dispositional mindfulness.

2.3.2. Attention network test

Attentional processes were measured using the ANT. Participants were instructed to indicate as rapidly as possible the direction of the central arrow in a row of five arrows, by pressing either a left or right arrow key on a computer keyboard. Flanker arrows pointing in either congruent or incongruent directions to the central arrow introduced distraction, and were used to assess executive attention. Alerting and orienting attention were assessed through the use of temporal and spatial visual cues, indicating when and where the target would occur.

Four cue conditions preceded the target: no cue, centre cue, double cue, and spatial cues. Centre cues, double cues, and spatial cues appeared 500 ms prior to target onset, thereby temporally alerting the participant to target onset. In centre cue trials, a single asterisk appeared at the fixation point, while in double cue trials, asterisks appeared simultaneously both above and below the fixation point. Centre and double cues provided no orienting information indicating where the target would appear. For spatial cue trials, a single asterisk was presented either \( 1^\circ \) of visual angle above or below the fixation point and was 100% predictive of target location, thereby orienting participant’s attention to the location of the target. On no-cue trials, the fixation point remained throughout the cue period, and thus no temporal alerting or spatial orienting information was given.
Each trial began with the presentation of a central fixation point on a light grey background for a variable interval (VI) of between 400 and 1600 ms, followed by the presentation of one of four cue conditions for 100 ms. The fixation point was presented again for 400 ms after cue offset, followed by presentation of the target stimulus for a maximum period of 1700 ms. The target was equally likely to appear above or below the fixation point, and contained arrows 0.55° of visual angle away from each other. Reaction time (RT) from target presentation to participant response was recorded. The target was immediately withdrawn at participant response, followed by the fixation point for the next trial for a variable period, calculated to maintain a trial constant period of 4000 ms (3500 ms – RT – VI previous angle in length, 0.06° of visual angle away from each other. Reaction time (RT) from target presentation to participant response was recorded. The target was immediately withdrawn at participant response, followed by the fixation point for the next trial for a variable period, calculated to maintain a trial constant period of 4000 ms (3500 ms – RT – VI previous trial).

All participants began with a 24-trial full feedback practice block to familiarise themselves with the test, followed by three experimental blocks, each consisting of 96 trials (4 cue conditions × 2 target locations × 2 target directions × 3 flanker conditions × 2 repetitions) presented in a random order. Participant responses less than 100 ms or greater than four standard deviations above or below the mean within a specific condition were excluded from analysis, and only RTs from correct trials were used to calculate scores. Alerting attention scores were calculated by subtracting participant’s mean RT on double cue trials from their mean RT on no cue trials. Orienting scores were calculated by subtracting mean RT on spatial cue trials from mean RT on centre cue trials. Executive attention score was calculated by subtracting mean RT of all congruent trials from mean RT on incongruent trials. A total error score was calculated as the percentage of total trials participants responded incorrectly to in the experimental block. Lower scores on these measures indicate improved performance of the subcomponents of attention.

2.3.3. Experiences questionnaire

Decentering was measured using the decentering subscale of the EQ. The 11-item decentering subscale has shown good internal consistency (α = .83) for the factor of decentering (Fresco et al., 2007). Participants responded on a 5-point Likert scale from 1 (never) to 5 (all the time) to items assessing the ability to adopt a decentred perspective upon one’s cognitions, such as “I can separate myself from my thoughts and feelings.” Participant’s EQ decentering score was calculated as the sum of their responses to the 11 items, with higher scores representing higher decentration.

2.3.4. Stroop task

Participant’s ability to override automatic cognitive processes was measured using the Stroop task (Stroop, 1935). Colour words (red, green, blue, yellow) were presented on a computer screen in either congruent or incongruent colour conditions, with participants instructed to identify the colour of the letters of the word as quickly as possible by pressing a coloured keyboard button.

