FACILITATING HEALTHY AGEING: NEUROPROTECTIVE EFFECTS OF MINDFULNESS PRACTICE

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Abstract

Mindfulness-based meditation practices involve various attentional skills including the ability to sustain and focus ones attention. During a simple mindfulness based breath awareness meditation, sustained attention is required to maintain focus on the breath while meta-cognitive awareness and executive control is required to detect and correct mind wandering. The purpose of this thesis was to investigate whether a simple, mindfulness based breath awareness meditation, administered over a short period to meditation naïve individuals could modulate core attentional functions and associated task related neural activity. Two longitudinal randomised control studies were conducted. The aim of the first study was to establish if said modulations were possible in a sample of healthy adults, meeting a current research need for longitudinal evidence in this field and providing important information regarding a potential mechanism for the salutary effects widely observed from the use of mindfulness based interventions. It was found that short term engagement with a mindfulness based breath awareness meditation can modulate core attentional functions and task related neural activity, with specific modulations found in electrophysiological markers of sustained attention to the goal/task at hand and perceptual stimulus discrimination. In line with current theoretical models it is argued that modulations to such core attentional processes following short term training may provide a platform upon which mindfulness related salutary effects are built. The second study was designed to establish if such modulations were possible in older adults. It is argued that mindfulness training may have utility for increasing cognitive reserve, a potential mechanism by which age related declines in cognitive functions may be mitigated. It was found that both behavioural and electrophysiological markers of core attentional functions were modulated following 8 weeks mindfulness training but not following a matched active control group condition (simple brain training exercises). The reviewed extant evidence and findings of this study suggest that mindfulness meditation may enhance cognitive reserve through the repeated activation of attentional functions and associated neural activity during practice and are consistent with recent theoretical models of cognitive reserve. The potential for mindfulness training to positively modulate core attentional functions in older adults and to potentially impact cognitive ageing demands further investigation.

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List of Abbreviations

Abbreviations listed in alphabetical order.

ABTask - Attentional Blink Task
ACC - Anterior Cingulate Cortex
ACTIVE - Advanced Cognitive Training for Independent and Vital Elderly
AD - Alzheimers Disease
ADHD - Attention Deficit Hyperactivity Disorder
ANT - Attention Network Test
BT - Brain Training
BTG - Brain Training Group
cStroop - Counting Stroop
CR - Cognitive Reserve
CRN - Correct Related Negativity
df - Degrees of Freedom
DLPFC - Dorsal Lateral Prefrontal Cortex
DMPFC - Dorsal Medial Prefrontal Cortex
ECStroop - Emotional Counting Stroop
EEG - Electroencephalography
ERN - Error Related Negativity
ERP - Event Related Potential
FA - Focussed Attention
FASTER - Fully Automated Statistical Thresholding for EEG artifact Rejection
FFMQ - Five Factor Mindfulness Questionnaire
FFMQ-A - FFMQ acting with awareness subscale
FFMQ-D - FFMQ describe subscale
FFMQ-NJ - FFMQ non-judging subscale
FFMQ-NR - FFMQ non-reactivity subscale
FFMQ-O - FFMQ observe subscale
FFMQ-Total - FFMQ total score
fMRI - Functional Magnetic Resonance Imaging
GSE - Generalized Self-Efficacy Scale
HR - Hit Rate
IBMT - Integrative Body-Mind Training
IC - Independent Component
ICA - Independent Components Analysis
IF - Inter-sensory Facilitation
IMPACT - Improvement in Memory with Plasticity-based Adaptive Cognitive Training
IPL - Inferior Parietal Lobe
LJMU - Liverpool John Moores University
LN - Late Negative ERP component
LS1 - Longitudinal Study 1

LS2 - Longitudinal Study 2
MBI - Mindfulness Based Intervention
MBCT - Mindfulness Based Cognitive Therapy
MBSR - Mindfulness Based Stress Reduction
MCI - Mild Cognitive Impairments
MPFC - Medial Prefrontal Cortex
MRI - Magnetic Resonance Imaging
MT - Mindfulness Training
MTG - Mindfulness Training Group
NMBSR - Non-Mindfulness Based Stress Reduction
n/a - Not Applicable
n/s - Not Stated
OM - Open Monitoring
PCC - Posterior Cingulate Cortex
PFC - Prefrontal Cortex
PL - Parietal Lobe
PO - Parietal-Occipital
RSVP - Rapid Serial Visual Presentation
RT - Reaction Time
SART - Sustained Attention to Response Task
SHS - Subjective Happiness Scale
SPAN - Spatial and Temporal Attention Network task
SSTM - Spatial Short Term Memory task
Tar1 - 1st target in the Attentional Blink Task
Tar2 - 2nd target in the Attentional Blink Task
T1 - Time 1, the same follows for T2, T3
VARETA - Variable Resolution Electromagnetic Tomography
WCG - Waitlist Control Group
WEMWBS - Warwick-Edinburgh Mental Well-Being Scale
WM - Working Memory

Chapter 1. Overview of Thesis

This Chapter provides a brief overview of each Chapter of this thesis. This thesis consists of 2 randomised longitudinal studies. The first longitudinal study was conducted to establish whether a singular, brief mindfulness training exercise would lead to modulations of attentional functions and task related neural activity, meeting a current research need for longitudinal evidence in this field and providing important information regarding a potential mechanism for the salutary effects widely observed from the use of mindfulness based interventions. The second study was designed to establish if such modulations were possible in older adults, providing information regarding the use of mindfulness training to strengthen cognitive reserve and positively influence attentional functions in old age.

Chapters 2-8 are concerned with longitudinal study 1. Chapter 2 introduces the concept of mindfulness and discusses its link to attentional functions. Chapter 3 reviews the extant literature concerning mindfulness and attentional functions. First, studies that examined the use of attentional functions and associated neural networks during mindfulness meditation are introduced, establishing that said functions and networks are engaged during meditation. Second, cross sectional studies which compare expert meditators to controls are discussed, with the available evidence suggesting that long term mindfulness meditation may modulate said functions and networks. A review of the longitudinal evidence follows, including a review of studies which assessed modulations following brief mindfulness inductions, mindfulness based interventions and retreats. It is established that although the available evidence suggests that mindfulness training may modulate attentional functions, direct links between specific mindfulness training techniques and such modulations are problematic as extant studies typically included multiple meditations and a number of potentially active ingredients. Chapter 4 introduces the electrophysiological techniques that were used to generate dependent variables throughout this thesis. Chapter 5 provides an overview of the design and methods of the first longitudinal study whilst Chapters 6 and 7 present the theoretical background, associated hypotheses and outcome measures and the detailed analysis and results obtained from the use of the Stroop task and Attention Network Test respectively. Chapter 8 reviews the findings of longitudinal study 1, which establish that short term engagement in a simple mindfulness based breath awareness meditation can modulate electrophysiological and behavioural markers of core attentional processes.

Chapters 9-14 are concerned with the second longitudinal study. Chapter 9 presents the theoretical background to the study of mindfulness training and attentional modulations in older adults. Age related declines in executive and sustained attention are identified and discussed. Further, older adults typically exhibit enhanced task related neural activity which may reflect compensatory mechanisms that attempt to utilise adaptive plasticity to improve or maintain performance despite age-related neurodegenerative modulations. It is established that methods for increasing cognitive reserve, a potential mechanism by which the ageing brain produces said compensatory activity, are much needed and that mindfulness training may be an ideal mental activity to increase cognitive reserve due to the repeated use of attentional functions and associated neural activity during practice. Chapter 10 provides an overview of the design and methods of the second longitudinal study whilst Chapters 11, 12 and 14 present the theoretical background, associated hypotheses and outcome measures and the detailed analysis and results obtained from the use of the Continuous Performance Task, the Emotional Counting Stroop task and the Attentional Blink task respectively. Chapter 14 reviews the findings of longitudinal study 2, which establish that short term engagement in a simple mindful breathing meditation can modulate electrophysiological and behavioural markers of core attentional processes in older adults.

The final Chapter is a general discussion which brings together the results of both longitudinal studies. Chapter 15 evaluates the implications of the findings of this thesis with respect to the observed salutary effects of mindfulness based interventions and the potential for mindfulness training to positively influence cognitive ageing.

Chapter 2. Mindfulness

2.1 What is Mindfulness?

The word ‘mindfulness’ has become common place in western psychology during the past decade. However, a recent review (Chiesa & Malinowski, 2011) found marked differences as to how mindfulness is understood and practiced. Mindfulness has been referred to as a psychological construct, as a mental state and as the practices designed to achieve said state. This lack of consistency makes it difficult to understand whether one is referring to the process of developing mindfulness skills or to the state of mindfully attending to one’s own experiences.

Historical descriptions suggest that mindfulness is best understood as a ‘state’ that is different from usual ‘wakefulness.’ Whilst ‘wakefulness’ characteristically involves several biases, defences, or ruminative thinking (Brown, Ryan, & Creswell, 2007), mindfulness does not. The word mindfulness itself is translated from the Pāli word ‘sati’ which is frequently described as a state of ‘presence of mind.’ Whilst in this ‘state’ both internal and external phenomena are seen as transient, allowing the individual to view arising thoughts and emotions as mental events rather than true representations of reality. Consequently, mindfulness is said to provide an awareness of what is occurring, before or beyond conceptual and emotional classifications about what is or has taken place. Unfortunately, such descriptions are not easily operationalised for use in psychological and neuroscientific studies into mindfulness. As such, the majority of such studies adopt an operational definition put forward by Jon Kabat-Zinn, who proposed that ‘mindfulness’ describes “the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally[1] to the unfolding of experience moment by moment” (Kabat-Zinn, 2003, p.145). Herein, it is this definition that is used to describe ‘mindfulness’.

Other authors use similar rhetoric when describing mindfulness. Grossman et al. (2004) characterized mindfulness as a dispassionate, non-evaluative, and sustained

[1] This non-judging awareness requires the practitioner to take the position of an impartial witness to their own ongoing streams of consciousness, thus it refers to the attitude and orientation that the practitioner applies to their practice. Specifically, it requires the awareness of arising streams of consciousness and the ability to step back from them, and to simply observe them. Non-judgmental awareness requires the practitioner to refrain from habitual patterns of positive and negative categorizations and to allow an experience to be as it is without any attempts to avoid, escape or change it (Baer, Smith & Allen, 2004).

moment to moment awareness of perceptual mental states and processes; including a continuous, immediate awareness of physical sensations, perceptions, affective states, thoughts and imagery. Additionally, Brown et al. (2007) describe mindfulness as a receptive attention to and awareness of present events and experience. Consistent across descriptions is the importance of attention and a ‘receptive/non-evaluative’ attitude. The development of these skills are said to underpin improvements in mindfulness. Importantly, as detailed in the following section, these skills may be learnt and developed through specific training.

2.2 Mindfulness Training

It is generally accepted that a clearly formulated mental training, usually referred to as ‘*meditation’*, is required for developing and improving levels of mindfulness (Chiesa & Malinowski, 2011). Lutz et al. (2008) distinguished two main components of meditation practices, focused attention (FA) and open monitoring (OM), by using traditional meditation texts and modern neuroscientific conceptions. Mindfulness meditations, herein referred to as mindfulness training (MT), involve components of FA and OM. Initially the FA component is required to develop attentional stability, clarity, and awareness of the current mental state. Building upon this attentional stability, which allows the meditator to remain in the ‘present moment’, it is possible to meaningfully engage in OM practice which is characterised by an open, nonjudgmental awareness of the sensory and cognitive fields. OM incorporates a meta-awareness or observation of the entire field of awareness, including the ongoing contents of thoughts. During MT, practitioners are instructed to maintain a curious, open, nonjudgmental attitude to arising fluctuations in the mind, regardless of their content. The practitioner is instructed to simply observe any experienced distractions whilst refraining from judgment, avoidance or elaboration (Bishop et al., 2004; Chiesa & Malinowski, 2011; Malinowski, 2008, 2013; Shapiro et al., 2006). In this respect, MT and OM are in stark contrast to concentrative forms of meditation that emphasize the restriction of attention to one particular stimulus and the immediate dismissal of distracting/arising thoughts, feelings and emotions.

Mindful breathing practices form the backbone of MT. They are the basic components of various traditional Buddhist meditations, ranging from early Buddhist sources like the Anāpānasati Sutta or the Satipatthāna Sutta (Bhikkhu Bodhi, 1995) to classical Tibetan Buddhist instructions (Karmapa Wangchug Dorje, 2009). More recently, they are also employed as part of contemporary mindfulness based interventions (MBIs) such as Mindfulness Based Stress Reduction (MBSR; Kabat-Zinn, 1990) and Mindfulness Based Cognitive Therapy (MBCT; Segal, Williams, & Teasdale, 2002). Mindful breath awareness meditations require the meditator to focus their attention on the sensations accompanying their breathing, either attending to the experience at the nostrils, around the diaphragm or the movement of the abdomen when in-and exhaling, without manipulating the breath in any form. Whenever attention slips or wanders off, the task is to become aware of it and, without further elaboration, to redirect the focus of attention back to the sensation of breathing. This process represents a basic FA component. In addition to this focusing of attention, an OM component is included as meditators are instructed to observe other mental experiences, arising thoughts, feelings or sensations, trying not to judge or evaluate them, and maintain a curious, non-elaborating attitude toward them. With extensive practice, OM practice will become less reliant on FA to a singular focus and can eventually be maintained without focusing on the breath or any other explicit object. However, FA will always be a central part of MT, even for expert meditators as it is FA that allows the practitioner to remain in the present moment.

Mindfulness may be cultivated through the described interplay between FA and OM during breath awareness techniques. However, it is important to note that mindfulness, as described by Jon Kabat-Zinn, is not confined to occurring during MT. Through MT, a ‘trait’ like mindfulness will be developed which enables the practitioner to apply mindfulness in everyday situations. Being ‘mindful’ in daily life, allows the practitioner to engage in ‘mindful behaviours’ and apply mindfulness to ongoing experience. Whereas historical descriptions of mindfulness emphasize qualities of awareness, it’s these ‘mindful behaviours’ and the manifestation of mindfulness in experience that current self report measures of mindfulness describe (Chambers, Gullone, & Allen, 2009; Rapgay & Bystrisky, 2009).

In addition to the cultivation of mindfulness, the development of attentional skills is considered a central part of MT (Hölzel, Carmody, et al., 2011; Lutz et al., 2008; Tang & Posner, 2009; Wallace & Shapiro, 2006). Findings from a wide range of studies have suggested that attentional processes become more efficient through training (e.g. Newman, Keller, & Just, 2007; N. B. Sarter, Mumaw, & Wickens, 2007; Slagter, Giesbrecht, et al., 2007; Vidnyanszky & Sohn, 2005). As MT requires that a variety of attentional skills are utilised in order for attention to remain focussed in the present moment (e.g. to focus on the breath), it may be expected that MT will strengthen and develop attentional skills. Extant research is moving in this direction with MT related improvements in attentional functions repeatedly observed (see Chiesa, Calati, & Serretti, 2011 for review). Accordingly, most modern conceptions position attention as a core component of mindfulness and as a potential mechanism for the observed effects of MT (Bishop et al., 2004; Hölzel, Lazar, et al., 2011; Malinowski, 2013; Shapiro et al., 2006; Wallace & Shapiro, 2006). As will be detailed in Chapter 3, the majority of findings related to attention and MT stem from either cross sectional studies which compared expert meditators to controls or from studies examining the effects of MBIs which typically include a variety of different meditations (examples include: breath-awareness, body scanning, open monitoring, walking meditations and physical exercises such as yoga) and a variety of didactic and group elements in addition to MT. Consequently, it is difficult to attribute the observed attentional improvements to specific MT techniques. This limitation must be overcome in order to better understand the active ingredients of modern MBIs and what is causing the observed improvements in attentional functions.

The following Chapters will highlight that there is a current need for research that longitudinally examines whether a singular MT can influence attentional functions in meditation naïve individuals. A mindful breathing MT is chosen as the examined singular practice herein as it is the basic component of traditional Buddhist meditations, is employed as part of modern MBIs and because it can be undertaken by meditation naïve individuals following minimal instruction. Confirming the relationship between a specific MT and modulation of attentional functions will enable researchers to better understand the role of attentional improvements in the increasingly observed positive effects of MT, providing valuable information to health care practitioners who administer MT as part of MBIs, to those practitioners who are interested in disorders that involve attentional dysfunction (e.g. ADHD and Schizophrenia) and to any individual who may be considering incorporating MT into their daily lives. Establishing this link is the main objective of the first longitudinal study that will be presented in this thesis.

Building upon the results of this first study, the overall objective of this thesis is to assess whether a singular MT may positively modulate attentional functions in older adults. A second longitudinal study was designed and conducted to meet this overall objective, the results of which provide valuable information for researchers and health care practitioners interested in the prevention, management and treatment of age related cognitive declines. The theoretical background to this study will be detailed in Chapter 9. Firstly, the following Chapter reviews the extant literature regarding MT and attention in order to establish the theoretical background upon which the first longitudinal study was conceived.

Chapter 3. Theoretical Background to Longitudinal Study 1: The Effects of Mindfulness Training on Attentional Functions

Research into mindfulness, its associated processes and its potential positive effects has grown increasingly popular during the past two decades. A wide variety of studies have assessed the efficacy of self reported mindfulness as a predictor/mediator and MT as an intervention, with extant studies covering a wide range of conditions and pathologies. A literature search will find a diverse cross section of topics including stress and anxiety (e.g. Kabat-Zinn et al., 1992), chronic pain (e.g. McCracken, Gauntlett-Gilbert, & Vowles, 2007) and substance abuse (e.g. Alterman et al., 2004). A main objective of this thesis, and specifically of longitudinal study 1 (LS1), is to establish whether a singular MT can modulate behavioural and electrophysiological markers of attentional functions. Therefore this literature review focuses on studies that detail the engagement of attentional functions during MT and studies examining the effects of MT on attentional functions.

In order to provide a structure for this review, mindfulness research studies will be grouped loosely as follows: 1) Examinations of the meditative state; studies of this nature examine the attentional skills and brain regions involved *during* meditation. 2) Cross sectional studies that compare expert meditators to novices; such studies attempt to examine the long term effects of MT. 3) Longitudinal studies which examine the effects of participation in MT; this group of studies includes research that seeks to examine the effects of both short and long term MT on predefined dependent variables.

Firstly, a recently published model of mindfulness is introduced in order to position the current thesis in relation to other ongoing streams of mindfulness research.

3.1 The Liverpool Mindfulness Model

The Liverpool Mindfulness Model (Malinowski, 2013; Figure 1) captures and integrates the core components involved in MT and provides a framework for how MT may produce positive effects. Consistent with the previous research and traditional descriptions discussed in Chapter 2, the Liverpool Mindfulness Model gives the development of attentional skills a central role in the overall process. The model structures the process into five main tiers: the driving *motivational factors* (tier 1) determine whether and how an individual engages in MT (tier 2). Regular engagement in MT develops and refines the mental *core processes* (tier 3), primarily based on the refinement of attentional functions that interact with and facilitate regulatory processes of emotions and cognitions. Improvements in these core processes result in a changed and more balanced *mental stance* or attitude (tier 4), that will result in a positive *outcome* (tier 5) in terms of physical and mental well-being, and the quality of behaviour.

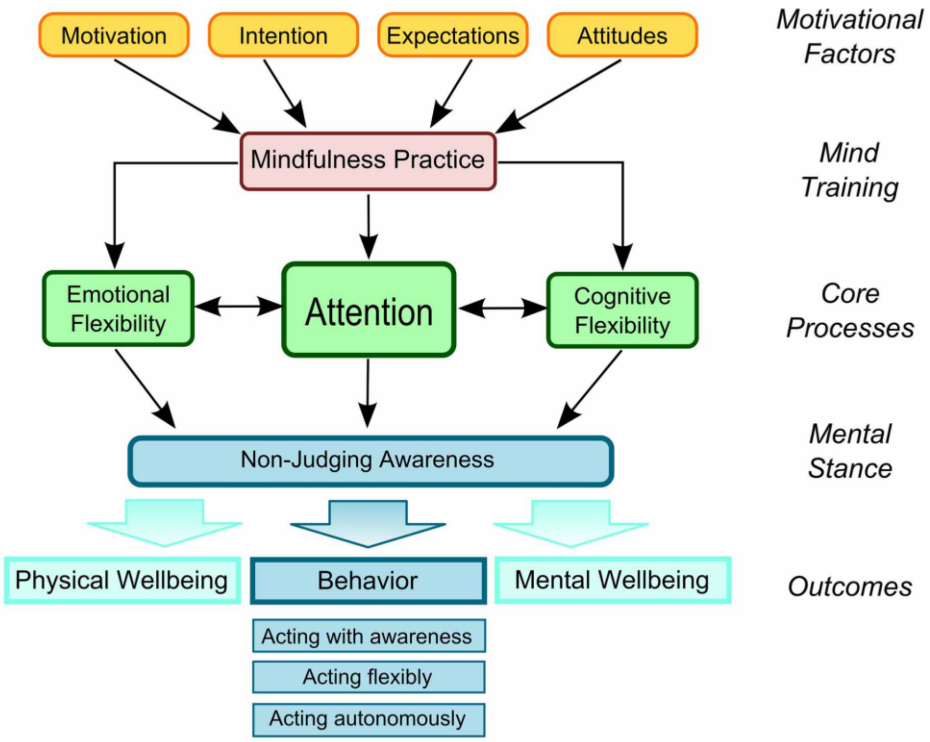

Figure 1: The Liverpool Mindfulness Model (Malinowski, 2013)

With reference to the presented model this thesis is concerned with providing information regarding how MT may influence the core process of attention. Such information will help to establish the role of attention modulation as a mechanism for MT related positive outcomes at tiers 4 and 5 and whether MT may have utility as a strategy for improving attentional functions in older adults. Thus, improvements to attentional processes themselves would be considered a positive outcome of the experiments detailed in this thesis, irrespective of changes to mental stances and other outcomes. Other ongoing streams of mindfulness research are concerned with how tiers 4 and 5 are influenced by MT and attempt to seek out the mechanism/mediators of action. Therefore, in keeping with the presented model, Chapter 15 will discuss how the empirical results detailed in this thesis may relate to the changes in tiers 4 & 5 that have been found to result from MT.

3.2 Mindfulness Training and Attentional Functions

In cognitive neuroscience, ‘attention’ is commonly referred to in terms of three main functions that are subserved by three different though often overlapping networks (Corbetta & Shulman, 2002; Fan et al., 2005; Posner & Petersen, 1990; Posner & Rothbart, 2007; Raz & Buhle, 2006): (1) The modulation of arousal, alertness, and attentional engagement. These functions are carried out by the *alerting* network which is thought to consist of the right frontal and right parietal cortex and the thalamus. (2) The function of stimulus selection which involves an *orienting* network consisting of the superior parietal cortex, temporal parietal junction, frontal eye fields, and superior colliculus. (3) Attentional/Executive control processes that rely upon an *executive* network consisting of the anterior cingulate cortex (ACC), lateral ventral cortex, prefrontal cortex (PFC), and basal ganglia. Two further networks are relevant to the discussion of attentional networks and MT. Firstly, the *salience* network, a subdivision of the executive network that is thought to comprise of the dorsal ACC, the ventrolateral PFC, and the neighbouring anterior insula. This network provides an attentional monitoring function and has been implicated in the immediate, present moment processing/detection of goal relevant/salient events across modalities (cognitive, homeostatic and/or emotional) and the subsequent signalling of the executive network to act in line with ongoing/current goals (Dosenbach et al., 2007; Dosenbach et al., 2006; Seeley et al., 2007; Sridharan, Levitin, & Menon, 2008). The *default mode* network, which has been shown to become active when individuals involuntarily engage in task-unrelated cognitions or mind wandering (Buckner, 2004; Mason et al., 2007; Schooler et al., 2011), is the final network relevant to this discussion. Functional neuro-imaging suggest that this network entails the posterior cingulate cortex (PCC), the medial prefrontal cortex (MPFC), the posterior lateral parietal/temporal cortices, and the parahippocampal gyrus (Buckner, 2004; Hasenkamp et al., 2012; Mason et al., 2007).

Malinowski (2013) produced a schematic representation (Figure 2) depicting how the phenomenological experience of a meditator may be linked to the aforementioned attentional processes and associated networks. Using a simple mindful breathing based MT as an example, the meditation process may be outlined as follows. At the phenomenological level the meditator will engage with the training by focusing on the somatosensory sensation that accompanies the breath. This phase of focussed attention relies upon the alerting network. Once focus on the breath is lost, the default mode network will become more active. As is the task of the meditator, sooner or later the meditator will recognise this mind wandering by means of the attention monitoring function of the salience network. During MT the meditator observes this task irrelevant fluctuation of the mind without judgment or evaluation whilst maintaining a curious open attitude. The meditator is now tasked with letting go by means of attentional disengagement and the involvement of the executive network. Shifting the focus of attention back to the breath is accomplished by a combination of the executive and orienting networks. An increase in periods of sustained attention to the breath would be indicative of improved attentional stability. Such improvements are expected as the individuals level of expertise increases (Wallace & Shapiro, 2006), whereas beginners often allow the mind to wander unnoticed for long periods.

Figure 2: A schematic representation of the meditation process (Malinowski, 2013). The inner circle outlines the phenomenological layer, presenting the typical sequence (clockwise) a meditator will go through. The middle circle represents the attentional processes that lie underneath, while the outer circle states the different brain networks that are involved in carrying out these functions. The different attentional processes and the brain networks are represented as partially overlapping to indicate that in many instances more than one process/network is involved.

As Malinowski notes, these attentional functions and networks may overlap during MT. This assertion appears valid when viewed with respect to a commonly used model of executive attention. Miyake and colleagues (2000) model of executive attention proposed that executive functioning may be broken down into three key constructs: 1) mental set *shifting*, 2) information updating and *monitoring*, and 3) the *inhibition* of pre-potent responses. Successfully sustaining attention to the breath during breath awareness MT requires effective use of each of these key constructs. Firstly, the breath is selected as the mental set which is the selected focus of attention. Secondly, the meditator must *monitor* for slips of attention, *shifting* attention back to the breath once such slips are noticed. Finally, the meditator must not elaborate or get caught up in arising thoughts, feelings and sensations, thus they are *inhibiting* the typical response of engaging with whatever arises. The salience network is believed to play a key role in this kind of attentional monitoring and thus is likely to be engaged throughout even a simple breath awareness MT. The executive network is also likely to play a crucial role during MT as it is involved in the inhibition of pre-potent and/or habitual responses. The executive network will also play an important role in enabling the practitioner to disengage from distractions during MT. The repeated activation of these functions during MT suggests that the executive and salience networks are key candidates for improvement with extended MT.

At this juncture it is important to clarify how the term sustained attention will be used within this thesis. Often the terms ‘selective attention’, ‘concentrative attention’ and ‘focussed attention’ are used interchangeably with ‘sustained attention’, however, said terms are best used to describe a singular focus of attention (e.g. the breath). Typically, sustaining attention, i.e. sustaining the focus of attention over extended periods of time, will require a multitude of attentional skills and networks. Using the mindful breathing exercise as an example, wherein the task is to sustain attention to the breath, all five of the discussed networks would be utilised at some stage, and often concurrently, in order for an individual to engage in the task for extended periods. Therefore, within this thesis, sustained attention will be used to describe the ‘task of sustaining attention,’ i.e. sustaining attention to current/ongoing goals. If ‘sustaining attention’ required a multitude of attentional skills and networks they will be detailed as fully as possible. A link between this definition of sustained attention and mindfulness can be seen in Robertson and Garavan (2004) conception that failures of sustained attention occur when there is a transient decrease in *mindful*, endogenous control of behaviour, leaving one prone to goal neglect and distraction by irrelevant stimuli.

Consistent with Malinowski's schematic of the meditation process, a growing body of research has evidenced the use of attentional skills and networks during MT and meditation in general. Brefczynski-Lewis et al. (2007) obtained functional magnetic resonance imaging (fMRI) recordings whilst participants engaged in a form of concentrative meditation (a fixation dot presented on a screen in front of the participant was used as the object of meditation). They found that both expert Tibetan buddhist[2] meditators and novice meditators (1hour per day practice for 7 days prior to the recordings) were able to activate multiple attention-related brain regions during meditation, specifically regions related to the alerting, executive and salience networks (including frontal parietal regions, lateral occipital, insula, multiple thalamic nuclei, basal ganglia, and cerebellar regions). Interestingly, expert meditators displayed more sustained activation in attention networks and were able to reach maximum activation quicker than novice meditators. Hölzel et al. (2007) recorded fMRI during breath awareness meditation and an arithmetic control task, finding greater activation during meditation in a number of regions implicated in attentional processing such as the left precuneus, left PCC, and bilaterally in the MPFC and ACC. It is important to note that this contrast between MT and arithmetic included both expert Vipassana meditators[3] and matched non-meditators thus it is feasible to suggest that the PCC and MPFC activation, which may be linked to the default mode network, may be related to mind wandering in the non-meditators as experts self reported greater levels of sustained attention to the breath and less boredom during meditation than the non-meditators.

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[2] In Tibetan Buddhism, mainly based on the Abhidhamma and its commentaries, mindfulness is classified and defined as one of the ascertaining mental factors that are responsible for all mental activities (Rabten, 1992). Mindfulness is referred to as a 'state' that is both used as an antidote to deal with forgetfulness encountered during the practice of single-pointed concentration practice (Londro, 1992), and as a practice of introspective awareness as a part of a larger body of practices known as the 37 altruistic practices (Berzin, 2002).

[3] Vipassana meditation: In this common style of meditation, one starts by focusing or stabilizing concentration on an object such as the breath. Then one broadens one's focus, cultivating a non-reactive form of sensory awareness or bare attention. This form of attention is non-reactive in the sense that, ideally, one does not become caught up in judgments and affective responses about sensory or mental stimuli.

A number of other studies, focussed solely on expert meditators, have provided further evidence for the activation of attentional networks during meditation. Baron Short et al. (2007) examined expert meditators whose practice routinely involved breath awareness techniques. During meditation, as compared to a control condition which involved identifying the colour of geometric shapes, said experts had sustained activity in regions associated with the executive and salience networks, specifically in the dorsal lateral prefrontal cortex (DLPFC) and the ACC. This finding suggests that brain regions associated with attentional monitoring are engaged during meditation as the ACC has previously been said to support the process of monitoring current behaviour in relation to a desired goal, before feeding the outcome of this comparison to the DLPFC for action (Kerns et al., 2004). Support for this assertion can be found in the results of a further study. Hasenkamp et al. (2012) obtained fMRI recordings during breath awareness meditation from expert meditators in order to assess the activation of the salience, executive and default mode networks during meditation. Participants were instructed to press a button when they noticed that their mind had wandered from the breath during meditation. Based on this button press, approximations of activity related to 4 intervals in a cognitive cycle where obtained: 1) periods when attention was focussed on the breath[4], 2) mind wandering, 3) awareness of mind wandering and 4) shifting of attention (back to the breath). It was found that brain regions associated with the default mode network (PCC, MPFC, posterior parietal/temporal cortex and parahippocampal gyrus) were activated during mind wandering, the salience network (bilateral anterior insula and dorsal ACC) was activated during awareness of mind wandering and the executive network (ventral and DLPFC, and lateral inferior parietal cortex) was active during shifting and focussed attention. Further, Farb, Segal, and Anderson (2013) recorded fMRI during tasks of interoceptive (breath monitoring) and exteroceptive (cognitive suppression and working memory maintenance[5]) attention. Contrasting interoceptive and exteroceptive activation patterns, they found that graduates of a MBSR program, as compared to wait list controls, had reduced activity in the dorsomedial prefrontal cortex (DMPFC) during interoceptive attention. Whilst the

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[4] Hasenkamp et al. define this period as sustained attention, however, this period is referred to as focussed attention herein, consistent with the predefined description of sustained attention in Chapter 2.

[5] For the cognitive suppression task, participants were asked to read foveally presented words while inhibiting any cognitive or emotional response, keeping their minds blank while attending to the word stimulus. For the working memory maintenance task, participants were asked to press a key whenever a word was repeated in a visually presented sequence (a ‘1-back’ task).

authors primary objective was to examine the role of interoceptive attention as a mediator for positive change following MBSR, the finding of lower DMPFC activity during breath awareness for MBSR graduates suggests greater levels of sustained attention to the breath, as compared to controls, as the DMPFC has been implicated in the default mode network which becomes active during mind wandering (Hasenkamp & Barsalou, 2012; Schooler et al., 2011; Smallwood et al., 2012).

A final subset of studies used electrophysiological recordings to gain insights into the meditative state. Cahn and collaborators have reported 3 findings utilising the same group of expert Vipassana meditators. Cahn and Polich (2009) found reduced automated reactivity and evaluative processing of task irrelevant attention-demanding stimuli during meditation, as compared to a control condition which involved generating neutral thoughts. In light of Hasenkamp et al. findings, the finding of reduced automated reactivity and reduced evaluation of non-goal related stimuli is most likely resultant from consistent salience and executive network activation during meditation. Further, Cahn, Delorme, and Polich (2010) utilised time frequency analysis and found increased sensory awareness during Vipassana meditation, as compared with a control condition (mind-wandering), evidenced by increased oscillation over parieto-occiptal brain areas in the gamma frequency range (35–45 Hz). Lastly, Cahn, Delorme, and Polich (2013) used a three-stimulus auditory oddball to probe meditation versus mind wandering, finding 1) decreased evoked delta (2–4 Hz) power to distracter stimuli concomitantly with a greater event-related reduction of late (500–900 ms) alpha-1 (8–10 Hz) activity, 2) standard stimuli were associated with increased early event-related alpha phase synchrony (inter-trial coherence) and evoked theta (4–8 Hz) phase synchrony, and 3) during meditation there was a greater differential early-evoked gamma power to the different stimulus classes. The observed pattern of results lead the authors to propose that, relative to mind wandering, meditation evokes a brain state of enhanced perceptual clarity and decreased automated reactivity. In a similar study Berkovich-Ohana, Glicksohn, and Goldstein (2012) found that, relative to a resting state, short, intermediate and long term mindfulness meditators demonstrate higher posterior gamma power during meditation, indicative of enhanced attention and sensory awareness.

The abovementioned studies suggest that various attentional networks are activated during meditation. Importantly, both expert meditators and novice meditators

(Brefczynski-Lewis et al., 2007; Hölzel et al., 2007) activate similar networks during MT. Despite differences in strength and consistency of activation, this suggests that attentional networks are utilised during MT. As the activation of these networks likely reflects the engagement of attentional functions during MT, these findings are consistent with both traditional and modern conceptions of mindfulness which consider attention a central component of MT (Bishop et al., 2004; Hölzel, Lazar, et al., 2011; Lutz et al., 2008; Malinowski, 2013; Shapiro et al., 2006; Tang & Posner, 2009; Wallace & Shapiro, 2006). It must be acknowledged that a general weakness of the evidence pool in this research area is that the utilised expert meditator samples lack consistency across studies, especially regarding their meditative traditions and length of experience (see Table 1). Nonetheless, all of the studies detailed herein utilised expert meditators who are likely to have had extensive practice in breath awareness meditation, thus the discussed findings demonstrate that attentional functions are utilised during MT.

Table 1: Summary of Meditative State Studies. Previous experience and ongoing practice are mean values. Experience and ongoing practice values are group means unless stated otherwise.

Study	Meditative Tradition	Previous Experience	Ongoing Practice	Comparison Group
Brefczynski-Lewis et al., 2007	Tibetan Buddhist meditation	10,000-54,000 hrs	n/s	Novice meditators who meditated for 1hour per day for 7 days prior to examination.
Hőlzel et al., 2007	Vipassana	7.9 yrs	n/s	Age, gender and education matched non-meditators
Baron-Short et al., 2007	Varied. Included Tibetan Buddist, Zen and open monitoring yoga	4 yrs	30 mins per day	n/a
Hasenkamp et al., 2012	Shamatha, Tibetan and Vipassana. All incorporate breath-focus meditations	1386 hrs	n/s	n/a
Farb et al., 2013	MBSR graduates	8 wks	n/a	Waitlist controls matched for age and gender.
Cahn & Polich 2008; Cahn, Delorme & Polich, 2010; Cahn, Delorme & Polich, 2013	Vipassana	20 yrs	n/s	n/a
Berkhovich-Ohana et al. 2011	States only that participants were mindfulness practitioners	*Short Term:* 894hrs *Intermediate:* 2570hrs *Long Term:* 7556hrs	n/s	n/a

3.3 Cross Sectional Studies: The Effects of Long Term Mindfulness and/or Open Monitoring Based Training

Recent research has been building towards a consensus view that MT is beneficial for attentional functions (Chiesa et al., 2011; Lutz et al., 2009). The following sections contain an overview of the current knowledge base concerning the positive effects of MT on attentional functions. The review will establish the theoretical background upon which the experiments detailed in this thesis were conceived. Precedence is given to studies assessing executive and sustained attention skills as the studies discussed in section 3.2 implicate the salience and executive networks as playing a key role and that a state of enhanced sensory awareness and reduced automated reactivity is present during meditation.

This section will detail the findings from cross sectional studies which compared expert meditators to matched controls. Whilst this cross sectional approach inherently involves a number of limitations (discussed in section 3.5), including issues related to causality, these studies have provided first insights into how attentional skills may differ between meditators and controls, with long term meditation practice the proposed primary source of differences. Herein, the included studies had to include meditators from mindfulness based traditions and/or elements of OM, which is considered an integral part of mindfulness practices. Of note, an overview of the cognitive tasks introduced in this section and over the course of the remaining Chapters of this thesis is contained in Appendix A. However, pertinent task details needed for understanding the ongoing discussion will be presented as necessary. A summary of the meditative traditions and experience of the expert meditator samples for the studies detailed in this section is contained in Table 2 at the end of this section.

Differences between expert meditators and controls have been found in a wide range of attentional skills. In an earlier study conducted by our group (Moore & Malinowski, 2009), experienced meditators were compared to matched controls on 2 measures of attention, the Stroop Task (Stroop, 1935) and the d2-test of attention (Brickenkamp & Zilmer, 1998). The experts significantly outperformed controls on both tasks suggesting that MT may be associated with an enhanced ability to focus/sustain attention and with improved conflict monitoring and inhibition skills, all of which are indicative of enhanced executive attention. Chan and Woollacott (2007) provide further evidence for enhanced executive functions, with expert meditators displaying less Stroop interference than matched controls. Additionally, an exploratory analysis, including just the experts, found that the amount of daily ongoing practice, but not total overall experience was associated with higher levels of performance. Although the experts in this study came from predominantly OM based meditative backgrounds which would typically involve mindfulness meditations (30 of 50 meditators from OM backgrounds), generalising the results to MT is difficult as FA based concentrative meditators were also included. Other studies have drawn closer links between MT and executive measures of attention. Utilising a computerised Stroop task, Teper and Inzlicht (2013) found that experienced mindfulness meditators committed less Stroop errors compared to a control group. In a further study which included a different executive measure, Jha, Krompinger, and Baime (2007) found lower levels of executive and inhibitory control, as measured by the Attention Network Test (ANT, Fan et al., 2002), when comparing experts to controls with no prior meditation experience.

A number of authors have hypothesised that MT and OM based meditations may improve sustained attention since these meditations are built upon a foundation of FA. Valentine and Sweet (1999) found that meditators outperformed controls on a test of focussed sustained attention (Wilkins Counting Test; Wilkins, Shallice, & McCarthy, 1987). An exploratory analysis of just the meditators found that long term (mean experience ≥ 25months) outperformed short term (mean experience ≤ 24months) meditators. In a further analysis, meditators were split into concentrative or mindfulness meditators respectively based on whether they had a singular or open focus[6] during meditation, with mindfulness meditators performing better when the stimulus was presented at an unexpected rate. Whilst these results suggest better sustained attention based on meditation experience and less expectancy effects for mindfulness vs concentrative meditators, they should be interpreted cautiously as the analysis involved small group sizes. van Leeuwen, Muller, and Melloni (2009) provided further evidence for enhanced sustained attention in expert meditators using the attentional blink task (ABtask), which requires participants to sustain focus to a rapidly presented stream of

[6] The distinction between meditators with a singular focus and those with an open focus is analogous to the previously discussed distinction between FA and OM. Meditators with a singular focus use an object (e.g. the breath) to sustain their attention during meditation, thus this is akin to FA meditation. Meditators with an open focus are able to sustain attention to all ongoing experience and are able to maintain present moment awareness without the need for an anchor, thus they are engaging in OM.

visual stimuli in order that 2 temporally close target stimuli may be identified. Expert meditators, who routinely engaged in meditations that included elements of FA and OM, outperformed both age matched and younger controls. In addition to suggesting a difference between meditators and non-meditators, these results also suggest that age related performance decrements may be mitigated by long term meditative practice.

In a recent study Greenberg, Reiner, and Meiran (2012) utilised a water jug paradigm (based on Luchins, 1942) designed to measure the Einstellung effect[7], finding that experienced mindfulness meditators displayed less cognitive rigidity than matched controls. Hodgins and Adair (2010) found that current meditators performed better than non-meditators on measures of concentration derived from a change blindness paradigm (Simons & Chabris, 1999), demonstrated more flexible visual processing by identifying more alternative perspectives in an ambiguous images perspective switching task, and displayed less interference from invalid cues on a Posner cuing task designed to measure selective attention (Posner, 1980). Taken together these findings suggest that meditators have more flexible executive attention, enabling them to adapt cognitive processing strategies to current goals.

A smaller subsection of studies have utilised Electroencephalography (EEG) in an attempt to ascertain the underlying neural mechanisms that may produce these positive effects. The aforementioned study by Teper and Inzlicht (2013) found that expert meditators produced a larger error related negativity (ERN) event related potential (ERP) component than controls. As the ERN had previously been shown to be generated by the ACC (Dehaene, Posner, & Tucker, 1994), the authors reasoned that their results were indicative of greater executive control and attentional monitoring. Using a global-to-local task, van Leeuwen, Singer, and Melloni (2012) found that expert buddhist meditators, with training in FA and OM meditation, displayed higher mean amplitude N1, N2 and P3 ERP components than matched controls. Concurrently, it was found that the experts had a significantly reduced global precedence effect[8]. The authors suggest that taken together, these results represent a greater depth of information

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[7] The Einstellung effect is a term used to describe rigid thought patterns, formed through experience, that prevent the identification of more adaptive approaches and solutions.

[8] The global precedence effect describes quicker detection of targets at a global compared to a local level.

processing and increased speed at which attention can be allocated and reallocated for the experts compared to controls.

A final subgroup of studies have utilised structural brain imaging, typically using magnetic resonance imaging (MRI), in an attempt to determine structural changes in the brain related to long term meditation practice. As the findings of these studies are more pertinent to a discussion regarding MT and the ageing brain, they are reviewed in more detail in Chapter 9. In short, it has been found that mindfulness meditators display greater grey matter density than controls in various attention related brain regions (Hölzel et al., 2008), whilst similar findings have been found from expert samples that included a mixture of mindfulness and other practices (Luders et al., 2009) and from closely linked meditation practices such as Zen (Pagnoni & Cekic, 2007), which normally involve breath focused meditation. Additionally, cortical thickness has been shown to be increased in attention related areas for expert insight meditators (Lazar et al., 2005) whose meditation typically involves training to improve present moment awareness and mindfulness. This pattern of results suggests that the repeated activation of attention networks during meditation may strengthen these networks and the neural substrate which supports them. The implications of these findings are discussed in Chapter 9.

In sum, long term MT and/or OM practice may result in improvements to various attentional skills with long term meditators able to evoke more consistent levels of sustained attention and more flexible executive attention, characterised by a reduction in habitual responding, interference and rigidity. These findings are consistent with the previously reviewed meditative state literature which suggested consistent activation of attentional networks, enhanced sensory awareness and reduced automated reactivity during meditation. They are also commensurate with findings from a wide range of studies that have suggested plasticity in attentional functions, with attentional processes becoming more efficient through training (e.g. Newman et al., 2007; N. B. Sarter et al., 2007; Slagter, Giesbrecht, et al., 2007; Vidnyanszky & Sohn, 2005). However, given that skill learning is usually very task-specific and does not easily generalise beyond the specific tasks, stimuli, or contents (Green & Bavelier, 2008), it is encouraging to see these positive results across a wide range of tasks that were completed outside of the meditative state. This suggests that the attentional improvements developed through long term MT may be utilised to complete other tasks as the employed tasks were very different from what is practiced during MT. The findings of enhanced activation of attentional networks and structural changes in attention related brain areas provide further encouragement. Taking together the reviewed literature concerning the meditative state and the effects of long term meditation, the overall pattern of results is consistent with the assertion that attention is critically involved in MT and OM practices and that it may be enhanced through long term meditative practice, supporting its central position in the Liverpool Mindfulness Model and other modern conceptions of mindfulness.

Table 2: Summary of relevant participant details for studies introduced in section 3.3. Experience and ongoing practice values are group means unless stated otherwise.

Study	Meditative Tradition	Previous Experience	Ongoing Practice	Comparison Group
Moore & Malinowski 2009	Not recorded	Minimum of a 6 weeks beginners MT course	Not recorded	Age and gender matched controls.
Chan & Woolacott, 2007	30 of 50 meditators were from OM backgrounds including Vipassana and Tibetan Buddhist. The remaining meditators were concentrative and included some Vipassana, Transcendental meditation and Sufi meditation	Ranged from 82 to 19,200 hrs	Ranged from 6-150mins per day	Age, gender and education matched controls.
Teper & Inzlicht, 2013	States only that 'participants were from various meditation backgrounds Vipassana, Shambhala, concentrative etc'	3.2 yrs	n/s	Non-meditators. No details given regarding demographics of comparison group.
Jha et al., 2007	Not stated but as participants had signed up to a mindfulness retreat it may be speculated that they were from mindfulness backgrounds	5yrs	n/s	Non-meditators. It was not confirmed if the groups differed with respect to demographic variables.
Valentine & Sweet, 1999	Split into concentrative and mindfulness groups but no details given regarding traditions other than they were recruited from a Buddhist centre.	n/s but meditators were split above and below 24months of experience for an explanatory analysis, thus 24months may be a mean or median value	n/s	Controls. States 'comparable' but no details given.
van Leeuwen et al., 2009	Shamatha and Zen.	Range from 1 to 29yrs	n/s	1) Age, gender and education matched controls. 2) Younger controls, n/s if matched for gender or education.

Study	Meditative Tradition	Previous Experience	Ongoing Practice	Comparison Group
Greenberg et al., 2012	Vipassana	8.4 yrs	3.2 hrs	Controls matched for age, gender and academic ability.
Hodgins & Adair, 2010	States only that participants were recruited from 2 meditation centres, MBSR classes and the local community	n/s	*Meditators:* 9.95 hrs per week. *Non-meditators:* 0.38 hrs per week	Non-meditators, classed as individuals who meditated very little or not at all. Matched for age and income.
van Leeuwen et al., 2012	Buddhist monks and nuns recruited from a Vietnamese Zen centre	5 yrs	n/s	Age and education matched controls.

3.4 Longitudinal Studies: The Relationship between Mindfulness Training and Attentional Functions

Whilst the reviewed cross sectional approach has provided first information regarding the relationship between MT and attention, the attribution of attentional improvements to MT cannot be causally argued using this approach. For example, it may be that expert meditators already had well developed attentional functions which enabled them to quickly master FA, allowing them to meaningfully engage in OM and increasing the likelihood of them to continue practice, whereas individuals with poorly performing attentional functions may have quickly lost interest in MT and ceased practice. Furthermore, whether MT can produce positive change in the short to medium term is likely to be a major consideration for both health care professionals who may wish to employ MT as an intervention or treatment and for individuals who may be looking to take up MT, i.e. if improvements were only to occur after years of practice and/or required changes to established daily routines in order to incorporate hours of daily practice, MT may not be considered a valid proposition for these individuals. Thus, whilst it is positive that the aforementioned studies suggest attentional improvements following long term MT, longitudinal examinations of MT are required in order to 1) confirm that MT produces these changes and 2) that they occur within a timescale that is ecologically relevant for health care professionals and individuals interested in MT. Accordingly, longitudinal studies that examine the effects of MT are considered a priority for mindfulness research (Chiesa et al., 2011).

During the past decade a wide range of longitudinal studies, using varied methodologies, have begun to provide evidence for the effects of MT. This section contains a review of the studies relevant to attentional functions. The included studies are grouped into 2 main categories: 1) brief mindfulness inductions and 2) studies that examine the effects of MBIs and retreats. The former category includes studies that employ pre and post induction testing in an attempt to assess the effects of a) inducing a state of mindfulness or b) engaging in short term MT. The latter category includes studies that involve a longer exposure to MT and includes MBIs that ranged in length from 4 to 8 weeks and retreats that lasted from 4 days to 3 months.

3.4.1 The Effects of Brief Mindfulness Inductions

A number of studies have investigated whether brief mindfulness inductions can produce immediate positive effects on attentional functions. Rather than examining trait changes to attentional functions, such studies are interested in assessing whether inducing a mindfulness state produces state like changes to attentional functions. Encouragingly, positive results have been found with as little as 5 minutes of MT. Friese, Messner, and Schaffner (2012) found that 5 minutes of mindfulness meditation was able to improve self control following an experimental manipulation designed to deplete self control through emotion suppression (Hagger et al., 2010). The authors instructed two groups of participants to suppress emotions during a 5 minute video clip, whilst a final group was instructed to watch the video normally. Next, one of the suppression groups engaged in a 5 minute mindful breathing exercise whilst the remaining two groups engaged in a neutral task (line-drawing). The participants self control was then measured using the d2-test of attention (Brickenkamp & Zilmer, 1998) which measures two hall marks of self control, attention and inhibitory control (Baumeister, Schmeichel, & Vohs, 2007; Baumeister, Vohs, & Tice, 2007). The group that engaged in the brief MT performed similarly to the group who had not suppressed emotions, whilst the suppression group who had not engaged in MT performed significantly worse. These results suggest that improvements in sustained attention and executive functions are possible following the induction of a state of mindfulness.

Two further studies found positive effects of similar mindfulness based inductions that were also employed to induce a state of mindfulness. McHugh, Simpson, and Reed (2010) found that older adults who engaged in 10 minutes of focussed breath awareness were able to reduce emergent over-selectivity[9] compared to a matched group who engaged in 10 minutes of mind wandering. This finding is indicative of an improvement in goal directed attention[10]. In another study (Wenk-Sormaz, 2005), a 20

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[9] Over-selectivity typically occurs when behaviour is controlled by a limited number of the available stimuli in the environment. Habitual patterns of behaviour can cause over-selectivity to occur. For example, an individual may rely on information from a select number of stimuli that they may habitually attend to rather than adapting to current demands and seeking out additional information. Thus reductions in over-selectivity may evince improvements in present moment awareness and goal directed attention.

[10] Given the relevance of these results to the discussion regarding ageing and MT, these results and their implications are discussed in greater length in Chapter 9.

minute focussed breath awareness meditation[11] reduced Stroop interference as compared to rest and a cognitive control task (mnemonics). Additionally, the group who meditated were able to produce more atypical items in a word production task. Taken together, these results suggest a reduction in habitual responding, a hallmark of improved executive control, following the induction of a state of mindfulness.

It is important to note that the techniques utilised to induce a mindfulness state in the abovementioned studies relied mostly on FA, with participants simply instructed to maintain focus on the breath and redirect attention back once a slip had been noted. Given that it has been proposed that a well functioning FA is required in order to meaningfully engage in OM (Lutz et al., 2008), the hallmark of MT, it is logical that such short inductions attempt only to engage FA rather than attempt to incorporate the more difficult OM. However, it also means that they are unlikely to truly reflect the engagement of a mindfulness state, with the observed improvements in attentional performance most likely resultant from FA related state effects of meditation. Regardless of this, the abovementioned findings are still positive as they provide a link between attentional functions being engaged during FA and subsequent improvements in attentional performance during completion of a very different task.

A number of other studies have assessed the effect of short term MT administered over multiple sessions with attentional testing completed without the induction of a mindfulness state. A summary of the interventions and comparison groups used in these studies is contained in Table 3 presented at the end of this section. Zeidan et al. (2010) compared the effects of a 4 day, 4 session Shamatha breath awareness induction to an active control condition (listening to a recorded book). Compared to the controls, the meditators improved performance on measures of verbal fluency (The Controlled Oral Word Association Test; Benton, 1989) and working memory (The Symbol Digit Modalities Test; A. Smith, 1982). Additionally, meditators had more extended hit runs on an n-back task, which Zeidan et al. propose is indicative of improved sustained attention as said extended hit runs rely on accurate and sustained working memory discriminations. In a study of similar duration, Tang et al. (2007) utilised the ANT to examine the effects of 5 days of either integrative body-mind

[11] This meditation procedure was based on a Zen meditation on breathing. Attention is focussed on the sensations of breathing and re-oriented back to the sensations of breathing if the mind wanders.

training (IBMT) or progressive relaxation training (Bernstein & Borkovec, 1973). As compared to relaxation training, IBMT led to a reduction in ANT conflict scores, indicative of improved executive attention. Whilst each of these short term training inductions incorporated elements of OM, the results of these studies are still most likely to be caused by improvements to FA as FA is likely to be repeatedly engaged during the early stages of training in order to anchor attention in the present moment.

It must be noted that results from short term inductions are not universally positive. Polak (2009) found no differences in task performance on the ANT or Stroop task following a 2 x 15 minute mindfulness based focussed breathing induction (both sessions within 2 days) as compared to both active (muscle relaxation) and non active (neutral thought induction) control groups. However, there are a number of potential reasons for the null results. Firstly, the training was administered via audio recording only, thus there was no way of knowing if the participants had understood what the MT involved. Secondly, testing was conducted immediately after the second session of training, meaning that the tasks were being performed immediately after the participants had been required to attend to an audio recording in order to engage in a described task. Thus it is feasible that participants in each of the groups may have engaged FA during completion of the assigned task which may in turn have resulted in the null between group results. Lastly, Polak reported poor test-retest reliability across task administrations for both the ANT and Stroop tasks with performance increasing for all three groups, suggesting that practice effects resultant from such close administrations of the task may influence the null findings.

Further, whilst not explicitly related to the discussion of MT related attentional improvements, Zeidan et al. (2010) found no effect of meditation on a forward/backward digit span task, taken from the Wechsler Adult Intelligence Scale-Revised (Weschler, 1981), or in terms of overall accuracy on the 2 back n-back task, suggesting no improvement to working memory following a short MT induction. Also, Tang et al. (2007) did not find any positive effects on the alerting or orienting networks of attention, following their short IBMT induction. However, given that brain regions implicated in the executive network are the most active during MT, even when individuals engage in MT for the first time (Brefczynski-Lewis et al., 2007; Hölzel et al., 2007), it is unsurprising that only this network was affected by short term MT.

In conclusion, various attentional skills, including both sustained and executive attention, appear to be improved following breath awareness meditations designed to induce a state of mindfulness and following short term MT based inductions. However, as mentioned these positive findings should be interpreted with caution given that they most likely reflect state related effects of FA. Taken together with the results from the meditative state literature, and the wide range of studies that have suggested that attentional processes become more efficient through training (e.g. Newman et al., 2007; N. B. Sarter et al., 2007; Slagter, Giesbrecht, et al., 2007; Vidnyanszky & Sohn, 2005), the results discussed in this section suggest that improvements in attentional functions and/or FA aspects of MT are an achievable short term goal of MT. This assertion is in line with Lutz et al. (2008) proposal that FA must first be trained in order for the individual to remain in the present moment and consistently engage a non-reactive and non-judgmental OM state. Whilst the consistent engagement of a non-reactive and non-judgmental OM state, both during and outside of MT, may ultimately lead to long lasting state and trait positive change, attentional improvements developed through the repeated activation of attentional functions and the neural substrate that subserves them during meditation appears to be a key mechanism for this to occur.

Table 3: Summary of short term intervention study details.

Study	Type and Amount of MT	MT Intervention details	Comparison Group Details
Zeidan et al., 2010	*Type:* Shamatha breath awareness meditation. *Amount:* 4days, 4 sessions. Session length not stated.	Basic Shamatha breath awareness meditation. Attention was focused on the flow of breath occurring at the tip of the nose while arising thoughts were passively noticed, acknowledged and let go. Thus the practice involved both FA and OM components.	*Type of intervention:* 4days, 4 sessions of listening to an audio book. *Demographics matched:* Age and gender
Tang et al., 2007	*Type:* Integrative Body Mind Training (IBMT) *Amount:* 5 days x 20mins	IBMT involves several body–mind techniques including: (*i*) body relaxation, (*ii*) breath adjustment, (*iii*) mental imagery, and (*iv*) mindfulness training, accompanied with selected music background.	*Type of intervention:* Progressive relaxation training of matched duration. *Demographics matched:* States 'matched' but specific details not given.
Polak et al., 2009	*Type:* Mindfulness based mindful breathing induction *Amount:* 2 x 15 minute sessions completed within 2 days.	Recorded instructions were given via CD. The meditation was a breath focussed sitting meditation typically included in MBSR.	*Type of intervention:* 1) Progressive relaxation training 2) Neutral task, e.g. make a list of places visited yesterday. *Demographics matched:* Not recorded

3.4.2 The Effects of Mindfulness Based Interventions and Mindfulness Retreats on Attentional Functions

As evidence regarding the potential efficacy of long term MT and OM practice grew, researchers increasingly incorporated such practices into MBIs in an attempt to ascertain their potential efficacy in a wide range of milieus. The two most common and widely used MBIs are MBSR and MBCT. Both MBSR and MBCT incorporate MT via a number of different meditations, although mindful breathing awareness meditations are the most prominent. As both MBSR (Kabat-Zinn, 1990) and MBCT (Segal et al., 2002) were designed as 8 week programs, they provide an opportunity to measure the positive effects of MT that may be derived in the short term. However, because MBSR and MBCT were designed as interventions for specific conditions, stress and major depression respectively, the majority of studies assessing their efficacy predictably do so in relation to improvements in said conditions. Nonetheless, as such studies have often provided positive results (for examples of the efficacy of MBSR see Grossman et al., 2004 and Chiesa & Serretti, 2009; for MBCT see Segal et al., 2002 and Fjorback et al., 2011), a number of recent studies have attempted to ascertain the mechanisms by which MBIs may produce positive change. Perhaps unsurprisingly given the literature reviewed thus far and the proposed central importance of attention to MT, changes to attentional functions are one of the proposed mechanisms for change. Accordingly, a number of MBI studies have incorporated measures of attention. Mindfulness based retreats provide a further opportunity to examine the effects of a relatively short term MT. Retreats ranging from as little as 1 week up to 3 months have been found to produce positive effects, including reductions in depressive symptoms and reduced rumination (e.g. Chambers, Lo, & Allen, 2007). Improvements to attentional functions have also been found and are discussed herein. This section reviews the extant evidence from longitudinal studies that have examined modulations of attentional functions following short term MBIs and retreats. Table 4 contains an overview of important details relating to the administered interventions and comparison conditions. A number of limitations are identified and will be discussed in more detail in section 3.5.

Utilising a longitudinal 3 arm design, Jha et al. (2007) assessed attentional network performance, using the ANT, prior to and following either an 8 week MBSR course, an intensive 1 month vipassana retreat (10-12hrs of MT daily) or a wait list control period. Baseline findings were discussed previously (section 3.2), with the retreat participants (expert mindfulness meditators) demonstrating lower conflict monitoring scores at baseline than the MBSR and wait list groups combined (meditation naïve at baseline). Somewhat surprisingly, no between groups differences in the executive network were found at T2. In light of the retreat participants having significantly lower executive network scores at T1, it is plausible that the expert meditators that make up this group had already reached a performance ceiling based on a well functioning executive network developed through repeated activation of said network during their ongoing MT. However, this would not explain why the MBSR group did not significantly improve executive network scores by T2. Thus, it is possible that practice effects resultant from repeated task administrations may influence this null finding, an assertion given weight by an overall main effect of *Time* which evidenced an overall improvement in RTs across groups from T1 to T2. However, following MBSR but not the retreat, orienting network scores were reduced in comparison to controls, suggesting more efficient use of valid spatial cues. This result suggests that MBSR was related to improvements in voluntary attention as the orienting network relies on top-down attentional control. The MBSR and waitlist control groups both demonstrated no change in alerting network scores from time 1 (T1) to time 2 (T2), thus they were pooled to examine the hypothesis that retreat participation may improve exogenous stimulus detection. Consistent with this hypothesis, the retreat participants significantly reduced alerting network scores as compared to the MBSR + wait list control group. This finding suggests that the retreat participants were able to detect targets more efficiently when no information was provided as to when targets would appear, suggesting they were in a more readied attentional state. Such attentional readiness following the intensive practice engaged in during retreat participation is in line with the proposal that through extensive MT, OM will become less reliant on FA to a singular focus (Lutz et al., 2008), with present moment attention maintained without the need for a particular focus (e.g. the breath). Given that the retreat was associated with such an improvement it may be considered surprising that no concurrent improvements were found in the orienting network. However, the retreat participant's improvement in attentional readiness is likely to similarly influence conditions with both spatial and non-spatial cues, leading to no reduction in orienting network scores which are calculated by subtracting the reaction times (RTs) of trials with spatial cues from the RTs of trials with non-spatial cues. The fact that no difference in the alerting network was observed between the experts (retreat group) and meditation naïve participants (MBSR + Control) at T1 suggests that retreat participation had an effect on the experts alerting network that was not obtained from their ongoing daily practice prior to the retreat. This is somewhat surprising as engaging in daily practice may be expected to produce the same kind of improvements in the alerting network that were observed following the retreat. One plausible explanation for this pattern of results is that the intensive practice (10-12hrs) that retreat participants engaged in during the month long retreat may have caused transient state like changes in the alerting network. It is important to note that T2 testing occurred immediately after the retreat for the retreat participants, thus it is likely that the attentional states that they were employing during their daily MT would be similarly engaged during task performance, as was seen in the aforementioned studies in which a mindfulness state was induced (Friese et al., 2012; McHugh et al., 2010; Wenk-Sormaz, 2005). For the MBSR group T2 testing occurred up to 10 days after the end of the MBSR intervention (equivalent period for waitlist controls) thus any transient effects of the intervention may be expected to have worn off. This suggests that the modulation of the orienting network that was observed for the MBSR group at T2 and the more efficient executive network scores observed for the retreat participants at T1 may reflect trait attentional change whereas the alerting network may be more susceptible to transient state change. However, this conclusion is tentative as it is not possible to know whether the alerting difference observed at T2 for the retreat group would have remained robust if T2 testing had occurred after a cooling off period rather than immediately after the retreat. The results of Jha et al. study are further confounded by the fact that the test retest interval was different between the retreat group (30days) and both the MBSR and waitlist groups (mean = 59days). Whilst this study produced a number of positive findings it must be concluded that further research is required to better understand the effects of MT on attentional networks.

In another study, Gaden Jensen et al. (2012) attempted to isolate MBSR related attentional effects by utilising three comparison groups and a variety of measures of attention. MBSR was compared to a non-mindfulness based stress reduction (NMBSR), and an inactive control group which was further split into incentive (offered $50 to improve performance compared to baseline) and non-incentive subgroups at post test sessions in order to control for attentional effort. As compared to all other groups, the MBSR group significantly reduced the amount of errors committed on the d2 test of attention (Brickenkamp & Zilmer, 1998). As the majority of errors were omission errors, this result suggests that MT improved sustained attention to a degree that was not achieved by stress reduction or attentional effort alone. The MBSR participants also produced less Stroop errors than the non-incentive controls at T2. However, the incentivised group also outperformed the non-incentive controls, and no group significantly improved performance from T1 to T2 despite the between group differences that emerged at T2. Based on this finding, the authors argue that attentional effort may account for attentional improvements seen in other studies, citing Jha et al. (2007) acknowledgement that increased attentional effort from their own MBSR group (as compared their waitlist controls) could not be ruled out. However, similar performance for the MBSR and incentivised controls does not objectively show that the

MBSR group improvement in Stroop performance was caused by attentional effort. The addition of an incentivised MBSR group may have provided a better explanation, had an incentivised and non-incentivised MBSR group performed similarly it may have been concluded that the MBSR group were already applying as much attentional effort as participants offered a financial reward for improved performance. Null results were also found between the MBSR group and all other groups on three further attentional tasks, the dual attention to response task (Dockree et al., 2006), the spatial and temporal attention network task (SPAN; Coull & Nobre, 1998), and the CombiTVA paradigm (see Vangkilde, Bundesen, & Coull, 2011). The null findings on the SPAN task were particularly surprising given Jha et al. (2007) finding of improvements to the orienting network following MBSR. However, the SPAN task uses non-valid cues to assess re-orienting, whereas the orienting network of the ANT assesses the orienting benefit of valid spatial information, thus the two tasks are likely to involve relatively distinct skills. Of note, the stress-reducing effects of MBSR were supported because only those in the MBSR group showed significantly less perceived and physiological stress, while concurrently increasing their self-reported mindfulness levels (the mindfulness, attention and awareness scale; MAAS, Brown & Ryan, 2003) significantly.

Another recent study looked at executive processes related to habitual responding. As discussed previously (section 3.2), Greenberg et al. (2012) found differences in cognitive rigidity between expert mindfulness meditators and non-meditators. In the same paper the authors present the findings of a longitudinal study that was conducted to determine whether the differences in cognitive rigidity related to long term mindfulness training could be trained via a short term MBI. A waitlist control period was compared to a MBI that was based on MBCT. Also, in order to avoid practice related effects, cognitive rigidity was assessed using an alphabet-maze task (Cowen, Wiener, & Hess, 1953) at T1 and a Water Jug Task (see Appendix A) at T2. The intervention group performed significantly better than the waitlist control group on the water jug task at T2, with both groups performing similarly on the alphabet-maze task at T1. This result is suggestive of a reduction in cognitive rigidity following the intervention and further confirms the proposal that modulation of executive functions is an achievable short term goal of MT.

As intimated by the partial null findings presented thus far, the relationship between MBIs and attentional improvement is not entirely clear. Anderson et al. (2007)

compared an MBSR program to a wait list control period and found no difference between the groups on a number of measures of attentional control, including a Stroop paradigm, a continuous performance task (CPT) and a switching task. However, these results should be interpreted in light of the following potential confounds. Firstly, the Stroop paradigm was included to measure the inhibition of elaborative processing and was dissimilar to the Stroop paradigms that have been discussed thus far. In addition to the neutral (e.g. general) and incongruent (e.g. blue) words that are typically used, the task included both negative and positive words (5 most negatively and positively rated adjectives said to be self-characteristic), and words that are semantically suggestive of colours (e.g. sun). Accordingly, data were analysed using a *Time* (2) x *Group* (2) x *Condition* (5) ANOVA. Whilst these null results should not be easily dismissed, they should be interpreted as distinct from the other Stroop findings discussed herein as the task, and the statistical method used, will have incorporated both attentional and affective regulation rather than attentional regulation alone. Floor effects may also have played a part in this null finding as overall RT's did not improve from T1 to T2. Secondly, whilst CPT performance, which was utilised to assess sustained attention, displayed the expected drop in performance (increased errors and RT's) from block to block during task administration, errors surprisingly increased significantly across both groups from T1 to T2. Given that the task included 1600 total stimuli and only 160 potential responses (10%) over the course of the 2 testing sessions, the sheer monotony of the task may confound results. A final, and potentially the most problematic confound, is that the authors requested the MBSR participants to 'invoke' mindfulness during task completion at T2. Although the authors do not elaborate further, it is likely that they instructed participants to approach the tasks with a mindful attitude (MBSR typically involves instruction on how to approach everyday situations with a mindful attitude that can be engaged without meditation) rather than to meditate. However, as the evocation of mindfulness is unlikely to come easy to relative beginners with only 8 weeks practice, the overall task difficulty for the MBSR participants may have been increased as they now had the additional difficult task of attending mindfully in addition to the attentional tasks which are already difficult in themselves. Thus the two groups actually had slightly different tasks at T2. Interestingly, outside of task engagement MBSR was related to positive effects in the direction of better well being on a wide range of self report measures. In addition to increases in self reported mindfulness (10 item version of the Toronto Mindfulness Scale; Bishop et al., 2003), larger changes were seen in the MBSR group than the control group on measures of depression, anxiety, anger, positive affect, general rumination, anger rumination and anger sensitivity. Thus, whilst not engaged in a concurrent attentional task the ability to evoke a mindful attitude may well be improved by MBSR, leading to the observed positive effects on the self report measures. Further, an improved ability to evoke mindfulness may result in more frequent engagement in mindful experiences and behaviours, which together may evidence improved present moment awareness which is a potential cause of these positive findings. Possible evidence for this assertion may be seen in the results of the final task employed in this study. Whilst no overall differences in accuracy or errors were found between the groups on an object detection task (Hollingworth & Henderson, 1998), changes in self reported mindfulness were associated with reduced consistency effects[12] in the MBSR group, but not the waitlist group. The authors propose that reduced consistency effects may be interpreted as an improvement in non-focused attention, thus an improved ability to evoke mindfulness appears to be related to an enhancement of present moment awareness. An alternative explanation may be that attention was more consistently directed to the goal of the task (object present/absent) than to non-goal directed aspects of the display (scenes), this interpretation suggests that changes in self reported mindfulness may be linked to improved goal directed attention and salience network functioning. Of note, the object recognition task had no upper temporal limit before the next trial was presented, thus it may have been easier to invoke a mindful attitude during this task as opposed to the previously discussed tests of attentional control which inherently impose temporal limits on each trial.

The above finding of reduced consistency effects with increased mindfulness is positive when taken together with Jha et al. (2007) aforementioned finding of reduced alerting network scores following an intensive 1 month mindfulness retreat. Regardless of whether these findings are interpreted as improved attentional readiness, improved non-focussed attention or improved goal directed attention, they are indicative of greater control over the limited amount of available attentional resources. A further retreat study that assessed the temporal limits of attention provides insight into how MT may modulate this attentional resource allocation. Slagter, Lutz, et al. (2007) incorporated

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[12] Consistency effects are evident as an increased reaction time being needed to identify objects in inconsistent vs. consistent scenes.

both behavioural and electro-physiological methods to assess the changes in sustained attention resultant from a 3 month intensive vipassana retreat (approx. 8hours daily practice). A group of expert meditators were tested on the ABtask, both prior to and immediately after the retreat, with performance compared to that of a matched control group. Both groups were instructed to complete the task in a non-meditative state. The so called ‘attentional blink effect’, occurs when 2 targets (Tar1 and Tar2) embedded in a rapid stream of events are presented in close temporal proximity, which often causes the second target to be missed. Improvements in behavioural performance were seen for retreat participants only, evidenced by a reduced attentional blink size (reduced difference between performance on temporally close and distant Tar2 in relation to Tar1). In addition, a well established electrophysiological marker of attentional resource allocation (P3 ERP component elicited by Tar1) was shown to reduce in the retreat group. Given the concurrent increase in performance in the temporally close Tar2 condition, this reduction in P3 mean amplitude suggests greater top down control over limited attentional resources, resulting in resources being split across both targets rather than being wholly exhausted by Tar1. This assertion was supported by a significant correlation between reduced blink size and reduced P3 amplitude. A decrease in the cross-trial variability of oscillatory theta-band activity after successfully identified tar2 was also found for those individuals who showed the greatest reduction in P3 to tar1 (reported in Slagter et al., 2009), suggesting that MT resulted in more efficient allocation of available attentional resources which enabled resources to become available more quickly to process new target information. Additionally, an increase in phase consistency of theta-band oscillatory neural responses over anterior scalp regions, to target stimuli only, was found using a dichotic listening task (reported in Lutz et al., 2009). Importantly, this change in cortical signal stability predicted an observed reduction in reaction time variability. Taken together, the findings from both tasks suggest improvements in attentional resource allocation and an improved ability to sustain attention following the retreat.

The results of two studies examining short, intensive retreats provide further evidence of the potential benefits of short term MT. As presented earlier, van Leeuwen et al. (2012) found evidence for faster allocation and reallocation of attention (reduced global precedence effect) in the expert meditators as compared to matched controls. In a follow up longitudinal study, the authors assessed the performance of expert FA meditators following a 4 day OM based intensive retreat, by comparing their performance to matched controls. At baseline, a robust global precedence effect was observed in both groups. However, the FA experts experienced a significant reduction in the global precedence effect following the OM retreat, whereas no difference was found in controls. Taking together the results of both studies, and consistent with the literature presented in this section thus far, OM based MT appears to uniquely alter the allocation of attentional resources. Nevertheless, a specific effect of intensive retreats themselves cannot be ruled out as both Jha et al. (2007) and Slagter, Lutz, et al. (2007) found no differences in non-focussed/temporal attention between expert meditators and non-meditators at baseline. In a further study (Chambers et al., 2007), meditation naïve participants were given an intensive 10 day vipassana meditation course analogous to an intensive retreat (11hrs daily practice), with their performance compared to that of matched controls on an internal switching task (detailed in Appendix A) designed to assess sustained attentional focus and attention switching. Reductions in overall RTs on the internal switching task, indicative of improved sustained attention, were observed in the mindfulness meditation group but neither group improved switch costs, thus MT was not associated with improvements in attention switching. Of note, improvements in mindfulness (MAAS) were associated with improvements on self report measures of depressive symptoms, rumination and positive affect. Additionally, the mindfulness meditation group significantly improved digit span backward scores (Digit Span backward subscale of Wechsler Adult Intelligence Scale; The Psychological Corporation, 1997) following the course, indicative of improvements in working memory capacity, whereas no change was observed in the control group

Whilst positive findings were observed in all of the retreat studies discussed thus far, the results of Chambers et al. study are particularly relevant for a number of reasons. Firstly, the participants were meditation naïve at baseline, thus the positive findings in comparison to controls are more easily attributable to participation in the meditation course. The other retreat studies discussed herein have measured the impact of retreat participation on participants who were already experts, thus retreat participation may have capitalised on previously well trained attentional skills in order to produce positive results. Secondly, the follow up testing sessions were completed 7-10 days after the course. Therefore the participants should have readjusted back into their daily routines, causing the more transient effects of the retreat to diffuse and meaning that results are more likely to reflect trait attentional improvements. The other retreat studies discussed herein had tested participants at the end of the respective retreats, meaning transient state like changes to attention may have influenced results. Lastly, as the course was only 10 days long the study evidences attentional benefits after short term exposure to MT. This is important as a 10 day course is more accessible to the majority of people, particularly those in full time employment, than the intensive 1 to 3 month retreats discussed herein.

Moving on, a number of studies have found functional differences in brain activity following MBIs. In a recent fMRI study, Goldin et al. (2013) found that MBSR, administered to individuals with social anxiety disorder, was associated with increased activity in attention related parietal cortices (right anterior inferior parietal lobe, right posterior inferior parietal lobe and right superior parietal lobe) during a cognitive reappraisal task (Goldin et al., 2009), as compared an active control intervention (aerobic exercise). Whilst the main aim of this study was to assess the impact of MBSR on emotional regulation, the authors concluded that enhanced recruitment of parietal attentional regions may reflect greater attentional engagement (rather than avoidance or distraction) because similar brain regions have previously been implicated in attentional alerting to a stimulus (Fan et al., 2005). A further fMRI study (Kilpatrick et al., 2011), comparing MBSR participation to a waitlist control period, found significant changes related to a more consistent attentional focus, enhanced sensory processing and reflective awareness of sensory experience. Structural changes have also been found following participation in MBSR. Hölzel, Carmody, et al. (2011) found increased grey matter concentration in a number of brain areas following MBSR, compared to a waitlist control group, including the left hippocampus, PCC, the temporo-parietal junction, and the cerebellum. Given that these regions are associated with learning and memory processes, emotion regulation, self-referential processing, and perspective taking, the potential effects of MBSR are wide reaching. Further, taken together said functional and structural changes suggest that long lasting trait like change may result from MBSR. However, studies with long term follow up schedules are required to confirm this assertion.

Finally, a small group of studies have attempted to explore the relationship between MT, emotion regulation and cognitive/attentional functions. On the whole these studies have demonstrated that MT has a positive effect on affective regulation with improvements in attentional functions a likely mechanism of change (e.g. Allen et al., 2012). As these findings are most relevant to a discussion regarding the implications of the findings of LS2, wherein a measure of affective processing was included, these studies are discussed more fully in Chapter 14.

Summing up, the longitudinal studies reviewed in this section suggest that MBIs and intensive retreats may positively influence attentional skills, with improvements observed in non-focussed, goal directed, sustained, and executive attention. Additionally, improvements in the allocation of limited attentional resources, and functional and structural changes in attention networks were also observed. These findings are positive as they suggest that the use of attentional functions during MT may result in trait changes to said functions, which in turn enables improved performance on tasks very different from the practiced meditation. This is consistent with the proposal that attentional processes become more efficient through training and further establishes the potential link between MT and attention. Moreover, as with the findings from mindfulness inductions, it is positive that engagement in MT may influence attentional functions in the short term, which is consistent with both traditional and modern conceptions of mindfulness that suggest attentional development, and FA, provide the building blocks for meaningful OM (Lutz et al., 2008) and its related improvements in mindfulness. Said short term gains are likely to be of major importance to both health care practitioners interested in employing MT and for individuals looking to take up MT.

However, whilst these results appear to be consistent with the cross-sectional findings of enhanced attentional performance in expert meditators, the direct attribution of the observed improvements to specific MT practices remains problematic as a number of potentially active ingredients are incorporated into both MBIs and retreats. MBIs typically include multiple meditation techniques (completed both in group sessions and at home) and involve non mindfulness instruction (e.g. dealing with daily stress). The variety of MBI content is evident from the descriptions provided herein (Table 4) and the inconsistent results are likely to stem from the variety of different components, durations and comparison groups utilised in the extant literature. Retreats similarly include a variety of meditation techniques and other potential active ingredients such as changes in the sleep-wake cycle, mood and arousal, long periods in silence and with eyes closed, spending a large amount of time away from home and daily life, and spending a large amount of time with limited social interaction. Further, given that Jha et al. (2007) found differing effects of MBSR and retreats, retreat participation appears to have unique effects due to the intensive MT involved. Also, as retreat studies typically involved expert meditators it is unknown whether retreat participation produces attentional improvements or capitalises upon and boosts already well developed attentional functions. It must be noted that as retreat participation has consistently produced positive effects on attentional functions (e.g. Jha et al., 2007; Lutz et al., 2009; Sahdra et al., 2011; Slagter, Lutz, et al., 2007; van Leeuwen et al., 2012) and improved socio-emotional functioning (Sahdra et al., 2011), their utility is not in question. However, the discussed confounds mean that retreats may be unsuitable for identifying improvements in attentional functions that may be attributed to specific MT practices. The varying depth of information regarding MBI and retreat content that was disclosed by authors provides a further problem in attributing attentional change to specific practices, making it even more difficult to critically assess the observed findings.

In conclusion, whilst phenomenological accounts (e.g. Lutz et al., 2008; Wallace & Shapiro, 2006), the findings from the meditative state literature (e.g. Hasenkamp et al., 2012), findings from expert meditators (e.g. Chan & Woollacott, 2007) and findings from brief inductions (e.g. Tang et al., 2007) all suggest that MT may develop attentional functions, the MBI and retreat findings discussed in this Chapter are unable to conclusively confirm this relationship. Thus, there is a stark need for longitudinal studies that assess a singular MT in order that 1) the development of attentional functions resulting from MT may be better understood and 2) we may improve our understanding of the potential mechanisms by which MT may exert positive effects.

Table 4: Summary of the reviewed intervention studies, including details relating to the type and amount of MT utilised, specific intervention content and comparison group information. Studies are presented in the order they appeared in the discussion.

Study	**Type and Amount of MT**	**MT Intervention Details**	**Comparison Group Details**
Jha et al., 2007	*Type:* 1) MBSR 2) Vipassana Retreat. The retreat participants were expert meditators (see table 2 for details). *Amount:* 1) 8 wks, 8 x 3hr group sessions. 30 Mins of daily take home practice. 2) 1 month, 10-12 hrs of daily practice	1) The mindfulness meditation instruction mostly emphasized attention to a single focus. For most concentrative exercises this focus was on the breath, however, a number of other exercises were included that had separate objects as the meditative focus, including bodily sensations during a body scan exercise and the sensations of walking during walking meditation. Elements of receptive attention introduced from wk 5. 2) The retreat included sitting and walking meditation and instruction, although minimal, emphasised concentrative attention to the out-breath.	*Type of intervention:* Waitlist controls. *Demographics matched:* No.
Gaden Jensen et al., 2012	*Type:* MBSR *Amount:* 8 wks, 8 x 2.5hr group sessions, 45mins of daily take home practice. 7hr intensive retreat held in wk 6.	As the MBSR conducted in Jha et al., 2007 (detailed above).	*Type of intervention:* 1) Non-mindfulness based Stress reduction. Resembled the MBSR but did not include meditation or training in a non-judgemental attitude. 2) Inactive Control. *Demographics matched:* The 3 groups were matched for gender, age, education, marital status and perceived stress.

Study	Type and Amount of MT	MT Intervention Details	Comparison Group Details
Greenberg et al., 2012	*Type:* MBCT *Amount:* 6 wks, 7 x 2hr group sessions, 20 mins of daily take home practice.	MBCT was adapted to include the handling of general stress and everyday difficulty rather than a specific focus on depression. Various meditations such as breathing meditation, body scan, open awareness, walking meditation and compassion meditation) were included, as were stories and group discussions designed to foster an understanding of mindfulness.	*Type of intervention:* Waitlist controls. *Demographics matched:* Age, gender and academic ability.
Anderson et al., 2007	*Type:* MBSR *Amount:* 8 wks, 8 x 2hr group sessions. Daily practice not stated.	Formal meditation practices such as body scan, mindful stretching, mindfulness of breath/ body/ sounds/ thoughts were included. Informal practices, which encouraged the application of mindfulness skills in everyday life (e.g., eating a meal mindfully) in order to cope more effectively with stress and anxiety were also included.	*Type of intervention:* Waitlist controls. *Demographics matched:* Age, education and marital status.
Slagter et al., 2007	*Type:* Vipassana Retreat. Participants were expert meditators (mean = 2967 hrs) from varied traditions including Zen, Theravada and Tibetan that all included mindfulness techniques. *Amount:* 3Months, 10-12 hrs of daily practice.	The retreat training included Vipassana meditation and *metta*, a loving kindness and compassion meditation.	*Type of intervention:* Matched controls. who were given a 1 hr mindfulness meditation class, 1 wk before each testing session and were instructed to meditate 20 mins daily during the intervening week *Demographics matched:* Age and education.
van Leeuwen et al., 2012	*Type:* OM based retreat *Amount:* 4 days. No other detail given.	Participants were expert Zen meditators (mean = 3 yrs). No specific details given regarding retreat content.	*Type of intervention:* Matched controls. *Demographics matched:* Age, gender and education.

Study	Type and Amount of MT	MT Intervention Details	Comparison Group Details
Chambers et al., 2007	*Type:* Vipassana Mindfulness Course (analogous to a retreat). Participants were meditation naïve at baseline. *Amount:* 10 days, 11hrs per day.	The taught vipassana meditation emphasised developing mindful awareness of body sensations. This is thought to anchor the individual in the present moment, helping them to recognise their emotional state. This practice is designed to insight into the nature of mind through mindful awareness of the present moment.	*Type of intervention:* Matched controls. *Demographics matched:* Age, gender and education.
Goldin et al., 2013	*Type:* MBSR. Participants had social anxiety disorder. *Amount:* 8wks, 8 x 2.5hr group sessions. 1 day retreat. Daily practice amount was not detailed.	Authors report that participants were trained in formal meditation; including breath-focus, body scan and open monitoring	*Type of intervention:* Aerobic exercise. 8 wks, 1 group session per wk and at least 2 individual sessions. *Demographics matched:* Age and education.
Kilpatrick et al., 2011	*Type:* MBSR *Amount:* 8 wks. 8 x 2.5hrs group sessions. 30 mins daily take home practice. 7hr retreat (6^{th} or 7^{th} wk).	States that the group sessions included different guided meditations, awareness exercises, mindful movement, and group discussions, with the intent of fostering mindful awareness of how one responds to stress.	*Type of intervention:* Waitlist control. *Demographics matched:* Not reported.

Study	Type and Amount of MT	MT Intervention Details	Comparison Group Details
Hőlzel et al., 2011	*Type:* MBSR. Participants were seeking stress reduction. *Amount:* 8 wks, 8 x 2.5hr group sessions, 6.5hr retreat. Instructed to undertake 45mins daily take home practice.	The program included formal mindfulness training exercises aimed at developing the capacity for mindfulness such as awareness of present-moment experiences with a compassionate, non-judgmental stance, including a body scan, mindful yoga, and sitting meditation. Open monitoring meditation was introduced later in the course, with participants instructed to expand their field of awareness to include anything that appears in consciousness.	*Type of intervention:* Matched controls. *Demographics matched:* Age and education.

3.5 Summary of Reviewed Literature and the Identified Limitations of Extant Research

The reviewed literature establishes the importance of attentional functions to MT. Attentional functions, and the neural networks that subserve them, were observed to be engaged during mindfulness meditation using both fMRI and EEG recordings. Engaging in even a simple mindfulness of breathing meditation, a fundamental mindfulness based meditation, requires a number of attentional functions, including sustained attention functions that allow the meditator to remain focussed on and re-orient back to the breath, and executive functions that allow the meditator to monitor for distractions and to disengage from said distractions. The alerting, orienting, executive, salience and default mode networks are all thought to be engaged during the meditation process. Whilst phenomenological accounts (Lutz et al., 2008) and recent findings (Brefczynski-Lewis et al., 2007) suggest that said skills and networks may be required less following extensive MT, the importance of FA and attentional development to MT is acknowledged in all modern conceptions of mindfulness (Bishop et al., 2004; Hölzel, Lazar, et al., 2011; Malinowski, 2013; Shapiro et al., 2006; Wallace & Shapiro, 2006). Further, as attention is central to MT, attentional development through MT has been proposed as a key mechanism for mindfulness related positive effects (Malinowski, 2013).

Cross sectional research found that expert meditators outperformed non-meditators on a variety of attentional tasks. As these tasks were completed outside of a meditative state they are suggestive of a crossover of skills learnt during meditation into very different tasks. Additionally, structural and functional differences in brain regions and networks associated with attention were observed in experts, as compared to non-meditators. The pattern of results suggests that long term MT may produce significant changes to attentional skills and the neural networks subserving them. However, the cross-sectional approach utilised in these studies has a number of inherent limitations. Firstly, results may be affected by a self-selection bias and a non-randomised design. Comparisons of experts and controls provide no information regarding why experts may have taken up MT in the first place. Therefore, such studies cannot rule out that meditators may possess better cognitive and attentional abilities independent of their engagement with meditation. It is feasible that pre-existing abilities may facilitate an individuals' positive perception of MT, which in turn may keep them engaged with MT over the long term. Secondly, the intention and motivation of the experts are uncontrolled in such studies. As proposed by the Liverpool Mindfulness Model (Malinowski, 2013), motivational factors play a key role in determining how an individual may engage in MT. Also, it is possible that expert meditators may be more motivated during testing sessions, their alertness and attentional focus may be heightened by their wish to prove that the time and energy they invested in meditation was worth the while. Thirdly, descriptions of prior and ongoing MT were varied and limited (see Table 2). Without explicit detail regarding prior and ongoing MT techniques, and/or the meditative traditions upon which they are based, attribution of positive effects to specific MT techniques is not possible. Lastly, whilst the cross sectional approach provides the most logical way to assess the effects of extensive MT, as it may be considered unfeasible to run a longitudinal study that incorporates such vast amounts of MT, this approach does not provide definitive information as to how attention may be developed through MT.

Next, the effect of brief mindfulness inductions and short term MT were discussed. The longitudinal design, with a pre and post testing schedule, that such studies employ exerts more control over such extraneous variables and provides the most appropriate way of assessing the development of attentional functions through MT. Overall, the general pattern of results suggests that short term exposure to MT may produce attentional changes similar to those observed in expert meditators. However, a number of issues were identified with the extant studies reviewed herein. The brief 1 to 2 session induction studies represented an attempt to assess the effect of a singular MT on attentional functions. However, the assessed MT typically involved FA rather than a combination of FA and OM and also did not include elements of a non-judgmental and/or non-evaluative awareness of ongoing experience. Thus the MT utilised in these studies may not actually include a number of the core elements of mindfulness and may be more closely linked to concentrative forms of attention. Thus the observed positive effects most likely evince transient state induced changes in attentional functions resultant from FA being invoked during the utilised MT, rather than the findings being caused by the participant invoking mindfulness. These findings are still positive as they demonstrate that techniques utilised to invoke a particular way of relating to experience can be useful even before they result in trait change. Attentional improvements were also seen following inductions of slightly longer duration (4-5 days) and MBIs, when testing was not completed immediately after the induction of a mindfulness state, suggesting that short term exposure to MT may result in trait like change. The findings of functional and structural changes in attention related brain areas following MBSR further suggests that short term exposure to MT may produce lasting changes. A number of limitations specific to the MBI studies were identified. As MBIs are typically based on well described, well defined programs, they may superficially appear to provide an ideal way in which to assess MT related attentional development. However, as mentioned earlier MBIs were specifically designed to treat certain conditions. Thus, they include various potential active ingredients on top of MT, making it difficult to directly attribute attentional change to specific MT practices. Further, the design of the studies reviewed herein was not entirely consistent with differing levels of group work and group content, differing MT techniques and take home practices (see Table 4). The descriptions of the included content were also varied and often lacked sufficient depth, making it even more difficult to critically assess the observed findings.

The mindfulness retreat studies also utilised a longitudinal design with a pre and post testing schedule, with improvements to attentional functions observed post retreat. However, such intensive retreats may capitalise on transient state attentional change from large amounts of daily MT (typically >8hrs daily). Further, as such studies typically examined expert meditators it is unclear whether retreat participation produces attentional improvements or capitalises upon and boosts already well developed attentional functions. Encouragingly, positive effects were seen when meditation naïve participants completed a mindfulness course that was analogous in intensity to a retreat, with testing occurring 7-10 days following course completion.

It must be noted that not all the reviewed studies found positive effects. Whilst the discussed limitations may account for part of this observed inconsistency, the variety of comparison groups utilised in longitudinal examinations of MT provide a further reason for inconsistent results. A representative review of 25 longitudinal studies from a wide range of study areas (Appendix B) revealed comparison groups ranging from no practice and waitlist control groups to active control groups including relaxation techniques, listening to music or stories, mind wandering exercises, learning exercises (e.g. mneumonics) and treatment as usual. For future research, the selection of an appropriate control or comparison condition is essential in longitudinal studies of

MT (Chiesa et al., 2011; Tang & Posner, 2013) in order that the results of such studies may be comprehensively interpreted.

Overall, the reviewed literature establishes a sound theoretical basis for the study of MT and attentional functions. Future research must now attempt to establish clear links between specific MT techniques, the core attentional processes they involve and how they may develop over time. Such research will enable the potential mechanisms and positive effects of MT to be better understood. The following sections discuss how the design of longitudinal studies included in this thesis attempt to overcome the limitations of extant studies in order to address this clear research need. Further, the global aim of this thesis will be discussed.

3.6 Current Study: Objectives, Hypotheses and Overcoming Past Limitations.

3.6.1 Objectives and Hypotheses

The global objective of this thesis was to investigate the potential for MT to positively modulate attentional functions and their associated neural mechanisms in older adults. However, before this investigation could take place it was first necessary to conclusively establish the link between attentional development and MT. Thus, this thesis includes 2 longitudinal studies with distinct objectives. The objectives and related hypotheses for each of these studies are detailed below.

<u>Longitudinal Study 1</u>

The main objective of longitudinal study 1 (LS1) was to investigate whether a singular, brief, MT technique, carried out regularly for 18 weeks, would lead to modulations of attentional functions and task related neural activity. A singular MT technique (described in detail in section 5.2.3) is used so that attentional improvements may be directly attributable to a specific MT. In short, the technique is a simple mindful breathing meditation whereby the task is to sustain attention to the breath, without manipulating it, if/when attention slips the task is to become aware of said slip and without further elaboration to re-direct attention back to the breath. Arising thoughts, feelings and sensations are observed with a curious non-judgmental attitude during this meditation. Thus the meditation includes key elements of MT such as FA, OM and the emphasis on a non-judgmental, curious attitude. As discussed in Chapters 2 and 3, this kind of meditation requires a variety of attentional functions, most notably sustained and executive functions, and engages five attentional networks. Further, as mindful breathing meditations are incorporated into both traditional buddhist meditations and as part of contemporary MBIs, the assessment of this technique will provide valuable information regarding a potential mechanism for the improved attentional skills found in expert meditators and regarding a possible active ingredient of MBIs.

Given that the prior research discussed in this thesis has demonstrated the importance of attentional functions and their associated networks during meditation, and the potential for both to be improved following MT, it was hypothesised that a singular, brief, MT technique would positively modulate attentional functions. Specifically, it was hypothesised that MT would lead to improvements in sustained and executive attention. Additionally, it was expected that MT would lead to changes in task related neural activity associated with attentional resource allocation. EEG and the ERP technique were employed to measure task related neural activity. Further details regarding the inclusion of this technique are detailed in the following sections.

The specific hypotheses and outcome measures (behavioural and electrophysiological) relevant to each of the two experimental tasks administered for LS1 are detailed in their own respective Chapters (6 and 7).

Longitudinal Study 2

The main objective of longitudinal study 2 (LS2) was to investigate the potential for MT (the same MT was used in LS1 and LS2) to positively modulate attentional functions and task related neural activity in older adults. Chapter 9 contains the theoretical background for investigating the effects of MT in older adults. In sum, it is generally accepted that systematic age-related cognitive declines occur with increasing age; yet said declines may be influenced by non-biological factors such as education, diet, exercise and other life style choices (Hedden & Gabrieli, 2004; National Research Council, 2000). It has been suggested that such factors help build up a *cognitive reserve* that allows the brain to compensate for age related cognitive declines. The *cognitive reserve* hypothesis proposes that higher cognitive ability, and the factors associated with higher cognitive ability, lower the risk of dementia (Stern, 2003; Whalley et al., 2004).