Each trial began with the presentation of a fixation point (+) in the centre of a grey background for 500 ms, followed by the stimulus word presented for a maximum period of 2000 ms during which participants were required to respond. On response, the stimulus word was withdrawn, and an inter-trial pause of 1000 ms consisting of a blank grey background was presented. After this pause the next trial began. Reaction time from stimulus presentation to response was recorded for each trial. Responses greater than 2000 ms were excluded.

A practice block of 10 full feedback trials was followed by two experimental blocks, each consisting of 72 trials (12 congruent and 12 incongruent with three repetitions) presented in random for a total of 144 experimental trials. Responses less than 100 ms or greater than four standard deviations above or below the mean within a specific condition were excluded from analysis. RT was calculated for each condition as the average RT for correct responses, providing congruent RT and incongruent RT scores. Stroop interference was calculated by subtracting the average RT on incongruent trials from the average RT on congruent trials. Stroop total error score was calculated as the percentage of incorrect responses made across the entire experimental block.

3. Results

Descriptive statistics for all measures as a function of group are presented in Table 1. To control the Type 1 error rate for multiple comparisons, a Bonferroni correction was applied, and alpha retained at .005 for all ten comparisons (Keppel & Wickens, 2004). All statistical analyses were performed using IBM SPSS version 20 software and R software package.

An independent groups t test revealed no significant differences between the experienced and non-mediator groups in age, t(42) = 0.97, p = .339, η² = .02, observed power = .16. Chi squared analyses revealed no significant differences between groups in gender, χ²(1, N = 44) = 0.00, p = .989, Φ = .002; or educational level, χ²(2, N = 44) = 1.11, p = .574, Φ = .16. Table 2 presents the educational level for participants in each group.

3.1. Between groups comparisons

3.1.1. Mindful attention awareness scale

MAAS scores reported by participants in each group were similar to those reported by Orzech, Shapiro, Brown, and McKay (2009). An independent groups t test confirmed that experienced meditators reported significantly higher MAAS scores than non-meditators, t(42) = 4.04, p < .001, η² = .28, observed power = .98.
3.1.2. Attention network test

Scores on all ANT measures were similar between groups, as shown in Table 1. Participant reaction times across all conditions were comparable to those previously reported by Fan et al. (2002) and Fan et al. (2009). Levine’s test for homogeneity of variance was non-significant for all ANT tests. Independent groups t tests confirmed there were no significant differences between groups in the total number of errors made, \( t(42) = 0.63, p = .529, \eta^2 = .01 \), observed power = .10; alerting attention, \( t(42) = 0.83, p = .410, \eta^2 = .02 \), observed power = .13; orienting attention, \( t(42) = -0.10, p = .923, \eta^2 < .001 \), observed power = .05; or executive attention, \( t(42) = -0.07, p = .942, \eta^2 < .001 \), observed power = .05.

3.1.3. Experiences questionnaire

Participant EQ decentering scores were similar to those previously reported by Carmody, Baer, Lykins, and Olendzki (2009). An independent groups t test confirmed that experienced meditators reported significantly higher EQ decentering scores than non-meditators, \( t(42) = 3.70, p = .001, \eta^2 = .25 \), observed power = .95.

3.1.4. Stroop test

Table 1 shows that experienced meditators had similar RT and error scores to non-meditators, but higher Stroop interference than non-meditators. Experienced participants showed higher variability in Stroop interference scores than non-meditators, resulting in significant inequality of variance between the two groups, Levene’s \( F(1,42) = 7.38, p = .010 \). The breach of homogeneity of variance between groups in Stroop interference was addressed by using an independent groups t test where equal variances was not assumed. This test confirmed that there was no significant difference between groups in Stroop interference, \( t(35.15) = -2.46, p = .019 \) (Bonferroni adjusted alpha of .005), \( \eta^2 = .12 \), observed power = .65. Independent t tests with equal variances assumed confirmed that there were no significant differences between groups in total errors, \( t(42) = 0.45, p = .656, \eta^2 = .005 \), observed power = .07; congruent RT, \( t(42) = 1.22, p = .227, \eta^2 = .03 \), observed power = .22; or incongruent RT, \( t(42) = 0.15, p = .880, \eta^2 = .001 \), observed power = .05.