As stated, it was expected that LS1 would demonstrate that even a singular, brief, MT would improve attentional functions. Furthermore, a number of cross sectional studies that compared older expert mindfulness meditators to age matched controls have observed that older expert meditators had better attentional performance (Pagnoni & Cekic, 2007; van Leeuwen et al., 2009) and potentially positive structural differences in brain regions relevant to cognitive declines (Kang et al., 2013; Lazar et al., 2005; Leung et al., 2013; Pagnoni & Cekic, 2007). Accordingly, a strong case can be made for investigating the potential for MT to positively influence attentional functions in older adults, especially so when these findings are taken together with the previously reviewed literature that suggests MT may improve behavioural performance (e.g. Jha et al., 2007) and produce functional (e.g. Goldin et al., 2013) and structural (e.g. Hölzel, Carmody, et al., 2011) changes within attention related brain regions. It was hypothesised that administering MT to a sample of older adults would improve behavioural performance and task related neural activity associated with core attentional functions. Similarly to LS1, it was specifically expected that MT would lead to improvements in sustained and executive attention and to changes in task related neural activity associated with attentional resource allocation. The specific hypotheses and outcome measures relevant to each of the 3 experimental tasks administered for LS2 are detailed in their own respective Chapters (11-13).

A secondary objective of LS2, specific to the use of an emotional counting Stroop task (Chapter 12), was to examine whether a singular MT may modulate the attentional processing of emotional stimuli. Recent research has begun to suggest that MT related improvements in attention may foster improvements in emotion regulation (e.g. Allen et al., 2012). Thus it was hypothesised that MT would concurrently lead to improvements in attentional functions and the attentional processing of emotional stimuli.

Key Objectives For both LS1 and LS2

As the general pattern of results emerging from MT studies suggests that engaging in MT may produce positive attentional (see Chiesa et al., 2011) and emotional (see Chiesa, Serretti, & Jakobsen, 2013 for review) effects, it is becoming clearer that MT may be useful for a wide range of individuals. However, the extant literature has mostly assessed extensive MT and MBIs. Extensive MT may not be appropriate for most people due to ongoing daily commitments (e.g. work, family) and MBIs are typically only administered to individuals with ongoing psychological conditions. Thus, research that assesses an easily accessible MT is much needed. Accordingly, a key objective of this thesis, that was consistent across both studies, was to ensure that the examined MT was highly accessible and easily incorporated into daily life without change or disruption to established daily routines. In order to meet this objective the administered MT involved only 10-15mins of practice, 5 days per week, and a minimal amount of group contact time. In LS1participants engaged in MT for 18 weeks, whilst participants in LS2 engaged in MT for 8 weeks. Thus both studies examine short term and highly accessible exposure to MT.

A further objective was to ensure that the findings of LS1 and LS2 could be linked to trait, rather than state, attentional improvements. In order to establish that MT produces trait attentional improvements it was necessary that the induction of a mindfulness state and/or engaging in MT did not precede task completion. Thus, all of the experimental tasks detailed herein were completed in a non-meditative state by all participants. Further, the experimental tasks that are utilised in LS1 and LS2 are able to assess whether attentional functions developed through MT may crossover and improve performance on other tasks as all of the employed tasks are very different from the task of meditation.

3.6.2 Overcoming Past Limitations

Section 3.6.1 briefly introduced how LS1 and LS2 were designed with specific objectives to overcome the main limitations of previous research. The current section details how the design of these studies overcomes some of the more general limitations of prior research.

Comparison Groups

The attribution of attentional improvements to specific MT practices is difficult when assessing extant studies as they have incorporated a wide range of control and comparison groups (see Table 4 and Appendix B). In order to comprehensively assess the attentional effects of MT, LS1 and LS2 incorporated comparison groups that allow for the control of a wide range of extraneous variables.

LS1 incorporated a waitlist control design. Wait list control periods are the most widely used control condition in longitudinal research. Comparing MT to a waitlist control condition allows the experimenter to control for a range of extraneous variables such as intention and motivation for enrolment, as well as for repeated administrations of self report measures and cognitive tasks, whilst demographic variables are typically controlled via random group allocation (discussed briefly below). As such, a wait list control design provides an appropriate comparison group for first empirical explorations of a singular MT technique and attentional performance. It must be noted that there are a number of potential non-specific effects of even a singular MT technique, such as group and instructor contact time. Thus, in LS1 it was decided that only a minimal amount of group and instructor contact time would be incorporated (3hours).

As a logical next step, LS2 incorporated an active control condition in order to provide a more robust exploration of the effects of MT. The selection of an active control condition is discussed in section 10.2.4. In short, the selected active control condition allowed for an even wider range of extraneous variables to be controlled including group contact time, daily exercise time, experimenter contact and motivation, group allocation, learning new information, participants' intention and motivation, and exercise environment. Additionally, all advertising for LS2 described the study as an "investigation into the effects of two cognitive training exercises." Thus, participants' intention and motivation were controlled between groups as they were not aware that they may be asked to engage in MT and consequently they were not primed to incorporate MT into their daily routines.

Meditation Naïve Participants and Randomisation

In section 3.5 a number of limitations were discussed concerning the cross sectional and retreat studies that included expert meditators. In order to overcome these limitations, both LS1 and LS2 explored the effects of MT in meditation naïve participants. This ensures that the findings of this study are generalisable to anybody who is interested in taking up MT. Further, group allocation was randomised for both studies in order to prevent systematic differences between groups at enrolment, including differences that can occur due to allocation and self selection bias.

Self Reported Mindfulness

The use of self report measures of mindfulness is very inconsistent across mindfulness studies with a large number of longitudinal studies omitting such measures. This inconsistency is likely to stem from uncertainty regarding whether such measures are measuring mindfulness or mindful behaviours (Chambers et al., 2009; Rapgay & Bystrisky, 2009). Despite such uncertainty it was decided to include a measure of self reported mindfulness in both LS1 and LS2 to ensure that no differences existed between groups at baseline and to assess if self reported mindfulness was modulated following MT. Herein self reported mindfulness was measured using the Five Factor Mindfulness Questionnaire (FFMQ; Baer et al., 2006). The FFMQ was expected to provide the most comprehensive assessment of different facets of mindfulness as the questionnaire was derived from an exploratory factor analysis of 6 existing self- report measures of dispositional mindfulness. More details regarding the FFMQ may be found in section 5.3.2.

Electrophysiological methods

A key objective of both LS1 and LS2 was to examine the neural mechanisms that subserve the observed attentional improvements associated with MT. Accordingly, EEG and the ERP technique were employed to measure the neural activity produced during task completion.

EEG is a procedure that measures the electrical activity of the brain over time using electrodes placed on the scalp. The recorded EEG reflects thousands of simultaneously ongoing brain processes, meaning the brains response to a single stimulus or event is usually not visible in the EEG recording of a single trial. However, repeatedly administering the same event allows an experimenter to average out the random activity that does not result from the examined event, providing a useful estimate of the activity related to said event, namely, the ERP.

The ERP technique is one of the most widely used methods for studying the neural activity that is linked to perceptual, motor and cognitive processes. ERPs provide insight into how the human brain processes signals and prepares for action. A major advantage of ERP’s is that they offer the opportunity to examine changes to the underlying processes that produce behavioural and emotional responses, whereas behavioural measures only allow us to examine the outcome of this underlying neural activity. A further major advantage of ERP’s is that they offer excellent temporal resolution (typically in the 1ms range). Therefore ERP’s provide a continuous measure of the processing that occurs between a stimulus and a response, making it possible to determine which stage(s) of processing may be affected by a specific experimental manipulation. Importantly, such changes may occur even in the absence of any observable behavioural change.

Over many decades researchers have identified specific components within ERP’s that are associated with specific neural processes. A number of these ERP components have been implicated in stages of attentional processing. Thus, said ERP components are examined herein to provide information regarding the effects of a singular MT on attentional processing. As the ERP components that are analysed herein represent ongoing neural activity during stages of attentional processing, they provide information regarding the allocation of attentional resources during task completion. Furthermore, as ERP’s have been shown to be sensitive to age related change (Onofrj et al., 2001), ERP analyses provide an appropriate method for assessing MT related changes in underlying attentional processes in older adults. The ERP components of interest and related hypotheses are presented separately for each task in the relevant theoretical backgrounds as they are somewhat distinct across tasks.

Chapter 4. General Experimental Procedure and Data Analysis Strategies

Five experiments (two LS1 and three LS2) detailed in this thesis involved the use of EEG recordings during task completion. The EEG setup, data processing and data analysis techniques were largely consistent across tasks. Chapter 4 provides details of these procedures. The Spatial Short Term Memory task (SSTM), which was a strictly behavioural experiment used to control for working memory capacity between groups, did not involve EEG recordings. However, the SSTM had a similar set up to the other tasks detailed in this section and is referred to as required.

4.1 Visual Stimulation Software

The Stroop task, ANT, ABTask and Emotional Counting Stroop (ECStroop) task were all controlled by the Cogent 2000 toolbox[13] (v1.25) running in the Matlab environment (Mathworks, http://www.mathworks.com). The SSTM was also run in the Matlab environment but was controlled by the Psychophysics Toolbox v2.54 (Brainard, 1997).The CPT was run using E-Prime version 2.0 (Sneider, Eschman, & Zuccolotto, 2012).

4.2 Equipment

Whilst the participants completed the computerised tasks, their EEG was recorded continuously from 64 active Ag/AgCl electrodes with a BioSemi Active-Two amplifier system (BioSemi, Amsterdam, Netherlands). The electrode caps used by this system ensure that the electrodes are placed in locations according to an extended version of the 10-20 system (Figure 3). In addition, horizontal and vertical electro-oculogram were recorded to monitor for eye movements and blinks with supra and infra-orbital electrodes on the left eye and two electrodes placed next to the external canthi. Participants were instructed to refrain from blinking and all stimuli were presented centrally on the monitor in order to minimise ocular artifacts. EEG and EOG were sampled at 512Hz.Two additional electrodes (Common Mode Sense and Driven

[13] Cogent 2000 Acknowledgement: This experiment was realised using Cogent 2000 developed by the Cogent 2000 team at the FIL and the ICN and Cogent Graphics developed by John Romaya at the LON at the Wellcome Department of Imaging Neuroscience

Right Leg) were used as reference and ground (for details see www.biosemi.com/faq/ cms&drl.htm).

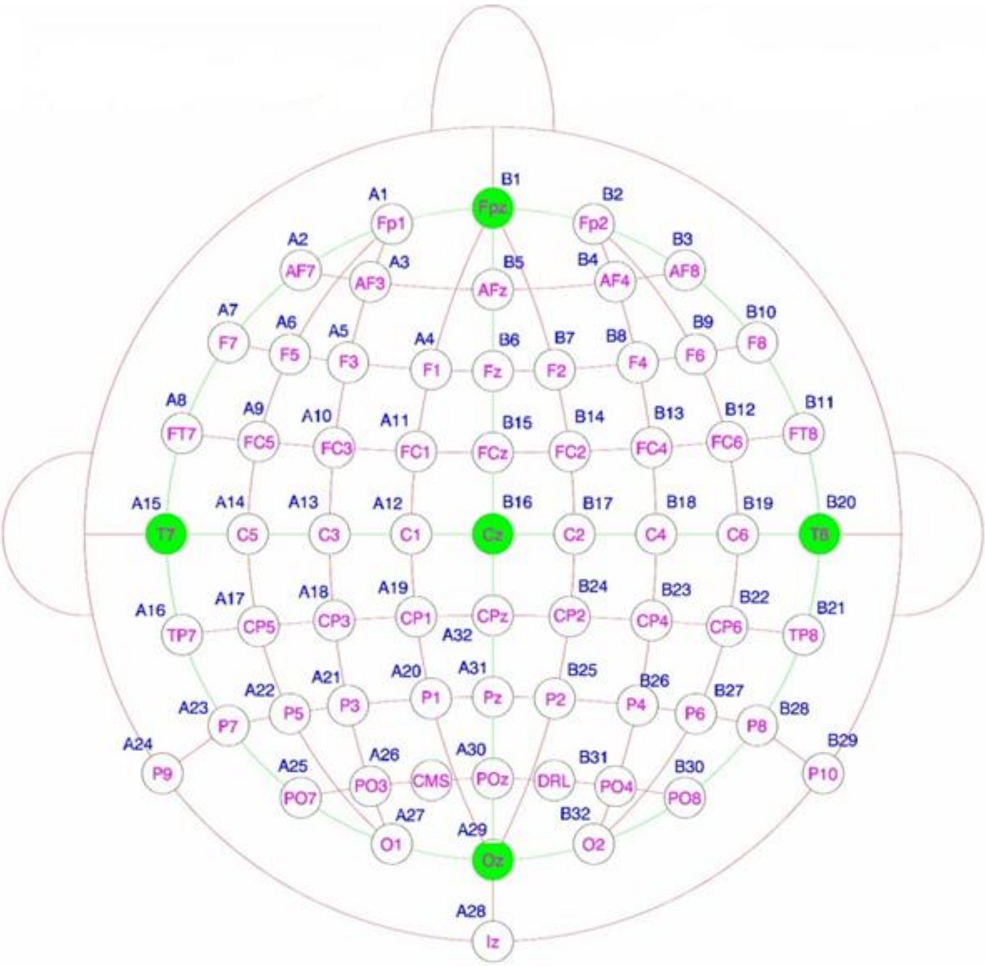

Figure 3: Extended 10-20 electrode locations

4.3 Stimulus Presentation

Each task was presented on a 21 inch CRT monitor with a 100Hz vertical refresh rate and 1024 × 768 screen resolution. Participants viewed the monitor from a distance of approximately 90cm through an electrically shielded window. An adjustable chair allowed the centre of the monitor to be aligned with the participants' eye level. For each of the tasks involving EEG recordings the participants responded using pre-specified keys on a standard QWERTY keyboard which was placed on a desk in front of the participant. SSTM responses were input via a mouse which was similarly placed on a desk in front of the participant. The participants were sat in an electrically shielded chamber throughout the EEG recording sessions whilst the experimenter monitored the recordings from a computer terminal situated immediately outside.

4.4 EEG Pre-Processing and Artifact Rejection

The standardized EEG pre-processing and artifact rejection procedure that was used for each of the ERP experiments is outlined below. All of the analyses described in this thesis were conducted using stimulus onset locked event related potentials. EEGLAB (Delorme & Makeig, 2004), ERPLAB (http://erpinfo.org/erplab) and the *Fully Automated Statistical Thresholding for EEG artifact Rejection* procedure (FASTER, Nolan, Whelan, & Reilly, 2010) were employed during the pre-processing of data. ERPLAB and FASTER are plugins that run using EEGLAB functions. ERPLAB was utilised for epoching, low and high pass filtering of EEG data, automated and manual artifact rejection of EEG data, generating averaged ERPs, plotting ERP waveforms and topographies, and for exporting data for statistical analysis. FASTER was employed to remove or correct artifacts in the data using built in automated artifact detection processes and independent components analysis (ICA). The pre-processing of data was conducted as follows:

Step 1: Epoching

The continuous EEG recordings were segmented offline into epochs starting 200ms prior to and ending 800ms post stimulus onset.

Step 2: Removal of epochs containing blinks that occurred during stimulus presentation

Blinks occurring during stimulus presentation fundamentally change the processing of the stimulus (especially if the stimulus is not seen or only part seen because of the blink). As such, epochs containing said blinks were excluded from further processing rather than simply being corrected and included. ERPLABs moving window peak to peak function (100 µV amplitude threshold, 200ms window, 50ms steps) was used to exclude epochs with blinks that occurred around the time of stimulus presentation (-200ms to 200ms post stimulus) prior to the data being run through FASTER.

Step 3: Automated artifact identification and correction using FASTER

FASTER was utilised as a first step for artifact detection and to correct for stereotyped ocular artifacts as it contains automated routines for artifact detection and correction that have been shown to perform better than visual artifact detection by experts (Nolan et al., 2010). FASTER was run using a predefined rejection threshold of ±3 z-scores for each parameter. Artifacts were detected and corrected regarding single channels[14], epochs[15], independent components[16] (based on the infomax algorithm, Bell & Sejnowski, 1995) and single-channel single-epochs[17]. Data were baseline corrected prior to ICA (-60 to 0ms for LS1 Stroop task and -100 to 0ms for all other tasks). Fz was used as reference during pre-processing as per instructions detailed in the FASTER manual. The output from FASTER produces data that is algebraically re-referenced to average reference.

Step 4: Filtering

ERPLAB was used to low pass filter the data in order to exclude high frequency noise (eg. muscle tension). A 16Hz low pass filter was used for the data acquired during LS1 and a 30Hz low pass filter was used for the data acquired during LS2. An analogous 0.16hz online high pass filter was applied during data acquisition. For LS2 no further high pass filter was used whilst a 1Hz high pass filter was used for LS1.

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[14] Artifactual activity within specific channels: Potential causes include movement of electrode during recording, poor contact with the scalp or mechanical fault. Specific channels were classified as artifactual based on their correlation with neighbouring channels and the variance of the channels signal over time. Bad channels were removed from further analysis and replaced with data reconstructed by interpolating from neighbouring electrodes.

[15] Artifactual activity within specific epochs: The most likely cause would be participant movement which physically moves the electrodes and causes all channel noise within an epoch. FASTER identifies such artifactual epochs by examining the amplitude range and variance within an epoch and the deviation from the channels average. Artifactual epochs were removed from further analysis.

[16] Artifactual independent components (IC): ICA was used to identify artifactual independent components. ICA is a computational method that separates time series data into statistically IC waveforms. ICA outputs a matrix that transforms EEG data to IC data, and its inverse matrix to transform IC data back to EEG data. These matrices give information about an IC's spatial properties, and the data gives information about the IC's temporal activity. Data recorded from scalp electrodes can be considered summations of EEG data and artifact, which are independent of each other. ICA may thus be used to separate artifact from EEG signal. FASTER contains algorithms for unsupervised removal of artifactual IC's and was mostly used herein to correct for eye blinks. Removed IC's can be and were viewed to ensure that they were indeed artifactual.

[17] Artifacts in single channels in single epochs: The above 3 methods remove a high percentage of artifacts, however, small transient artifacts may remain on single channels, within single epochs. For example, short bursts of white noise due to transient electrical faults, or electrodes that lost contact during a recording and were not sufficiently noisy to be detected as bad channels. Such artifacts were corrected by interpolating the single channel within the single epoch.

Step 5: Additional automated artifact rejection

Three of ERPLABs built in artifact detection functions were used to exclude any epochs containing artifacts that had been missed by FASTER. These functions were applied to the entire epoch. The *simple voltage threshold function* was used to exclude epochs with voltages that exceeded -100 and +100 µV. The *step function* was used to remove epochs with saccadic eye movements using a 60 µV threshold, 400ms wide window and 10ms steps. Finally, the *moving window peak to peak function* was used twice, firstly to identify any remaining blinks using a 100 µV threshold, 200ms window and 20ms steps and secondly to identify slow drifts using a 75 µV threshold, 400ms window and 20ms steps.

Step 6: Visual inspection of EEG data and manual artifact rejection

As a final step the EEG data were inspected visually. This served 2 purposes. Firstly, to identify any epochs containing artifacts that had been missed by the rigorous pre-processing strategy. Secondly, to ensure that the epochs being excluded by the automated routines were being excluded correctly. No issues with the automated rejection and correction routines were identified during the visual inspection.

Outcome of artifact rejection and correction procedures

The stringent artifact detection and artifact correction procedures detailed above resulted in an average trial loss of 11.8 % per task, across the 5 tasks, for the participants who are included in the final ERP analyses (see Table 5). Importantly, t-tests computed for each time point for LS1 and LS2 found that the amount of available data was comparable across groups, for all tasks, at all time points (all p >.05).

Individual data sets with more than 30% loss of data were considered candidates for exclusion. The most common reason for data set exclusion was an excessive loss of trials due to movement related artifacts. This problem was more severe in LS2 as the sample included a large number of participants who had limited prior computer use, with unfamiliarity of computers being the most likely cause of excessive movement during task completion.

Table 5: Summary of trial loss due to artifact rejection procedures. Includes only the participants who were included in the final statistical ERP analyses.

	Time	Trial Loss Per Task (%)		
Longitudinal Study 1		Stroop Task (N= 28)	ANT (N= 28)	
	T1	9.4	6.0	
	T2	8.2	7.7	
	T3	9.0	8.6	
Longitudinal Study 2		CPT (N= 44)	ECStroop (N= 43)	ABTask (N= 45)
	T1	15.7	13.8	14.5
	T2	19.7	17.6	10.9

4.5 ERP Component Identification Strategy

A standardized procedure for identifying and analysing ERP components was employed for each of the experiments described in this thesis. The procedure was as follows:

Step 1: Grand mean evoked potential

To ensure that task relevant ERP components were identified based on the largest amount of available data, time 1 (T1) data for all subjects who completed the task were pooled to create a grand mean evoked potential.

Step 2: Identification of potential ERP components and time windows of interest

The grand mean evoked potential was used to generate instantaneous amplitude spherical spline interpolated scalp topographies. Said topographies allow for the inspection of the amplitude at all electrode sites at the chosen moment in time. This method allows identification of time windows during which ERP components appear to be occurring. Topographies were generated in 10ms intervals, from stimulus onset to 800ms post stimulus, depicting time-dependant amplitude changes across electrode sites. Figure 4 provides an example of topographies that clearly illustrate a positive central posterior ERP component developing from 350ms onwards, peaking around 540ms and then slowly fading away.

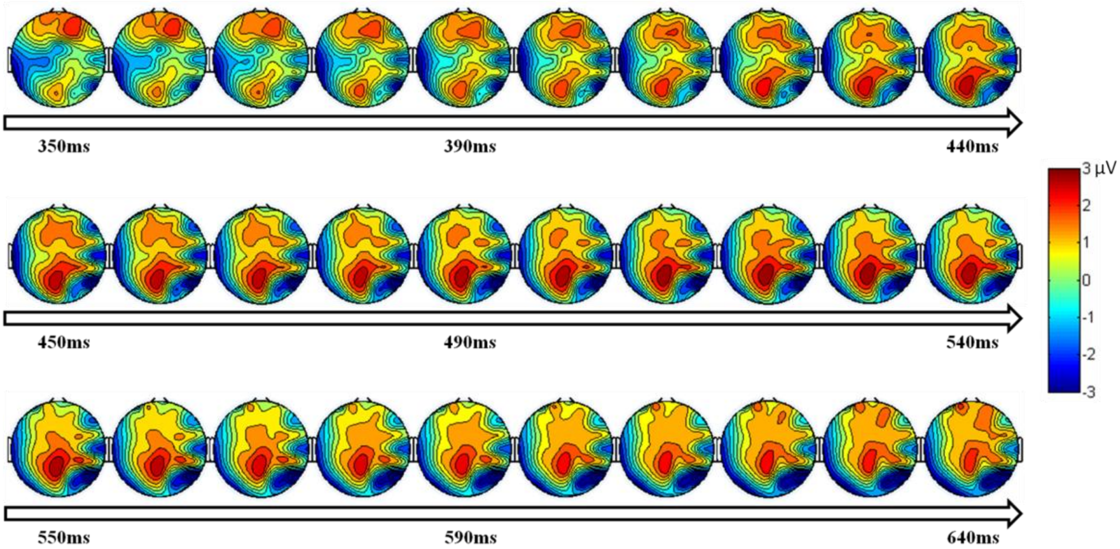

Figure 4: Example instantaneous amplitude spherical spline scalp topographies displayed in 10ms steps from left to right for a time window of 350ms to 640ms

Step 3: Identification of electrode sites of interest

The next step was to identify electrode sites that were representative of the maxima of the identified ERP component. This step was completed by using the grand mean evoked potential to produce two further plots. Firstly, a mean amplitude spherical spline topography was produced based on the time window that was identified in step 2 (Figure 5). Secondly, a topographical arrangement of ERP waveforms was produced (Figure 6).

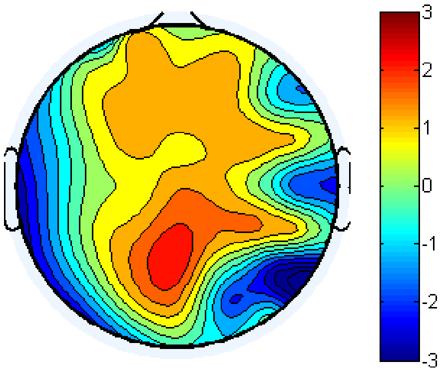

Figure 5: Example mean amplitude spherical spline interpolated topography for 350 to 640ms time window

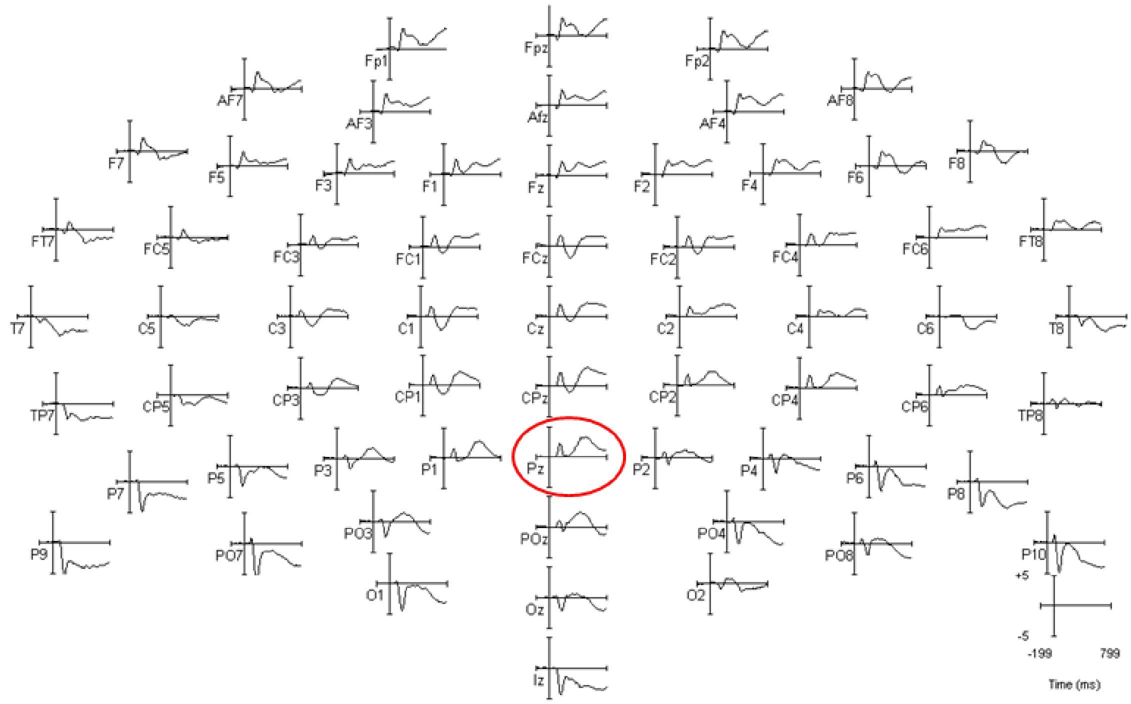

Figure 6: Example topographical arrangement of ERP waveforms

Visual inspection of the mean amplitude spherical spline scalp topographies allowed the general area of important electrode sites to be identified and guided the visual inspection of the topographical arrangement of ERP waveforms. It is clear that the identified ERP component’s maximum was best represented by electrode site Pz for the examples shown in Figure 5 and Figure 6. In certain instances, if the topography of a particular component was widespread across multiple electrode sites, the data from adjacent electrode sites were averaged to best capture the maxima of an ERP component. This process often provides a more robust reflection of the maxima of a component in instances where the topography of an ERP component may vary slightly between participants.

Step 4: Finalise time window

The ERP waveform of the identified electrode site (or cluster of sites) was visually inspected to precisely identify the time window that best captured the component of interest.

Step 5: Data exported for statistical analysis

The ERP component of interest was measured by calculating the mean amplitude, at the chosen electrode site (or cluster of sites), for the chosen time window. Said mean amplitudes were exported to SPSS and used as dependent variables for statistical analysis.

Additional information

Time windows, ERP components and electrode sites of interest often vary across conditions. Thus, the specific time windows, ERP components and electrode sites that were used during data analysis will be reported in the relevant *outcome measures and hypotheses* sections. Each of these sections will discuss the identified ERP components in the context of prior research.

4.6 Statistical Analysis Procedures

The employed statistical analysis procedures were similar across LS1 and LS2. The main analyses utilised either Mixed ANOVAs or Repeated Measures ANOVAs to explore both behavioural and electrophysiological changes over time. As both studies are longitudinal examinations of MT, *Group x Time* interactions were the focus of each analysis as said interactions would evince differential changes over time between groups. Planned contrasts and Paired Samples t-tests were used in certain instances to further qualify observed *Group x Time* interactions. Effect size r was calculated for significant focussed effects only, e.g. significant *Group x Time* interactions between 2 time points. Potential baseline differences between groups were analysed using independent samples t-tests.

Throughout this thesis degrees of freedom (*df*) were corrected using Greenhouse-Geisser estimates of sphericity on the rare occasions that Mauchly's test indicated that the assumption of sphericity had been violated. Similarly, if Levene's test for equality of variances was violated *df* were adjusted and the corresponding 'equality of variances not assumed' value was reported. Whenever the above occurs it is clearly denoted throughout.

Chapter 5. Longitudinal Study 1: The Effect of Mindfulness Training on Attentional Functions and Task Related Neural Activity

5.1 Longitudinal Study 1 Overview

Contents of Chapters 5-8

Chapter 5 describes the study design, methods and materials utilised in LS1. Chapter 5 also contains the results of the analyses concerning the administered self report measures and from the tests for baseline differences between groups. Chapters 6 and 7 are the empirical Chapters related to LS1, detailing the use of the Stroop task and ANT respectively. Each of these Chapters contains the theoretical background for the use of the respective experimental task, the associated hypotheses and outcome measures, the task design and the empirical results. Chapter 8 contains a discussion regarding the implications of the findings from LS1.

Longitudinal Study 1 summary

LS1 was conducted to meet a main objective of this thesis, to investigate whether a singular, brief, MT technique, carried out regularly for approximately 18 weeks, would lead to detectable changes in attentional functions and their associated neural mechanisms. To this end, 40 participants were randomised to a mindfulness training group (MTG) or wait list control group (WCG) prior to completing two different tests of attentional functions (Stroop Task and ANT), at three time points, approximately nine weeks apart.

A series of Mixed ANOVAs, planned contrasts and paired samples t-tests demonstrated that even a singular, brief, MT technique is able to modulate neural processes related to attentional and object recognition processes (Stroop Task), to improve behavioural performance associated with improved sustained and executive attention (ANT) and to increase self reported mindfulness (FFMQ). The results detailed in Chapters 5-8 lay the empirical foundations for LS2 and an examination of the potential for MT to positively modulate attentional functions and their associated neural activity in older adults.

5.2 Methods

5.2.1 Design and Procedure

LS1 was a randomised wait list control group study. The study design incorporated a number of key features in order to more directly attribute improvements in attentional functions and their associated neural activity to MT. First and foremost, a singular MT technique was used (described in section 5.2.3), making it easier to demonstrate MT related change. Second, an approach with a minimum of group contact time (3 hours) and limited amount of daily MT (10-15 minutes) was employed, ensuring the assessed MT was a viable option for people who may consider integrating mindfulness practice into daily life without change or disruption to established daily routines. Lastly, as all of the enrolled participants would eventually be offered MT (post study in the wait list control group), participants' intention and motivation for enrolment were controlled.

Participants were tested at 3 time points. For the participants who were included in the statistical analyses the average time between T1 and T3 was 18.4 weeks, with 9.8 weeks occurring between T1 and T2 and 8.6 weeks from T2 to T3[18]. Importantly, these times were controlled across groups (t-tests all $p > .3$). The inclusion of T2 midway through the study allowed for a more complete assessment of the trajectory of change. Prior to T1 participants were randomised to MTG or WCG. Participants were pre-screened to ensure they were meditation naïve (no previous meditation experience), had normal or corrected to normal visual acuity, confirmed no ongoing or recent mental health problems or neurological disorders (e.g., epilepsy) and confirmed they were not receiving any psychopharmacological treatments.

LS1 employed two well established tasks in order to assess a wide range of attentional functions and their associated neural mechanisms. A computerised version of the Stroop task was employed to examine the behavioural and electrophysiological changes related to the processing of conflicting stimulus material that may occur following MT. The ANT was employed to assess behavioural and electrophysiological modulations of attentional functions related to the alerting, orienting and executive

[18] The logistics of conducting such a vast amount of testing sessions dictated the detailed time frames. The initial idea had been for testing sessions to occur at baseline and after 8 and then 16 weeks.

networks of attention. At each time point, participants first completed the self-report questionnaires (see 5.3 Materials) before completing the ANT followed by the Stroop Task. The participants' EEG was recorded during task completion. Testing sessions were approximately 2 hours long.

5.2.2 Participants

The flow of participants through the study is detailed in Figure 7. In total, 40 healthy adults (13 males; mean age 35.4 years) were recruited via a combination of online advertisements and from a psychology participant panel maintained at Liverpool John Moores University (LJMU). Of these participants, 38 described themselves as "White" or "White/British," 1 as "White/Irish" and 1 as "White/Caribbean." The majority of participants stated no religion, of the remaining participants 15 classed their religious background as Christian (Christian, Roman Catholic, Church of England), 1 as Atheist and 1 as Agnostic. The sample was mostly made up of working adults who were in full-time/part-time employment or in voluntary work. The sample only included 3 students. The majority of participants were educated to at least undergraduate level and 11 participants held postgraduate qualifications. All participants provided written, informed consent and were reimbursed with £10/h for time spent attending LJMU.

The study was carried out in line with the ethics guidelines of the British Psychological Society and was approved by the LJMU Research Ethics Committee.

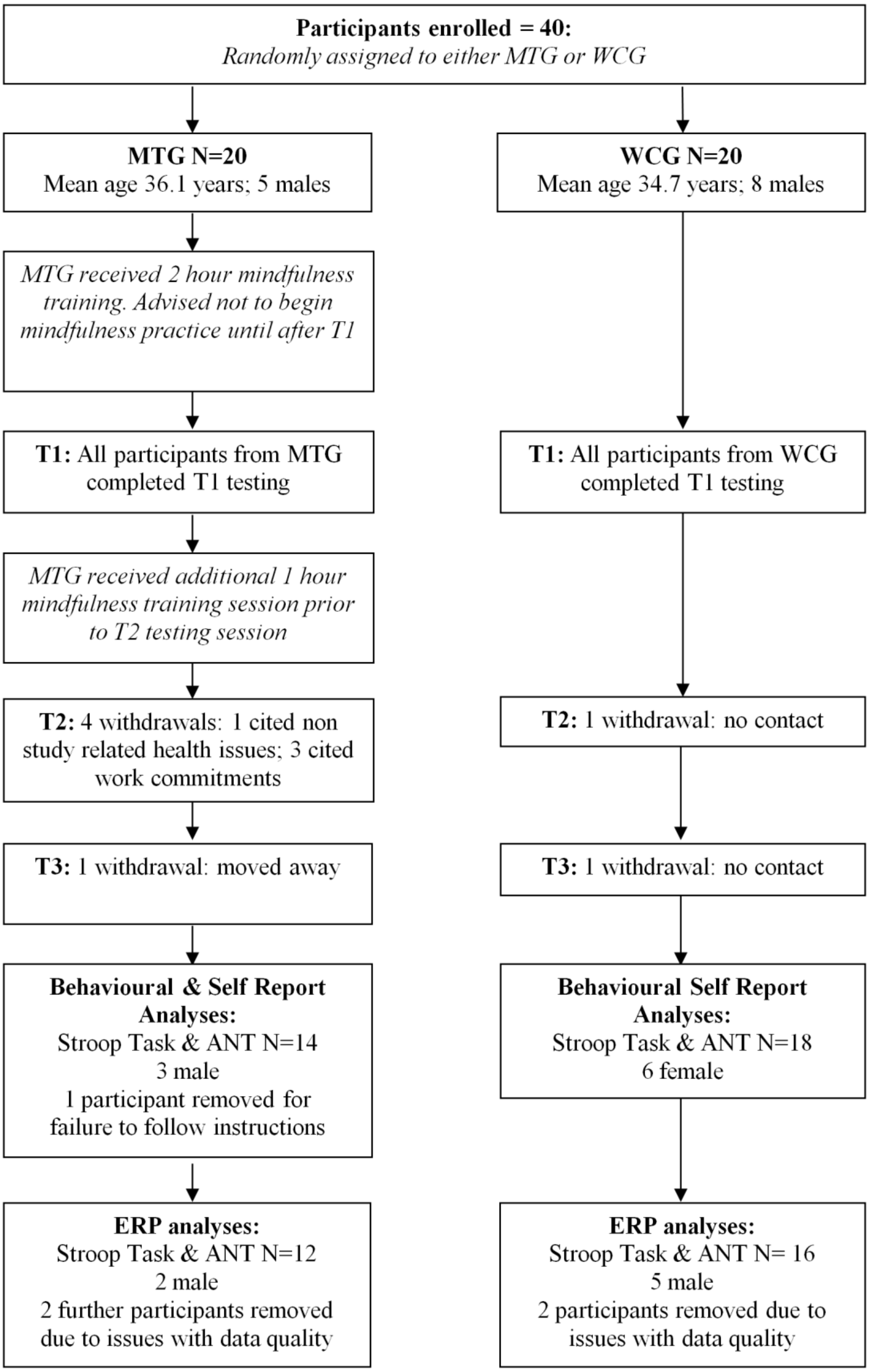

Figure 7: Flow of participants through the study

5.2.3 Mindfulness Training

Prior to T1 testing, the MTG received an introductory 2 hour MT session. In order to obtain accurate baseline data the MTG were instructed not to begin practicing meditation until after T1 testing was complete. A follow up 1 hour meditation training session was given to the MTG prior to T2. Throughout the study the participants had an experienced meditation teacher available to answer questions or give further instruction at all times. Only one participant made use of this opportunity, on one occasion.

The MT involved a simple mindfulness based breath awareness meditation taught by a meditation teacher with more than 15 years of teaching experience. In this meditation the meditator is required to focus their attention on the sensations accompanying their breathing, either attending to the experience at the nostrils, around the diaphragm or the movement of the abdomen when in-and exhaling, without manipulating the breath in any form. Whenever attention would slip or wander off, the task would be to become aware of it and, without further elaboration, to redirect the focus of attention back to the sensation of breathing. In addition to this focusing of attention, participants were instructed to observe other mental experiences, arising thoughts, feelings or sensations, trying not to judge or evaluate them, and maintain a curious, non-elaborating attitude toward them. This meditation instruction is in line with common psychological mindfulness conceptualisations that emphasise the development of attentional abilities combined with a specific, non-judgmental and non-evaluative attitude toward the different mental experiences that may arise (e.g., Bishop, 2002; Chiesa & Malinowski, 2011; Malinowski, 2008; Shapiro et al., 2006). For the period between T1 and T3 (18 weeks) participants were asked to meditate regularly for a minimum of 10 minutes per day, at least 5 days per week and to record frequency and duration in their meditation log (section 5.3.3) on a weekly basis.

The participants did not receive any particular instructions regarding body posture beyond the emphasis of trying to sit in an upright, relaxed position with a straight back. They had the liberty to meditate on a chair, meditation stool, or cushion. Given the low dosage of meditation it was not expected that the specific meditation posture would produce a discernible effect and thus these details were not recorded.

5.3 Materials

5.3.1 Global Well-Being

The Subjective Happiness Scale (SHS, Lyubomirsky & Lepper, 1999) was used to assess the global, subjective assessment of participants' own happiness and well-being. The SHS is a brief four-item questionnaire scored on a seven-point Likert scale (range: 4-28) and includes items like "In general I consider myself a very happy person." High total scores reflect high levels of global well-being/happiness. The SHS has been successfully used in different community-based and college-student samples, showing Cronbach's alpha values between 0.79 and 0.94 (Lyubomirsky & Tucker, 1998 Lyubomirsky & Lepper, 1999).

5.3.2 Mindfulness

The FFMQ was used to assess different aspects of mindfulness that were expected to be influenced by MT. This 39-item questionnaire was derived from an exploratory factor analysis of 6 existing self- report measures of dispositional mindfulness (Baer et al., 2006). Validation on 2 samples (Baer et al., 2006; Baer et al., 2008) suggests a 5 factor structure: (1) *Non-reactivity* to inner experience (FFMQ-NR; 7 items), e.g., "I watch my feelings without getting lost in them"; (2) *Observing* internal and external sensations including thoughts, emotions, sights, sounds, and smells (FFMQ-O; 8 items) e.g., "I intentionally stay aware of my feelings"; (3) *Acting with awareness* describes attending to one's actions in the present moment and can be contrasted with automatic, impulsive, or habitual behaving (FFMQ-A; 8 items), e.g., "It seems I am running on automatic without much awareness of what I'm doing"; (4) *Describing* involves labelling internal experiences with words (FFMQ-D; 8 items), e.g., "When I have a sensation in my body, it's hard for me to describe it because I can't find the right words"; (5) *Non-judging of experience* means refraining from value judgments or self-criticism (FFMQ-NJ; 8 items) "I tend to evaluate whether my perceptions are right or wrong." The response format comprises a 5-point Likert scale (1 = never or very rarely true, rarely true, sometimes true, often true, and 5 = very often or always true). After reversing the scores for the 19 negatively worded items, scores between 1 and 5 are summed to produce totals for each subscale and a total scale score (range: 39–195). The FFMQ has been shown to have good internal consistency and significant relationships in the predicted directions with a variety of constructs related to mindfulness. The internal consistencies (Cronbach α) for these facets have been reported as 0.75 for FFMQ-NR, 0.83 for FFMQ-O, 0.87 for FFMQ-A, 0.91 for FFMQ-D, and 0.87 for FFMQ-NJ (Baer et al., 2006).

5.3.3 Meditation Log

On a weekly basis participants in the meditation group completed a brief meditation diary (online or paper-pencil version), which recorded how often they meditated in a given week and the average length of the meditation sessions.

5.4 Overall Results

This section contains a brief summary of the results that are applicable to LS1 as a whole. Included are the results of tests for baseline differences between the groups and the self report questionnaire results.

5.4.1 Test for Baseline Differences Between Groups

Importantly, as summarised in Table1, there were no baseline differences between the MTG and WCG in terms of age, dispositional mindfulness and subjective happiness.

Table 6: Summary of tests for baseline differences, with mean values (standard deviations) and respective statistical values (all two tailed) for the comparison between MTG and WCG. Includes only the participants who are included in the statistical analyses

	MTG (N=14)	**WCG (N=18)**	**Statistical Values**	
Age (years)	36.2 (12.4)	35.4 (11.1)	$t(30) = .185$,	$p = .885$
FFMQ-total	126.9 (14.6)	134.8 (13.2)	$t(30) = -1.594$,	$p = .121$
SHS-total	22.0 (2.9)	21.3 (3.4)	$t(30) = .618$,	$p = .542$

5.4.2 Self Report Results

Mindfulness

Total mindfulness score (all 5 subscale scores combined) and the scores for each of the 5 FFMQ subscales were subjected to separate *Time* (3) x *Group* (2) Repeated Measures ANOVAs. For the total mindfulness score (FFMQ-total), which combines the scores on the 5 FFMQ subscales, a significant main effect of *Time* [F(2,60) = 6.167, p = .006] was observed, indicating that overall the mindfulness scores increased from T1toT3 (T1:131.3, T2:134.1, T3:136.7). The significant *Group* x *Time* interaction [F(2,60) = 5.302, p =.008] indicated that MTG and WCG had modulated mindfulness scores differently. Planned contrasts revealed significant interactions when comparing MTG and WCG scores from T1-T3 [F(1,30) = 6.067, p = .020, r = .410] and T1-T2 [F(1,30) = 7.730 p = .009, r = .453], but no significant interactions were found when comparing MTG and WCG totals from T2-T3 [F(1,30) = .031 p = .862]. The mindfulness increase from T1 toT3 was more pronounced in MTG (T3–T1: 10.9 points, t(13)= -3.039, p = .009) than WCG (T3–T1:1.1 points, t(17)= -.486, p = .633).

The analysis of the FFMQ subscales revealed a stronger increase in MTG than WCG in FFMQ-O [*Group x Time*, F(2,60) = 4.252, p = .019] and FFMQ-NR [*Group x Time*, F(2,60) = 4.562, p = .015]. No other significant effects emerged from the analysis of the FFMQ subscales.

Meditation time

In general, the participants in the meditation group managed to adhere to the required meditation schedule. Based on the meditation logs, the mean time spent meditating during each session was 11.3min (range: 6.2–21.5mins) and the average number of meditations per week was 5.0 sessions (range: 2.6–8.7).

Subjective Happiness

SHS scores were subjected to a *Time* (3) x *Group* (2) Repeated Measures ANOVA, revealing a significant main effect of *Time* [F(1.55, 46.35) = 6.353, p = .007] which indicated that mean scores pooled across groups (N=32) changed slightly throughout the study (T1 = 21.7, T2 = 20.7, T3 = 22.0). No significant between group or interaction effects were found.

Chapter 6. Mindfulness Training and Executive Functioning: The Stroop Task

6.1 Theoretical Background

The literature reviewed in Chapters 2 and 3 provided the theoretical background for the study of MT and attention, establishing the importance of both executive and sustained attention. Section 3.6.1 detailed that a main objective of LS1 was to examine the effect of a singular, breath awareness MT technique on executive and sustained attention functions and their associated neural activity. To this end the Stroop task (Stroop, 1935), a canonical measure of executive attention was employed. This Chapter discusses the detailed analysis and results obtained by using the Stroop task as well as the reasons for why this task was chosen, the tasks design, its associated outcome measures and specific hypotheses.

The Stroop Task, Executive Attention and Mindfulness Training

The Stroop task (Stroop, 1935) was chosen for use in LS1 as it is a canonical measure of executive attention. During the Stroop task participants are asked to name the colour in which words are presented. When this colour is incongruent to the words semantic meaning, e.g. BLUE, the participant must deliberately engage executive functions in order to inhibit the automatic/habitual response of word reading. The successful completion of the Stroop task requires an ongoing monitoring of attention for conflict in order that the goal of attending to the salient/goal directed aspect of the stimulus (i.e. ink colour) may be accomplished via the inhibition of automatic/habitual responses. As word reading is highly automatic in proficient readers, participants' responses are significantly slower and less accurate in the incongruent condition compared to when the word meaning is semantically congruent or neutral to the ink colour (C. M. MacLeod, 1991). The so called 'Stroop Effect' is the decrement in reaction time or increase in error rates found for incongruent as compared to congruent, or neutral, words. A number of EEG studies have identified a late negative ERP component (LN) that is associated with this behavioural Stroop effect (Hanslmayr et al., 2008; Liotti et al., 2000). Further, these studies have identified the ACC as the generator of the LN. Given the ACC's involvement in the executive and salience networks and its proposed function in 1) monitoring current behaviour in relation to a desired goal

(Kerns et al., 2004) and 2) the anticipatory regulation of attention (Aarts, Roelofs, & van Turennout, 2008; Roelofs, van Turennout, & Coles, 2006), ACC activation during Stroop task completion suggests that the task provides an effective measure of executive functions and their related neural mechanisms.

The Stroop task may be especially effective as a measure of MT related executive improvements as it taps key attentional processes that have been implicated during meditation. A number of studies have observed executive and salience network activation whilst meditators and non-meditators meditated (Baron Short et al., 2007; Hasenkamp et al., 2012; Hölzel et al., 2007), with the salience network carrying out an attentional monitoring function (Hasenkamp et al., 2012). Furthermore, as previous studies (e.g. Greenberg et al., 2012; Jha et al., 2007) have observed enhanced executive functioning in expert meditators when they completed tasks outside of and very different from meditation, it appears that MT may capitalise on the plasticity of attentional functions and produce changes that crossover out of meditation into other tasks. Moreover, a number of studies observed greater Stroop task performance in expert meditators as compared to controls (Chan & Woollacott, 2007; Moore & Malinowski, 2009; Teper & Inzlicht, 2013), suggesting that executive attention as measured by the Stroop task may be modulated through long term MT. However, the improvements in executive functions that have been found following short MT inductions (Friese et al., 2012; Tang et al., 2007; Wenk-Sormaz, 2005) have not been replicated over longer periods of time (Anderson et al., 2007; Polak, 2009). The design of LS1 overcomes the limitations of previous studies (detailed in Sections 3.5 and 3.6.2) and allows for a more direct examination of the effect of MT on executive functions through the use of a singular MT technique and the concurrent examination of behavioural and electrophysiological data. Based on the evidence detailed in Chapter 3 and the abovementioned prior results it was hypothesised that MT would improve both behavioural and electrophysiological markers of attentional functions. The specific behavioural and electrophysiological outcome measures and associated hypotheses are detailed below.

Behavioural Outcome Measures & Hypotheses

Mean RTs, the behavioural Stroop effect (incongruent RTs – congruent RTs) and response accuracy (in terms of hit rates[19]; HRs) were the focus of the behavioural analyses. It was hypothesised that MT would be linked to improvements in all markers of behavioural performance. It was expected that the behavioural Stroop effect may be reduced following MT as reduced behavioural Stroop effects (Chan & Woollacott, 2007) and reduced conflict effects (ANT, Jha et al., 2007) have been found in expert meditators and following brief mindfulness inductions (Tang et al., 2007; Wenk-Sormaz, 2005). Said reduction would be indicative of improved executive attention. Reductions in mean RTs and error rates were also expected. As such reductions would rely on improved attentional focus to the goal relevant aspect of the presented stimulus (i.e. ink colour naming) they would likely evince improvements in sustained attention.

Electrophysiological Outcome Measures & Hypotheses

The use of EEG recordings and the ERP methodology allowed for an examination of the attentional processing that occurs between the presentation of a Stroop stimulus and the behavioural response. The ERP component identification strategy detailed in section 4.4 resulted in the identification of 4 main ERP components of interest to be used as outcome measures.

Two components were identified in the 160 to 240ms post stimulus time window in small clusters of parietal-occipital (PO) electrode sites of the left (PO7, PO3 and O1) and right (PO8, PO4 and O2) hemispheres, for both the congruent and incongruent conditions (see Figure 12and Figure 13). These PO components are typically labelled N2 components when they appear around 150ms post stimulus onset and are typically seen in lexical decision making tasks[20] (Cohen & Dehaene, 2004; Cohen et al., 2002; Shaywitz et al., 2004). N2 components (elicited by visual stimuli) with posterior scalp distributions have been implicated in attentional processes (Folstein & van Petten, 2008). As a moment to moment monitoring of attention is engaged during

[19] Throughout this thesis accuracy is measured using hit rates, i.e. % correct. Hit rates rather than errors were chosen to represent accuracy as hit rates reflect positive task performance and provide a closer link to sustained attention to salient/goal directed information.

[20] Lexical decision making tasks require the semantic categorisation of words and non-words.

MT (Hasenkamp et al., 2012), it is proposed that MT may influence early stimulus discrimination processes that are relevant to the goal of the task (i.e. ink colour naming). It was hypothesised that MT may result in increased N2 mean amplitude across conditions. As ERP components of this latency and topography have previously been shown to be influenced by semantic category (Adorni & Proverbio, 2009), increased N2 mean amplitude would be indicative of enhanced attentional processing of the Stroop word stimuli.

A further ERP component was observed in the 310 to 380ms time window, peaking at electrode site Pz (see Figure 15 and Figure 16). ERP components of this latency and location are typically labelled P3 or P3b and have been linked to various attentional processes depending on the task at hand. In paradigms such as the Stroop task, where conflicting stimulus information is present, P3 ERP components are typically linked to inhibition processes and attentional resource allocation that is generated when perceptual stimulus discrimination occurs (Polich, 2007), i.e. during object recognition processes. First electrophysiological examinations of attention effects in mindfulness meditators have reported reductions in the P3 component in response to distracter sounds (Cahn & Polich, 2009) and as an indicator of improved resource allocation in the ABtask (Slagter, Lutz, et al., 2007). Thus, it was hypothesised that MT may lead to less resource intensive object recognition processing when conflicting stimulus information was present (i.e. the incongruent condition), evinced by a reduction in P3 mean amplitude.

A final ERP component, peaking at electrode site POz, was observed in the 400 to 600ms time window (see Figure 18). In order to confirm that this final component was the LN component observed in previous Stroop studies (Hanslmayr et al., 2008; Liotti et al., 2000) the T1 POz mean amplitudes for the incongruent and congruent conditions were pooled across groups and subjected to a Paired Samples t-test. A significant difference between these conditions ($t(27)=2.785$, $p = .010$) demonstrated a robust electrophysiological Stroop effect. Given that the behavioural Stroop effect was expected to reduce following MT, it was concurrently hypothesised that the LN ERP component would be similarly modulated following MT.

6.2 Task Design and Stimuli

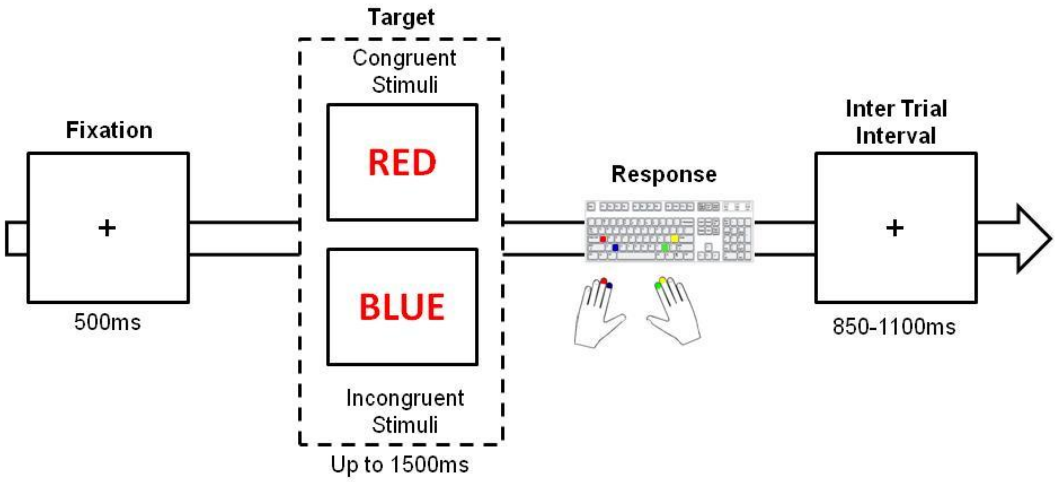

Figure 9: Stroop task trial design and timings

Stimuli consisted of 4 colour words (red, blue, green and yellow) presented in the same colour as the written word in congruent trials (e.g. '**RED**') and in different colours in incongruent trials (e.g. '**BLUE**'). Words were presented in Arial font (size 48pt) against a black background. Each incongruent stimulus appeared in each of the 3 colours not matching its meaning an equal number of times. The participants' task was to report the colour in which the word was printed, ignoring the words meaning. Responses were mapped to the "**a**" (red, left middle finger), "**x**" (blue, left index finger), "**.**" (green, right index finger), and " **'** " (yellow, right middle finger) keys of a standard QWERTY keyboard. The keys were colour-coded and chosen to provide optimum comfort for the participant whilst responding. Participants were instructed to respond as quickly and accurately as possible.

Each trial began with the presentation of a fixation cross for 500ms, followed by the colour word for 1500ms. The stimulus always appeared centrally, replacing the fixation cross. There was a variable inter-trial interval of between 850 and 1100ms (see Figure 9). The experiment began with a colour to key acquisition phase which consisted of 48 trials that were similar to those used in the experimental blocks. Mistakes were highlighted by an audible tone during this phase only. The experimental phase consisted of 3 blocks of 48 trials (50% of trials congruent and 50% incongruent) for a total of 144 trials (72 trials per condition). Each trial block lasted approximately 3 minutes and was followed by a 20 second break before the subsequent block. The experiment took approximately 12 minutes in total.

6.3 Results

One participant was removed from both the behavioural and ERP analyses due to failure to follow task instructions.

6.3.1 Behavioural Analyses

Importantly, no differences in behavioural performance were found between MTG and WCG at baseline (Table 7).

Table 7: Summary of tests for baseline differences, with mean values (standard deviations) and respective statistical values (all 2 tailed) for the comparison between MTG and WCG. Only participants who completed the study are included in this analysis

	MTG (N=14)	WCG (N=18)	Statistical Values	
Stroop RT Overall (ms)	781 (115)	747 (124)	$t(30) = .817$,	$p = .420$
Stroop RT Congruent (ms)	730 (109)	691 (113)	$t(30) = .987$,	$p = .332$
Stroop RT Incongruent (ms)	836 (129)	806 (145)	$t(30) = .613$,	$p = .544$
Stroop Effect (ms)	106 (63)	115 (66)	$t(30) = -.384$,	$p = .703$
Stroop HR Overall (%)	95.1 (4.1)	94.7 (6.2)	$t(30) = .209$,	$p = .836$

<u>*Reaction Times*</u>

RTs were subjected to a *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVA (Table 8) to examine between group differences. Significant main effects of *Time* and of *Congruency* were observed. The significant main effect of *Congruency* confirms the efficacy of the behavioural manipulation, with incongruent trials producing slower RTs than congruent trials (795 vs. 688ms) when RTs were pooled across groups and time points. The significant main effect of *Time* was caused by an overall (pooled across groups and congruencies) decrease in RTs from T1 (762ms) to T2 (731ms) and again to T3 (729ms). A series of planned contrasts revealed a significant difference between RTs at T1 and T2 [$F(1,30) = 7.162$, $p = .012$, $r = .439$] and T1 compared with T3 [$F(1,30) = 8.177$, $p = .008$, $r = .463$], however, there was no significant change between T2 and T3 [$F(1,30) = .087$, $p = .770$].

Table 8: Summary of Mixed ANOVA results for RT mean (*Time* (3) x *Congruency* (2) x *Group* (2)) and the Stroop Effect (*Time* (3) x *Group* (2))

	Effect	**Statistical Values**	
<u>RT mean</u>			
	Time	F(1.52, 45.65*) = 6.456,	*p* = .006
	Group x Time	F(1.52, 45.65*) = .843,	*p* = .436
	Group	F(1,30) = .334,	*p* = .567
	Congruency	F(1,30) = 129.318,	*p* < .001
	Congruency x Group	F(1,30) = .003,	*p* = .960
	Time x Congruency x Group	F(1.66, 49.74*) = .790,	*p* = .438
	Time x Congruency	F(1.66, 49.74*) = .346,	*p* = .669
<u>Stroop Effect</u>			
	Time	F(1.66, 49.74*) = 346,	*p* = .709
	Group x Time	F(1.66, 49.74*) = .790,	*p* = .438
	Group	F(1,30) =.003,	*p* = .960

* Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity

Figure 10 depicts the RT change over time and includes the per group change in RTs (pooled across congruencies) for information. This pattern of results suggests that T1 to T2 changes reflect a general practice related improvement and that no further change occurred following T2. The non-significant *Group x Time* interaction confirms that MTG did not modulate RT differently to WCG, most likely due to a performance ceiling being reached by both groups at T2.

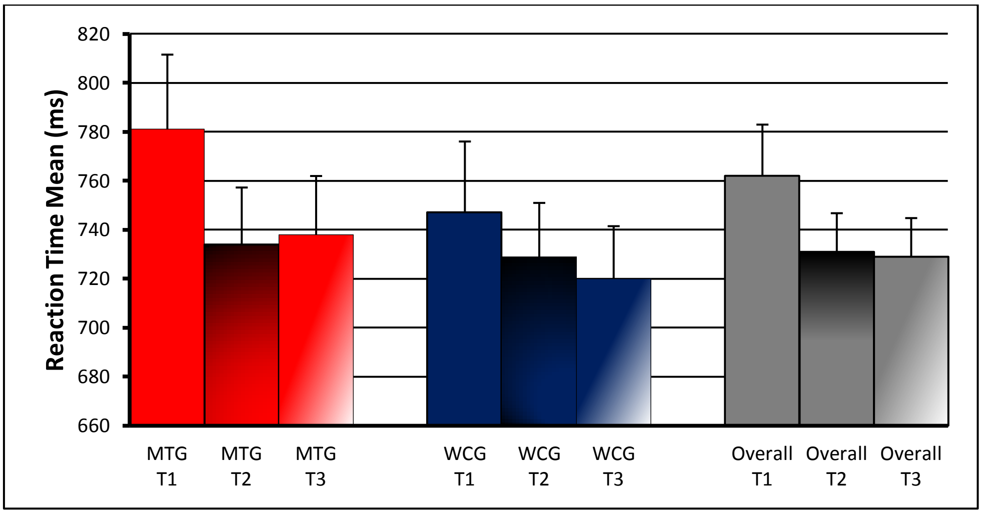

Figure 10: Change in RTs (pooled across congruencies) from T1 to T3. Error bars depict standard error of the mean.

A Repeated Measures ANOVA (Table 8) was computed to examine the behavioural Stroop Effect (incongruent RTs – congruent RTs). However, no significant effects were observed as the behavioural Stroop Effect, pooled across groups, remained robust throughout (T1 = 111ms, T2 = 104ms, T3 = 106ms).

Accuracy

HRs were subjected to a *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVA (Table 9), revealing no between group differences. A significant main effect of Congruency was observed, reflecting differences in HRs between the incongruent and congruent conditions across groups (94.4 vs 97.4%) and further evidencing the difficulty of overcoming Stroop interference in the incongruent condition. Additionally, a significant *Time* x *Congruency* interaction was found, caused by HRs improving significantly in the incongruent condition from T1 to T3 [t(31) = -2.267, p = .031]. A series of planned contrasts revealed that this interaction effect was significant for T1 compared to T2 [F(1,30) = 4.741, p = .037, r =.369] and T1 compared with T3 [F(1,30) = 4.722, p = .038, r =.369], however, there was no significant effect between T2 and T3 [F(1,30) = .055, p = .816], reflecting the fact that incongruent HRs were not improved from T2 to T3[t(31) = .117, p = .908]. HRs in the congruent condition were already high at T1 and were not improved further. Figure 11 depicts the change in HRs overall (pooled across congruencies) and separately for the congruent and incongruent conditions. The overall bars (pooled across groups) demonstrate the significant *Time* x *Congruency* interaction, with observable improvements from T1 to T2 found in the incongruent condition only, whilst the individual group values are included for additional information only. The observed pattern of results is consistent with the assertion that performance ceiling effects prevented improvements beyond the general practice effects caused by repeated administration of the task.

Table 9: Summary of Mixed ANOVA results for Stroop HRs (*Time* (3) x *Congruency* (2) x *Group* (2))

Effect	**Statistical Values**	
Time	F(1.58, 47.46*) = 2.965,	p = .073
Group x Time	F(1.58, 47.46*) = .599,	p = .516
Group	F(1,30) = .003,	p = .954
Congruency	F(1,30) = 32.448,	p < .001
Congruency x Group	F(1,30) = 1.291,	p = .265
Time x Congruency x Group	F(2,60) = 1.398,	p = .255
Time x Congruency	F(2,60) = 3.489,	p = .037

* Mauchly’s test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity

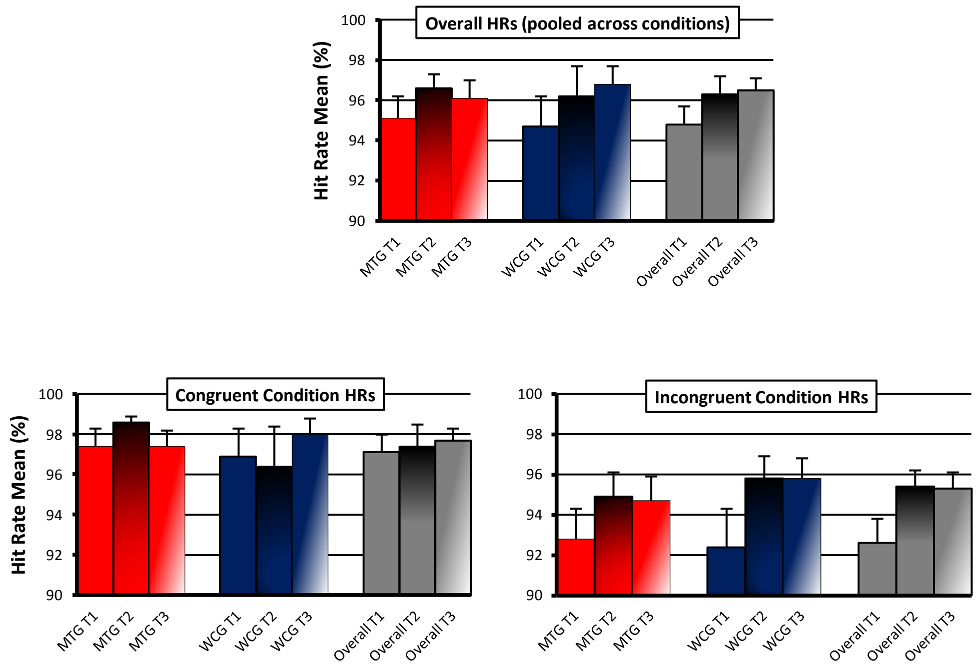

Figure 11: Change in HRs from T1 to T3. Error bars depict standard error of the mean.

6.3.2 ERP analyses

As displayed in Table 10 there were no baseline differences between the groups in any of the ERP components that were analysed.

Table 10: Summary of tests for baseline differences in Stoop ERP components, with mean values (standard deviations) and respective statistical values for the comparison between MTG and WCG

	MTG (N=12)	**WCG (N=16)**	**Statistical Values**	
N2 PO Left Congruent (µV)	-5.00 (1.88)	-4.25 (2.27)	*t*(26) = -.927,	*p* = .363
N2 PO Left Incongruent (µV)	-5.07 (1.91)	-4.00 (2.06)	*t*(26) = -1.412,	*p* = .170
N2 PO Right Congruent (µV)	-3.26 (1.69)	-3.34 (2.02)	*t*(26) = .117,	*p* = .908
N2 PO Right Incongruent (µV)	-3.40 (1.77)	-3.36 (1.88)	*t*(26) = -.067,	*p* = .947
P3 Pz Congruent (µV)	.96 (1.25)	.70 (2.00)	*t*(25.34*) = .401,	*p* = .691
P3 Pz Incongruent (µV)	1.10 (1.20)	1.00(1.48)	*t*(26) = .178,	*p* = .860
LN POz Congruent (µV)	.67 (.54)	.92 (1.10)	*t*(26) = -.713,	*p* = .482
LN POz Incongruent (µV)	.17 (.45)	.65 (.81)	*t*(26) = -1.844,	*p* = .077

* Levene's test for equality of variances violated, therefore degrees of freedom were adjusted accordingly

N2 ERP component

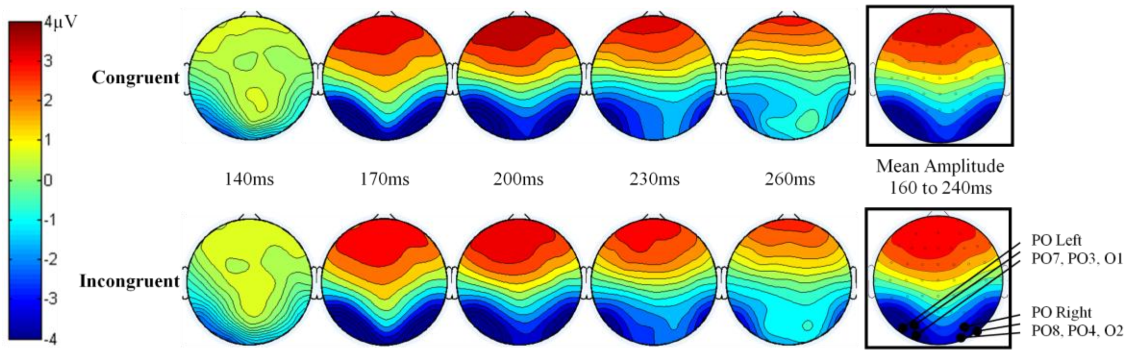

Figure 12: Pooled T1 data (N=28). A time lapse topographical view of the N2 ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 140ms to 260ms (30ms steps from left to right). Mean Amplitude spherical spline interpolated scalp topography is included for the N2 time window (160 to 240ms). The pooled electrode sites are included for illustration and apply to both the congruent and incongruent conditions.

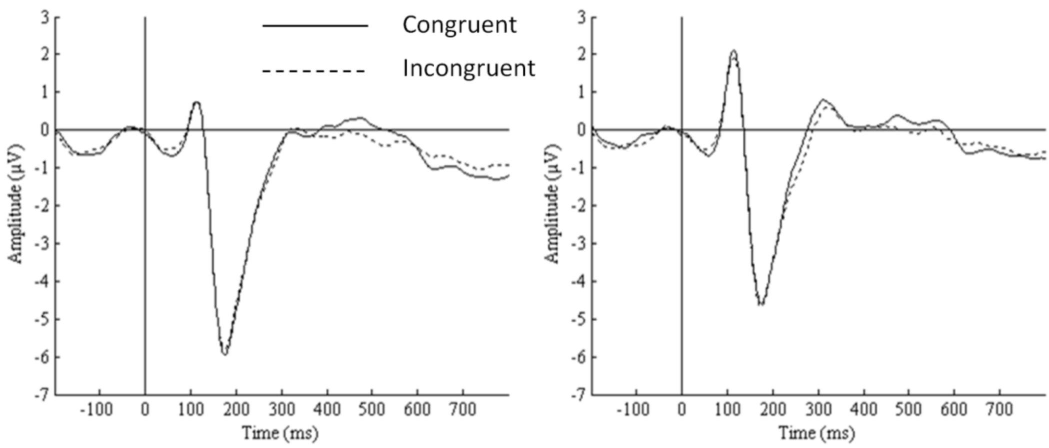

Figure 13: Grand mean evoked potential, from pooled T1 data (N=28), for the congruent and incongruent conditions for a cluster of left PO electrodes (PO7, PO3 and O1), and right PO electrodes (PO8, PO4, O2) displayed from left to right respectively.

Using pooled T1 data (N=28), Figure 12 displays the time course and topography of the PO N2 ERP component for the congruent and incongruent conditions. The maxima of the PO left (PO7, PO3 and O1) and right (PO8, PO4 and O2) N2 ERP components were best captured by a time window of 160 to 240ms (Figure 13).

PO left and right N2 mean amplitudes were subjected to separate *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVAs (Table 11) to examine between groups differences.

Table 11: Summary of Mixed ANOVA (Time (3) x Congruency (2) x Group (2)) results for PO N2 mean amplitude from the left and right PO clusters

	Effect	Statistical Values	
N2 (PO Left)			
	Time	$F(2,52) = .020$,	$p = .980$
	Group x Time	$F(2,52) = 3.862$,	$p = .027$
	Group	$F(1,26) = 3.711$,	$p = .065$
	Congruency	$F(1,26) = 1.858$,	$p = .184$
	Congruency x Group	$F(1,26) = .029$,	$p = .865$
	Time x Congruency x Group	$F(2,52) = 1.163$,	$p = .321$
	Time x Congruency	$F(2,52) = .692$,	$p = .505$
N2 (PO Right)			
	Time	$F(2,52) = 1.129$,	$p = .331$
	Group x Time	$F(2,52) = 4.273$,	$p = .019$
	Group	$F(1,26) = 1.181$,	$p = .287$
	Congruency	$F(1,26) = .018$,	$p = .895$
	Congruency x Group	$F(1,26) = .099$,	$p = .755$
	Time x Congruency x Group	$F(2,52) = .248$,	$p = .781$
	Time x Congruency	$F(2,52) = .428$,	$p = .654$

Significant *Group x Time* interaction effects were observed for both PO left and PO right, indicating that MTG and WCG had modulated N2 mean amplitude differently from T1 to T3. Figure 14 illustrates how N2 was modulated differently by MTG and WCG from T1 to T3. *Group x Time* planned contrasts revealed that a relative increase in mean amplitudes from T1 to T3 for the MTG contrasted with a relative decrease for WCG for both PO left and PO right. For PO left, between group differences manifested gradually over the 3 testing sessions and were only significant overall from T1 to T3 [$F(1,26) = 6.421$, $p = .018$, $r = .445$], not for T1 to T2 [$F(1,26) = 1.531$, $p = .227$] or T2 to T3 [$F(1,26) = 2.776$, $p = .108$]. For PO right, between group differences manifested already between T1 and T2 [$F(1,26) = 6.235$, $p = .019$, $r = .440$], and were significant overall from T1 to T3 [$F(1,26) = 4.987$, $p = .034$, $r = .401$], with no between group differences observed from T2 to T3 [$F(1,26) = .051$, $p = .824$].

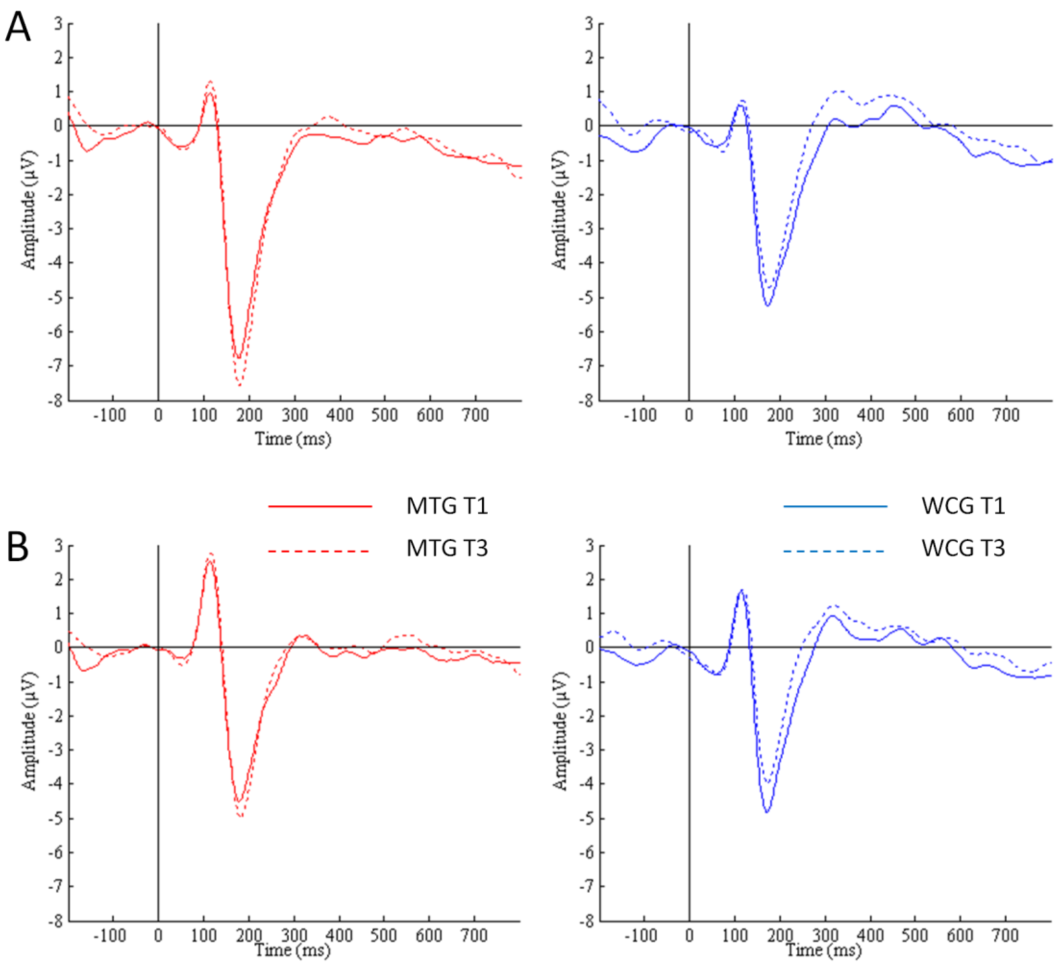

Figure 14: MTG and WCG differences in N2 (pooled across both congruencies) for PO left cluster (panel A) and PO Right cluster (panel B) from T1 to T3, displaying a relative increase for MTG and relative decrease for WCG.

P3 ERP component

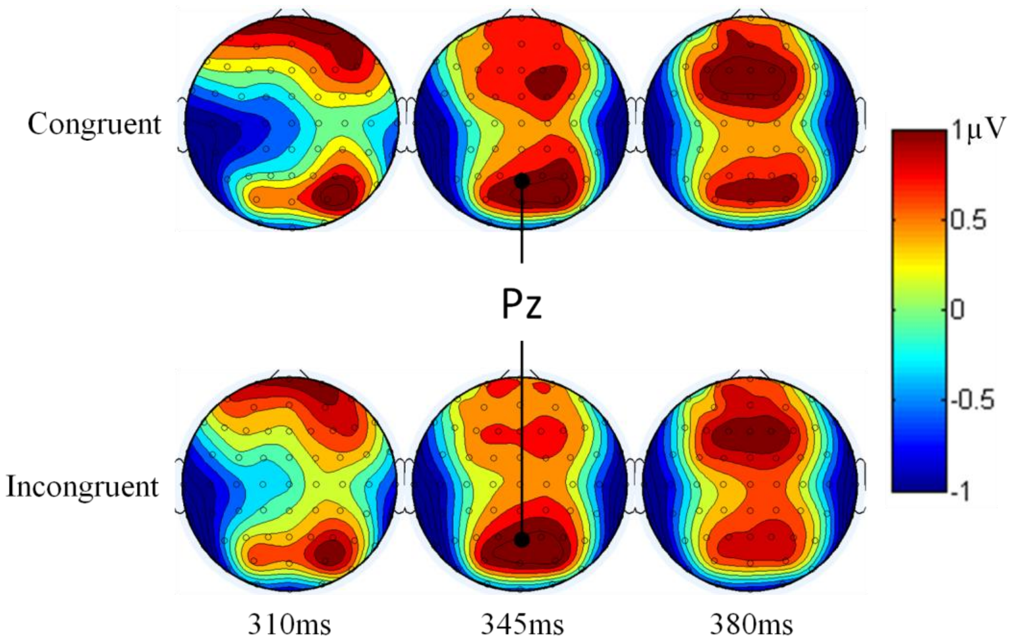

Figure 15: Pooled T1 data (N=28). A time lapse topographical view of the P3 ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 310ms to 380ms (35ms steps from left to right)

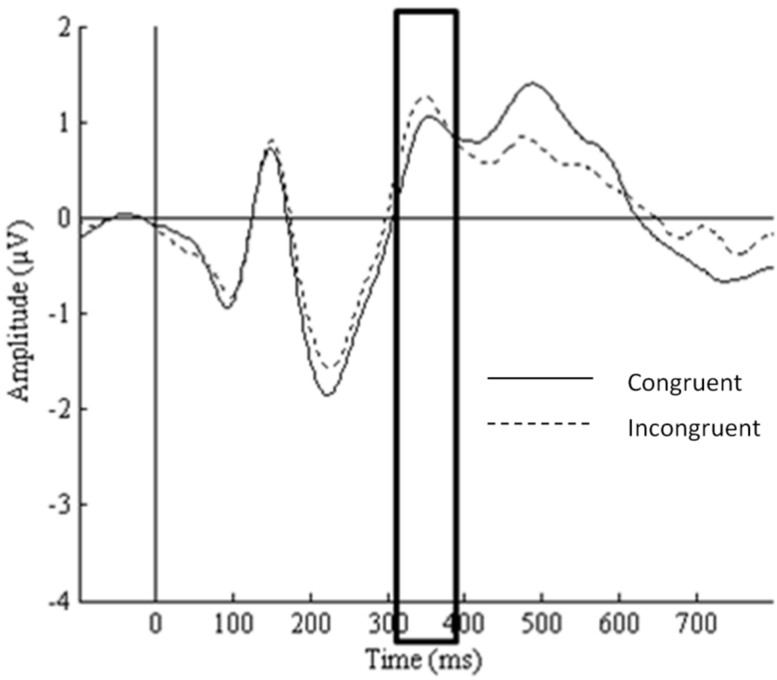

Figure 16: Grand mean evoked potential at Pz for both the congruent and incongruent conditions, from pooled T1 data (N=28). P3 (310-380ms) is highlighted.

Using pooled T1 data (N=28), Figure 15 displays the topography of the P3 ERP component. The maxima of the P3 ERP component was best captured by a time window of 310 to 380ms at electrode site Pz (Figure 16).

P3 mean amplitudes were subjected to a *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVA (Table 12), revealing a significant main effect of *Congruency* and a significant *Time x Congruency x Group* interaction.

Table 12: Summary of Mixed ANOVA (*Time* (3) x *Congruency* (2) x *Group* (2)) results for P3 mean amplitude at Pz

Effect	**Statistical Values**	
Time	F(2,52) = .877,	*p* = .422
Group x Time	F(2,52) = 1.665,	*p* = .199
Group	F(1,26) = .068,	*p* = .797
Congruency	F(1,26) = 8.083,	*p* = .009
Congruency x Group	F(1,26) = .630,	*p* = .435
Time x Congruency x Group	F(2,52) = 4.711,	*p* = .013
Time x Congruency	F(2,52) = .807,	*p* = .452

The main effect of *Congruency* was caused by higher P3 mean amplitudes, pooled across groups, for the incongruent condition as compared the congruent condition over time (1.09 vs. 0.79 μV). This finding suggests that incongruent stimulus information requires more resources to be allocated during object recognition processes.

The significant *Time x Congruency x Group* interaction suggests that MTG and WCG had modulated P3 mean amplitude differently, from T1 to T3, in either the congruent or incongruent condition. Figure 17 panels A and B illustrate that there was little to no change to P3 mean amplitude in the congruent condition for either group. However, panels C and D illustrate that the MTG decrease incongruent P3 mean amplitude from T1 to T3, whereas there is a relative increase for the WCG. Incongruent P3 mean amplitudes were subjected to a *Time* (3) *x Group* (2) Repeated Measures ANOVA to explore this apparent between groups difference, revealing a significant *Group* x *Time* interaction [$F(2,52) = 4.887$, $p = .011$]. A series of planned contrasts revealed that this interaction was significant overall from T1 to T3 [$F(1,26) = 9.267$, $p = .005$, $r = .513$] and from T2 to T3 [$F(1,26) = 6.905$, $p = .014$, $r = .458$], but not from T1 to T2 [$F(1,26) = .001$, $p = .979$]. This pattern of results suggests that the MTG were able to reduce the amount of resources allocated to object recognition processes when presented with incongruent stimulus information following MT.

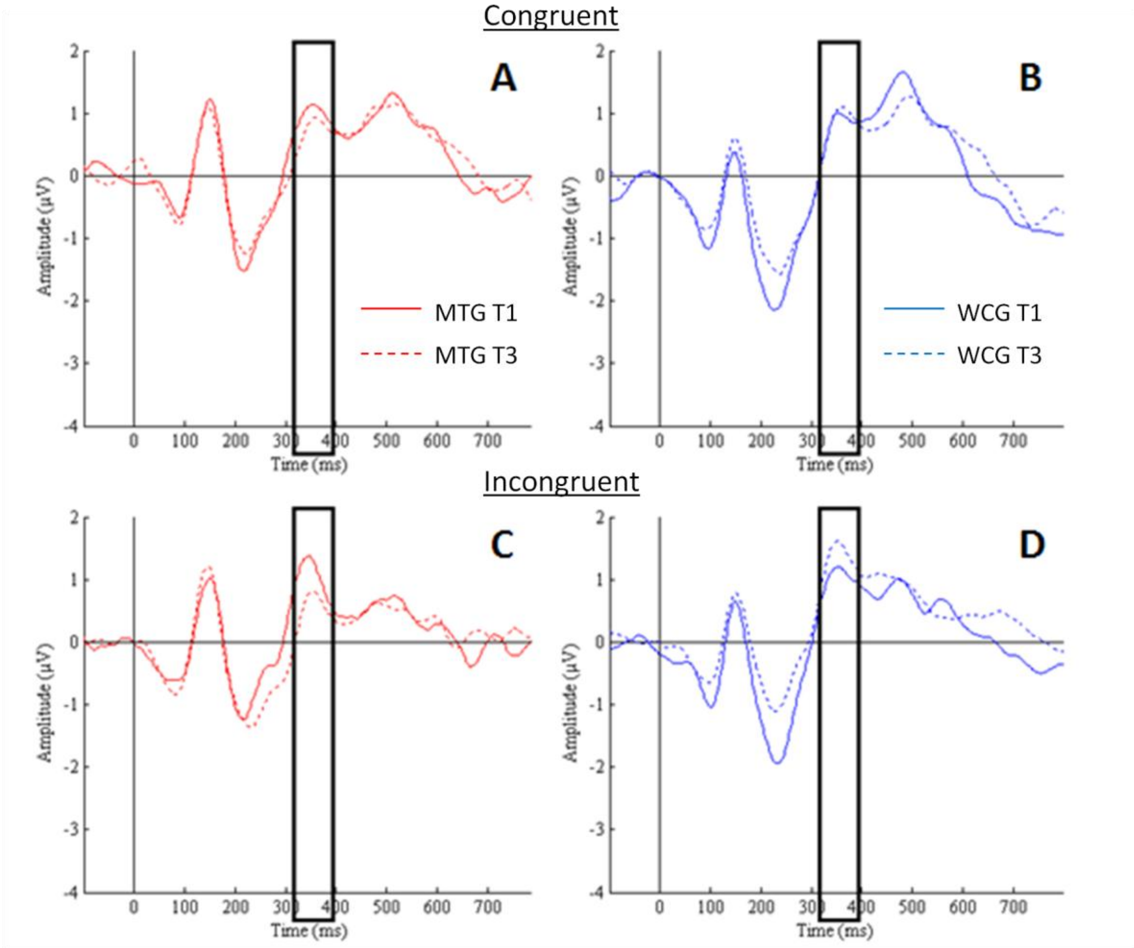

Figure 17: Difference in P3 at Pz from T1 to T3 for the MTG and WCG for both the congruent (panels A and B) and incongruent (panels C and D) conditions. The figure displays a relative decrease in P3 for MTG in the incongruent condition.

LN ERP component

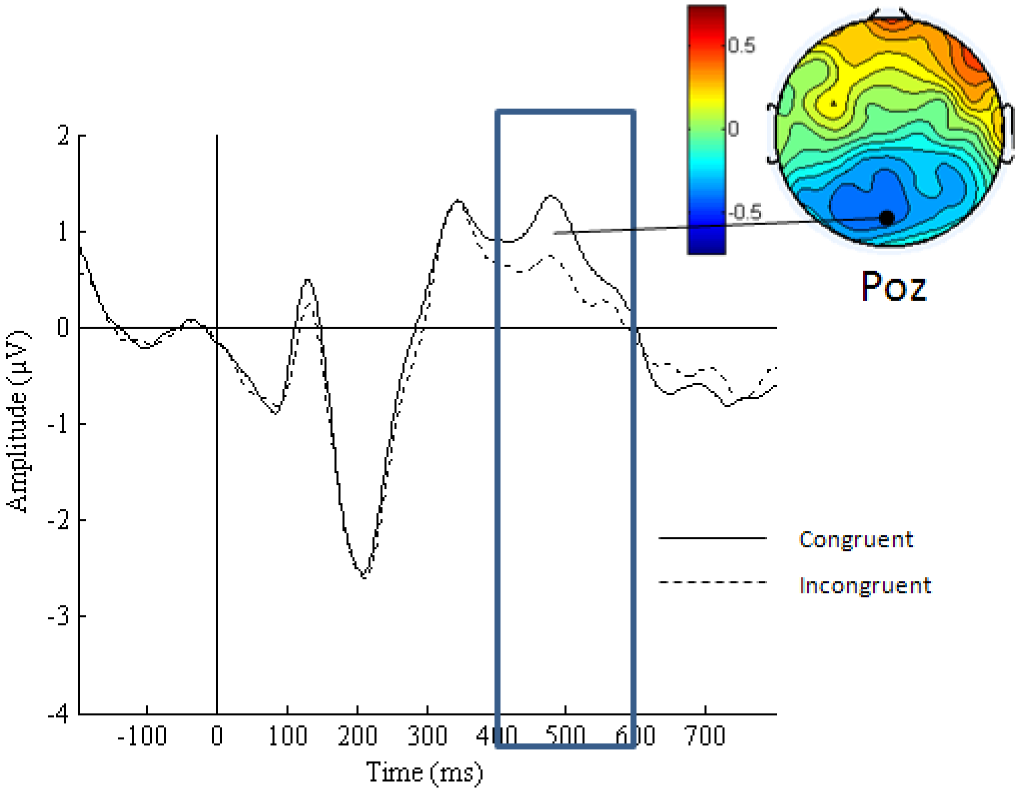

Figure 18: Grand mean evoked potential at POz for both the congruent and incongruent conditions, from pooled T1 data (N=28). N400 is highlighted. A mean amplitude spherical spline interpolated scalp topography for the 400 to 600ms time window is included to depict the difference between the 2 conditions across all sites during this time window.

As the LN (see Figure 18) has been linked to the behavioural Stroop effect, the lack of a behavioural between groups' effect suggested that no differences would be found in the LN. Unsurprisingly, a *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVA found only a main effect of *Congruency* [F(1,27)= 5.554, p = .026] with incongruent trials producing a smaller mean amplitude for the LN time window than congruent trials (.528 μV vs. .762 μV). As no between group effects were found for the LN, results are not fully presented herein. However, the implication of this finding is discussed in Chapter 8.

Chapter 7. Mindfulness Training and Attentional Networks: The Attention Network Test

7.1 Theoretical Background

Chapter 7 details the use of the ANT, a measure of attention based on the attention network theory proposed by Posner and Petersen (1990). This Chapter discusses the detailed analysis and results obtained by using the ANT as well as the reasons for choosing this task, its design, the associated outcome measures and specific hypotheses.

The Attention Network Task, Attentional Networks and Mindfulness Training

The ANT (Fan et al., 2002) was developed to provide a measure of the efficiency of three relatively distinct attentional networks, namely the alerting, orienting and executive networks. Said networks, their associated functions, their proposed neural substrates and their engagement during MT were introduced and discussed in Chapter 2 and will only briefly be elaborated upon further herein.

The ANT measures the efficiency of the three networks by combining cued detection (Posner, 1980) with a flanker type paradigm (Eriksen & Eriksen, 1974). In order to measure the efficiency of the alerting network warning cues are utilised to vary alertness by providing temporal information regarding the appearance of targets. Subsequently, performance in warning cue trials is compared to no warning cue trials to measure the alerting effect. The use of warning cues in the ANT means that alerting in the context of the ANT refers to the ability to phasically increase response preparation in reaction to an external warning stimulus (Neuhaus et al., 2010). Measurement of the orienting network is accomplished via the use of spatial cues. The benefit of spatial cueing to task performance was reported in a seminal study more than three decades ago (Posner, 1980) with spatial cues providing a significant RT improvement. For the ANT, trials with spatial cues that indicate where in space a target is likely to occur, and thereby directing attention to the cued location, are compared to trials that utilise warning cues with no spatial information. Finally, the ANT taps executive functions by requiring it to resolve a flanker compatibility conflict. Efficiency of the executive network is measured by comparing trials wherein the target stimulus (a left or right facing arrow) is flanked by conflicting/incongruent stimuli (arrows facing the opposite way to the target) to trials wherein the target is flanked by congruent stimuli (arrows facing the same direction as the target), with RTs and accuracy typically diminished when conflicting/incongruent stimuli are presented (Fan et al., 2002). Key to the successful completion of the ANT are attentional monitoring functions, in order to identify conflict, and conflict resolution/response inhibition functions, in order to resolve flanker incompatibility and prevent automatic responses.

The acceptance of the ANT as a tool for measuring attention network performance is evinced by its use in a wide range of populations, including normal children (Mezzacappa, 2004; Rueda et al., 2004) and those with disorders (Bish et al., 2005; Kratz et al., 2011; Sobin et al., 2004), adults with borderline personality disorder (Klein, 2003; Posner et al., 2002), patients with schizophrenia (K. Wang et al., 2005) and older adults with Alzheimer's disease (Fernandez-Duque & Black, 2006). As presented in Chapter 3, the ANT has also been used with mixed results in a number of studies that were designed to assess the effect of MT on attentional network performance. In short, executive differences were found between expert mindfulness meditators and controls (Jha et al., 2007) and following 5 days of MT compared to relaxation training (Tang et al., 2007), alerting differences were found following an intensive 1 month mindfulness retreat (Jha et al., 2007) and orienting differences were found following an 8 week MBSR course that focussed on elements of FA during MT (Jha et al., 2007). Differences in the flexibility of the orienting network have also been found recently between experienced mindfulness meditators and matched controls (van den Hurk, 2011) but only after the experienced mindfulness meditators had completed an intensive mindfulness retreat. However, no significant differences were found following a brief 2 x 15mins MT induction (Polak, 2009).

Importantly, recent functional imaging studies have established the anatomical differentiation of the three attentional networks by utilising the ANT. The alerting network has been associated with activity in thalamic, frontal and parietal regions (Coull, Nobre, & Frith, 2001; Fan et al., 2005), the orienting network to activation of the parietal lobe and frontal eye fields (Fan et al., 2005) and the executive network to the ACC and lateral PFC (Bush, Luu, & Posner, 2000; Fan, Kolster, et al., 2007; Fan et al., 2005). The activation of the ACC and lateral PFC in resolving the flanker compatibility conflict suggest that the ANT activates brain regions associated with core attentional processes and thus is likely to prove an effective measure of MT related attentional improvements.