3.2. Correlational analysis

Bivariate correlations of MAAS and EQ scores with test variables for the experienced group are shown in Table 3. The positive correlation of MAAS scores with ANT orienting scores contradicts the predicted negative correlation. EQ decentering scores in this group were significantly positively correlated with Stroop incongruent RT and Stroop interference, contrary to the predicted negative correlation.
4. Discussion

The primary purpose of this study was to examine the cognitive mechanisms of mindfulness proposed by Bishop et al. (2004), Shapiro et al. (2006), Kang et al. (2012) and Holas and Jankowski (2013). These models predict that the training of attentional subsystems in mindfulness practitioners leads to enhanced decentering.

4.1. Mindfulness and decentering

In line with this study’s first hypothesis, experienced mindfulness practitioners reported significantly higher MAAS scores and EQ decentering scores than non-meditators. This finding is consistent with previous studies indicating that mindfulness can be increased through intentional training. It also supports the predictions of the models that mindfulness practice leads to enhanced decentering in experienced practitioners.

4.2. Attention network test

The four models reviewed predict improved performance on all ANT measures as a result of mindfulness practice. No significant differences were found between experienced meditators’ and non-meditators’ attentional performance as measured by the ANT. These findings add to those of previous studies that have failed to find the predicted increases in alerting, orienting and executive attention.

It may be that the model’s prediction of increased alerting, orienting, and executive attention with mindfulness practice is too simplistic. In the early stages of mindfulness practice, mind-wandering is prevalent and executive attention is predominant as one seeks to detect distraction. In advanced stages however, familiarity with the object of attention is gained and distraction subsides, with less recruitment of executive attention (Chiesa, Calati, & Serretti, 2011). Both Ainsworth et al. (2013) and Tang et al. (2007) used very brief mindfulness interventions to provide support for such a practice-related trajectory of effects. The failure to replicate these results in the current study may have resulted from the use of practitioners with an average experience of 10 years.

Moreover, the absence of enhanced alerting, orienting, and executive attention in experienced mindfulness meditators may have resulted from the fact that the ANT is a timed reaction task. Tests where performance is measured by speed of response may not capture the improvements in attention that result from a practice characterised by states of deep relaxation, which involve a withdrawal of attention from external stimuli, an absence of time pressure, and a stilling of physical movement (Lykins et al., 2012; Wallace, 2006). Mindfulness practice is primarily directed towards internal objects of awareness, and these form the basis for the cultivation of attention (Bishop et al., 2004; Josefsson & Broberg, 2011). In this way, practitioners induce a metacognitive awareness observing the contents of internal thoughts and experiences, which is another internally focussed awareness (Teasdale et al., 1995). Thus, while mindfulness may lead to increased attentional performance towards internal processes of cognition, this does not guarantee that such increases will be observed in tasks where one is required to respond rapidly to an external stimuli with a physical response such as a key press.

4.3. Stroop test

It was hypothesised that experienced meditators would display less Stroop interference than non-meditators due to an enhanced ability to override automatic cognitive processes resulting from mindfulness-induced decentering. No significant difference in Stroop interference between groups was found.

While previous studies have reported some improved Stroop performance in experienced meditators, there is little consistency in the nature of that improvement across test formats and measures. The decentering proposed to result from
mindfulness practice is described as leading to insight into the nature of one’s relationship with the contents of experience. It is not certain that this changed perspective should lead to an ability to rapidly override automatic cognitive processes. Rather, what is of greater emphasis is that the practitioner becomes aware of and gains insight into such processes, rather than actively altering or manipulating them (Wallace, 2006). Thus, the lack of consistent evidence for a mindfulness-induced ability to override automatic cognitive processes may be due to the fact that the role of decentering in these models has been miscast.