Herein EEG recordings and the ERP analysis technique are utilised in an attempt to obtain temporal information regarding the underlying task related neural activity, specifically regarding the time period from target presentation to response. Whilst the ANT is typically used for behavioural analysis only, a small number of recent studies have recorded EEG during ANT completion. Neuhaus et al. (Neuhaus et al., 2010) found that the ANT produced a robust target locked P3 ERP component that peaked 300-600ms after target onset. As stated in Chapter 6, P3 ERP components are typically linked to inhibition processes when perceptual stimulus discrimination occurs and attentional resource allocation (Polich, 2007). For the ANT, perceptual stimulus discrimination would occur during the resolution of the flanker compatibility conflict. Neuhaus et al. found that the P3 ERP component was significantly reduced at a posterior electrode site (Pz) in the incongruent as compared to the congruent condition. Thus, the P3 ERP component is likely to be a key electrophysiological marker for executive network modulations following MT. A further study which utilised time frequency analysis (Fan, Byrne, et al., 2007) found that the executive control network showed an early increase in gamma-band power following incongruent as compared congruent flanked targets. Fan, Byrne et al. linked this finding to the time course of the electrical activity of the ACC (Abdullaev & Posner, 1997; Snyder et al., 1995) and proposed that their findings may evince the effect of attention on the integrative process, given that early latency gamma-band power increase in medial-frontal channels has been found to be related to the effect of attention on the integrative process in previous studies (Herrmann, Mecklinger, & Pfeifer, 1999; Senkowski et al., 2005). This finding is consistent with the proposal that the ACC plays a major role involving response selection and monitoring (Botvinick et al., 2001; Fan et al., 2003) and is commensurate with the neuroimaging findings regarding the ACC's activation during the ANT (Bush et al., 2000; Fan et al., 2003; Fan, Kolster, et al., 2007; Fan et al., 2005).

As stated throughout, the executive network and its salience sub section are key candidates for improvement following extended MT and are the primary focus of LS1. Herein the ANT is primarily used to provide a further assessment of the performance of these networks following MT. Additionally, it was initially envisaged that the ANT may provide both behavioural and electrophysiological evidence for the modulation of the alerting and orienting networks following MT. However, a task manipulation check utilising the T1 data (section 7.3) resulted in the modification of the specific hypotheses that may be tested by the ANT. The hypotheses related to the analyses that were conducted are detailed in the following section.

Behavioural Outcome Measures and Hypotheses.

Mean RTs (for incongruent and congruent trials) were the focus of the behavioural analyses. As improvements in RTs would rely on improved attentional monitoring in order to promptly identify and overcome flanker incompatibility, and an improved focus to the goal relevant aspect of the presented stimulus array (centre arrow), it may be said that they would evince improvements in sustained attention to the task. It was hypothesised that MT would improve goal directed attention and attentional monitoring, thus MTG were expected to significantly improve RTs. It was also expected that the MTG may reduce the RT difference between the incongruent and congruent conditions, evincing improved conflict resolution, following MT as reduced executive network scores have been found in expert meditators (ANT, Jha et al., 2007) and improved executive functioning has been found following brief mindfulness inductions (Tang et al., 2007; Wenk-Sormaz, 2005). However, rather than specifically calculating the executive effect as part of a separate analysis, RT differences between congruencies over time were analysed as part of an overall *Time* (3) x *Congruency* (2; incongruent vs. congruent) x *Group* (2) Mixed ANOVA. Thus interactions with *Congruency* would evince modulations of the executive network.

Overall accuracy on the ANT is typically >98% (e.g. Fan et al., 2005; Fan et al., 2002), suggesting that despite the well established RT decrement caused by the flanker incompatibility, participant responses are generally very accurate and unlikely to be modulated further following MT. The analysis of accuracy data is presented in section 7.4.1, demonstrating that no between group differences were found.

Electrophysiological Outcome Measures and Hypotheses.

Based on issues identified with the centre cue condition (a significant alerting effect was not seen due to the limited alerting benefit gained from the centre cue condition, see section 7.3 for full details) it was decided that the ERP analyses would focus solely on target locked ERPs and thus on modulations of ERPs related to executive functions only. The ERP component identification procedure detailed in section 4.4 resulted in the identification of 3 ERP components of interest.

A robust posterior P3 ERP component (See Chapter 6 for brief explanation) was observed in the 300 to 430ms time window, peaking at electrode site PO4 (see Figure 22 and Figure 23). The P3 ERP component was the main focus of the ERP analyses. It was hypothesised that the P3 ERP component would be modulated following MT and specifically that MT may lead to a reduction in P3 mean amplitude resulting from improved attentional monitoring and more efficient conflict resolution.

For consistency with the Stroop ERP analyses, and to rule out the influence of early stimulus processing, two further components were analysed in the 160 to 220ms post stimulus time window in small clusters of left (PO7, PO3 and O1) and right (PO8, PO4 and O2) PO electrodes. The results of this analysis are not presented here as no between groups effects were found and neither group modulated mean amplitudes to either congruency, at either location, across testing sessions.

7.2 Task Design and Stimuli

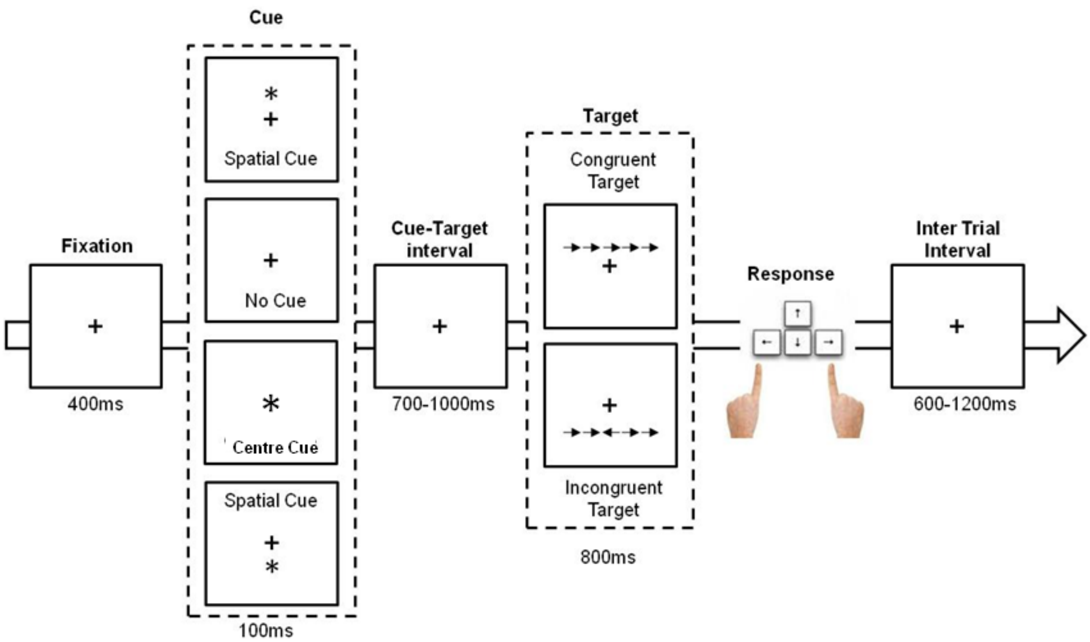

Figure 19: ANT trial design and timings

Stimuli consisted of a row of five visually presented horizontal black lines, with arrowheads pointing left or right against a white background (total 3.27 degrees of visual angle). The target is a left or right arrowhead at the centre. To introduce a conflict-resolution component the central arrow is ‘flanked’ on either side by 2 arrows in the same (congruent condition) or opposite direction (incongruent condition). The participants’ task was to identify the direction of the centrally presented arrow by pressing the left or right arrow key on a standard QWERTY keyboard when the central arrow pointed left or right respectively. To introduce attentional orienting and alerting components to the task, the row of five arrows were presented in 1 of 2 locations outside the point at which the participant was fixating, either 1.06 degrees of visual angle above or below the fixation point, and there were 3 possible warning cue conditions, a centre cue, no cue, and a spatial cue, for a total of 6 possible cue-target conditions.

Figure 19 provides an outline of the trial design and timings. Each trial consisted of 5 events. First, there was a fixation period for 400ms. Then, a warning cue for 100ms (in no cue trials the fixation cross was displayed for an extra 100ms). A variable cue target interval of 700-1000ms separated cue from target. Next, the target and flankers appeared simultaneously and were presented for 800ms. This was followed by a variable inter-trial interval of 600-1200ms before the next trial and sequence of 5 events began again. The fixation cross appeared at the centre of the screen during the whole trial (except in centre cue trials were it was replaced by a cue for 100ms) and participants were instructed to attend to the cross until they oriented attention to the target location to respond or until they were cued otherwise. The spatial cues were always valid (appeared at the correct location of the target). The variable duration of the cue-target and inter-trial intervals was used to produce additional uncertainty about cue and target onset.

At each testing session participants completed a 24 trial practice block (during which auditory feedback was given to highlight mistakes) and 8 experimental blocks of 48 trials (3 cue conditions x 2 target locations x 2 target directions x 2 flanker conditions x 2 repetitions). The trial order was random. The experimental blocks were separated by a 2 minute break. The experiment took approximately 40 minutes to run.

7.3 Task Manipulation Check

Pooled T1 data (N=39) revealed a robust executive effect of 78ms, indicating that the task manipulation designed to engage executive functions was working as incongruent trials were producing higher RTs than congruent trials. A robust orienting effect of 84ms suggested that participants were able to derive a RT improvement from valid spatial information as compared a non-spatial alerting cue. However, the task did not produce a robust alerting effect, with only a 13ms difference in RTs found between the no cue and centre cue trials. This suggests that the centre cue was providing a very limited ‘alerting’ benefit and may have been difficult to identify. The orienting effect of 84ms is over 30ms higher than that found in previous studies (e.g. Fan et al., 2002 = 51ms; Neuhaus et al., 2010 = 52ms), further suggesting that the centre cue was providing limited benefit, thus causing a greater than expected difference between centre and spatial cue conditions.

The alerting effect reported in Fan et al. original paper (Fan et al., 2002) was 47ms. However, the original study design utilised a double cue (used to diffuse attention between the two possible target locations), rather than the centre cue, to calculate the alerting network. The same study found redundancy between the double and centre cue conditions and as such the double cue was removed in future ANT studies (e.g., Fan et al., 2005), leading to its omission in the current study. Studies utilising the centre cue for the alerting network calculation have found a significant alerting benefit from its use, although the benefit has varied (e.g. Fan et al., 2005 = 60ms; Fan, Byrne, et al., 2007 = 20ms). A recent review paper (J. W. Macleod et al., 2010), published after data collection had begun for LS1, reviewed the psychometric properties of the ANT and found that only 15 of 39 studies utilising the ANT produced a significant alerting effect whilst only 12 of 39 found a significant orienting effect. For completeness, 31 of 39 found an executive effect. Of importance, it should be noted that the majority of these studies included clinical populations (e.g. schizophrenia, bipolar, depression) or populations selected to answer specific research questions (e.g. older adults, smokers, heavy caffeine users), thus they may be expected to display deficits in the different attentional networks.

Fan et al. (2002) found that the raw RTs have better test-retest reliability (.87) than the executive (.77), orienting (.61) and alerting (.52) network scores. J. W.

Macleod et al. (2010) note that these reliability findings bear a striking resemblance to the frequency at which significant network effects were observed (detailed above). Taking this finding and the above stated problems with the centre cue condition into account, the main behavioural analysis of the ANT was focussed on the raw RTs, pooled across cue conditions and split by flanker congruency, and the different cue conditions were not entered as factors into the analysis. It should be noted that the raw RTs would have allowed for the best estimate of sustained attention to the task and improvements in goal directed attention regardless of the abovementioned issues. As the pooled T1 RTs suggest that the centre cue condition was not producing an alerting benefit it was decided that ERP analyses should focus on an analysis of ERPs related to executive functions. Thus the ERP analyses were restricted to target locked ERPs with data pooled across cue conditions and split by flanker congruency.

7.4 Results

One participant was removed from both the behavioural and electro-physiological analyses due to failure to follow task instructions. As summarised in Table 13, direct comparisons at T1 revealed no significant differences between the MTG and WCG, confirming that MTG and WCG had comparable baseline behavioural performance.

Table 13: Summary of tests for baseline differences, with mean values (standard deviations) and respective statistical values (all 2 tailed) for the comparison between MTG and WCG. Only participants who completed the study are included in this analysis.

	MTG (N=14)	**WCG (N=18)**	**Statistical Values**	
ANT RT Overall (ms)	654 (83)	623 (75)	$t(30) = 1.089$,	$p = .285$
ANT RT Congruent (ms)	617 (78)	585 (75)	$t(30) = 1.178$,	$p = .248$
ANT RT Incongruent (ms)	693 (94)	663 (76)	$t(30) = .984$,	$p = .333$
ANT Executive (ms)	75 (42)	78 (22)	$t(18.20^*) = -.201$,	$p = .843$
ANT HR Overall (%)	97.7 (2.5)	97.2 (2.5)	$t(30) = .537$,	$p = .595$

* Levene's test for equality of variances violated, therefore degrees of freedom were adjusted accordingly

7.4.1 Behavioural Analyses

<u>*Reaction Times*</u>

RTs were subjected to a *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVA (Table 14) to examine between groups differences in behavioural performance.

Significant main effects of *Congruency* and of *Time*, and significant *Group x Time* and *Time x Congruency* interactions were observed. The significant main effect of *Congruency* confirms the efficacy of the executive behavioural manipulation, with incongruent trials producing slower RTs than congruent trials across groups and time points (640 vs. 575ms). The significant main effect of *Time* was caused by a reduction in overall RTs (pooled across both congruencies) from T1 (637ms) to T2 (598ms) and again to T3 (586ms). Planned contrasts revealed that this reduction was significant from T1 to T2 [$F(1,30) = 43.786$, $p < .001$, $r = .770$] and continued from T2 to T3 [$F(1,30) = 9.629$, $p = .004$, $r = .493$].

Table 14 Summary of Mixed ANOVA, *Time* (3) x *Congruency* (2) x *Group* (2), results for RT mean.

Effect	**Statistical Values**	
Time	F(1.49, 44.65*) = 41.87,	$p < .001$
Group x Time	F(1.49, 44.65*) = 4.51,	$p = .025$
Group	F(1,30) = .199,	$p = .659$
Congruency	F(1,30) = 232.99,	$p < .001$
Congruency x Group	F(1,30) = .174,	$p = .680$
Time x Congruency x Group	F(2,60) = .759,	$p = .473$
Time x Congruency	F(2,60) = 22.761,	$p < .001$

* Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity

The significant *Group x Time* interaction suggests that MTG and WCG modulated RTs differently over the course of the study. A series of planned contrasts revealed that this interaction was only significant when MTG and WCG scores were compared from T1 to T3 [$F(1,30) = 5.913$, $p = .021$, $r = .406$], showing only a non-reliable trend for between group differences from T1 to T2 [$F(1,30) = 3.08$, $p = .090$] and T2 to T3 [$F(1,30) = 3.10$, $p = .089$].

Table 15: Summary of means (standard deviations) and paired samples t-tests displaying RT differences for all trials from T1 to T3 for MTG and WCG.

	MTG (N=14)	**WCG (N=18)**
	T1: 654 (83)	T1: 623 (75)
	T2: 603 (79)	T2: 594 (65)
	T3: 582 (76)	T3: 588 (70)
Paired Samples t-test T1vsT3	$t(13)= 5.338$, $p < .001$	$t(17)= 4.201$, $p = .001$
Paired Samples t-test T1vsT2	$t(13)= 5.239$, $p < .001$	$t(17)= 3.761$, $p = .002$
Paired Samples t-test T2vsT3	$t(13)= 2.841$, $p = .014$	$t(17)= 1.141$, $p = .270$

To explore this interaction data were pooled across congruencies (as there was no *Time x Congruency x Group* interaction) and a T1 to T3 Paired Samples t-test (Table 15) was conducted for each group. However, this analysis revealed that both groups had significantly reduced RTs from T1 to T3 and was thus unable to explain the *Group x Time* interaction. In order to further explore the cause of the *Group x Time* interaction T1 to T3 difference scores (T1 minus T3) were calculated for each participant and were subjected to an independent samples t-test. This further analysis resulted in a significant between groups difference ($t(30) = 2.400$, $p = .023$) which was caused by a greater reduction in RTs for the MTG (71ms) as compared the WCG (35ms). Thus, the observed pattern of results suggests that MTG were able to significantly improve RTs above and beyond the level that could be associated with general practice effects (see Figure 20).

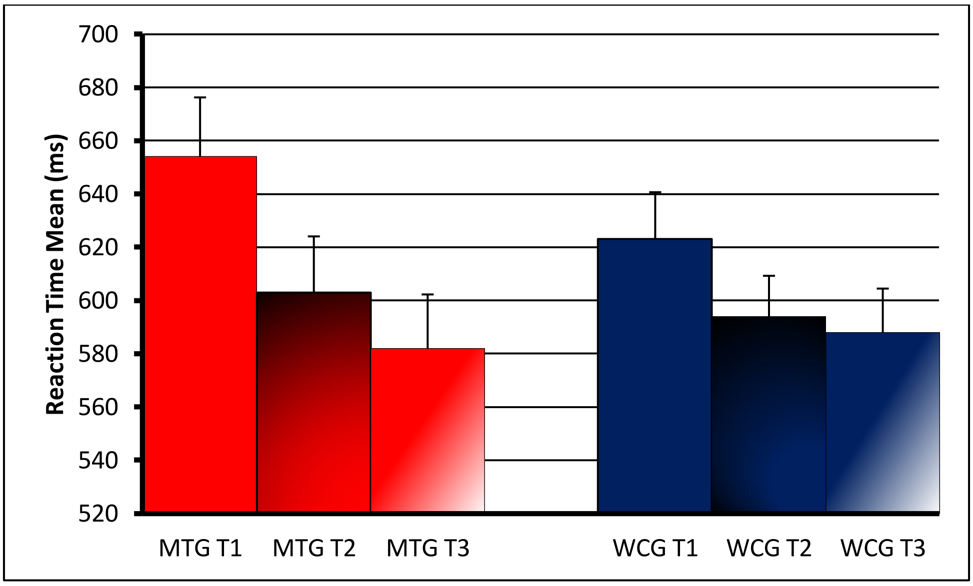

Figure 20: Change in RTs, pooled across congruencies, from T1 to T3 for MTG and WCG. Error bars represent standard error of the mean.

However, despite there being no statistically significant differences between groups at T1 there was a 31ms between groups baseline difference in overall RT mean (pooled across congruencies). Thus, as a purely exploratory step, further Paired Samples t-tests (Table 15) were conducted to examine if ceiling effects may have influenced these findings. Whilst MTG and WCG both improved RTs significantly from T1 to T2, only the MTG improved further from T2 to T3 suggesting that WCG may have reached a performance ceiling at T2. However, given the ease of the ANT it is unlikely that one group would be able to reach a performance ceiling quicker than the other. Figure 21 depicts the changes in RT mean (pooled across congruencies) from trial block to trial block over the course of each of the 3 testing sessions. The level of improvement clearly reduces for both groups after only 5 blocks of trials during the first testing session (240 trials). A significant main effect of *Block*[21] at T1 [$F(3.47,107.54)=11.515$, $p< .001$] provides evidence for improved performance across trial blocks. It should be noted that despite the stated T1 difference there was very little difference between the MTG and WCG at T2, and no per block improvement occurred across groups during T2 [*Block*, $F(4.50,139.42) =.664$, $p = .636$], suggesting that a performance ceiling may have already been reached in both groups. Therefore, the additional T2 to T3[22] difference in

[21] Overall RTs were split by block and pooled across groups before being subjected to a Repeated Measures ANOVA.

[22] A non significant main effect of *Block* was still observed at T3 [$F(4.01,124.32) = 1.420$, $p = .231$].

the MTG may reflect a change in the upper boundary of performance following MT. However, as the *Group x Time* T2 to T3 planned contrast only reached the non-reliable trend value (p =.089) further study is required in order to establish if upper boundaries in performance can be modulated following MT.

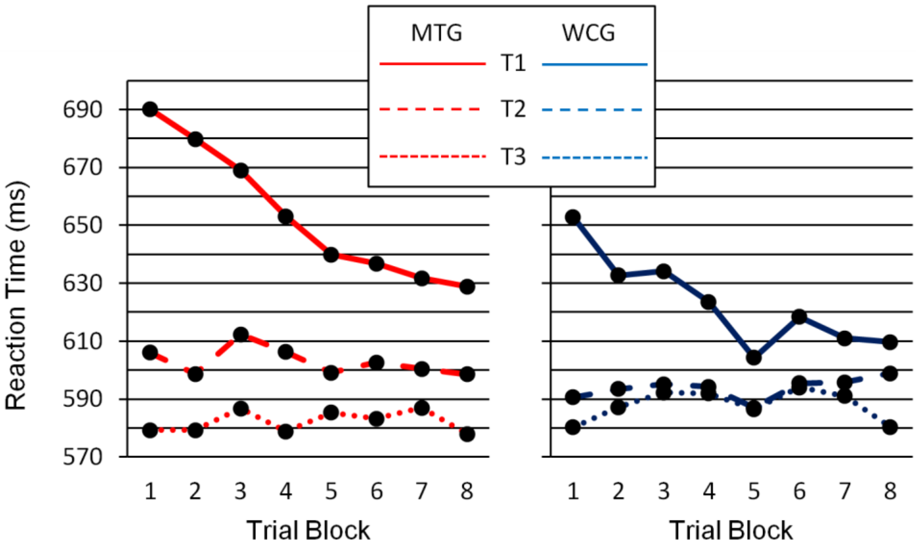

Figure 21 Per block RT means, pooled across congruencies, displayed for MTG and WCG from T1 to T3

The significant *Time x Congruency* interaction is caused by a reduction in the difference between incongruent and congruent conditions (executive effect) from T1 (77ms) to T2 (63) and again to T3 (54ms), and reflects a general practice related effect, suggesting that the difficulty of the task reduces following repeated administrations. However, the non-significant *Time x Congruency x Group* interaction demonstrates that the executive effect was not modulated differently between the groups, suggesting that the observed between groups differences were not specific to improvements in conflict monitoring and conflict resolution. The observed *Group x Time* interaction was most likely caused by overall improvements in attentional monitoring and an improved focus to the goal relevant aspect of the presented stimulus array (centre arrow), enabling the MT to respond faster across congruencies. Thus, MT resulted in improvements to goal directed attention, i.e. sustained attention to the task.

As a final manipulation check the RT analyses were re-run excluding trials that included the centre cue condition. This was in order to ensure that the observed between-groups differences were not caused by differential processing of the problematic centre cue condition. The same pattern of results were observed with or without the centre cue included. Lastly, the RT data were entered into a *Time* (3) x *Cue* (3; centre cue, spatial cue, no cue) x *Congruency* (2) x *Group* (2) Mixed ANOVA to ensure that differential processing of the centre cue over time was not the cause of the between groups differences in RTs. Importantly, non-significant interactions were observed for *Cue x Group, Congruency x Cue x Group, Time x Cue x Group,* and *Time x Congruency x Cue x Group* (all p >.500). Thus it may be concluded that differential processing of the centre cue condition between groups did not cause the observed between groups differences.

<u>*Accuracy*</u>

HRs were subjected to a *Time* (3) x *Congruency* (2) x *Group* (2) Mixed ANOVA (Table 16), revealing no between groups differences. Only a significant main effect of *Congruency* was found, indicating that HRs to congruent trials were higher than HRs to incongruent trials across groups and time points (99.4 vs. 96.4 %), further confirming that the executive element of the task were working.

Table 16: Summary of Mixed ANOVA (*Time* (3) x *Congruency* (2) x *Group* (2)) results for HRs.

Effect	**Statistical Values**	
Time	F(1.31, 39.34*) = 3.491,	p = .058
Group x Time	F(1.31, 39.34*) = .934,	p = .399
Group	F(1,30) = .036,	p = .851
Congruency	F(1,30) = 32.459,	p < .001
Congruency x Group	F(1,30) = .042,	p = .839
Time x Congruency x Group	F(1.36, 40.93*) = 2.138 ,	p = .145
Time x Congruency	F(1.36, 40.93*) = .368,	p = .613

* Mauchly’s test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity

7.4.2 ERP analyses

As displayed in Table 17, there were no baseline differences between the groups in any of the identified ERP components.

Table 17: Summary of tests for baseline differences in ERP components on the ANT, with mean values (standard deviations) and respective statistical values for the comparison between MTG and WCG

	MTG (N=12)	WCG (N=16)	Statistical Values	
P3 PO4 Congruent (µV)	1.81 (1.42)	1.93 (1.36)	$t(26) = -.229$,	$p = .820$
P3 PO4 Incongruent (µV)	1.63 (1.03)	1.78 (1.45)	$t(26) = -.310$,	$p = .759$
N2 Pos Left Congruent (µV)	-3.17 (2.78)	-3.50 (1.63)	$t(16.56^{*}) = .362$,	$p = .722$
N2 Pos Left Incongruent (µV)	-2.85 (2.57)	-3.42 (1.67)	$t(26) = .717$,	$p = .480$
N2 Pos Right Congruent (µV)	-3.31 (2.54)	-3.26 (1.41)	$t(26) = -.069$,	$p = .945$
N2 Pos Right Incongruent (µV)	-3.03 (2.54)	-3.18 (1.40)	$t(26) = .217$,	$p = .830$

* Levene's test for equality of variances violated, therefore degrees of freedom were adjusted accordingly

<u>*P3 ERP component*</u>

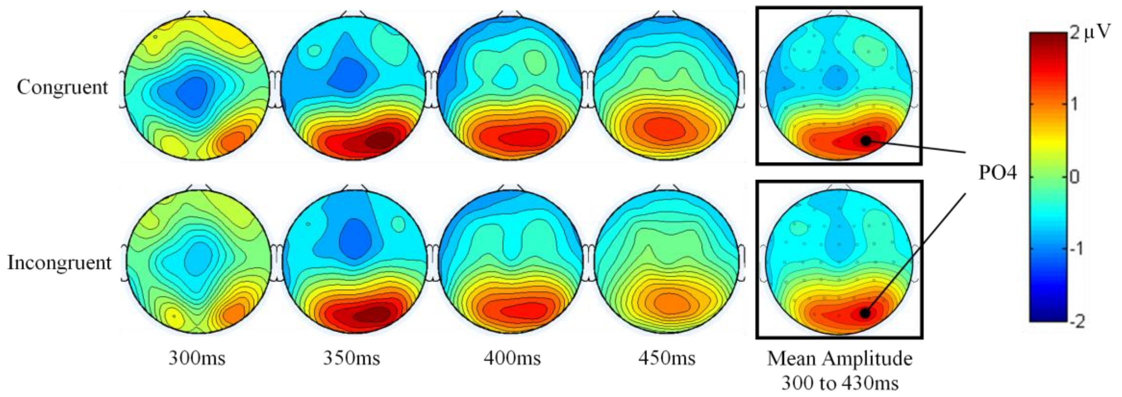

Figure 22: Pooled T1 data (N=28). A time lapse topographical view of the P3 ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 300ms to 450ms (50ms steps from left to right)

Figure 22 displays the time course and topography of the P3 ERP component for both congruent and incongruent conditions using pooled T1 data (N=28). As shown in Figure 23, the P3 maximum was best captured by a time window of 300 to 430ms at PO4. P3 mean amplitudes were subjected to a *Time* (3) x *Congruency* (2) x *Group* (2)

Mixed ANOVA (Table 18), revealing significant main effects of *Time* and of *Congruency*.

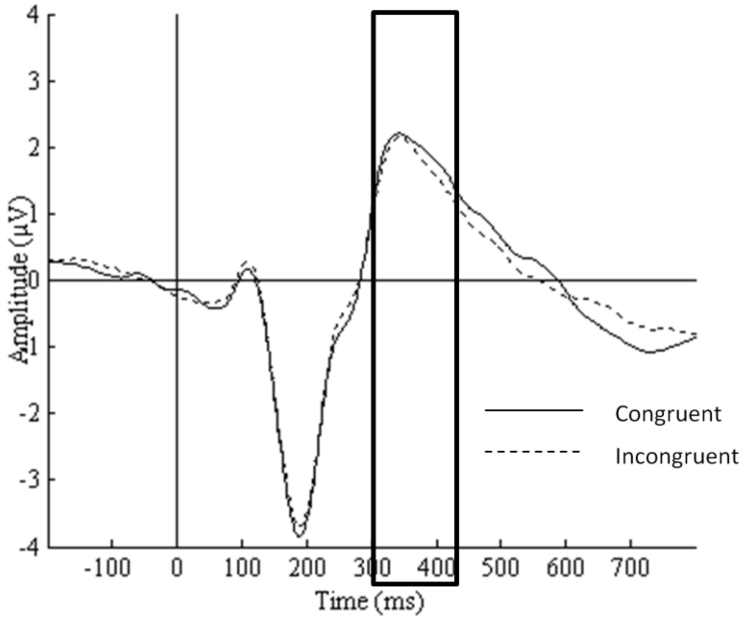

Figure 23: Grand mean evoked potential at PO4 for both congruent and incongruent conditions, from pooled T1 data (N=28). P3 (300-430ms) is highlighted

The significant main effect of *Time* is caused by increases in P3 mean amplitudes across congruencies and groups from T1 to T3 (T1 = 1.80µV; T2 = 2.32µV; T3 = 2.40µV). Planned contrasts revealed that the main effect of *Time* was significant overall from T1 to T3 [$F(1,26) = 19.512$, $p < .001$, $r = .655$] and from T1 to T2 [$F(1,26) = 13.074$, $p = .001$, $r = .578$], but not for T2 compared with T3 [$F(1,26) = 563$, $p = .460$]. These results confirm that no further modulations of P3 occurred after T2 (Figure 24). The ERP modulation from T1 to T3 across groups and congruencies is depicted in Figure 25.

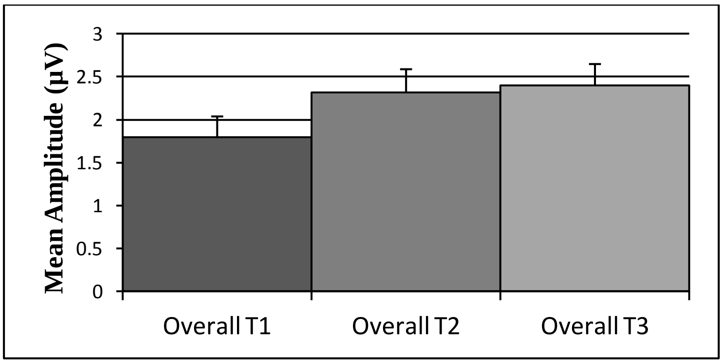

Figure 24: Difference in P3 (P04), pooled across groups and congruencies from T1 to T3. Error bars represent standard error of the mean.

The increase in P3 mean amplitude across groups (group waveforms included for information in Figure 26) was surprising as it had been predicted that the MTG would improve the efficiency of conflict monitoring and conflict resolution processes, thus a reduction had been predicted for the MTG. Given that both groups also improved RTs, it was thought that the P3 increase may enable improved task performance. However, change (T3-T1) in P3 mean amplitude pooled across congruencies and groups was not significantly correlated with change in RTs pooled across congruencies and groups (N=28, r = .012, p = .475). This pattern of results suggests that P3 mean amplitude changes are most likely caused by practice effects resultant from repeated administrations of the task, with an optimum amount of resources applied to conflict resolution and attentional monitoring processes by T2. Thus, the electrophysiological data are unable to explain the MTGs T2 to T3 improvement in RTs. This finding is discussed further in Chapter 8.

Table 18: Summary of Mixed ANOVA (*Time* (3) x *Congruency* (2) x *Group* (2)) results for P3 mean amplitude at PO4

Effect	**Statistical Values**	
Time	F(1.64,42.66*) = 13.241,	p < .001
Group x Time	F(1.64,42.66*) = .642,	p = .502
Group	F(1,26) = .003,	p = .960
Congruency	F(1,26) = 10.430,	p = .003
Congruency x Group	F(1,26) = .148,	p = .704
Time x Congruency x Group	F(2,52) = 1.882,	p = .163
Time x Congruency	F(2,52) = 1.825,	p = .171

* Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity.

The significant main effect of *Congruency* was surprising given that a Paired Samples t-test, conducted using the pooled T1 data (N=28), found no P3 difference between congruencies (t(27)= 1.276, p =.213), which suggested that P3 had not been modulated by flanker interference. However, pooling the data across time points and groups there is a significant difference in P3 mean amplitude between congruent and incongruent trials (2.27 vs 2.09 µV; t(83) = 4.293, p < .001), suggesting that the flanker incompatibility produces a negative deflection in the P3 ERP, similar to that observed by Neuhaus et al. (2010).

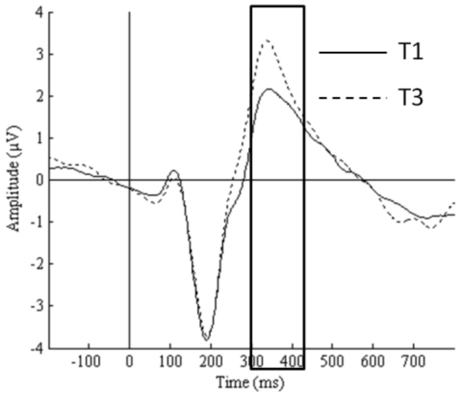

Figure 25: Difference in P3 mean amplitude (PO4), pooled across groups and congruencies from T1 to T3

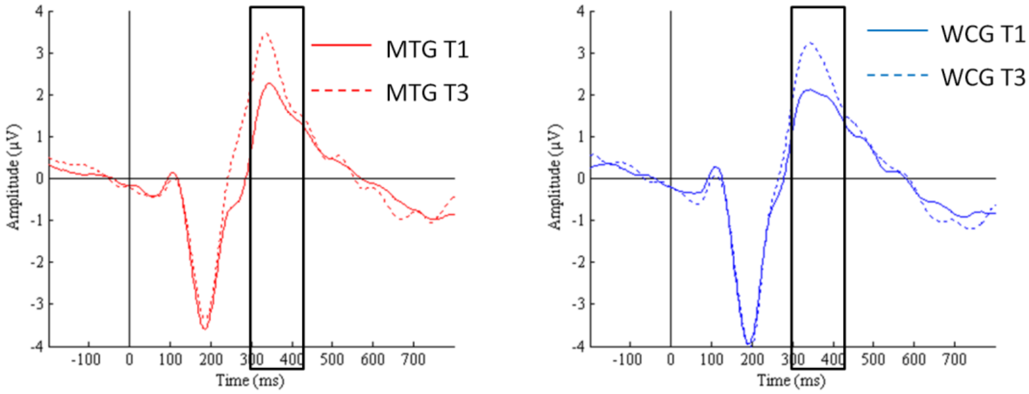

Figure 26: MTG and WCG difference in P3 mean amplitude (PO4), pooled across congruencies, from T1 to T3

Chapter 8. Discussion 1: Implications of Longitudinal Study 1

Chapter 8 contains a discussion of the specific implications of LS1. A broader discussion of the findings of LS1 in relation to the overall implications of this thesis is contained in Chapter 15.

8.1 The Positive Effect of Mindfulness Training on Core Attentional Skills and Associated Neural Activity

The use of the Stroop task produced a number of significant electrophysiological findings. Firstly, as hypothesised the lateral posterior N2 ERP component was modulated differently between MTG and WCG. Whereas a relative increase in N2 mean amplitude was observed for MTG from T1 to T3 for both congruencies, a relative decrease was observed for the WCG. Source localisation was carried out by external collaborators in order to localise the cortical generators of the N2 ERP component (Moore et al., 2012, see Appendix D)[23]. Source localisation suggested that the changes in the MTG were primarily driven by increased activity in the left medial and lateral occipito-temporal areas for congruent stimuli, contrasted by decreased activity in similar brain areas in WCG. These left-hemispheric areas of the ventral processing stream have previously been identified as being selectively involved in lexical tasks (Cohen & Dehaene, 2004; Cohen et al., 2002; Shaywitz et al., 2004), with a similar posterior N2 component as observed here. The posterior N2 has also been shown to be influenced by semantic category (Adorni & Proverbio, 2009), thus it seems plausible that this effect reflects more successful or consistent attentional amplification of the word stimuli that were used in this task. This interpretation is in line with the time course of enhanced stimulus processing when attending to non-spatial features of a stimulus, wherein enhanced negative posterior ERP amplitudes typically appear from around 100 to 150ms after stimulus onset (Hillyard & Anllo-Vento, 1998; Hillyard, Vogel, & Luck, 1998). Moreover, the posterior N2 has been shown to be particularly enlarged when attending to the colour as compared to the form of a stimulus (Eimer,

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[23] Variable Resolution Electromagnetic Tomography (VARETA; Bosch-Bayard et al., 2001) was completed post hoc by external collaborators and is thus not detailed herein with respect to any specific hypotheses. Details regarding the VARETA analysis can be found in Moore & Malinowski, 2012. Of note, the presented VARETA findings relate to differences between T1 and T3 only. The VARETA findings are presented herein as they are peer reviewed and provide additional information regarding the interpretation of the Stroop findings.

1997). Thus, while the WCG have exhibited a habituation effect over the course of the study (and 3 × 144 trials), expressed by a reduction of the ERP amplitudes and the related cortical source strengths, MTG showed the opposite pattern as increased activation of task relevant cortical areas developed following MT.

The pattern of results observed for the N2 suggest that the MTG were able to more consistently attend to the goal relevant dimension of the Stroop stimuli (ink colour). Results from a number of other studies may be similarly interpreted as improvements in goal directed attentional processing. van Leeuwen et al. (2012) finding of a reduced global precedence effect in expert meditators, and following a brief intervention, may be interpreted as more consistent goal directed attention with participants more consistently directing attention to the target, i.e. the goal directed aspects of the presentation, than the level at which the target was presented (local vs. global). Additionally, Anderson et al. (2007) finding of reduced consistency effects in an object recognition task may evince enhanced attentional amplification of the object to be detected (goal) irrespective of the presented scene (non-goal). Further, van den Hurk et al. (2010) found that expert mindfulness meditators (Table 19) demonstrated attenuated inter-sensory facilitation[24] (IF) effects in a choice RT task as compared to controls. As IF effects are considered to reflect involuntary, automatic processing (Kirchner & Colonius, 2005; R. A. Schmidt et al., 1984), their reduction would suggest a reduced reactivity in bottom up processing that would likely be caused by improved top down control of attention, i.e. improved focus on current goal would reduce reactivity to non-goal related stimuli across modalities. Thus enhanced control over bottom up processing is a further mechanism by which the MTG in the current study may have been able to enhance processing of task relevant stimulus dimensions. An alternative potential cause of the N2 findings relates to a further interpretation of van den Hurk et al. findings. The meditators in their study may have employed an enhanced alert state during the task and thus received no further alerting/arousing benefit from the auditory stimulus. This explanation is in line with Jha et al. (2007) finding of a reduced

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[24] IF are the reduction in RT to a stimulus presented in one modality when it is accompanied, close in time, by the presentation of a stimulus in another modality (Keuss, van der Zee, & van den Bree, 1990; Kirchner & Colonius, 2005; R. A. Schmidt, Gielen, & van den Heuvel, 1984; Stoffels, Van der Molen, & Keuss, 1985). For example, Keuss et al. (1990) demonstrated that non-informative sounds (auditory accessories) of low to moderate intensity reduce RT to a visual stimulus. Even more, they showed that visual choice reactions become faster with increasing intensity of the auditory accessory, which is remarkable since the auditory stimulus does not provide any information about the correct response.

alerting effect following an intensive Vipassana retreat which was interpreted to evince a more readied attentional state. Thus it is equally feasible that such an enhanced alert state may have resulted in the observed enhancement of early stimulus processing for the MTG herein. A similar interpretation is also possible for the observed results in Anderson et al. and van Leeuwen et al. studies with enhanced top down attention ensuring that early attentional processing was maintained on goal directed aspects of the presentation.

The second difference between MTG and WCG was observed in the P3 ERP component. P3 changes were primarily observed for incongruent stimuli with the MTG decreasing P3 mean amplitude from T1 to T3 whilst an increase was observed for WCG. Source localisation revealed that the MTG P3 decrease in the incongruent condition was accompanied by significantly decreased signal strength in lateral occipito-temporal and inferior temporal regions of the right hemisphere. These areas have been implicated in object recognition processes (Schendan & Kutas, 2002; Schendan & Stern, 2007). In addition, the temporal/parietal P3 component is considered to reflect attentional resource activation that is generated when perceptual stimulus discrimination occurs and is linked to related inhibition processes that are required when conflicting stimulus information is present (Polich, 2007). Thus, the P3 findings suggest that through MT the perceptual processing of incongruent stimuli becomes less resource demanding. This interpretation is in line with Cahn and Polich (2009) finding that during meditation experienced meditators had reduced P3 amplitude to a distracter tone to auditory oddball stimulation. Therefore, the reduced P3 observed herein during non-meditative task completion suggests that state effects that develop and are present during meditation practice appear to generalise to different tasks performed when not meditating. This assumption underlies the idea that meditation practice generalises into daily activities and extends to contexts separate from meditation practice itself (Hodgins & Adair, 2010; Slagter, Davidson, & Lutz, 2011). As described in Chapter 3, Slagter, Lutz, et al. (2007) similarly found a reduction in P3 mean amplitude outside of meditation following an intensive 3 month mindfulness retreat, a result that when taken with a reduced cross-trial variability in oscillatory theta activity (Slagter et al., 2009) was considered to indicate that the deployment of attention was more consistent and that through MT attentional resources become more rapidly available to process additional information (Slagter, Lutz, et al., 2007). Further, a recent fMRI Stroop study (Kozasa et al., 2012) also demonstrated reduced activity in various attention related brain areas in expert meditators (Table 19) as compared to controls, despite similar behavioural performance. The authors proposed that their findings evince enhanced attentional efficiency in meditators that may result from improved sustained attention and impulse control.

The findings of increased N2 and decreased P3 amplitudes and source strengths for the MTG appeared to be complimentary. Thus, as an exploratory post hoc step differences (T1 minus T3) in N2, pooled across groups and congruencies for PO left and PO right, and P3 for the incongruent condition were submitted to a correlational analysis. It was found that change in N2 mean amplitude was significantly correlated with change in P3 mean amplitude at both PO left (r = .479, p = .005, 1 tailed) and PO right (r = .452, p = .008, 1 tailed) sites. Therefore, it is feasible that the more successful attentional amplification of the colour word stimuli evidenced by increased N2 amplitudes/source strengths had the subsequent effect that fewer resources were needed during object recognition processes, especially when incongruent stimulus information was processed, indexed by the decrease in P3 amplitudes/source strengths. Conversely, the WCG may have needed to increase P3 amplitude to maintain task performance following a habituation related decrease in N2. Kozasa et al. (2012) similarly speculated that their finding of lower activation in attention related areas during Stroop task completion may have resulted from meditators maintaining focus on naming the colour (goal), causing less interference with naming the word and subsequently requiring less effort for conflict monitoring.

Table 19: Summary of relevant participant details for studies introduced in Chapter 8. Experience and ongoing practice values are group means unless stated otherwise.

Study	Meditative Tradition	Previous Experience	Ongoing Practice	Comparison Group
van den Hurk et al., 2010	Vipassana	14 yrs	n/s	Age and gender matched controls.
Kozasa et al., 2012	States only that the expert meditators engaged in a variety of FA and OM practices such as Zazen, mindful breathing and mantra meditation.	8.5 yrs	At least 3 times weekly but duration not stated	Age, gender and education matched controls.

An unexpected result of this study was the concurrent null behavioural and LN ERP component findings. This finding is at odds with the results of several studies that showed better performance of expert mindfulness meditators, as compared controls, on similar measures of executive attention and conflict resolution (Chan & Woollacott, 2007; Jha et al., 2007; Moore & Malinowski, 2009). There are a number of potential explanations for these null findings. Firstly, the longitudinal design of the current study dictated that the Stroop task be administered repeatedly whereas experts and controls were only compared after one administration of the task in cross sectional studies. Herein, overall RTs did not improve from T2 to T3 and accuracy was above 95% for incongruent trials, suggesting that a performance ceiling may have been reached. Secondly, the role of the ACC during Stroop completion may influence results. The ACC has been shown to be the generator of the LN and to be involved in performance monitoring and response selection (Hanslmayr et al., 2008; Liotti et al., 2000). However, two recent event-related fMRI studies suggest that the role of the ACC is more related to anticipatory regulation of attention rather than the specific selection of responses itself (Aarts et al., 2008; Roelofs et al., 2006). The lack of differential effects in the LN might thus reflect that with repeated exposure to the Stroop task anticipatory regulation was perfected in both groups, resulting in the observed ceiling effect. Herein it appears MT has improved earlier stages of processing (indexed by N2 and P3 changes) that reflect more fundamental changes in attentional processing and are less amenable to simple task repetition effects. Although speculative, this would explain why clear behavioural differences are found when meditators encounter the Stroop task for the first time (Chan & Woollacott, 2007; Jha et al., 2007; Moore & Malinowski, 2009), while they did not develop on repeated presentation of the same task herein (see also Anderson et al., 2007; Polak, 2009). Lastly, the large disparity between the levels of MT undertaken during the current study (18wks), as compared to studies of expert meditators with vast amounts of prior MT experience (see Table 2), may account for these differential results. However, as executive improvements have been reported following short term MT (e.g. Tang et al., 2007; Wenk-Sormaz, 2005) and the MT used herein appears to modulate core attentional processing, the potential benefits from short term MT are still apparent.

As hypothesised, a between groups difference in RT demonstrated that the MTG improved RTs above and beyond the level that may be associated with practice effects resultant from repeated administrations of the task (i.e. WCG performance). Whereas both groups improved RTs from T1 to T2, only MTG improved further from T2 to T3. This raises the question 'why did MT produce additional improvements in ANT behavioural performance and not in the Stroop task?' Differences in task difficulty are the most likely explanation for the differential findings across tasks. Although both tasks purport to measure executive function by requiring conflict monitoring and inhibitory control to deal with conflicting stimulus information, the source of conflict is different for each task. For the ANT the conflict is caused by flanker incompatibility, thus the conflict comes from additional stimuli as part of a stimulus array, whereas Stroop conflict is caused by competing aspects of the same stimulus (word meaning vs. ink colour). As evidenced by the robustness of the Stroop effect across 3 administrations of the task, the integrative nature of the Stroop conflict is very difficult to overcome. Conversely, ANT executive scores reduced significantly following repeated administrations (*Time x Congruency* interaction). Unsurprisingly, overall RTs for the Stroop task were more than 130ms slower than for the ANT across all 3 time points, further demonstrating the difficulty of the Stroop task. The added difficulty of the Stroop task may provide a further explanation of the null between groups behavioural differences on said task and for why differences are only seen between experts with vast amounts of experience and controls, whereas the lower task difficult of the ANT may have made the task more susceptible to improvements following short term MT. Potentially, MT may have enabled the MTG to focus attention more consistently to the target stimulus during ANT completion, ignoring the flanker stimuli, thus improving RT more so than the WCG improvements which was most likely caused by repeated administrations of the task. This interpretation is consistent with the proposal that MT improved electrophysiological markers of goal directed attention on the Stroop task.

The electrophysiological examination of the ANT was limited to target locked ERPs and thus limited to neural activity related to the attentional processing of conflicting stimulus information. No between groups differences were observed. However, P3 mean amplitude, pooled across groups and congruencies did increase over the course of the study. This finding is in opposition to the hypothesised reduction in P3 that was expected for the MTG. This leads to a further question 'Why was Stroop P3 but not ANT P3 differentially modulated following MT?' A plausible explanation is that the P3 ERP component may reflect different neural processes on the ANT and Stroop task. Whereas the P3 has been shown to be modulated by flanker congruency on the ANT (Neuhaus et al., 2010), a finding which only developed over the course of repeated administrations of the task in this study, it is the LN that is typically modulated by conflict in the Stroop task. Thus, the null P3 ANT findings are best associated with the null LN Stroop findings and may relate to anticipatory regulation being perfected in both groups by T2. However, whereas the null LN findings on the Stroop were consistent with the null behavioural findings, the MT related behavioural performance improvements found from T2 to T3 for the ANT cannot be explained by the electrophysiological findings. Interpreting ERP modulations on the ANT is difficult due to the dearth of extant studies utilising ANT and ERP methods. However, a recent ANT study[25] (Kratz et al., 2011) which did include both behavioural and ERP measures found that children with inattentive ADHD had lower P3 mean amplitude and higher RT variability (assessed using RT standard deviation) than matched controls. The inattentive subtype of ADHD is characterised by difficulties in directing and maintaining goal directed attention and P3 reductions have been said to reflect a reduced amount of attention being allocated to stimulus processing and evaluation (Banaschewski et al., 2003). Whilst speculative, it may be suggested that P3 was not modulated further after T2 as an optimum amount of attentional resources were already available to participants of both groups for task completion. Herein, the observed

[25] This study was published after data collection for LS1 had completed and thus had no bearing on hypotheses herein.

increase in P3 across groups is in line with the observed reduction in RTs across groups, although changes in P3 mean amplitude were not correlated with changes in RTs. The aforementioned reduction in task difficulty over time is a possible reason for this modulation occurring across groups rather than being specific to MTG. Thus as suggested above, rather than a further enhancement of attentional resource allocation, MT related improvements in goal directed attention may best explain the observed between groups behavioural difference.

Finally, for the ANT no N2 modulations were found within or between groups over the course of the study. Again this is in opposition to the MT related modulation on the Stroop task. However, differences in N2 mean amplitude were less likely on the ANT as the stimuli (words vs. arrows) and sources of conflict are very different for each task. As stated previously, conflict in the ANT is produced by incompatible flanker stimuli, thus unlike in the Stroop task, there is no need for attentional amplification of different aspects of the same stimulus during early stages of stimulus processing. Additionally, overcoming the automaticity of word reading is a much more difficult task than ignoring incongruent flanker stimuli (as evinced by the aforementioned robustness of the Stroop effect and reduced executive network scores), thus ANT performance is less reliant on attentional control over early stimulus categorisation and recognition processes than the Stroop.

In conclusion, it must be recommended that the ANT is not an ideal tool for use in longitudinal research due to the clear reduction in task difficulty following repeated administrations of the task, evinced by the strong main effect of *Time* and the *Time x Congruency* interaction. Thus whilst the observed between groups difference in RTs is a positive result it must be interpreted cautiously.

8.2 Mindfulness Based Breath Awareness Meditation and Self Reported Mindfulness

As hypothesised, MTG increased self reported mindfulness from T1 to T3, whereas no difference was found in the WCG. This finding suggests that even a singular MT technique, completed over a brief period, may improve the frequency with which one may engage in mindful behaviours and apply mindfulness in ongoing experience.

This suggests that mindfulness based breath awareness meditation plays a fundamental role in increasing mindfulness.

In addition to an overall improvement in mindfulness, increases were specifically found in the FFMQ-O and FFMQ-NR facets of mindfulness. FFMQ-O is purported to measure behaviours that involve the observation of one's internal and external sensations (e.g. thoughts, emotions, sights, sounds, and smells) whilst FFMQ-NR measures non-reactivity to inner experience. These facets bare close relation to two key elements of the mindful breathing MT, the ability to observe/focus on one's breath and the ability to not react to arising thoughts, feelings, emotions and sensations. Thus, increases in mindful behaviours related to these two facets of mindfulness suggest that techniques learnt during meditation are being applied outside of meditation with increased frequency following MT. Interestingly, Paul et al. (2013) recently found that FFMQ-NR scores, in a non-meditating sample, were inversely correlated to insula activation[26] during the inhibition of negative stimuli following a 5 minute mindful breathing task, leading the authors to suggest that non-reactivity to inner experience is a key facet of mindfulness that may reduce automatic emotional processing and protect individuals from psychological risk for depression. Said reduction in insula activation suggests that the individuals scoring highly in FFMQ-NR were able to focus on the goal directed aspect of the stimulus (i.e. was it a go or no go stimulus) rather than the non-goal directed aspect of the stimulus (i.e. its emotional valence) as the insula is typically engaged during emotional processing. This finding is consistent with the assertion that MT led to improved attentional amplification of goal relevant aspects of a Stroop stimulus in the current study and that increased control over bottom up processing may be possible through MT. Thus the increase in non-reactivity that appears to have been fostered by the MT herein may be a key factor in the observed improvements to core attentional processes.

[26] Higher FFMQ-NR score was related to lower insula activation during an emotional Go/No-go task that required participants to respond only to certain kinds of emotional faces during each trial block. Enhanced insula activation is typically seen during the processing of affective stimuli.

8.3 Summary

In sum, short term exposure to a singular MT technique positively modulated core attentional processes and increased self reported mindfulness in a sample of meditation naïve individuals. The design of LS1 ensured that MT related changes were measured outside of a meditative state, meaning that the observed improvements seem to generalise from the specific situation of a meditation exercise to the processing of visual stimuli and into everyday behaviours. Slagter et al. (2011) proposed that MT, developed over longer periods of time, should lead to the enhancement of cognitive core processes including the sustained monitoring of one's own mental states, the ability to disengage from distracting objects and the skill to redirect attention back to the chosen focus. The observed changes in the N2 and P3 on the Stroop task and the improved behavioural performance on the ANT may partially reflect the enhancement of such core processes, and more specifically to processes related to sustaining attention to the goal/task at hand. Further, the increases in self reported mindfulness suggest that said improvements may lead to positive effects outside of the laboratory environment.

Whilst the current study was not specifically designed to assess the potential mechanism by which MT produces positive effects, the pattern of results observed herein suggest that attentional functions are amenable to change following short durations of MT and that they may be a potential mechanism for MT related positive effects. In line with the Liverpool Mindfulness Model (Malinowski, 2013), it may be proposed that improvements in attentional control, fostered through MT, may provide the platform upon which cognitive and emotional flexibility may be improved, leading to a myriad of potential positive outcomes. In support of this assertion, a number of recent studies have begun to link the attentional improvements obtained through MT to improvements in emotion regulation (Allen et al., 2012; Paul et al., 2013; Sahdra et al., 2011). Thus, the findings observed from LS1 and LS2 will be discussed with reference to this potential mechanism for MT related positive effects in Chapter 15.

It is important to note that a general weakness of the waitlist control group design of LS1 is that it cannot rule out an alternative explanation for the observed results, that the observed results may be related to the fact that meditators engaged in a novel regular activity per se, rather than being specific to MT. However, given that the observed effects are in line with the results of several other studies, appear to have generalised into activities outside of the laboratory and were observed outside of the meditative state, the effects appear to be related to the MT. Whilst LS1 utilised a waitlist control group as a practical first step in investigating MT related changes, LS2 incorporated an active control comparison condition to provide a more complete assessment of MT related changes. Thus this weakness is recursively addressed in LS2.

Chapter 9. Theoretical Background to Longitudinal Study 2: Cognitive Ageing and the Potential Positive Effect of Mindfulness Training.

9.1 Ageing and the Increasingly Important Problem of Age Related Cognitive Declines

It is generally accepted that systematic age-related declines occur in cognitive functioning in midlife and older age, including deficits in executive function, problem solving, decision making, verbal and visuo-spatial memory and working memory. The term '*cognitive ageing*' describes this pattern of impairments in cognitive functions with increasing age. Moreover, as cognitive function is a fundamental component of health and well being, cognitive impairments, even those not reaching the threshold for dementia diagnosis, are associated with a loss of quality of life, increased disability, and higher health-related expenditures (Albert et al., 2002; DeCarli, 2003; Ernst & Hay, 1997; Lyketsos et al., 2002; Salthouse, 2004; Tabert et al., 2002). These potential problems have come to the forefront of public and policy makers' consciousness in recent times as a major demographic shift is occurring. For example, in Europe the percentage of people aged 65 years or over is projected to increase from 17.1% (84.6million) in 2008 to 30.0% (151.5 million) in 2060 (Eurostat, 2008). If future 'aged' generations experience similar patterns of cognitive development to previous generations the prevalence of cognitive impairments, including dementia and Alzheimers disease (AD), will increase markedly over the coming years. Thus, the ageing population presents a great health, social and economic challenge.

Encouragingly, research over the past two decades has suggested that the adult brain has much greater capacity for plasticity[27] than previously believed, that the structure of the brain can change in response to training (Colcombe et al., 2006; Draganski et al., 2004; Driemeyer et al., 2008; Gage, 2002) and that age related cognitive declines may be influenced by non-biological factors such as education, diet, exercise and other life style choices (Hedden & Gabrieli, 2004; National Research Council, 2000). Such positive findings have led to somewhat of a paradigm shift with

[27] Brain plasticity refers to changes in neural pathways and synapses which are due to changes in behaviour, environment and neural processes, as well as changes resulting from bodily injury.

researchers increasingly interested in the causes of healthy brain ageing as opposed to the causes of dysfunction/impairment. However, before discussing the potential causes of healthy brain ageing it is necessary to discuss the extant literature regarding what declines and why. Accordingly, the following sections detail the declines that are seen in core cognitive functions, modulations in brain activity associated with ageing, why these modulations may occur, the theory of cognitive reserve and the potential for MT to capitalise on cognitive reserve and thus positively influence brain ageing.

9.2 Ageing and Decline in Sustained and Executive Attentional Functions

Most conceptualisations of cognitive ageing distinguish between 3 main kinds of cognitive abilities: effortful, automatic and crystallised. The classic pattern is one of age declines in tasks requiring effortful processing versus age invariance in tasks relying predominantly on automatic processes, with growth occurring across the life span in crystallised abilities such as vocabulary and knowledge (see Salthouse, 2004 for review). The focus herein is on two core effortful cognitive functions, sustained and executive attentional functions. The evidence presented in this section will demonstrate that both of these functions decline with age and the potential mechanisms by which these declines occur will be discussed. As a rule of thumb the term ‘older adults’ is utilised within this section to describe groups of participants that have a mean age of 65 or above whilst ‘younger adults’ refers to groups who are 30 or younger. Any significant deviations from this will be explicitly stated. As a reminder, an overview of the details of cognitive tasks introduced in this and the remaining Chapters of this thesis can be found in Appendix A.

A number of studies employing a wide range of paradigms have suggested that older adults’ exhibit age related declines in sustained attention. The majority of studies that have sought to examine said declines have used paradigms that require attention to be sustained over extended periods of time in order to respond to *rarely* presented stimuli. In this approach, sustained attention is typically defined as a state of readiness to detect and respond to certain changes in the environment, occurring at random time intervals over prolonged periods of time (e.g. D. R. Davies & Parasuraman, 1982). Performance is measured by two key indicators: 1) the *vigilance decrement,* which is typically observed as an increase in RTs and/or errors with time on task and 2) *overall vigilance,* which refers to performance measures that typically involve outcome measures such as RTs, HRs or errors derived from overall performance on the task. Differences in each of these indicators have been found between old and young adults. Using a digit discrimination task (Nuechterlein, Parasuraman, & Jiang, 1983) Deaton and Parasuraman (1993) found a vigilance decrement in older vs younger adults, with older adults exhibiting a greater decrease in HR and a greater increase in false alarms with time on task. Further, Thackray and Touchstone (1981) found decrements in a task that was designed to mimic air traffic control, with older adults increasing errors (both commission and omission) and RTs after a shorter amount of time than younger adults. Overall vigilance has also been shown to decrease with older, compared to younger, adults producing slower RTs on a CPT paradigm (Hammerer et al., 2010). A. D. M. Davies and Davies (1975) also reported a lower HR in an older vs. younger group and Mani, Bedwell, and Miller (2005) reported a reduction in HR and more false alarms with increasing age (age range 19-82yrs). Differences have even been found between older adults aged 50-69 and those aged 70-79 with the later requiring longer to complete a digit cancellation task (Filley & Cullum, 1994), suggesting that performance continues to worsen in old age. It must be noted that some mixed findings have also been reported. Using a 60 minute Mackworth Clock Test Giambra and Quilter (1988) found that whilst RTs increased from middle to older age, vigilance decrements (HRs) with time on task did not. Giambra (1997) found that older and young adults had similar overall HRs on a 30 minute sensory vigilance task although false alarms did increase with time on task for the older adults only. Other studies have reported that with time on task older adults do exhibit a greater decrease in HRs but comparable RTs (Surwillo & Quilter, 1964). The somewhat inconsistent findings across these studies may be explained by differences in task difficulty, task duration and reported outcome measures (e.g. HRs vs RTs and overall performance vs time on task) as these factors vary widely across studies. The overall pattern of results suggest that sustained attention deficits manifest with increasing age with older adults exhibiting vigilance decrements and deficits in overall vigilance across paradigms.

Sustained attention performance decrements may appear with advancing age due to a decrease in the availability of attentional resources. It has been proposed that the continuous nature of the effortful mental work that is required during a sustained attention task does not allow for attentional resources to be replenished and eventually leads to a decline in performance (e.g. Grier et al., 2003; Warm, Parasuraman, &

Matthews, 2008). Evidence for this assertion comes from studies that have shown that greater performance decrements accompany higher task demands (Helton et al., 2004; Sebastian, Baldermann, et al., 2013) and that the vigilance decrement is accompanied by a parallel decline in cerebral blood flow velocity, a possible indicator of the supply of physiological resources that is thought to provide a metabolic index of the utilisation of information processing resources during task performance (Hitchcock et al., 2003; T. H. Shaw et al., 2009). Thus if older adults have less available attentional resources to begin with, they are likely to be exhausted faster leading to worse performance both overall and with time on task. This explanation is consistent with the abovementioned vigilance decrements and decreases in overall vigilance reported in older adults.

The efficient temporal allocation of attentional resources also appears to decline with age. Evidence for this assertion comes from studies utilising the ABtask, an effortful task that requires participants to sustain attention to a rapidly presented stream of visual stimuli in order that two temporally close target stimuli may be identified. A number of studies have observed that the AB increases with age (Georgiou-Karistianis et al., 2007; Maciokas & Crognale, 2003; van Leeuwen et al., 2009). The increase in blink is two-fold. Firstly, older participants miss the second target more frequently. This increase may be explained by a reduction in overall attentional resource capacity, with too few resources left available for processing the second target when it appears during the time window in which the first target is still being processed (AB time window <500ms post first target). Secondly, older adults miss the second target for longer periods of time following detection of the first target. This suggests that older adults take longer to process the first target meaning attentional resources for processing the second target are unavailable for longer. A reduction in inhibitory control in older adults may also explain this pattern of results, with non-targets gaining access to and taking up a proportion of the limited available attentional resources if they are not inhibited from further processing. Age related deficits in executive functions such as inhibitory control are introduced and discussed below.

Evidence from a wide range of paradigms suggests that older adults experience declines in top down attentional control mechanisms, i.e. executive functions. Staying with tasks of sustained attention for the moment, said functions are required in order to modulate the processing of task specific information, to maintain task goals online, monitor performance and error, filter distracting information and suppress habitual pre-potent and conflicting responses (e.g. Carter et al., 1998; Matsumoto & Tanaka, 2004; M. Sarter & Paolone, 2011; van Veen & Carter, 2006). In a recent study, McAvinue et al. (2012) found that older adults had slower RTs and produced more errors (both commission and omission) than younger adults on the Sustained Attention to Response Task (SART; Robertson et al., 1997), a commonly used Go/No-Go paradigm which requires participants to utilise executive functions to inhibit pre-potent responses to rarely presented stimuli. Whilst the SART RT decrement in older vs. young adults has been replicated in other recent studies (Carriere et al., 2010; Jackson & Balota, 2012), errors are not typically found to be increased in older adults on said task, in fact both Carriere et al. (2010) and Jackson and Balota (2012) observed less errors in older as compared younger adults. Of importance, a closer inspection of Carriere et al. (2010) data, wherein participants were grouped based on decade of life (e.g. 3^{rd} = age 20-30), highlights that adults aged between the 3^{rd} and 7^{th} decade committed less than 5% errors (3^{rd} decade = 4.8%, 7^{th} decade = 4.0%), suggesting that the lack of old vs. young accuracy deficits in these studies may be accounted for by a lack of task difficulty. This explanation is feasible considering Go/No-go tasks typically only involve 1 response mapping and no conflict between perceptual and motor processes. A more careful response criterion, prioritising accuracy over response speed, may explain the slower RTs that were observed for older adults across studies and would account for why more errors of omission but not commission have been found as a function of age (Sebastian, Baldermann, et al., 2013).

Slower RTs on trials that follow an error have also been observed for old vs. young adults (Band & Kok, 2000; Jackson & Balota, 2012), a finding suggestive of a more careful response criterion and increased recruitment of top-down attentional control (i.e. attentional monitoring) to improve accuracy (Kerns et al., 2004). Findings from neuro-imaging and ERP studies support this assertion. A number of fMRI studies have observed increased activation of the ACC, a region implicated in attentional monitoring, for older vs. younger adults on the SART (Hester, Fassbender, & Garavan, 2004) and other tasks that require the inhibition of pre-potent responses (e.g. Milham et al., 2002; Nielson, Langenecker, & Garavan, 2002). A decrease in the difference between ERN[28] and the correct related negativity (CRN[29]) has also been found in old vs young adults (Endrass, Schreiber, & Kathmann, 2012). Recent studies utilising ICA have found that the ERN and CRN map on to a single IC with amplitude modulations found for errors and correct responses (Hoffmann & Falkenstein, 2010; Roger et al., 2010), thus the reduced difference between the ERN and CRN in older adults may reflect an increase in general monitoring of responses in the absence of errors. It is feasible that this increased use of top down resources over time may deplete attentional resources, which would explain why vigilance decrements with time on task were observed in a number of the earlier mentioned studies. Unfortunately, performance decrements with time on task were not reported in the abovementioned SART and Go/No-go studies, thus further research is required to determine whether the older adults were slower throughout the task or whether the mean overall RTs are lower due to a progressive slowing with time on task, potentially caused by the depletion of available attentional resources over time.

The inhibitory deficit hypothesis (Hasher, Zacks, & May, 1999), a leading hypothesis for observed age related declines in cognitive performance affords a plausible explanation for why older adults may employ a more careful response criterion and enhanced top down attentional control during tasks of even minimal difficulty. The inhibitory deficit hypothesis proposes that the ability to inhibit irrelevant information is impaired in older adults. Thus older adults may employ a more careful response criterion and/or require more top down attentional control in order to compensate for the fact that they find it more difficult to inhibit irrelevant information that may otherwise affect responses. A number of recent findings continue to demonstrate that older adults have impaired inhibitory control. A further finding of the aforementioned study by Hammerer et al. (2010) was that older vs. younger adults had a pronounced no-go P3a ERP component to infrequent non-cue stimuli, a finding that the authors interpreted as evidence of attentional distraction, which may be considered analogous to a failure to inhibit task irrelevant information. Similarly, in a series of

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[28] The ERN is a negative deflection in the ERP that is seen after an error. It is assumed to reflect the adjustment of cognitive control to prevent future errors (Kerns et al., 2004; Ridderinkhof et al., 2004). This is supported by several reports revealing an association of ERN amplitude with post-error slowing (Debener et al., 2005; West & Travers, 2008).

[29] The CRN is a negative deflection in the ERP that appears after a correct response. Typically the ERN is a larger amplitude negative deflection than the CRN.

studies utilising Go/No-go paradigms Vallesi and colleagues found that older vs. younger adults had more difficulty ignoring both high (Vallesi, 2011) and low conflict (Vallesi et al., 2009) no-go stimuli, evidenced by a larger P3 ERP component to said stimuli. Consistent with the earlier mentioned SART studies, RTs to go stimuli were also slower for older adults across both of Vallesi and colleagues studies, suggesting that difficulty in inhibiting the attentional processing of no-go stimuli may lead to slower responses.

Nigg (2000) proposed that inhibition is made up of both automatic and executive components, with inhibition tasks requiring varying amounts of executive control. Automatic inhibition occurs without awareness, i.e. when irrelevant information that is automatically and simultaneously activated in conjunction with relevant information is suppressed prior to cognitive awareness (S. P. Wilson & Kipp, 1998). Conversely, executive inhibition relies on controlled suppression of irrelevant stimuli or responses and is likely to be utilised during more difficult tasks of inhibition. Andres et al. (2008) found that negative priming[30], a form of automatic inhibition, was not influenced by ageing whereas executive inhibition, as measured by performance on the Stroop task and Stop signal task, was significantly worse for old vs. young adults. This finding remained significant when speed of processing was controlled for, suggesting that age related deficits in executive inhibition cannot simply be explained by a general slowing account of ageing. Other studies have also observed deficits in executive inhibition in older adults using the Stop-signal task (Hu et al., 2012; B. R. Williams et al., 1999) and deficits have also been observed using the Simon task (Kubo-Kawai & Kawai, 2010; Maylor, Birak, & Schlaghecken, 2011; van der Lubbe & Verleger, 2002; West & Alain, 2000). Whereas the Go/No-go tasks discussed thus far typically involve action withholding aspects of inhibition, i.e. the withholding of a pre-potent response in no-go conditions, the Stop signal task and the Simon task involve action cancellation and interference inhibition respectively (see Sebastian, Pohl, et al., 2013 for a recent review of these sub components of inhibition). The added difficulty of these forms of executive

[30] The ignored word on any 1 trial became the attended colour on the next trial, relative to sequences wherein successive words and colours were unrelated. Negative priming arises due to inhibition of the ignored distracter on trial n that results in a longer time to reach the activation necessary to permit accurate response production for the same stimulus when it appears as the target on trial n + 1 (Tipper, 2001).

inhibition may explain why age related declines are often more readily observable on such tasks (Sebastian, Baldermann, et al., 2013).

In addition to Andrés study, a number of other studies that employed the Stroop paradigm further suggest an age related decline in executive inhibition and conflict monitoring. Differences in Stroop interference (RTs) have been found between young and older participants (Cohn, Dustman, & Bradford, 1984; Mayas, Fuentes, & Ballesteros, 2012; Panek, Rush, & Slade, 1984; West & Alain, 2000; West & Bell, 1997), between young and middle aged (mean age = 50.9yrs) participants (Mager et al., 2007) and in a study that utilised normative data to correlate age with Stroop interference (Van der Elst et al., 2006). Further, modulation of ERP components has also been found with a greater P3 (West & Moore, 2005) and LN (Mager et al., 2007) mean amplitude observed in older vs. younger adults, suggesting more attentional resources are required by older adults to complete the Stroop task. Interestingly, increases in Stroop interference scores have also been associated with age related declines in dopamine activity (Volkow et al., 1998), a catecholamine neurotransmitter that is thought to modulate the executive network of attention (Posner & Rothbart, 2007). Recently, links between executive network declines, declining prefrontal lobe function and the dopaminergic system have also been found using the ANT (Zhou et al., 2011) and a negative effect of age on performance was also found using a colour version of the Eriksen flanker task (Waszak, Li, & Hommel, 2010) in a population based sample of 263 adults (age range 6-89). In sum, the converging evidence suggests that deficits in sustained attention and executive functions, most notably for executive inhibition, may play a crucial role in age related cognitive declines.

The majority of findings discussed thus far have utilised behavioural dependent variables (e.g. RTs and HRs). Such measures provide only part of the picture as they are indicative of the outcome of a series of complex and very rapid mental processes and give little information regarding the sub-processes that may be impaired. Thus ERPs that provide information regarding the processing that occurs between the presentation of a stimulus and a response and neuro-imaging recordings that provide information regarding active brain regions during task completion may provide valuable information regarding what is occurring in the ageing brain.

A number of ERP findings have been briefly mentioned thus far with older adults displaying ERPs that are indicative of more effortful attentional monitoring (Endrass et al., 2012), increases in attentional resources to task irrelevant information (Hammerer et al., 2010; Vallesi, 2011; Vallesi et al., 2009) and increases in attentional resources during response conflict (Mager et al., 2007) and for inhibition (West & Moore, 2005). Taken together these findings are indicative of older adults enhancing top down attentional control and requiring more attentional resources to complete tasks.

Research utilising neuro-imaging techniques goes in the same direction. Both Langenecker and Nielson (2003) and Nielson et al. (2002) found that older, not younger, adults exhibited bilateral activation patterns during the completion of Go/No-go tasks whilst the former study also found that these activation patterns remained stable over task repetitions. The primary areas of activation were highly comparable across both of these studies and included a variety of regions that have been implicated in inhibitory control such as the bilateral inferior and middle frontal gyri, IP areas, anterior cingulate gyri, supplementary motor area, as well as the left insula, claustrum, and putamen. These findings further suggest that older adults recruit additional neural resources to complete tasks involving inhibition. Similar findings have also been found during the completion of a working memory task (Piefke, Onur, & Fink, 2012) with older adults activating the PFC bilaterally whilst younger adults only activated left hemispheric regions. Enhanced activation of primary task related cortical areas have also been observed. Vallesi, McIntosh, and Stuss (2011) found that whilst old and young adults activated a similar extensive set of fronto-parietal regions in response to high conflict no-go stimuli, the older adults had greater activation in these regions, suggesting they had to over recruit to perform the same task. Similarly, Langenecker, Nielson, and Rao (2004) found comparable activation patterns for young and old adults during Stroop task completion with the later exhibiting enhanced activation in regions implicated in inhibition (inferior frontal gyrus). The general pattern of results emerging suggests that older adults require enhanced activation of task related cortical areas and/or activation of additional areas in order to perform the same task as younger adults.

A deficit in attentional control mechanisms has been proposed to account for age related activation differences. Milham et al. (2002) found that younger, but not older adults, exhibited increased activity in attentional control regions (e.g. DLPFC) in response to increased demand across task conditions (incongruent activity > congruent and neutral) during the Stroop task. Further, only older adults had both bilateralised activation patterns in regions associated with the inhibition of task relevant information and increased activation in regions associated with response monitoring (ACC). Taking these results together it was proposed that a lack of efficiency for attentional control mechanisms to respond to increased demand may result in additional resources being required for the inhibition of task irrelevant information if it was not dampened at earlier processing stages. This may ultimately lead to an increased need for response monitoring. However, more recently Lague-Beauvais et al. (2013) found DLPFC activation even on the neutral, non-executive condition, of the Stroop task for older but not younger adults, whilst task switching was also associated with more widespread frontal activation in older adults. Therefore, as older adults exhibit bilateralised and enhanced activation across a variety of paradigms, including those of relatively low difficulty, attentional control may manifest differently in older adults. Enhanced top down attentional control itself may result in this pattern of bilateralised and enhanced activation which may be required to manage demand across tasks and task conditions owing to a loss of neural specificity and efficiency with ageing (Colcombe et al., 2005). Recent ERP findings (Haring et al., 2013) support this assertion with older, as compared to younger, adults displaying an enhanced neural response when asked to attend to, as well as ignore colour letters, even when executive capacity[31] was controlled for between groups, suggesting that older adults attempt to meet task demands by enhancing top down resources across task conditions. Thus, an alternative explanation for the aforementioned findings of enhanced activation in no-go conditions (Vallesi et al., 2009) and to non-cue stimuli (Hammerer et al., 2010) may be that older adults are allocating more resources across conditions to meet task demands, rather than reflect enhanced attentional distraction.

If as suggested by the findings presented herein, deficits in sustained and executive attention are a natural part of ageing, then the enhanced activation and recruitment of additional neural resources detailed herein may reflect compensatory mechanisms that attempt to utilise adaptive plasticity to improve or maintain performance despite age-related neurodegenerative modulations (see Buckner, 2004;

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[31] A composite score of executive capacity was generated from a variety of executive measures including: the digit span backward subtest of the Wechsler Adult Intelligence Scale-IV (WAIS-IV; Weschler, 2008), Controlled Oral Word Association Test (Ivnik et al., 1996), WAIS-IV Letter-Number Sequencing, WAIS-IV Digit-Symbol Coding, and the Trail-Making Test Parts A and B (Reitan & Wolfson, 1985)

Cabeza et al., 2002). For this assertion to hold true individuals who continue to perform well in old age would be expected to display enhanced and/or bilateralised activation whereas poorly performing adults may display reduced and/or asymmetric activation patterns. Whilst extant evidence for this assertion is limited the findings of a number of studies indeed go in this direction. Cabeza et al. (2002) found that high performing older adults had bilateral activation patterns whereas asymmetric patterns were observed in both younger and poorly performing older adults. Further, Vallesi and colleagues found that in older adults, increased no-go P3 mean amplitude was associated with decreased RTs to go stimuli (Vallesi, 2011) and over recruitment of resources was associated with reduced errors (Vallesi et al., 2011). In line with the resource theory of sustained attention decrements, this enhanced need for attentional resources may be expected to deplete available resources and cause performance decrements with time on task and thus may account for some of the earlier discussed vigilance decrements. However, as enhanced and bilateralised activation have been linked to improved performance, such modulations may top up attentional resource capacity rather than cause an additional drain on available resources, with performance likely to be worse in their absence (e.g. Cabeza et al., 2002).

The evidence reviewed thus far in this Chapter highlights that identifying methods that can improve sustained attention, executive control functions and in particular inhibitory control, and increase attentional resources in older adults should be considered a priority for researchers. Herein it will be argued that MT may facilitate such improvements given the evidence presented in Chapter 3 and the findings of LS1. First, it is pertinent to introduce a potential mechanism by which MT may facilitate positive brain ageing, namely the concept of *reserve.* The following sections will introduce the concept of reserve, how it relates to the compensatory activity discussed in the current section and the factors that may influence it.

9.3 Cognitive Reserve: Definition and Proposed Mechanism

The concept of *reserve* has been proposed to account for differences that are often observed between clinical outcomes and degrees of brain damage. With respect to cognitive ageing, reserve may account for differences observed between individuals with age related pathology or disease. For example, Ince (2001) reported that 25% of older adults met full pathological criteria for AD at post mortem despite neuropsychological test performance being unimpaired prior to death. This suggests that the level of pathology does not invariably result in clinical dementia and that certain individuals may have a reserve that enables them to maintain function.

The extant literature provides a number of somewhat overlapping definitions regarding what constitutes reserve. According to Stern (2002, 2009), r*eserve* is best described in terms of both passive and active models. *Brain reserve* (e.g. Katzman, 1993) is an example of a passive model, which refers to neuro-protective brain capacity whereby reserve derives from brain size or neuronal count. In the simplest of terms, this model postulates that larger brains can sustain more insult before clinical deficits emerge because sufficient neural substrate remains to support normal function. Passive models such as this assume that individuals differ only in their overall brain reserve capacity. Thus, clinical or functional deficits will emerge once brain reserve capacity is depleted beyond a critical threshold. For example, in AD synapses may be depleted beyond this threshold resulting in clinical dementia. Critically, threshold models such as this do not account for how the brains of different individuals process cognitive or functional tasks following brain damage and its resultant disruption to established networks and processes. *Cognitive reserve* (CR) postulates that individual differences in the cognitive processes or neural networks underlying task performance allow certain individuals to cope better with brain damage than others (Stern, 2009). Active models such as CR propose that the brain may enlist compensatory processes (Stern, 2002) and/or utilise pre-existing cognitive networks and processes to cope in the face of brain damage. Hypothetically, two patients may display different levels of clinical impairment despite possessing the same amount of brain reserve capacity. Therefore, CR may allow individuals to maintain function and compensate for structural loss and is a mechanism that has the potential to produce positive effects for older adults.

Importantly, as the brain ultimately controls all cognitive function, the differences in CR must have a physiological basis. The line between CR and brain reserve is thus not clear cut as factors associated with CR (discussed below) are likely to have a direct effect on the brain. Stern (2009) suggests that the physiological variability subsumed by CR is at the level of variability in synaptic organisation, or in relative utilisation of specific brain regions. Thus, CR implies anatomic variability at the level of brain networks, while brain reserve implies differences in the quantity of available neural substrate. Steffener and Stern (2012) suggest that on a neural level CR may take two forms: *neural reserve* and *neural compensation*.

Neural reserve posits that there is inter-individual variability in brain networks and/or performance on cognitive paradigms that measure the functions associated with these networks. Said variability may be due to differences in network efficiency, capacity or flexibility. Thus, neural reserve may be the mechanism by which healthy individuals cope with both increased difficulty of ongoing task demands and to cope with brain pathology, i.e., an individual whose brain networks are more efficient, have greater capacity, and/or are more flexible is likely to cope better with the disruption caused by brain pathology. With respect to cognitive ageing, Stern & colleagues have shown that older vs. younger participants have less efficient[32] neural networks (Zarahn et al., 2007) and have less network capacity[33] available for task performance (Holtzer et al., 2009).

Neural Compensation refers to the process by which individuals suffering from brain pathology use brain networks and structures not normally used by individuals with intact brains in order to compensate for brain damage. This alternative compensatory network is not engaged in performing a task until demands exceed the neural capacity level of the primary networks. Said alternative networks may potentially be recruited to compensate for age-related neural changes and allow those who are more capable of recruiting them to perform better in the face of neural change. This assertion is consistent with the hemispheric asymmetry reduction in old adults model (HAROLD) proposed by Cabeza et al. (2002), which detailed that older adults who recruited additional PFC areas (bilateralised as opposed to asymmetric activation patterns) had better performance than those older adults who never recruited additional brain regions. The findings of bilateral or additional areas of activation (Cabeza et al., 2002; Piefke et al., 2012; Nielsen et al., 2002; Langenecker et al., 2003), enhanced activation of task

[32] Efficiency refers to the change in neural activity occurring with a change in task demand. For an equal increase in task demand, someone with greater efficiency requires less of an increase in neural activity than does someone with less efficiency.

[33] Better performance by the younger subjects was accompanied by increased expression of the underlying brain network. This suggests a capacity difference, with the younger subjects able to activate the common network to a greater degree than the older subjects.

relevant brain regions (Langenecker et al., 2004; Milham et al., 2002; Vallesi et al., 2011) enhanced ERPs (Endrass et al., 2012; Mager et al., 2007; West & Moore, 2005) and increased allocation of attentional resources across task conditions (Hammerer et al., 2010; Haring et al., 2013; Lague-Beauvais et al., 2013; Vallesi, 2011; Vallesi et al., 2009) that were discussed in the previous section are suggestive of age related neural compensatory mechanisms. However, performance is not always maintained to the levels of younger adults when compensatory activity is required. A number of studies have shown that compensatory resources may be recruited when primary neural networks are no longer adequately able to support successful task performance (e.g. Reuter-Lorenz, 2002; Steffener et al., 2009). In such instances the compensatory activity may be seen as enabling the individual to continue to perform the task, however, performance may not be as high as in individuals who have an intact, efficient, high capacity primary network. In AD, this compensatory activity may allow the individual to continue to perform despite pathology to the primary network. Compensation in this case is associated with maintenance of function as opposed to improved function.

It is important to stipulate that neural compensation is not limited to instances of brain pathology and/or to older adults. For example, younger adults have been shown to both enhance activation of primary networks and/or to recruit additional resources (e.g. bilateralised activation) when they are presented with increased demand on inhibitory control (e.g. Sebastian, Baldermann, et al., 2013) or attentional control (e.g. Milham et al., 2002).

In sum, CR may serve two main functions in older adults. Firstly, it may increase the efficiency and capacity of primary networks to enable cognitive performance to be maintained. Secondly, it may enable compensatory activation to support primary networks in the face of age related pathology or disease. Thus, improving CR has the potential to positively influence cognitive performance in older adults. Consequently, an ever increasing body of research is attempting to answer the question, ‘how may CR be increased?’ The following section discusses the main factors that appear to influence CR and provides the theoretical background for why CR is a potential mechanism by which MT may improve cognitive performance in older adults.

9.4 Key Factors in Cognitive Reserve

The potential for CR to positively influence the cognitive ageing process has resulted in somewhat of a paradigm shift in recent times. Rather than explicitly looking for the causes of declines, researchers are increasingly looking for the causes of healthy ageing. The main factors currently thought to improve CR are discussed below. Whilst the majority of early research in this area was focussed on animal models and environmental enrichment studies (see Frick & Benoit, 2010 for review), herein the focus is on the potential benefits of mental activity and cognitive training as this is where MT is positioned.

Education and Occupation

Based on epidemiological evidence, variables reflecting lifetime experience such as education and occupation appear to positively influence CR. Greater levels of education have been shown to have a protective effect against dementia and cognitive decline in a wide range of studies (see the following for reviews: Fratiglioni & Wang, 2007; Valenzuela & Sachdev, 2006a, 2006b). Further, the findings of a recent study (Foubert-Samier et al., 2012) suggest that education may be related to brain reserve as education was significantly associated with cerebral volume (including both grey and white matter) in a sample of non-demented over 65's. Beyond the brief period spent in education, occupational environment and intellectually stimulating occupations in particular, have similarly been associated with greater levels of CR in healthy adults (Andel et al., 2005; Potter, Helms, & Plassman, 2008; Potter et al., 2006; Staff et al., 2004) and with the attenuation of AD symptoms (Stern et al., 1994).

Whilst both education and occupation may be key factors in determining the level of CR with which individuals enter old age, the rate of cognitive decline may not be mitigated by these factors. R. S. Wilson et al. (2009) found that prior education was not linked to the rate of cognitive decline, concluding that reduced cognitive decline in well educated individuals is likely to be in part due to the well established correlation of education with cognitive test performance at all ages, i.e. individuals with higher levels of education, relative to those with less, are likely to enter old age at a higher level of cognitive function and would thus require a greater level of decline before reaching a significant level of impairment (e.g. meeting criteria for dementia or AD). Thus whilst it is important to enter old age with as much CR as possible as a buffer for potential pathology, other factors may play a more vital role in slowing the rate of cognitive decline during the period that follows retirement.

Mental Activity and Cognitive Training

Ongoing and prior mental activity appears to play a crucial role in mitigating CR. Mental activity may come from a variety of sources including education, occupation, leisure activities or even from specific cognitive training regimens. Retirement may play a crucial role in depleting CR as individuals may engage in reduced levels of mental activity following the inevitable changes to daily routines that result from occupational retirement, leading to what Rohwedder and Willis (2010) termed mental retirement. Accordingly, a number of recent reviews have argued that retirement has a negative impact on cognitive functioning (Bonsang, Adam, & Perelman, 2012; Mazzonna & Peracchi, 2010; Rohwedder & Willis, 2010) whilst other authors have shown that retirement may accelerate cognitive decline (Adam et al., 2007). Importantly, mental activity derived from leisure activities and cognitive training provides a potential mechanism for increases in CR over which individuals may exert a level of control, as opposed to mental activity through occupational factors which are temporally limited due to the inevitability of retirement.

A number of high profile observational studies have reported positive effects of mentally stimulating leisure activities. The Einstein Ageing Study (Verghese et al., 2003) found that a number of cognitively stimulating leisure activities (including reading, playing board games such as chess, and playing a musical instrument) were associated with a reduced risk of dementia. Similarly, the Religious Orders Study (R. S. Wilson et al., 2002) found that engaging in mental activities was associated with a 33% reduced risk of developing AD at a 4 year follow up and with a 47% reduced risk of developing general cognitive problems.

A number of clinical trials have been designed to address whether mental activity administered via cognitive training techniques can have a similar positive effect in healthy older adults. Valenzuela and Sachdev (2009) conducted a systematic review which resulted in seven such trials being assessed, concluding that cognitive training in healthy older adults produces persistent protective effects on longitudinal neuropsychological performance. The reviewed literature included the largest trial to date, the ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly; Ball et al., 2002) study, which found that cognitive training in 1 of 3 domains (memory strategy, reasoning, and speed of processing) lead to improvements in said domains at a 2 year follow up with no crossover of improvements across domains being found. This lack of cross over effects into global cognitive domains and into tests of everyday functioning is consistent with the literature suggesting that skill learning is usually very task-specific and does not easily generalise beyond the specific tasks, stimuli, or contents (Green & Bavelier, 2008). However, the findings of a more recent study suggest that such cross over effects are possible by training core cognitive functions which are called upon during many varied tasks. The IMPACT (Improvement in Memory with Plasticity-based Adaptive Cognitive Training; G. E. Smith et al., 2009) study utilised a broadly-available brain plasticity–based computerised cognitive training program which included elements that relied upon core cognitive functions. For example, conflict monitoring skills were required to discriminate between confusable syllables, working memory functions were required to reconstruct sequences of verbal instructions and selective attention was required to identify details from a verbally presented story. Completing this training for a total of only 40hours (1hour per day, 5 days per week for 8weeks) was able to significantly improve performance on measures of attention and memory that were not specifically trained, in comparison to an active control condition[34]. Thus cognitive training techniques that are able to improve core cognitive functions are likely to have wide reaching effects in older adults.

In line with the CR hypothesis the training of core cognitive functions is likely to enhance CR by increasing both the efficiency and capacity of primary neural networks and/or enabling the recruitment of additional compensatory resources. As mentioned earlier, such increases may be expected to not only have benefits in healthy older adults who may be experiencing age-related brain pathology and/or cognitive declines, but also in those individuals who suffer disease related pathology from conditions such as AD. In addition to the improvements in the former group detailed above, a number of recent findings have begun to suggest that cognitive training interventions may have utility in the latter group also. Whilst cognitive training is yet to

[34] The active control condition employed a learning-based training approach in which participants used computers to view DVD based educational programs on history, art, and literature.

prevent incident dementia in an appropriately designed trial (Valenzuela & Sachdev, 2009), a number of smaller trials have shown efficacy in slowing the progression of cognitive declines in early stages of mild cognitive impairment (Cipriani, Bianchetti, & Trabucchi, 2006; Rozzini et al., 2007; Talassi et al., 2007) and AD (Galante, Venturini, & Fiaccadori, 2007; Tarraga et al., 2006) whilst a number of trials have shown that combining cognitive training with medication has greater efficacy than medication alone (Loewenstein et al., 2004; Rozzini et al., 2007, Yesavage et al., 2008). Caution is advised when interpreting these results as this field is very much in its infancy and a number of methodological flaws have been noted. For example, a major criticism of the majority of the trials conducted thus far is that they do not have adequate follow up periods and lack active control and/or placebo conditions (see Papp, Walsh, & Snyder, 2009 for critique). Such criticisms largely extend to the earlier mentioned studies conducted with healthy older adults, however a number of trials have shown that the positive effects of training are maintained at follow up of up to 5 years (Oswald et al., 2006; Willis et al., 2006), thus cognitive training techniques may have long-lasting positive effects.

To summarise, CR may play a pivotal role in positive brain aging and cognitive training techniques that train core cognitive skills may provide a way in which older adults can exert some control over age related cognitive outcomes, even in the face of age and disease related pathology. Identifying easily accessible cognitive training techniques that older adults can engage in is thus a priority for ongoing research. Thus far previous research has mostly focused on preventing or slowing AD and clinical dementia. Whilst this is understandable given the likely increase in prevalence of said conditions, the impending rise in retirement age and the potential deleterious effects of cognitive declines in the absence of disease means that any cognitive training technique that can improve core cognitive skills in older adults is likely to have great utility in improving occupational efficacy pre retirement and cognitive ability post retirement, regardless of whether it is able to delay/prevent or compensate for disease. The following section presents the theoretical argument for why MT may be positioned as a form of cognitive training that may influence CR, and consequently cognitive performance, in older adults.

9.5 Mindfulness Training, Cognitive Ageing and Cognitive Reserve

Despite empirical evidence for the effect of MT in older adults being limited, the findings of a number of studies suggest positive effects may be achieved. Hölzel et al. (2008) found that long term mindfulness meditators displayed greater grey matter density than controls in the left inferior temporal gyrus, the right anterior insula and the right hippocampus, key regions in the default and salience networks. This finding may be interpreted as an increase in neural reserve and suggests that brain networks associated with attentional functions are strengthened by MT. Pagnoni and Cekic (2007) also found grey matter differences between expert meditators and controls with only the latter displaying the expected negative correlation of both grey matter volume and attentional performance with age. In this study the effect was most pronounced in the putamen, a part of the basal ganglia's corpus striatum which has been implicated in cognitive flexibility and attentional processing (Nieoullon, 2002), further suggesting that engagement in meditations such as MT may positively modulate neural reserve in attention related brain regions. Greater grey matter density has also been found in expert meditators in the right hippocampus, left temporal lobe, right thalamus and right orbito-frontal cortex (Luders et al., 2009). Whilst these regions are mostly associated with emotional stability and the generation of positive emotions, they have also been implicated in response control, suggesting that long term meditation may significantly modulate neural reserve in regions associated with emotional and cognitive control. Additionally, as compared matched controls, cortical thickness has been observed to be thicker for long term insight meditators in regions associated with attention, interoception and sensory processing (Lazar et al., 2005), including the PFC and right anterior insula which are key parts of the salience and executive networks. Between groups differences in PFC thickness were most pronounced in older participants, suggesting that MT might offset age-related cortical thinning. The aforementioned studies involved meditators with many years meditation experience. However, increased availability of neural substrate may be possible after a short duration of MT considering that increases in grey matter have previously been found following 8 weeks of MBSR (Hölzel, Carmody, et al., 2011) whilst as little as 11 hours of IBMT (see Chapter 3 for details regarding IBMT) has been shown to improve white matter integrity in ACC (Tang et al., 2010).

The emerging pattern of results is particularly encouraging as it is generally assumed that increased grey matter results from repeated activation of a brain region (Ilg et al., 2008; A. May et al., 2007). Thus repeated activation of attention networks during meditation may strengthen these networks and the neural substrate which supports them, leading to increased brain and neural reserve. Of note, a wide range of cross sectional studies have established that differences in regional grey matter are associated with a variety of attentional problems, including those observed in ADHD (e.g. Batty et al., 2010; Seidman et al., 2011) and schizophrenia (e.g.Rusch et al., 2007), and with decreased attentional performance (e.g. Takeuchi et al., 2012). Thus it may be hypothesised that MT related increases in grey matter may result in improved cognitive performance in older meditators. Whilst evidence for this hypothesis is scarce, the few behavioural studies that have been conducted with older adults have reported results in this direction. Recently (van Leeuwen et al., 2009), a reduced AB has been found for expert mindfulness meditators as compared to both age matched and younger controls. Given that AB size typically increases with age (Georgiou-Karistianis et al., 2007; Maciokas & Crognale, 2003), this finding suggests that MT may help to overcome age-related attentional deficits in the temporal domain by improving the efficiency of neural networks in older adults, a finding significant with regards to CR. The induction of a mindfulness state has also been shown to have efficacy in older adults with a simple 10 minute mindfulness induction, as compared to mind wandering, shown to reduce over-selectivity (McHugh et al., 2010). Over-selectivity typically occurs when behaviour is controlled by a limited number of the available stimuli in the environment. Prior research has suggested that older adults may seek less information due to well established rules of thumb or intuitive decisional styles gained through experience, rather than by adapting to current demands (Finucane et al., 2005; McHugh & Reed, 2007). Thus McHugh et al. findings suggest that state effects of even a short MT induction can improve present moment awareness and may facilitate goal focussed attention in older adults in a way that allows habitual patterns of responding to be overcome.