4.4. Correlational analysis

MAAS scores were positively correlated with EQ decentering scores, supporting the models’ predictions of increased decentering with increasing mindfulness practice. The predicted negative correlation of MAAS scores with ANT scores and Stroop interference was not found.

Contrary to the predicted outcome, the positive correlation of the MAAS with ANT orienting scores indicates declining performance in orienting attention as MAAS scores increase. This finding aligns with the earlier assertion that attention becomes increasingly internally withdrawn with mindfulness practice, thereby negatively impacting participants’ ability to rapidly respond to external stimuli. This result supports the suggestion that there is a fundamental contradiction between the measures of the ANT and Stroop task and the type of attention cultivated in mindfulness practice.

It was predicted that EQ decentering scores would be negatively correlated with Stroop interference in the experienced group. This prediction was contradicted. Stroop interference was positively correlated with EQ decentering scores, indicating declining Stroop performance with increasing decentering. This is an unexpected and novel finding that has not been reported in previous studies. The mechanism behind these results requires further investigation through replication with differing test delivery formats.

4.5. Limitations and future directions

The current study employed a between-groups cross-sectional design, and thus does not permit inferences of causality regarding whether the differences in mindfulness and decentering were truly the result of mindfulness practice rather than pre-existing between-groups differences. In order to provide further evidence for this claim, longitudinal studies of mindfulness practice with random assignment employing active and neutral control groups are required.

A second limitation of the current study was the diversity of mindfulness-based practices reported in the experienced group, ranging from traditional Buddhist Vipassana practice to newly developed mindfulness-based techniques. The lack of significant difference between groups on the ANT and Stroop tests may have resulted from a differential activation of the subsystems of attention by differing mindfulness-based practices. Further studies using either experienced meditators with a homogenous mindfulness practice background, or incorporating various mindfulness practices as an independent variable are required to accurately determine the extent to which differing styles of mindfulness practice result in changes of attention and decentering.

A third limitation of the current study was the high level of education of participants, with 98% having completed at least Year 12 education, and 86% having completed tertiary education, resulting in possible ceiling effects on both the ANT and Stroop tests as evidenced by the very low error rates displayed on both measures. This also limits the generalisability of the findings to other populations. Since the ANT and Stroop tests both require fluid intelligence, and this type of intelligence is highly correlated with education, performance on these measures may have been influenced more by education than mindfulness (Lykins et al., 2012; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006).

Lastly, the significant findings reported here relate to self-report questionnaires, which have inherent limitations. It is possible that the difference between groups on these measures was the result of factors other than mindfulness and decentering, such as a difference in understanding of the terms and concepts used in the questionnaires, the value placed upon these concepts, and participants’ ability to accurately assess their own level of mindfulness and decentering (Grossman, 2008, 2011). It cannot be ruled out that responses differed between groups due to such a response shift rather than as a result of mindfulness practice.

5. Conclusion

This study sought to illuminate the cognitive mechanisms of mindfulness by testing the attentional components and metacognitive benefits that Bishop et al. (2004), Shapiro et al. (2006), Kang et al. (2012) and Holas and Jankowski (2013) propose as central to mindfulness practice. While this study did demonstrate increased levels of mindfulness and decentering in experienced meditators compared to non-meditators, the predicted increases in alerting, orienting, and executive attention, as well as an improved ability to override automatic cognitive processes, were not found.

The absence of evidence in this study for the cognitive mechanisms of mindfulness adds to the existing body of research that has provided mixed findings for such proposed mechanisms. The failure to find consistent evidence for these cognitive mechanisms may be due to the use of incompatible test methodologies in examining mindfulness-induced changes, or the fact that the current models of mindfulness reviewed here have not accurately described the cognitive mechanisms.
underlying the practice of internally self-regulating attention to present moment awareness. It is now time to re-examine the models of mindfulness and the cognitive mechanisms they propose in light of previous efforts to confirm them.

Conflicts of Interest

The authors declare no conflicts of interest.

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