A major limitation of the limited available evidence is that it is mostly cross-sectional and only involved expert meditators. Further, different meditative traditions (and thus various meditations) have often been pooled together and the length of previous and ongoing practice is varied and often not fully reported (see section 3.5 for discussion of the limitations of cross sectional expert meditator studies). It is also important to state that because brain reserve and cognitive performance have been shown to dissociate, with brain reserve not able to fully predict cognitive performance (Buckner, 2004), the above discussed findings of increased brain reserve and better cognitive performance in older meditators must be interpreted cautiously. As a next step, future research needs to demonstrate that change in CR is associated with improvements in cognitive performance over time. Thus longitudinal evidence is much needed to allow a more comprehensive assessment of the efficacy of MT to produce positive effects in older adults. A summary of relevant details for the samples involved in the studies introduced in this section is contained in Table 20 for information.

Table 20: Summary of relevant participant details for studies introduced in section 9.5. Experience and ongoing practice values are group means unless stated otherwise.

Study	Meditative Tradition/ Intervention	Previous Experience	Ongoing Practice	Comparison Group
Hőlzel et al., 2008	Vipassana	8.6 yrs	2hrs per day	Age, gender and education matched non-meditators
Pagnoni and Cekic, 2007	Zen	>3 yrs	n/s	Age, gender and education matched non-meditators
Luders et al., 2009	Vipassana, Samatha, Zazen and others	24.2 yrs	10-90 mins per day	Age and gender matched non-meditators
Lazar et al., 2005	Insight meditators (typically involves training of present moment awareness and mindfulness)	9.1 yrs	6.2 hrs per week	Age, gender, race and education matched non-meditators
Hőlzel et al., 2011	MBSR	8 wks	27 mins per day	Waitlist matched for age and gender
Tang et al., 2012	IBMT	11 hrs (30 mins x 22 sessions over 1 month)	n/a	Relaxation training. Per group demographics were not stated

A strong argument for conducting a longitudinal study to assess the impact of MT on attentional functions can be made when all of the evidence presented throughout this thesis is taken together. Chapters 2 & 3 presented the theoretical background to MT, with the reviewed literature suggesting that MT is an effortful mental activity that involves core attentional skills and networks. Chapter 3 presented the behavioural, electrophysiological and functional evidence for MT positively influencing said skills and networks, with repeated activation of core attentional skills and networks during MT the proposed cause of said positive effects. The results of LS1 confirmed that even a singular MT technique, completed for a short duration and with minimal daily practice, may positively influence both behavioural and electrophysiological markers of attention. The findings presented in the current Chapter suggest that long term MT may produce structural changes indicative of increases in CR in brain regions associated with attentional function.

Taken together, the available evidence suggests that the longitudinal examination of MT in older adults is warranted. Further, the repeated activation of attentional networks and core attentional functions during MT make it an ideal candidate for use as a cognitive training technique to increase CR and strengthen core cognitive functions in older adults. Thus it is proposed that MT may strengthen attentional functions in older adults by utilising CR mechanisms such as neural reserve and neural compensation to alter the efficiency, capacity and functional connectivity of neural networks. As a first step for research in this area, LS2 was designed to provide the first longitudinal examination of the effect of a single practice MT on core attentional functions in older adults, utilising both behavioural and electrophysiological measures to concurrently assess improvements in attentional performance and modulations of associated task related neural activity.

Chapter 10. Ageing, Mindfulness Training and Cognitive Performance: Longitudinal Study 2

The following Chapters detail the design of LS2, the theoretical background to the included experimental paradigms and the empirical results ascertained.

10.1 Longitudinal Study 2 Overview

Contents of Chapters 10 to 14

Chapter 10 describes the study design, methods and materials utilised in LS2. Chapter 10 also contains the results of the analyses concerning the administered self report measures and from the tests for baseline differences between groups. Chapters 11-13 are the empirical chapters related to LS2, detailing the use of the CPT, ECStroop, and ABtask. Each of these chapters contains the theoretical background for the use of the respective experimental task, the associated hypotheses and outcome measures, the task design and the empirical results. Chapter 14 contains a discussion regarding the implications of the findings from LS2.

Longitudinal Study 2 summary

To our knowledge LS2 is the first empirical study of its kind and was conducted to meet the overall objective of this thesis, to assess the utility for MT to positively influence attentional functions in older adults. Chapter 9 identified that sustained and executive attention skills appear to decline with age. Further, the evidence reviewed suggests that MT may capitalise on CR mechanisms in order to improve said skills in older adults. To assess this hypothesis, a randomised, longitudinal, active control group EEG study was conducted to compare MT to simple brain training (BT) exercises (arithmetic calculations). A sample of 56 older adults were recruited and randomised to either receive 8 weeks MT (MTG; N=28) or BT (BTG; N=28).

A comprehensive assessment of attentional functions was carried out pre and post intervention with a series of Mixed ANOVAs and Paired Samples t-tests demonstrating that MT modulated both behavioural and electro-physiological markers of sustained attention and executive functions. The observed pattern of results suggests that MT may increase the capacity and efficiency of neural networks and utilise both neural reserve and neural compensation. Thus MT may be considered an ideal candidate for use as a cognitive training technique to positively influence CR mechanisms in older adults. The findings of LS2 lay the foundations for developing targeted mindfulness based interventions that aim to improve attentional functions and improve well-being in aged individuals.

10.2 Method

10.2.1 Design and Procedure

LS2 was a randomised active control group study designed to provide the first rigorous longitudinal examination of MT and attentional functions in older adults. Participants completed three tests of attentional functions at two time points over the course of approximately 8weeks (T1, T2), their EEG was recorded during each testing session. Prior to enrolment, participants were screened to ensure they were meditation naïve (no previous meditation experience), had no diagnosed dementia, had normal or corrected to normal visual acuity, confirmed no ongoing or recent mental health problems or neurological disorders (e.g., epilepsy) and confirmed they were not receiving any psychopharmacological treatments.

At each testing session, participants first completed the self report questionnaires (demographics only taken at T1) before completing the CPT, ECStroop, ABTask and SSTM[35]. The order of administration was constant across all participants at both time points. The dependent variables utilised for each task are presented and discussed in their respective chapters. Following T1, participants were randomised to either receive MT (MTG) or BT (BTG). The MTG and BTG were instructed to continue the assigned intervention until the date of their second testing session. Importantly, the time elapsed from T1 to T2 testing [MTG = 66.8 days, BTG =67.8 days; $t(48)= -.319$, $p =.751$] and from the start of the intervention to T2 [MTG = 57.0 days, BTG =56.7 days; $t(48)= .118$, $p =.906$] was controlled between MTG and BTG.

As in LS1, the MT intervention involved a low amount of group contact time (6hours) and a limited amount of daily meditation (10-15minutes) to ensure it could be

[35] The SSTM was completed at both T1 and T2 in order to control for working memory capacity between groups.

easily incorporated into established daily routines. As detailed in section 10.2.4, the BT intervention was designed to control for a number of extraneous variables including group contact time, group session content, daily exercise time, experimenter contact and motivation, learning new information, participants' intention and motivation, and exercise environment. Additionally, the wide range of self report data and administered baseline tasks demonstrated that both intervention groups had comparable age, dispositional mindfulness, computer ability, years of education, health, speed of processing, self efficacy, mental well being, ongoing/current cognitive and physical activity, and working memory capacity (see Table 21 and section 10.4.3 for details).

All advertising and participant information sheets described LS2 as "an investigation into the effects of two cognitive training exercises that may affect our cognitive performance, in particular focussing on the aspects of our cognitive performance that weaken as we grow older." Thus, intention and motivation for enrolment were controlled between groups and participants remained naïve to the fact that an assessment of MT was the objective of the study. This offers an advantage over previous studies as participants were less likely to be enrolling due to a prior interest in meditation practice, limiting the possibility for an interest in meditation to influence self selection biases.

10.2.2 Participants

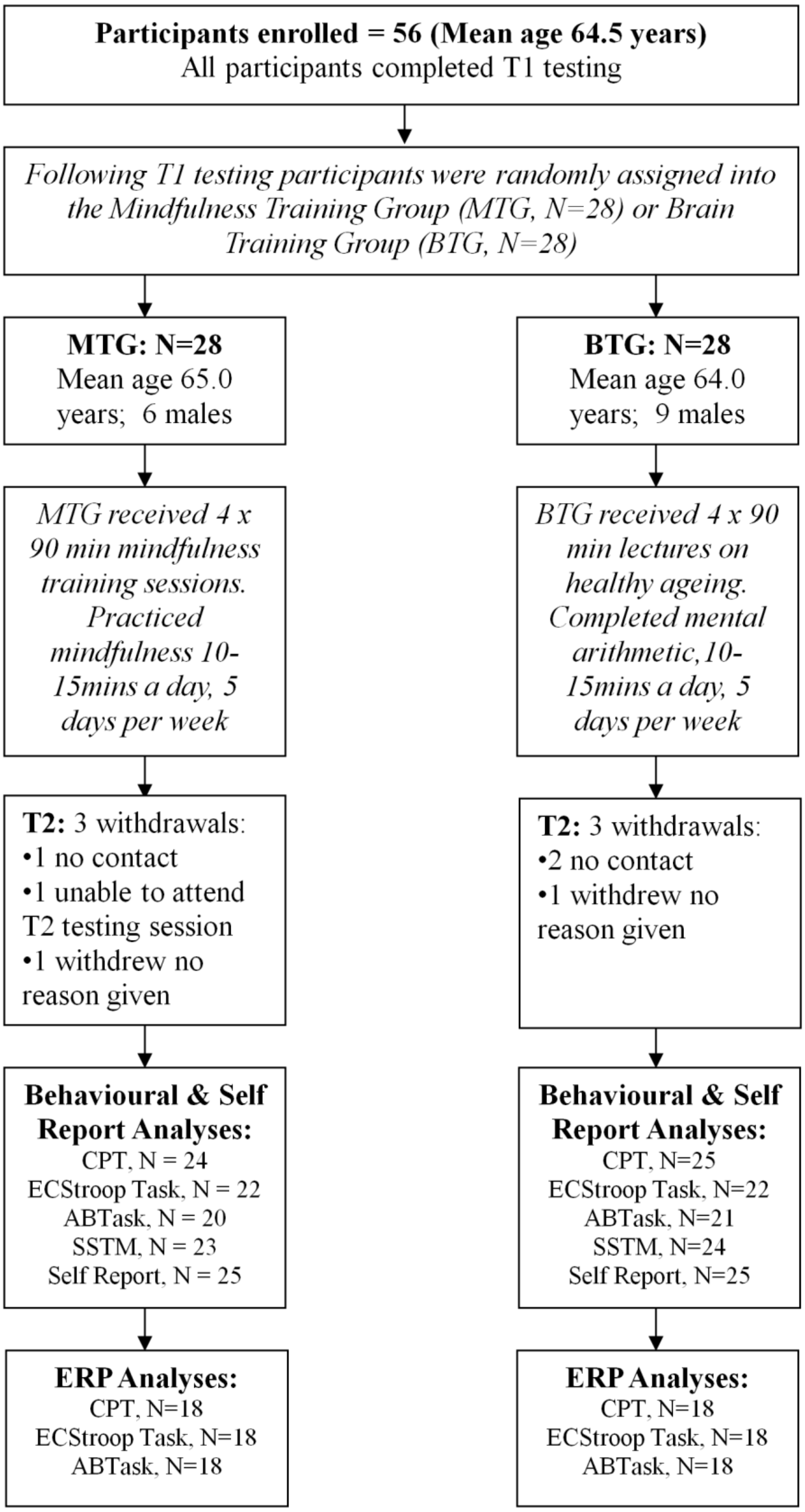

Figure 27: Flow of participants through the study

The flow of participants through the study is detailed in Figure 27. Fifty-six older adults (15 males; mean age 64.5 years) were recruited via a combination of online and newspaper advertisements, and from a psychology participant panel maintained at LJMU. Thirty-eight participants were retired whilst the remaining 18 were still in employment. The sample had a varied educational background with 27 educated to foundation degree level or higher (includes HNC, undergraduate degree and postgraduate degree), 21 with GCSEs, a-levels or equivalent, and 8 with no formal qualifications. The mean time spent in education for the sample was 13.0 years. All participants provided written, informed consent and were reimbursed with £40 worth of shopping vouchers upon completion of the study.

The study was carried out in line with the ethics guidelines of the British Psychological Society and was approved by the LJMU Research Ethics Committee.

10.2.3 Mindfulness Training

The administered MT and meditation teacher were the same as in LS1 (see section 5.2.3). The amount of training sessions offered and duration of intervention were changed with the MTG being offered 4 training sessions of 90 minute length over 8 weeks. As the experimenter was delivering the healthy ageing lecture series (detailed 10.3.4) the experimenter was also present during each of the MT sessions to control for experimenter contact time between the intervention groups.

10.2.4 Brain Training Group

As discussed in Chapter 3, the selection of an appropriate control or comparison condition is essential in longitudinal studies of mindfulness interventions (Chiesa et al., 2011; Tang & Posner, 2013). To ensure the results of LS2 could be comprehensively interpreted, a matched active control condition was selected for comparison with MT. As MT involves active, effortful cognitive processes, it was deemed important to select an active control condition that involved active cognitive components. Consequently, relaxation training was deemed an incompatible active control condition, also because it has already been shown to not fully account for the non-specific effects of MT (Ortner, Kilner, & Zelazo, 2007; Polak, 2009; Tang et al., 2007).

Simple BT exercises (mental arithmetic) and healthy ageing group lectures were chosen as the most appropriate matched active control condition. Mental arithmetic calculations were chosen because they involve effortful cognitive processing and activate a wide range of frontal and parietal brain regions implicated in attention (Fehr, Code, & Herrmann, 2007; Kong et al., 2005; Rickard et al., 2000). Additionally, they are included in various commercially available BT packages that claim to improve cognitive performance in older adults. Thus, the use of arithmetic calculations as an active control condition allowed for the concurrent assessment of the impact of both MT and simple BT exercises on cognitive performance in older adults, whilst simultaneously enabling a wide variety of confounding variables to be controlled.

Participants in the BTG attended a healthy ageing lecture series that was produced specifically for use in this study. The lecture series matched the MTG group sessions for frequency (4 sessions) and duration (6 hours total). Similar to the MT group sessions, the lectures included elements of learning, discussion and active practice (BT exercises). In short, the lecture series comprised information regarding what happens to the brain during normal and non normal ageing and the effects of lifestyle choices (nutrition, mental and physical exercise) on the ageing brain.

In addition to attending the healthy ageing lecture series, participants in the BTG were given BT exercise booklets to complete at home. The booklets contained 100 arithmetic calculations to be completed 5 days per week, for 8 weeks. The amount of calculations was finalised following a pilot test (N=6), with 100 calculations providing approximately 10-15minutes of practice. The booklets included additional calculations that the participant could complete if they had finished the set calculations within 10 minutes. As with MT, participants were instructed to complete the daily exercises whilst sat upright in a quiet area.

To summarise, the selected active control condition allowed for a wide range of extraneous variables to be controlled including group contact time, group session content, daily exercise time, experimenter contact and motivation, learning new information, participants’ intention and motivation, and exercise environment.

10.3 Materials

10.3.1 Demographics

A short self report demographic questionnaire was devised and administered to ascertain the following information: Age, gender, handedness, state of employment (retired y/n), years spent in education, highest qualification, computer ability (1 to 10 scale, where 1 = No ability at all, 10 = Very able) and current health (1 to 10 scale, where 1 = Very poor health, 10 = Excellent health).

As a general slowing in processing speed has previously been proposed as a cause for age related cognitive declines (Salthouse, 2000), a very short and simple RT task was administered at T1 to confirm that speed of processing was comparable between groups. The task was setup as follows: A white dot was displayed in the middle of a computer screen a total of 20 times, with the participant having to press the letter ‘P’ on a standard QWERTY keyboard as quickly as possible in response to seeing the dot. The first 5 trials were ignored with the final 15 trials averaged to give a mean reaction time for each participant that could be utilised to approximate speed of processing.

10.3.2 Mindfulness

As in LS1, the FFMQ was used to assess different aspects of mindfulness that were expected to be influenced by mindfulness practice (see section 5.3.2).

10.3.3 Self Efficacy

Self efficacy was measured using the Generalized Self-Efficacy Scale (GSE; Schwarzer & Jerusalem, 1995). The GSE is a self administered 10 item scale designed to assess a general sense of perceived self efficacy. Each item is scored from 1 (not at all true) to 4 (exactly true) with a possible score range of 10 to 40. Items are all of positive valence, e.g. “I can usually handle whatever comes my way.” Higher scores indicate stronger perceived self efficacy. The GSE has high reliability and construct validity (Leganger, Kraft, & Roysamb, 2000; Schwarzer, Meuller, & Greenglass, 1999) and Cronbach alpha ranges from 0.75 to 0.94 across a number of different language versions (Luszczynska, Scholz, & Schwarzer, 2005).

The GSE was used to ensure that any positive behavioural or electrophysiological between group differences could not simply be attributed to an increase in self efficacy. Such increases in self efficacy may feasibly be gained from positively attempting to address cognitive decline via enrolment in the study.

10.3.4 Mental Well Being

Mental well being was measured using the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS; Tennant et al., 2007). The scale contains 14 positively worded items (e.g. I've been dealing with problems well) scored from 1 (none of the time) to 5 (all of the time) for a range of scores between 14 and 70. Confirmatory factor analysis has supported the single factor structure (Cronbach's alpha 0.91) of the WEMWBS and criterion validity and test retest reliability are strong (0.83; Tennant et al., 2007).

The WEMWBS was used to ensure that any between-groups behavioural or electrophysiological differences could not be attributed to changes in mental well being over the course of the study.

10.3.5 Cognitive and Physical activity

Levels of cognitive and physical activity were measured using an adapted version of a widely used scale (Verghese et al., 2003), which was devised for use in a retired population. As such, the items only account for leisure activities that are typically carried out in free time. As retired individuals inherently have more free time than working peers, the scale is biased towards retired individuals reporting greater cognitive and physical activity, which is intrinsically untrue as the majority of jobs contain both cognitive and physical elements.

The recruited sample for LS2 included both retired and working individuals, rendering the original scale unsuitable. As such, 12 items were added to the original scale to attempt to provide a more comprehensive assessment of current/ongoing cognitive and physical activity. The revised scale included 29 items in total, 14 related to cognitive activities and 15 related to physical activities. As in the original scale, participants reported frequency of participation as “daily,” “several days per week,” “once weekly,” “monthly,” “occasionally,” or “never.” Responses were coded to generate a scale with 1 point corresponding to participation in 1 activity, for 1 day per week. The units of the scales are thus activity-days per week. For each activity, subjects received 7 points for daily participation; 4 points for participating several days per week; 1 point for participating once weekly; and 0 points for participating monthly, occasionally, or never. The activity-days for each activity were summed to generate a cognitive-activity score, ranging from 0 to 98, and a physical-activity score, ranging from 0 to 105.

This revised scale (see Appendix C) has not been tested previously so results should be interpreted with caution. Use of the scale herein was not to provide a comprehensive review of the relationship between cognitive and physical activity and cognitive performance. The scale is used to provide a broad assessment of current/ongoing cognitive and physical activity and to ensure that MTG and BTG were matched for both.

10.3.6 Training Logs

MTG and BTG both completed brief weekly training logs, recording how many days they had completed cognitive training that week and the amount of time they had spent on average each day completing the cognitive training exercises. The respective diaries were not intended to produce data that could be used for a between groups statistical comparison of adherence or to assess dose related effects on behavioural or electrophysiological markers of performance. They did however provide adequate amounts of data to ascertain if the interventions had been followed as instructed. Further, it was reasoned that a less rigorous diary would aid the incorporation of cognitive training into daily life without the added burden of additional paperwork.

10.3.7 Working Memory

Working memory (WM) may be best understood as a theoretical construct that defines our ability to maintain and manipulate information in mind, for brief periods of time, in order to guide subsequent behaviour (Baddeley, 2003). Whilst WM has traditionally been seen as a distinct cognitive domain, modern conceptions suggest an extensive overlap with attention (see Gazzaley, 2011 for recent review). It has been shown that selective attention, herein considered the ability to focus cognitive resources on goal relevant information, influences WM at multiple stages of processing. This includes the preparatory period before a memory task (Bollinger et al., 2010; B. K.

Schmidt et al., 2002), the selection and encoding of stimuli when encountered (Vogel & Machizawa, 2004; Vogel, McCollough, & Machizawa, 2005), the maintenance of relevant information in mind (Jha, 2002; Postle et al., 2004) and memory retrieval (Theeuwes, Kramer, & Irwin, 2011). WM capacity has been linked to reasoning ability (Kyllonen & Christal, 1990; Süß et al., 2002) and to fluid intelligence (Engle et al., 1999), and it is among the best predictors of individual differences in a variety of complex cognitive activities such as text comprehension (Daneman & Merikle, 1996), learning of complex skills (Shute, 1991), and arithmetic (Bayliss et al., 2003). Thus WM must be deemed a fundamental aspect of human cognition. Interestingly, a number of recent studies have observed improved WM following MT (Chambers et al., 2007; Jha et al., 2010).

It is well established that human ageing is associated with declines in WM function (Craik & Salthouse, 2000) and that said deficits may be linked to reductions in brain activity, particularly in the frontal and parietal cortices (Cabeza et al., 2002; Persson & Nyberg, 2006; Rypma & D'Esposito, 2000). Given the close links between attention and WM it was deemed important that WM capacity was controlled between groups in the current study so that any observed improvements in performance may be attributed to modulations of attentional functions and the neural mechanisms that subserve them, rather than to a pre-existing deficit or modulation of WM.

However, incorporating a full WM task battery into LS2 was beyond the scope of this thesis and would have placed an additional cognitive demand on the participants and vastly increased the testing session duration. Thus a single task from a pre-existing WM task battery was chosen to approximate WM capacity across groups. The SSTM (Lewandowsky et al., 2010) was chosen as it has been shown to have high loadings on WM capacity factors and is highly correlated with measures of reasoning and general fluid intelligence (Lewandowsky et al., 2010; Oberauer, 2005; Oberauer et al., 2003; Oberauer & Suss, 2000). WM tasks involving digit and operational span were specifically avoided due to a conflict with the arithmetic calculations included in the BTG take home training booklets.

In short, the SSTM consists of trials wherein 1 to 6 dots are consecutively displayed into cells of a 10x10 grid, with only 1 dot appearing on the screen at a time. Participants are instructed to remember the spatial relations between dots and to then reproduce the overall pattern of dots, using a standard mouse, into a blank grid following a brief mask at the end of the stimulus presentation. The dependent variable, SSTM total score, is calculated based on points awarded for how closely the participant reproduces the overall pattern (2 points awarded for reproducing a dot exactly and 1 point for a deviation of 1 cell in any direction). The full set up and calculation of scores for the SSTM are described in detail elsewhere (Lewandowsky et al., 2010).

10.4 Overall Results

This section contains a brief summary of the results that are applicable to LS2 as a whole. Included are the results of tests for baseline differences between the groups and the self report questionnaire results.

10.4.1 Test for baseline differences between intervention groups

Importantly, as summarised in Table 21, no significant differences between MTG and BTG were present when direct comparisons at T1 (t-tests) were calculated for the participants who are included in the final statistical analyses. The groups are comparable in terms of age, dispositional mindfulness, computer ability, years in education, health, speed of processing, self efficacy, mental well being, and ongoing/current cognitive and physical activity. Control over so many extraneous variables ensures that between group differences can be strongly interpreted as a consequence of the cognitive training interventions.

Table 21: Summary of tests for baseline differences, with mean values (standard deviations) and respective statistical values (all 2 tailed) for the comparison between MTG and BTG. Only participants who completed the study are included in this analysis.

	MTG (N=25)	**BTG (N=25)**	**Statistical Values**	
Age (years)	65.3 (6.0)	64.0 (6.7)	$t(48) = .691$,	$p = .493$
FFMQ-total	134.8 (17.6)	137.6 (18.6)	$t(48) = -.546$,	$p = .587$
Computer Ability	6.0 (2.5)	6.4 (2.5)	$t(48) = -.644$,	$p = .523$
Years in education (years)	13.2 (2.7)	13.3 (3.1)	$t(48) = -.147$,	$p = .883$
Health**	8.0 (1.3)	7.6 (2.0)	$t(47) = .849$,	$p = .400$
Speed of Processing (ms)	288 (46)	300 (46)	$t(48) = -.956$,	$p = .344$
GSE	31.1 (4.2)	33.2 (4.0)	$t(48) = -1.830$,	$p = .073$
WEMWBS	54.1 (7.0)	54.6 (9.8)	$t(48) = -.199$,	$p = .843$
Cognitive Activity	42.8 (11.4)	50.6 (18.8)	$t(39.42^*) = -1.764$,	$p = .084$
Physical Activity	32.5 (11.5)	33.6 (11.0)	$t(48) = -.351$,	$p = .727$

***** Levene's test for equality of variances violated, therefore degrees of freedom were adjusted accordingly

****** Only 24 participants from the MTG were included in this analysis due to missing data

10.4.2 Self Report Results

Training logs

In general, the participants in both intervention groups managed to adhere to the required exercise schedule. Based on the training logs, the approximate time spent completing daily exercises was 13 minutes for the MTG and 11minutes for the BTG. The average number of days per week spent engaging in daily exercises was 5 for both the MTG and BTG.

Mindfulness

Total mindfulness score (all 5 subscale scores combined) and the scores for each of the 5 FFMQ subscales were subjected to separate *Time* (2) x *Group* (2) Repeated Measures ANOVAs. For the total mindfulness score, no significant main or interaction effects were found. Analysis of the FFMQ subscales revealed a significant *Group x Time* interaction [F(1,48) = 15.907, p <.001, r = .499] for FFMQ-O with MTG significantly increasing FFMQ-O from T1 to T2 [t(24)= -3.642, p=.001], whilst there was a non-reliable trend for BTG to reduce FFMQ-O from T1 to T2 [t(24)=1.945,

p=.064]. A significant main effect of *Time* [F(1,48) = 4.438, p = .040, r = .291] was found in FFMQ-A. Surprisingly, this effect was caused by a relative decrease in FFMQ-A from T1 to T2 (T1=27.4, T2=26.1). No other significant effects emerged from the analysis of the FFMQ subscales.

Self Efficacy

GSE total scores were subjected to *Time* (2) x *Group* (2) Repeated Measures ANOVA, revealing a significant main effect of *Time* [F(1,48) = 5.617, p = .022, r = .324] which indicated that overall (N=50) mean scores changed from T1 to T2 (T1=32.2, T2=33.2). This small albeit significant overall difference may illustrate that being a part of the study helped raise self efficacy, potentially as the participants may have thought they were doing something positive by taking part. No significant between group or interaction effects were found.

Mental Well-Being

WEMWBS total scores were subjected to *Time* (2) x *Group* (2) Repeated Measures ANOVA, revealing no significant main or interaction effects.

10.4.3 Working Memory Task Results

SSTM data were only recorded in 54 participants at T1 due to computer saving errors. Consequently, data from 1 MTG and 1 BTG participant were not available for baseline or longitudinal analysis. In addition, the data of 1 further MTG participant was unavailable as they had asked for the SSTM to be stopped because it was “too difficult.” Direct comparisons at T1 were calculated and confirmed no difference between MTG (N=23, total score (SD) = 166.09 (19.45)) and BTG (N=24, total score (SD) = 168.58 (15.89)) in SSTM total score [t(45)= -.483, p =.632] [36]. Thus WM capacity was comparable between groups at baseline. Further, submitting SSTM data to a *Time* (2) *x Group* (2) Repeated Measures ANOVA revealed a non-significant *Group x Time* interaction [F(1,45) = 1.322, p = .256], confirming that results obtained from LS2 are unlikely to result from modulations of WM following cognitive training.

[36] Only participants who completed the study are included in this analysis

Chapter 11. Mindfulness Training, Ageing and Sustained Attention: Continuous Performance Task

11.1 Theoretical Background

This Chapter discusses the reasons for using a CPT to assess the efficacy of MT to improve sustained and executive functions in older adults, the tasks design, its associated outcome measures and specific hypotheses and concludes with the presentation of the CPT results. The CPT results are discussed together with the findings of the ECStroop and AB task in Chapter 14.

Continuous Performance Task, Sustained Attention, Executive Inhibition and Mindfulness Training

The use of the CPT allows for the evaluation of a number of behavioural and electrophysiological outcome measures that enable an assessment of whether MT may improve sustained and executive attentional functions in older adults. Importantly, the CPT is a test of sustained attention that has been shown to be sensitive to age related declines (e.g. A. D. M. Davies & Davies, 1975; Hammerer et al., 2010; Mani et al., 2005). As briefly discussed in Chapter 9, CPTs typically require attention to be sustained over extended periods of time in order to respond to *rarely* presented stimuli, with sustained attention considered to be a state of readiness to detect and respond to said stimuli, appearing at random time intervals over extended periods of time. However, for the CPT paradigm utilised herein the frequency of ‘go’ and ‘no-go’ responses was somewhat different to a typical CPT paradigm. Participants were required to respond or ‘go’ on 60% of trials and to inhibit responses or ‘no-go’ on 40% of trials, whereas CPTs typically involve very infrequent responses (e.g. 80% no-go) and Go/No-go Paradigms involve the infrequent inhibition of pre-potent responses (e.g. 20% no-go). Thus the CPT used herein is somewhat of an amalgamation of these 2 paradigms.

This presentation ratio was chosen for a number of reasons. Firstly, including 60% go and 40% no-go stimuli requires the participant to inhibit a pre-potent response when presented with a no-go stimuli and thus affords the opportunity to investigate the well established age related deficits in inhibitory control (discussed Chapter 9).

Secondly, given that the P3 ERP component is sensitive to oddball or infrequent stimuli (e.g. infrequent distracting stimuli produce a large P3 ERP component) and that said component was the focus of the electrophysiological analysis, the 60:40 ratio was expected to reduce the possibility that go or no-go stimuli would ‘pop-out’ and cause modulations of the P3 ERP components. Vallesi (2011) utilised a similar approach, albeit with a 50:50 ratio, in order to ensure that age related increases in P3 amplitude to irrelevant no-go stimuli were not caused by such a ‘pop out.’ The use of this method enabled Vallesi (2011) to conclude that older, as compared to younger adults, required additional attentional resources to inhibit responses to no-go stimuli and to rule out that the enhanced P3 was being caused by enhanced attentional capture of infrequent stimuli. Thirdly, the 60:40 ratio limits the potential for participants to use probability monitoring strategies as the difference in presentation frequency between go and no-go responses is minimal. Lastly, the 60:40 ratio reduces the difficulty of the task and requires participants to sustain attention to repetitive stimuli. Additionally, as both the go and no-go stimuli were letters, presented in white on a black background, the stimuli were non-arousing and there was no conflict between conditions. Thus, the CPT utilised herein was able to provide an assessment of sustained attention to a repetitive stimulus in the absence of endogenous and/or exogenous arousal.

Considering Robertson et al. (1997) definition of sustained attention as “the ability to self-sustain mindful, conscious processing of stimuli whose repetitive, non-arousing qualities would otherwise lead to habituation and distraction to other stimuli” (p. 747), the utilised CPT may be especially effective as a measure of MT related improvements in sustained attention as it assesses a number of the core components of the MT that was administered to the MTG. Firstly, MT required participants to sustain attention to the breath, a repetitive, non-arousing stimulus. Secondly, MT involved mindful, conscious processing, i.e. top down control, in order that attention was anchored in the present moment. Lastly, during MT arising stimuli were acknowledged and let go, with focus returned to the breath whereas the individual may have habitually ruminated or become distracted through more elaborative processing of the arising task-unrelated stimuli. Similarly, during the CPT no-go stimuli must be acknowledged and processed and let go without responding or the participant becoming distracted.

A number of ERP components have been identified as important to CPT completion. The focus of the electrophysiological examination herein was on the P3

ERP component that is produced by the no-go condition. A wide range of studies have observed that the P3 is increased in fronto-central regions for no-go compared to go trials (Bruin & Wijers, 2002; Fallgatter, Brandeis, & Strik, 1997; Fallgatter & Strik, 1999; Jodo & Inoue, 1990; Jodo & Kayama, 1992; Kok, 1986; Nieuwenhuis et al., 2003; Pfefferbaum et al., 1985; Roberts et al., 1994; Van 't Ent & Apkarian, 1999 Bekker, Kenemans, & Verbaten, 2004; J. L. Smith, Johnstone, & Barry, 2006). J. L. Smith, Johnstone, and Barry (2007) proposed that the fronto-central 'no-go P3' indexes attentional resource allocation to inhibition processes, i.e. to prevent the participant from responding to no-go stimuli. By manipulating cues to enable participants to prepare for no-go stimuli they found that the P3 ERP component was enlarged when a preparatory cue was present to warn participants that they would need to inhibit a response on the upcoming trial. Fronto-central P3 ERP components have also been labelled as P3a and it has been suggested that P3a may be linked to the orienting of attention to stimulus discrimination and/or to the engagement of focal attention (Azizian & Polich, 2007; Hartikainen & Knight, 2003; Kok, 2001; Polich, 2007). A further P3 ERP component is typically seen over parietal regions in the go condition and is often referred to as P3b. P3b is only seen in the go condition of Go/No-go tasks and is said to reflect response related processing (Falkenstein, Hohnsbein, & Hoormann, 1994; Kok, 2001). P3b has also been associated with the amount of cortical activity necessary for the processing of incoming information (Polich, 2007). In a recent review, Polich (2007) proposed that P3 ERP components may reflect neural inhibition/suppression of extraneous neuronal activity, i.e. the inhibition of ongoing activity in order to allocate resources to facilitate attentional processing on the task at hand.

Interestingly, both P3a and P3b have been shown to exhibit robust age-related reductions in amplitude and slowing of latency across multiple tasks and populations (e.g. Bekker et al., 2004; Bruin & Wijers, 2002; Fjell & Walhovd, 2001, 2003a, 2003b, 2003c, 2004, 2005; Nieuwenhuis et al., 2003; J. L. Smith et al., 2006; Stige et al., 2007; Walhovd & Fjell, 2001; Walhovd, Rosquist, & Fjell, 2008; J. Wang et al., 2006). With respect to Polich's aforementioned hypothesis, these P3 age-related changes may reflect deficits in underlying processes, such as degeneration of the functional cortical interconnection that occur with age (Bashore & Ridderinkhof, 2002; Reuter-Lorenz, 2002), resulting in a reduced ability to orient attention and suppress extraneous neuronal operations to facilitate attentional processing. Thus, the P3 decreases may represent an inability for older adults to allocate attentional resources. Interestingly, P3 ERP components have been utilised to demonstrate cognitive impairment in AD with AD patients having an increased P3 latency and decreased mean amplitude (e.g. Holt et al., 1995), whilst similar findings have also been found in patients with mild cognitive impairments (MCIs; e.g. Polich & Corey-Bloom, 2005).

In terms of the CPT utilised herein, it is feasible to suggest that increasing the allocation of attentional resources to inhibition processes in older adults would likely improve performance. This assertion is backed up by Vallesi (2011) finding of a significant negative correlation between no-go P3 mean amplitude and RTs to go stimuli, with higher no-go P3 related to quicker RTs. Further, Vallesi found that older adults had higher no-go P3 amplitude than younger adults and that those older adults who had higher no-go P3 mean amplitude had quicker RTs. Thus, enhancing attentional resource allocation to inhibition processes may be a compensatory mechanism in older adults that improves performance. This assertion is commensurate with Daffner et al. (2006) proposal that high performing older adults manage task demands by relying on additional neural resources.

It is important to note that whilst Vallesi (2011) finding of higher P3 to no-go stimuli in older vs. younger participants appears to be in opposition to the earlier discussed declines in P3 amplitude that are typically seen in observations of old vs. young adults, this finding was most likely caused by the limited difficulty of the task they employed. Due to the minimal task difficulty there is likely to be less extraneous neural activity ongoing and more resources may be allocated for task completion. In a recent study (Sebastian, Baldermann, et al., 2013) which utilised fMRI to assess older adults performance on three inhibition tasks of increasing difficulty, it was found that ageing was associated with enhanced activation in inhibitory networks to the simplest task (Go/No-go), enhanced activation in additional inhibitory control regions for the intermediate task (Simon task) but decreased activity in inhibitory networks to the most difficult task (Stop signal task). This suggests that older adults increasingly recruit the inhibitory network and, with increasing load, additional inhibitory regions. However, if inhibitory load exceeds compensatory capacity, performance declines in concert with decreasing activation. The CPT paradigm utilised herein is similar in difficulty to the one employed by Vallesi (2011). Thus, increasing no-go P3 mean amplitude and a concurrent improvement in behavioural performance would be a positive finding.

In Chapter 3 the reasons why MT may influence sustained and executive attentional functions were introduced and the potential for MT to improve said functions in older adults was covered within Chapter 9. In short, MT requires the repeated activation of these core attentional functions during practice and engagement in MT over time is thought to strengthen such functions and the neural substrate that supports them. Further, mental activity involving such core attentional functions may utilise CR mechanisms such as neural reserve and neural compensation to strengthen these functions in older adults. Thus it was hypothesised that MT may positively influence CR mechanisms, resulting in modulations of behavioural and electrophysiological measures of sustained attention and inhibitory control. The specific electrophysiological and behavioural outcome measures and hypotheses related to the use of the CPT are detailed below.

Electrophysiological Outcome Measures and Hypotheses

The use of EEG and the ERP methodology herein allowed for an electrophysiological examination of the attentional processing that occurred in response to both go and no-go stimuli and was able to provide information regarding modulations to attentional processing following MT and BT. The ERP component identification procedure detailed in section 4.4 resulted in the identification of 2 ERP components of interest (see Figure 31 & Figure 32 for no-go P3, Figure 35 & Figure 36 for go P3).

A no-go P3 ERP component was observed in the 370 to 530ms time window in a small cluster of fronto-central electrodes (FCz, FC1, and FC2). Consistent with recent findings (Vallesi, 2011), pooled T1 data (N=44) established that no-go P3 [r = -.527, p<.001, 1 tailed] mean amplitude was significantly negatively correlated with RTs, with higher no-go P3 mean amplitude related to faster RTs, thus confirming the importance of no-go P3 to task performance. As MT was expected to capitalise on CR mechanisms it was hypothesised that MT would lead to increased no-go P3 amplitude, evidencing an increase in the allocation of attentional resources following MT.

A positive central parietal component was observed in the 370 to 570ms time window at Pz for the go condition only. The go P3 ERP component mean amplitude was assessed to see if attentional resource allocation was enhanced across task conditions or specifically for inhibition processes only. It was hypothesised that MT may similarly lead to an increase in go P3 mean amplitude as MT was expected to enhance attentional resource allocation across task conditions. However, the pooled T1 data demonstrated that go P3 was not significantly correlated with RTs, only reaching the non-reliable trend level [r = -.235, p =.062, 1 tailed], further suggesting that the amount of resources allocated to inhibit responses to no-go stimuli is a critical factor in task performance.

Behavioural Outcome Measures and Hypotheses.

RT means were the focus of the behavioural analysis. In line with the hypothesis that MT would lead to increased allocation of attentional resources to inhibition processes (i.e. increased no-go P3 mean amplitude), it was hypothesised that said increase would make inhibition to no-go stimuli more efficient and enable the MTG to improve RTs to go stimuli.

As the task difficulty was minimal and the duration of the task was only approximately 7-8 minutes, errors of omission and commission were expected to be low and no between group differences were expected. The analysis of accuracy data is presented in section 11.3.1, demonstrating that no between group differences were found.

11.2 Task Design and Stimuli

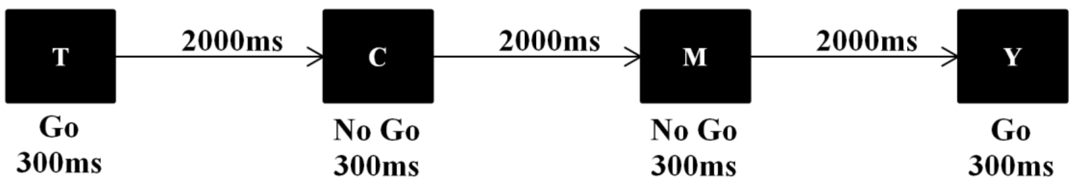

Figure 28: CPT example trials and timings

The CPT used here was a simple Go/No-go paradigm. Go/No-go stimuli were the letters B, C, F, H, L, M, T, or Y. At the beginning of each trial block the participants' were given instructions that introduced 4 letters, 2 of which would be go stimuli and 2 of which would be no-go stimuli. These 4 letters were changed for 4 new letters prior to the second block of trials in order to reduce the impact of stimulus familiarity, which may cause facilitation and/or automatic responding. Only 1 letter ever appeared on screen at a time. The letters administered as Go/No-go stimuli were counterbalanced across participants so that overall each letter was equally used as a go and no-go stimulus. Each participant completed the identical version of the task at T1 and T2. The letters were presented centrally on the screen in Arial font size 48, coloured white on a black background. Go responses were given by pressing the spacebar with the right index finger.

Each trial began with a Go/No-go stimulus lasting 300ms, followed by a blank screen. Participants performed 2 blocks of 100 trials (200 total), consisting of 60 go (120 total) and 40 no-go (80 total) stimuli for an overall 60:40 ratio. Figure 28 shows an example of a series of CPT trials and the associated timings. The stimuli were randomly intermixed within each block. Participants started block 2 manually after they had confirmed they had learnt the new go and no-go stimuli.

11.3 Results

An a priori decision was taken to exclude participants from both electro-physiological and behavioural analyses if they had a hit rate below 90% for go trials. Due to the inherent ease of the CPT, a hit rate below 90% would indicate poor task understanding or a problem remembering stimulus classification. Only 1 participant failed to meet this criterion and was excluded accordingly. Single trials were discarded on the very rare occasion (<1% of trials across groups) that RT was over 1000ms and only trials with correct responses were used to calculate the RT mean.

The pattern of behavioural results was similar if all available data or only the data of participants included in the ERP analyses were used. Thus, the behavioural analyses are presented for all available data.

11.3.1 Behavioural Analyses

Table 22 demonstrates that no significant behavioural differences were present between MTG and BTG when direct comparisons at T1 (t-tests) were calculated.

Table 22: Summary of tests for baseline differences, with mean values (standard deviations) and respective statistical values (all 2 tailed) for the comparison between MTG and BTG

	MTG (n=24)	**BTG (n=25)**	**Statistical Values**	
RT mean (ms)	482 (63)	467 (60)	$t(47) = .849$,	$p = .400$
Go HR (%)	99.6 (.8)	99.3 (1.4)	$t(47) = .863$,	$p = .393$
No-go HR (%)	94.6 (4.4)	94.7 (4.8)	$t(47) = -.011$,	$p = .991$

Reaction Times

A Repeated Measures ANOVA was conducted (Table 23), to determine intervention related changes in RTs to go trials. A significant *Group x Time* interaction was observed indicating that the MTG and BTG had modulated RTs differently from T1 to T2.

Table 23: Summary of Repeated Measures ANOVA results for RT mean

Effect	**Statistical Values**		
Time	$F(1,47) = .002$,	$p = .965$	
Group x Time	$F(1,47) = 4.244$,	$p = .045$	$r = .288$
Group	$F(1,47) = .018$,	$p = .894$	

Paired Samples t-tests were computed for each group to ascertain the direction of T1 to T2 differences (Table 24) and indicated that the MTG had significantly reduced RTs from T1 to T2 whereas no significant change was found for the BTG. Figure 28 illustrates these T1 to T2 differences.

Table 24: Summary of means (standard deviations) and Paired Samples t-tests displaying RT(ms) differences from T1 to T2 for MTG and BTG

	MTG (N=24)	**BTG (N=25)**
	T1: 482 (63)	T1: 467 (60)
	T2: 469 (55)	T2: 480 (73)
Paired Samples T-test	$t(23)=-2.776$, $p=.011$	$t(24)=1.108$, $p=.279$

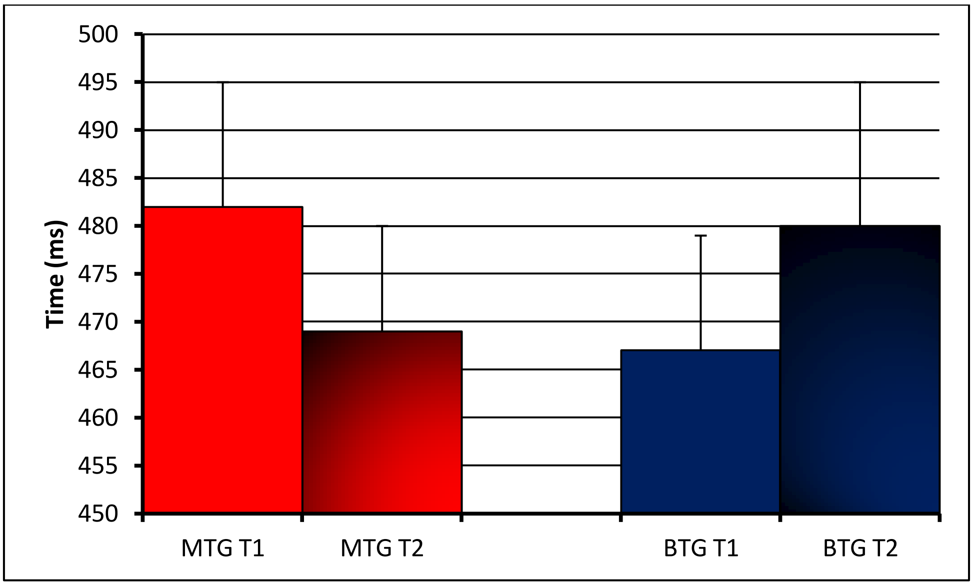

Figure 28: RT differences from T1 to T2 for the MTG and BTG. Error bars depict standard error of the mean.

Response Accuracy

Consistent with previous studies using a similar CPT paradigm (e.g. Vallesi, 2011), accuracy to go trials was very high (98.5%), reflecting the inherent ease of the task. Unsurprisingly, no main or between group effects were revealed (see Table 25 for summary) by a Repeated Measures ANOVA. The same pattern of results was observed for an additional Repeated Measures ANOVA of correctly ignored no-go trials.

Table 25: Summary of Repeated Measures ANOVA results for HRs in the go and no-go conditions. Includes T1 and T2 mean values (standard deviations)

	MTG (N=24)	BTG (N=25)	Effect	Statistical Values	
Go HR					
(%)	T1: 99.6 (.8)	T1: 99.3 (1.4)	*Time*	F(1,47) = 1.394,	*p* =.244
	T2: 98.9 (5.1)	T2: 98.1 (6.0)	*Group x Time*	F(1,47) = .083,	*p* =.775
			Group	F(1,47) = .404,	*p* =.528
No-go HR					
(%)	T1: 94.6 (4.4)	T1: 94.7 (4.8)	*Time*	F(1,47) = .252,	*p* =.618
	T2: 95.0 (6.5)	T2: 95.3 (6.4)	*Group x Time*	F(1,47) = .025,	*p* =.875
			Group	F(1,47) = .014,	*p* =.906

11.3.2 ERP analyses

No-go P3 ERP component

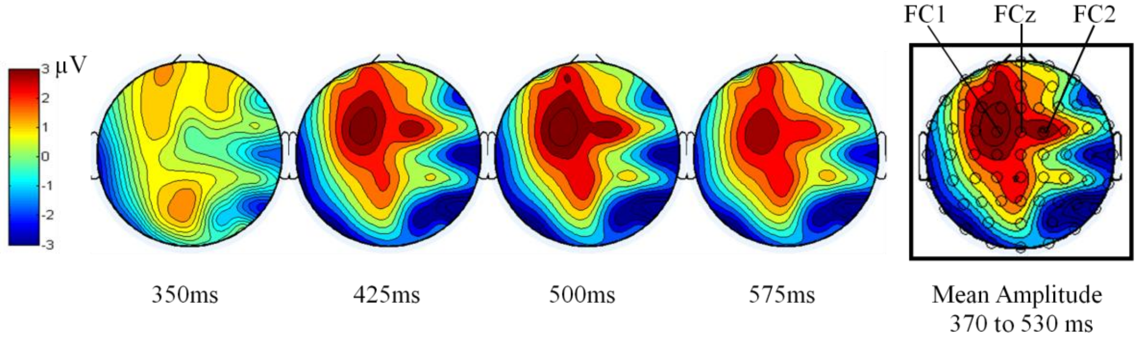

Figure 31: Pooled T1 data (N=44). A time lapse topographical view of the no-go P3 ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 350ms to 575ms (75ms steps from left to right). Mean Amplitude spherical spline interpolated scalp topography is included for the no-go P3 time window (370 to 530ms).

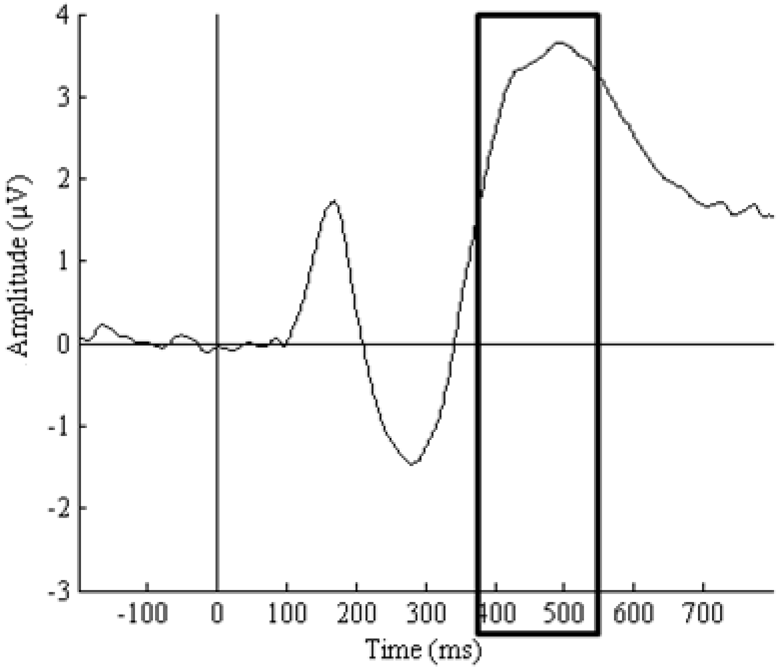

Figure 32: Grand mean evoked potential for a cluster of Fronto-Central sites (FCz, FC1 and FC2), from pooled T1 data (N=44). No-go P3 (370 to 530ms time window) is highlighted

Figure 31 displays the time course and topography of the no-go P3 ERP component using pooled T1 data (N=44) and suggests that a cluster of Fronto-Central electrodes (FCz, FC1 and FC1) best represents the components maxima. As shown in Figure 32, a time window of 370 to 530ms best captures the no-go P3 from this cluster of Fronto-Central electrodes. Importantly, there were no between groups differences at baseline (t(34) = -1.074, p = .290).

A Repeated Measures ANOVA (Table 26) revealed a significant *Group x Time* interaction, suggesting that no-go P3 mean amplitude was modulated differently for MTG and BTG.

Table 26: Summary of Repeated Measures ANOVA (*Time* (2) x *Group* (2)) results for no-go P3 mean amplitude in the 370to530ms time window for a cluster of fronto-central electrodes (FC1, FCz, FC2 cluster).

Effect	**Statistical Values**		
Time	F(1,34) = .372,	*p* = .546	
Group x Time	F(1,34) = 4.180,	*p* = .049	*r = .331*
Group	F (1,34) = .395,	*p* = .534	

Paired samples t-tests (Table 27) demonstrate that MTG significantly increased no-go P3 mean amplitude from T1 to T2 and that BTG exhibited no change. Figure 33 illustrates these between group differences.

Table 27: Summary of means (standard deviations) and paired samples t-tests displaying differences from T1 to T2 in no-go P3a mean amplitude (FC1, FCz, FC2 cluster, 370-530ms) for MTG and BTG

	MTG (N=18)	**BTG (N=18)**
	T1: 2.49 (2.41)	T1: 3.55 (3.12)
	T2: 3.17 (2.52)	T2: 3.18 (2.54)
Paired Samples T-test	*t*(17)= -2.228 *p* =.040	*t*(17)= .893 *p* =.384

These results suggest that the MTG increased the amount of resources allocated to response inhibition and are consistent with the findings of improved RTs. Pooling the data across groups (N=36), T1 to T2 differences (T2 minus T1) in RTs and no-go P3 mean amplitude (FC1, FCz, FC2 cluster, 370-530ms) were significantly negatively correlated [r = -.318, p = .029], with increases in no-go P3 mean amplitude related to decreases in RTs. This further suggests that increasing no-go P3 mean amplitude is an adaptive compensatory response that benefits performance. Importantly, a change in the latency of the no-go p3 ERP component can be ruled out as a cause of the observed between groups difference because no further between groups differences were found when no-go P3 peak latency values (calculated as a local peak between 370-530ms) were submitted to a Repeated Measures ANOVA (*Time x Group*: F(1,34) = .078, p = .782).

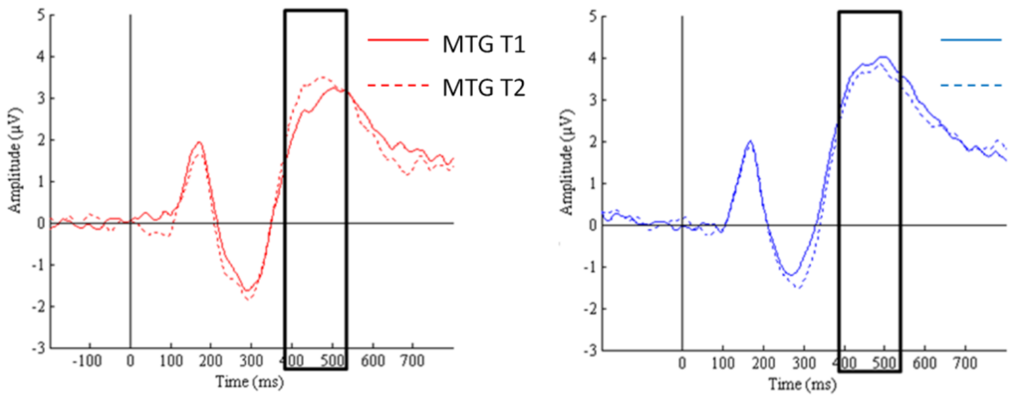

Figure 33: MTG and BTG difference in no-go P3 mean amplitude (FC1, FCz, FC2 cluster) from T1 to T2

As the no-go P3 ERP component was bilateralised, a final exploratory analysis was run to examine if left vs right hemisphere differences existed between the groups. The mean amplitude of the no-go P3 (370-530ms) at FC1 and FC2 were subjected to a *Time* (2) x *Site* (2) x *Group* (2) Mixed ANOVA (Table 28), revealing a significant main effect of *Site* and significant *Group x Time* and *Time x Site x Group* interactions. The main effect of *Site* was caused by higher mean amplitudes at FC1 as compared FC2 (3.64 vs 3.16 µV).

Table 28: Summary of Mixed ANOVA results for no-go P3 mean amplitude (FC1 vs. FC2) in the 370 to 530ms time window

Effect	**Statistical Values**	
Time	F(1,34) = .154,	*p* = .697
Group x Time	F(1,34) = 4.126,	*p* = .050
Group	F (1,34) = .334,	*p* = .567
Site	F (1,34) = 7.097,	*p* = .012
Site x Group	F (1,34) = 1.067,	*p* = .309
Time x Site	F (1,34) = 2.932,	*p* = .096
Time x Site x Group	F (1,34) = 6.491,	*p* = .016

A series of Paired Samples T-tests (Table 29) split by *Group* and *Site* were computed to examine the significant *Time x Site x Group* interaction, revealing that the interaction was caused by a significant increase in no-go P3 mean amplitude at FC2 for the MTG as compared a relative decrease for the BTG. Figure 34 illustrates this between groups difference and also demonstrates that no such difference occurred at FC1. Of note, whilst the difference topographies contained in Figure 34 suggest that the MTG increased no-go P3 across a number of right hemispheric sites, the no-go P3 ERP component and the between groups difference both peak at FC2, thus no further exploratory analyses were conducted.

As with the original no-go P3 cluster (FC1, FCz, FC2), it was found that differences in RTs (T2 minus T1) were significantly negatively correlated with change in no-go P3 mean amplitude (T2 minus T1) at both FC1 [*r* = -.318, *p* = .029, 1 tailed] and FC2 [*r* = -.291, *p* = .042, 1 tailed] when data were pooled across groups. Both significant correlations represented a relationship between increases in no-go P3 mean amplitude and decreases in RTs, further confirming the relationship between no-go P3 and task performance. As only MTG significantly improved RTs and significantly increased no-go P3 mean amplitude from T1 to T2, it is feasible to suggest that MT may aid the recruitment of additional neuronal resources which in turn facilitates improved task performance. These findings are indicative of improvements in sustained attention and a strengthening of executive attentional functions related to inhibitory control in older adults. This assertion is discussed in detail in Chapter 14.

Table 29: Summary of means (standard deviations) and paired samples t-tests displaying differences from T1 to T2 in no-go P3 mean amplitude (FC1 & FC2, 370-530ms) for MTG and BTG

		MTG (N=18)	**BTG (N=18)**
No-go P3 (FC1)			
Mean Amplitude (μV)		T1: 3.56 (2.45)	T1: 4.05 (3.07)
		T2: 3.43 (2.74)	T2: 3.53 (2.30)
	Paired Samples T-test	$t(17)$= .536, p =.599	$t(17)$= 1.165 p =.260
No-go P3 (FC2)			
Mean Amplitude (μV)		T1: 2.33 (2.50)	T1: 3.86 (3.33)
		T2: 3.31 (2.41)	T2: 3.13 (2.73)
	Paired Samples T-test	$t(17)$= -2.136, p =.048	$t(17)$= 1.841 p =.083

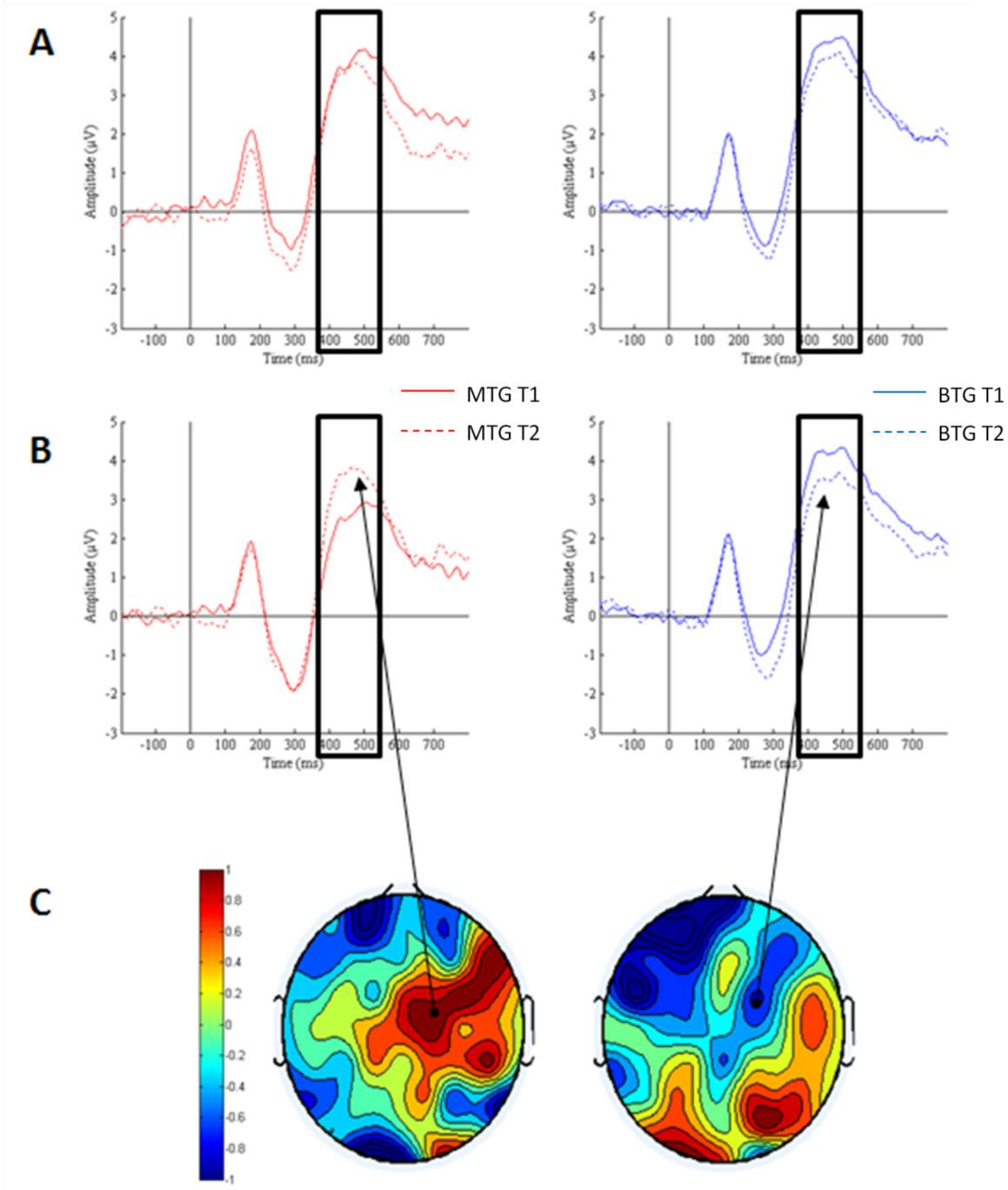

Figure 34: Panels A and B depict the T1 to T2 differences in no-go P3 mean amplitude between the MTG and BTG for FC1 and FC2 respectively. Panel C displays spherical spline interpolated difference topographies depicting T2 minus T1 differences in mean amplitude in the 370 to 530ms time window for the MTG (Left) and BTG (Right). Red areas indicate an increase from T1 to T2 and blue areas indicate a decrease. FC2 is highlighted.

P3b ERP component (go condition)

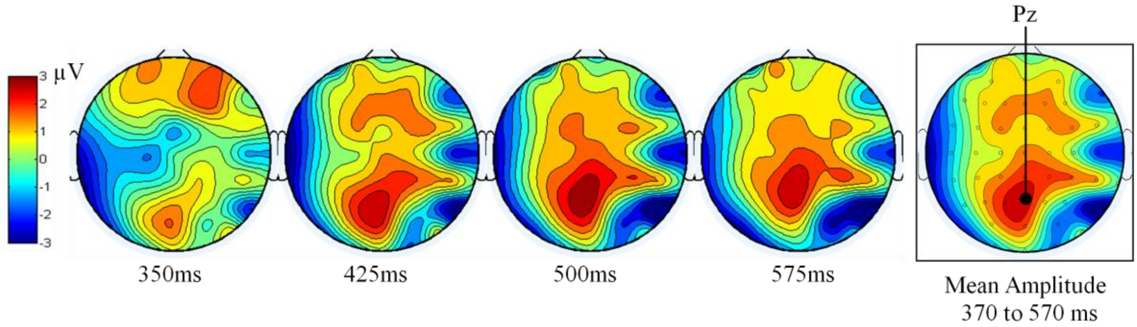

Figure 35: Pooled T1 data (N=44). A time lapse topographical view of the go P3b ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 350ms to 575ms (75ms steps from left to right). Mean amplitude spherical spline interpolated scalp topography is included for the go P3b time window (370 to 570ms).

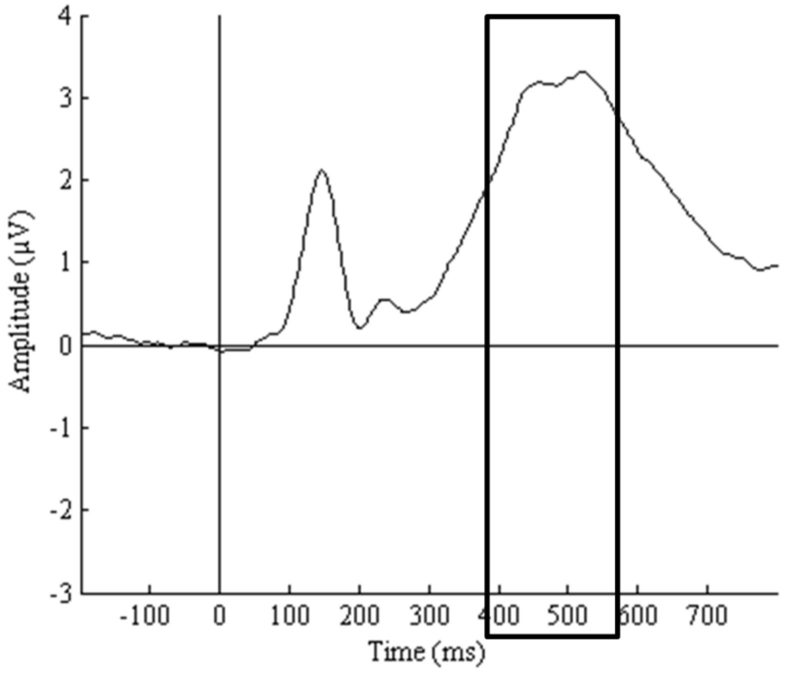

Figure 36: Grand mean evoked potential at Pz, from pooled T1 data (N=44). P3b (370 to 570ms time window) for go stimuli is highlighted.

Figure 35 displays the time course and topography of the go P3b ERP component using pooled T1 data (N=56). As shown in Figure 36, the maximum of the P3b was best captured by a time window of 370 to 570ms at Pz.

Repeated Measures ANOVA for go P3b mean amplitude (Table 30) revealed only a non-reliable effect of *Time*, suggesting that MTG and BTG had similarly modulated P3b from T1 to T2. Figure 37 illustrates that a relative increase was observed for both groups. Thus, between groups differences were limited to the condition requiring the use of inhibitory control (no-go P3) and were not consistent across task conditions.

Table 30 Summary of means (standard deviations) and Repeated Measures ANOVA results for go P3b mean amplitude (µV) in the 370to570ms time window

MTG (N=18)	BTG (N=18)	Effect	Statistical Values	
T1: 2.72 (1.99)	T1: 2.51 (2.95)	*Time*	F(1,34)= 3.656,	*p* = .064
T2: 3.55 (1.91)	T2: 2.90 (2.32)	*Group x Time*	F(1,34)= .489,	*p* = .489
		Group	F (1,34) = .364,	*p* =.550

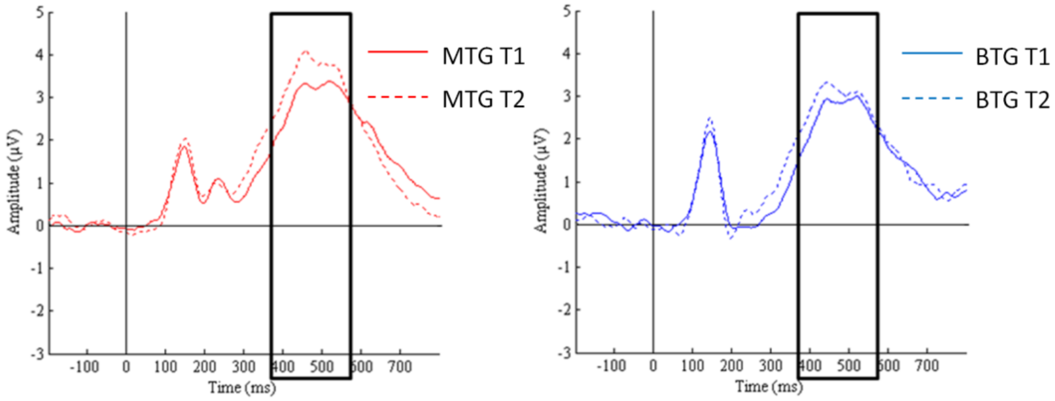

Figure 37: MTG and BTG difference in P3b mean amplitude at Pz from T1 to T2.

Chapter 12. Mindfulness Training, Ageing and Attentional/Emotional Conflict Monitoring: Emotional Counting Stroop

12.1 Theoretical Background

Chapter 12 details the use of an emotional counting Stroop (ECStroop) paradigm which was utilised to provide the assessment of executive functions (executive control and conflict monitoring) and the attentional processing of emotional stimuli within one task. This Chapter discusses the detailed analysis and results obtained by using the ECStroop task as well as the reasons for why it was chosen, the tasks design, its associated outcome measures and specific hypotheses.

Executive Control, Conflict Monitoring and Ageing

The literature reviewed in Chapter 3 established the use of executive attentional functions and associated neural networks during MT (e.g. Baron Short et al., 2007; Hasenkamp et al., 2012; Hölzel et al., 2007) and the potential efficacy of MT to improve said functions (e.g. Chan & Woollacott, 2007; Greenberg et al., 2012; Jha et al., 2007; Moore & Malinowski, 2009; Tang et al., 2007; Teper & Inzlicht, 2013; Wenk-Sormaz, 2005) and positively modulate neural activity (e.g. Cahn et al., 2010, 2013; Cahn & Polich, 2009; Moore et al., 2012; Teper & Inzlicht, 2013). Further, a number of findings discussed in Chapter 9 suggested that executive deficits exist in older adults, including increased Stroop interference (Andres et al., 2008; Cohn et al., 1984; Mayas et al., 2012; Panek et al., 1984; Van der Elst et al., 2006; West & Alain, 2000; West & Bell, 1997). Encouragingly, greater grey matter density (Hölzel et al., 2008; Luders et al., 2009; Pagnoni & Cekic, 2007) and cortical thickness (Lazar et al., 2005) have been found in attention related areas for older meditators vs. age-matched controls. Taken with the aforementioned positive effects of MT a strong case can be made for examining whether MT may improve executive performance and modulate associated neural mechanisms in older adults, thus a Stroop paradigm was employed in LS2.

Why Was The ECStroop Task Chosen?

As an emerging line of research suggests that MT related improvements in attentional functions may foster improvements in emotion regulation (discussed below), an ECStroop paradigm was chosen as it allowed for the inclusion of stimuli of emotional valance in order to concurrently assess modulations of executive functions and the attentional processing of emotional stimuli without significantly increasing the participants overall task burden. The ECStroop task[37] utilised herein is an amalgamation of two Stroop paradigms, a counting Stroop (cStroop; Bush et al., 1998) and one version of an emotional counting Stroop task (Whalen et al., 1998). Whereas this original emotional counting Stroop task only utilised negative and neutral stimuli, incongruent and positive stimuli were included in the current version to enable an assessment of both executive functions and the attentional processing of emotional stimuli. The reasons for using aspects of these two Stroop paradigms are discussed separately in the following two sections.

The cStroop, Executive Control, Conflict Monitoring and Ageing

The primary objective of using the ECStroop task was to measure executive control and conflict monitoring. Said objective is related to aspects of the cStroop paradigm employed by Bush et al. (1998). The cStroop was originally developed as a cognitive activation paradigm for probing ACC function related to cognition during fMRI recordings. Similar to the original Stroop task (Stroop, 1935) the cStroop produces cognitive interference by pitting two competing information processing operations against each other. Whereas word reading and colour naming are in competition in the classic Stroop, the cStroop utilises word reading and counting processes to create conflict. During task completion subjects are instructed to report, via button-press, the number of words (1 to 4) on the screen, regardless of word meaning. Incongruent trials (interference) consist of number words that are incongruent with the correct response (e.g., “two” written three times, correct answer: “three”) whereas neutral trials consist of words that are semantically neutral to the goal of the task (e.g. household items). Similar to the classical Stroop task, the pre-potent response of word reading must be over-ridden, resulting in slower and less accurate responses on

[37] The ECStroop moniker is retained herein to highlight that the utilised paradigm involves the counting aspect of the original cStroop with the addition of stimuli of emotional valence.

incongruent trials. Successful task completion relies on two proposed functions of the ACC; executive control is required to bias information processing to goal directed aspects of the stimulus array (number of words presented) whilst conflict monitoring is required to ensure the pre-potent response of word reading is overcome before making a response (Botvinick et al., 2001; Kerns et al., 2004; Ridderinkhof et al., 2004). Importantly, the cStroop activates the ACC (Bush et al., 1998) in a similar way to the classical Stroop (e.g. Hanslmayr et al., 2008; Liotti et al., 2000). The cStroop has become well established as a means to demonstrate ACC dysfunction in a wide range of conditions including ADHD (Bush et al., 1999), bipolar disorder (Roth et al., 2006; Strakowski et al., 2005), traumatic brain injury (Tlustos et al., 2011) and cocaine-dependency (Barros-Loscertales et al., 2011). Thus, cStroop stimuli provide an appropriate measure to assess MT related modulations in executive control and conflict monitoring in older adults.

Of particular interest to the ECStroop electrophysiological examination conducted herein (section 12.3.2) was a negative deflection of the ERP that peaks approximately 200-450ms post stimulus onset at fronto-central electrode sites. This fronto-central N2 ERP component has been associated with the process of monitoring for and/or resolving conflict (Albrecht et al., 2008; Johnstone, Watt, & Dimoska, 2010; Kopp, Rist, & Mattler, 1996). Gajewski, Stoerig, and Falkenstein (2008) suggested that the N2 is linked to the need for response selection/monitoring. This need is increased in tasks that involve conflict such as the cStroop. Of note, conflict monitoring is required across all four conditions in the utilised ECStroop task as no cues are given to warn the participant that an incongruent stimulus is due to appear. Neuro-imaging studies suggest that the ACC is involved in response conflict monitoring (see Botvinick, Cohen, & Carter, 2004 for review). Unsurprisingly then the ACC has also been implicated as a generator of the fronto-central N2 across a variety of paradigms that incorporate response conflict (e.g. Bekker, Kenemans, & Verbaten, 2005; Liotti et al., 2000; Nieuwenhuis et al., 2003; Van Veen & Carter, 2002). Thus, the use of cStroop stimuli and ERP analysis herein allows for an assessment of whether MT may lead to behavioural improvements (RTs and HRs) and modulations of neural markers of executive control and response monitoring. Interestingly the fronto-central N2 has been shown to be diminished (Ceponiene et al., 2008) or almost absent (Bertoli & Probst, 2005; Wild-Wall, Falkenstein, & Hohnsbein, 2008) in older adults. This suggests that executive control and the allocation of attentional resources for response monitoring may be diminished in older adults. Thus an increase in fronto-central N2 following cognitive training may be considered a positive result.

Before moving on, it is pertinent to state that the fronto-central N2 discussed above should be seen as somewhat distinct from the bilateralised posterior N2 observed in LS1 for the standard colour word Stroop paradigm. In addition to the difference in topography, the N2 observed in the standard Stroop appeared approximately 100ms earlier than that observed during the ECStroop, suggesting that it was related to earlier aspects of stimulus discrimination. Modulations of the N2 in LS1 were attributed to enhanced attentional amplification of goal related aspects of the stimulus. This additional attentional amplification may be required during the standard Stroop as the source of conflict is an incompatibility between two aspects of the same stimulus, whereas the conflict in the cStroop is caused by an incompatibility between the number of words presented in the stimulus array and the meaning of these words. Thus any observed modulations in fronto-central N2 should be considered distinct from those observed for the bilateralised posterior N2 in LS1.

ECStroop and the Attentional Processing of Emotional Stimuli

The secondary objective of utilising the ECStroop was to assess MT related changes in the processing of emotional stimuli. The original version of the emotional counting Stroop task was designed to activate the affective subdivision of the ACC (Whalen et al., 1998). By including stimuli of negative and neutral valence in a cStroop paradigm Whalen et al. (1998) found that the affective subdivision of the ACC was activated by stimuli of negative valence only. Emotional conflict in the ECStroop is caused by the automatic processing of the words meaning overriding the participants task to ignore the words meaning and count the number of words presented (e.g., “PAIN” written three times, answer = “three”). Emotional Stroop stimuli are typically used in patient samples. When patients are presented with colour words relevant to their current concerns or condition the automatic processing of the words meaning delays naming of the word’s colour (see J. M. Williams, Mathews, & MacLeod, 1996). Such increases in response latency have been found for general anxiety disorder (Mathews & MacLeod, 1985), phobias (Watts et al., 1986) post traumatic stress disorder (McNally et al., 1990), social phobia (Hope et al., 1990), panic disorder (McNally et al., 1992) and obsessive compulsive disorder (Foa et al., 1993). However, increased response latency is not typically seen in normal healthy adults (e.g. Kampman et al., 2002). Thus, RT differences between neutral and emotional stimuli are not a focus of the analysis herein.

ERP’s allow the stages of information processing occurring between the presentation of a stimulus and the participants’ response to be observed and thus may offer a more sensitive measure of the processing of emotional Stroop stimuli than RTs. The focus herein was on an electrophysiological examination of the P3 ERP component. A number of previous studies found that emotional word stimuli, irrespective of valence (pos/neg), produce larger P3 mean amplitudes than neutral words (Bernat, Bunce, & Shevrin, 2001; Johnston, Miller, & Burleson, 1986; Thomas, Johnstone, & Gonsalvez, 2007). Given that P3 amplitude has been proposed to indicate attentional resource allocation (Polich, 2007), the enhanced P3 observed in these studies may evince an attentional bias or enhanced reactivity to emotional stimuli. Interestingly, words of negative valence typically lead to larger ERPs than those of neutral or positive valence (Bernat et al., 2001; Carretie et al., 2001; Ito et al., 1998; Junghofer et al., 2001). This pattern may be indicative of a “negativity bias”, that is an attentional bias prioritising the processing of negative over mundane stimuli occurring in the general population (e.g. Carretie et al., 2001). Whilst such a bias may be adaptive in certain instances (e.g. warning signs) it is most likely maladaptive in a variety of conditions and may explain why emotional Stroop stimuli are processed slower in the aforementioned clinical conditions.

With respect to MT, an emerging line of research has begun to assess whether improvements in attentional functions may foster the improvements in emotion regulation that are often seen as a result of MT (see Chiesa et al., 2013 for review). In line with the Liverpool Mindfulness Model (Malinowski, 2013), it may be proposed that improvements in attentional control, fostered through MT, may provide the platform upon which cognitive and emotional flexibility may be improved, leading to a myriad of potential positive outcomes. This proposal is consistent with phenomenological accounts of MT (e.g. Lutz et al., 2008; Wallace & Shapiro, 2006) and is in line with the findings of a number of recent studies. Allen et al. (2012) investigated neural changes in cognitive and emotional processing using fMRI following a 6 week MT course. Using an emotional Stroop task which included the presentation of affective images with positive or negative valence, this study found that emotional conflict scores only diminished in the meditation group but not in an active control group. This was accompanied by a meditation related increase in activation of the DLPFC during the task. As this area is involved in the executive control network (Raz & Buhle, 2006; Seeley et al., 2007) this pattern of results suggests that enhanced attentional control lead to reduced emotional conflict. Similarly, Sahdra et al. (2011) reported that participation in a 3 month intensive meditation retreat concurrently resulted in enhanced response inhibition performance and improved socio-emotional functioning as measured by a broadly conceived composite measure of adaptive socio-emotional functioning (consisting of 14 self- report measures such as emotion regulation, depression, anxiety, well-being, ego resilience, empathy, etc.). Further analysis revealed that the socio-emotional functioning was influenced by enhancement of response inhibition skills, lending support to the hypothesis that attentional control skills fostered through MT may underpin the development of emotion regulation skills. Table 31 contains a summary of relevant study details for the abovementioned studies.

Table 31: Summary of relevant study details for studies introduced in section 12.1

Study	Type and Amount of MT	MT Intervention Details	Comparison Group Details
Allen et al., 2012	*Type:* Mindfulness Course *Amount:* 6 wks, 6 x 2hr group sessions. 20 mins of daily take home practice.	Focussed breath awareness was the core practice although body scanning, compassion and open monitoring were all taught. An additional “heart practice” aimed at developing fullness of feeling (Risom, 2010) was also included.	*Type of intervention:* Active control Group. Shared reading and listening. *Demographics matched:* Age, gender and education.
Sahdra et al., 2011	*Type:* Mindfulness retreat. Participants were expert meditators (mean = 13yrs). Tradition not stated. *Amount:* 3 months, 7 hrs per day.	Some elements of loving kindness, compassion, empathic joy and equanimity were taught but the participants were told to focus on mindfulness of breathing as this was key to training attention and self regulation	*Type of intervention:* Waitlist controls group. *Demographics matched:* Age, gender, income and education matched.

If MT does indeed improve attentional functions herein, it is feasible to suggest that this may result in improvements to emotion regulation. Including both negative and positive stimuli in the utilised ECStroop task afforded the opportunity to assess if such improvements to emotion regulation occurred. The MT employed for LS2 included instruction regarding a non-judgmental attitude and emphasised a non- reactive attentional state, thus it may be expected that it may similarly influence the processing of both positive and negative stimuli. As discussed above, the P3 ERP component may be utilised to assess attentional resource allocation to emotional stimuli, thus a reduction in P3 mean amplitude would be indicative of reduced reactivity to emotional stimuli following MT and would represent a positive result.

Of note, the emotional stimuli were not included to assess an identified dysfunction in emotional processing for older adults. Rather they were included to assess general MT related modulations in emotional processing. Emotional processing remains relatively robust into old age and older adults typically report decreased negative affect and increased or stable positive affect (e.g. Carstensen et al., 2000). However, recent research suggests that the functional efficacy of structures related to emotion regulation may be influenced by cognitive ability (Winecoff et al., 2011). Thus even in a sample of older adults, MT related improvements in executive control and conflict monitoring, as assessed by the cStroop stimuli, may lead to improved emotional processing as assessed by ECStroop stimuli. Thus the ECStroop provides an appropriate measure to assess modulations of both cognitive and emotional processing in a single paradigm.

Electrophysiological Outcome Measures and Hypotheses.

The ERP component identification procedure detailed in section 4.4 resulted in the identification of two main ERP components of interest.

Consistent with the literature reviewed in this section, a fronto-central N2 ERP component was observed in the 270 to 340ms time window, peaking at FCz (see Figure 44 and Figure 45). This component was the focus of the ERP analysis as it is thought to represent attentional resource allocation to executive control and conflict monitoring processes. As the repeated activation of executive functions and the neural substrate that subserves them during MT was expected to positively influence CR mechanisms, it was hypothesised that MT would lead to increased fronto-central N2 mean amplitude, evincing an increase in the allocation of attentional resources to executive control and conflict monitoring processes.

A second ERP component was observed in the 500 to 650ms time window, peaking at Pz (see Figure 48 and Figure 49). As mentioned in previous Chapters, this time window and topography are indicative of a P3b ERP component and thus the identified component will be labelled as such herein. As the employed MT involved the training of a non-judgmental, non- reactive attentional state to arising thoughts and emotions, it was hypothesised that P3b mean amplitude may be reduced for the MCG following MT for both the negative and positive stimuli.

Behavioural Outcome Measures and Hypotheses.

Raw RTs were the main focus of the behavioural analysis. It was hypothesised that MT would lead to a significant reduction in RTs for MTG as compared the BTG, evincing an improvement in executive control and conflict monitoring following MT. As detailed above RT differences to emotional stimuli do not typically occur in healthy adults and were not expected herein. Thus, no between groups RT analysis of an emotional interference effect was conducted. Of note, it was expected that RTs for incongruent trials would be significantly slower than for each of the other 3 conditions. Thus, as a task manipulation check a Repeated Measures ANOVA (presented in section 12.3.1) was conducted using T1 data, pooled across groups.

Accuracy was measured in terms of HRs for each individual condition. No between-group differences were expected given that HRs were expected to be high across conditions throughout. However, accuracy data were analysed and are presented to demonstrate no between-group differences. A Repeated Measures ANOVA (presented in section 12.3.1) was conducted as a task manipulation check to assess if HRs for incongruent trials were significantly lower than for each of the other 3 conditions.

12.2 Task Design and Stimuli

Stimuli consisted of 28 English language words spread across 4 semantic conditions: incongruent, negative, positive and neutral. Stimuli were presented in list sizes of 1 to 4 words. Figure 38 presents 4 example trials. The list sizes and associated word positions relative to the centre of the screen were as follows:

- List size 1 = 1 word presented centrally.
- List size 2 = 2 words presented 0.6 degrees of visual angle above and below centre.
- List size 3 = 1 word presented centrally and 2 words presented 1.2 degrees of visual angle above and below centre.
- List size 4 = 2 words presented 0.6 degrees of visual angle above or below the centre and 2 words presented 1.8 degrees of visual angle above or below the centre.

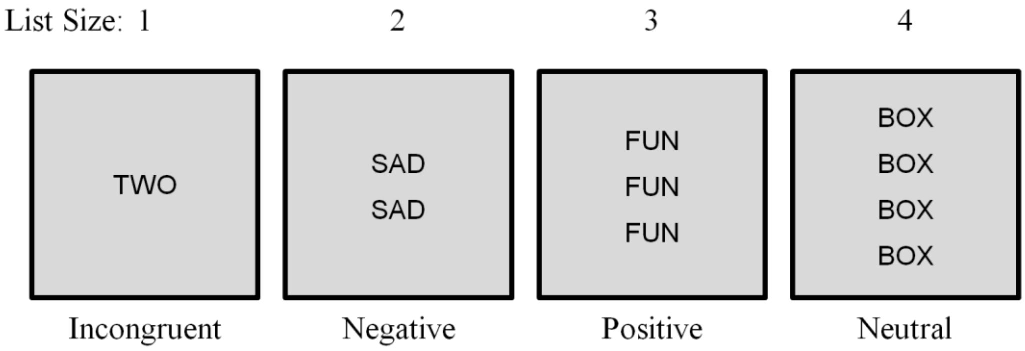

Figure 38: 4 example ECStroop trials, 1 per list size and condition. Note: This diagram is not to scale and word sizes relative to the size of the screen are exaggerated so that they may be viewed clearly.

Stimuli were presented in black (Arial, fontsize 48) on a light grey background. The participant's task was to respond to the number of words that appeared on the screen, ignoring the words meaning. Four keys on a standard QWERTY keyboard were used to enter responses; "V", "B", "N" and "M" were labelled with the numbers 1-4 for the responses 1 to 4 respectively. Only four number words were chosen in the incongruent condition to limit the number of potential responses for the task. Each of the other three conditions contained eight potential words in order to minimise exposure effects. Each incongruent stimulus could be presented in the three list sizes that do not match its meaning, whilst all other stimuli could be presented in all four list sizes.

The stimuli and their frequency of use in English language (Leech, Rayson, & Wilson, 2001) are detailed in Table 32. The mean frequency of use was matched across the negative, positive and neutral conditions[38] ($F(2, 21) = .002$, $p = .998$). It was neither possible nor necessary to match frequency of use across all four conditions because the 'number' words used in the incongruent condition are some of the most frequently used words in the English language and this is essential to the executive interference related task manipulation. In the incongruent condition, participants must ignore the meaning of the 'number' word in order to respond accurately to the number of words presented. Thus, the high frequency of use for the incongruent condition is essential as it drives the conflict element of the task. The stimuli were matched for word length across all four conditions.

Table 32: Summary of the word stimuli used in the ECStroop task. Frequency of use per million words is displayed for each word with a mean value presented for each semantic category

Incongruent Words		**Negative Words**		**Positive Words**		**Neutral Words**	
ONE	118	SAD	36	HUG	3	BOX	114
TWO	1563	CRY	23	JOY	27	CUP	134
THREE	800	WAR	297	FUN	34	BED	180
FOUR	465	BAD	264	FIT	33	FAN	48
	736.5	PAIN	84	NICE	134	DOOR	302
		HATE	50	LOVE	150	TOOL	54
		DEATH	250	HAPPY	129	TABLE	231
		BLOOD	102	GREAT	635	PLATE	64
			138.3		**143.1**		**140.9**

Each trial consisted of the following elements. The trial began with a fixation cross presented centrally for 500ms. This was replaced by word stimuli in list sizes of 1 to 4, which were presented for 1500ms. The trial ended with a variable inter-trial interval of between 850 and 1100ms, during which the fixation cross was presented again. The task consisted of 4 trial blocks of 63 randomly intermixed trials (252 total).

[38] Having been grouped by semantic condition, the frequency of use of each word were subjected to a one way ANOVA which demonstrated no statistical difference between the mean values for each condition.

Each trial block was separated by a 20 second break. The incongruent condition accounted for 60 trials (4 words x 3 list sizes x 5 repeats) whilst the remaining 3 conditions accounted for 64 trials each (8 words x 4 list sizes x 2 repeats).

12.3 Results

An a priori decision was taken to exclude the data of any participant who had less than 85% HR in the neutral condition as this would evince either poor task understanding or difficulty with key mapping. The data of 6 participants were removed from both behavioural and ERP analyses based on this criterion. The pattern of behavioural results was similar if all available data or only the data of participants included in the ERP analyses were used. Thus, the behavioural analyses are presented for all available data.

12.3.1 Behavioural Analyses

Table 33 demonstrates that no significant behavioural differences were present between MTG and BTG when direct comparisons at T1 (t-tests) were calculated.

Table 33: Summary of tests for baseline differences, with mean values (standard deviations) and respective statistical values (all 2 tailed) for the comparison between MTG and BTG.

	MTG (n=22)	**BTG (n=22)**	**Statistical Values**	
RT mean (ms)				
Incongruent	835 (140)	818 (120)	$t(42) = .437$,	$p = .664$
Negative	762 (118)	766 (107)	$t(42) = -.141$,	$p = .889$
Positive	759 (110)	761 (98)	$t(42) = -.084$,	$p = .933$
Neutral	758 (117)	761 (96)	$t(42) = -.091$,	$p = .928$
HR (%)				
Incongruent	92.5 (8.5)	96.5 (4.2)	$t(31^*) = -1.993$,	$p = .055$
Negative	97.1 (2.6)	98.3 (2.2)	$t(42) = -1.674$,	$p = .102$
Positive	97.7 (2.4)	98.6 (1.8)	$t(42) = -1.351$,	$p = .184$
Neutral	97.4 (2.3)	97.9 (2.9)	$t(42) = -.625$,	$p = .536$

* Levene's test for equality of variances was significant, degrees of freedom adjusted accordingly.

T1 pooled data (N=50) for RT means and HRs were separately subjected to Repeated Measures ANOVA as a task manipulation check to ensure that the incongruent condition was producing the slowest RTs and lowest HRs.

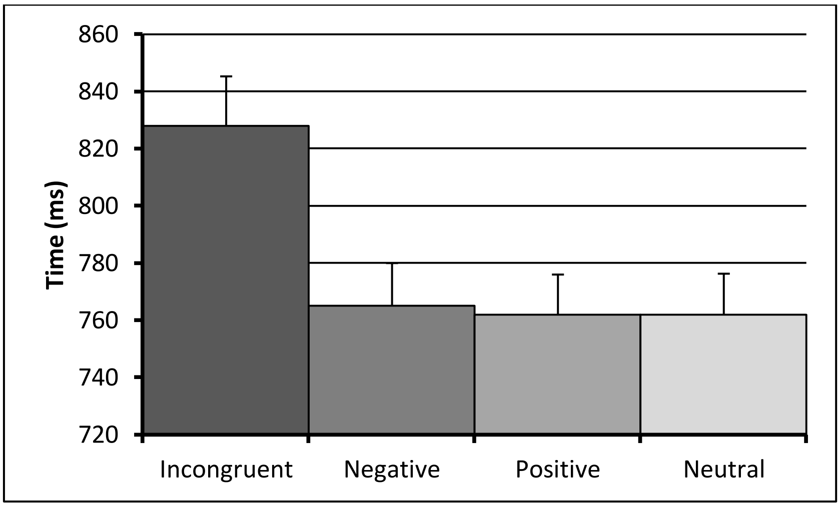

Figure 39: Pooled T1 data (N=50). RT mean at T1 is presented for each of the four conditions included in the ECStroop. Error bars represent the standard error of the mean.

RT mean was significantly different depending on the *Condition*[39] [F(1.95,95.85) = 82.238, $p < .001$] whilst post hoc comparisons [pairwise comparisons all Bonferroni adjusted $p <.001$] clearly demonstrated that the incongruent condition is producing slower RTs (Figure 39) than the other three conditions, suggesting that the task manipulation is working.

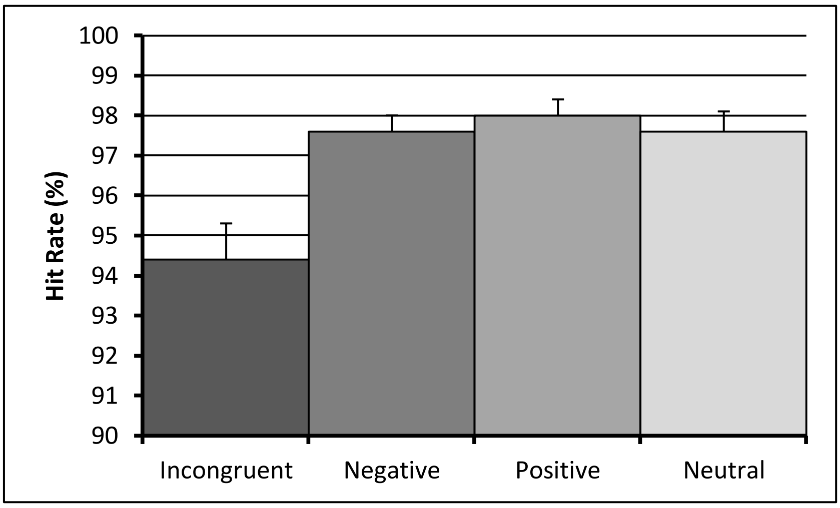

Figure 40: Pooled T1 data (N=50). RT mean at T1 is presented for each of the 4 conditions included in the ECStroop. Error bars represent the standard error of the mean.

[39] Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of *Condition*, x^2 (5) = 36.465, $p <.001$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .652).

Similarly, HRs were significantly different depending on the *Condition*[40] [F(1.42, 69.62) = 14.493, p <.001] and post hoc comparisons [pairwise comparisons all Bonferroni adjusted p <.005] clearly demonstrated that the incongruent condition is producing the lowest HRs (Figure 40), confirming that the incongruent condition is the most difficult of the 4 conditions.

Reaction Times

RTs were subjected to a *Time* (2) x *Condition* (4) x *Group* (2) Mixed ANOVA (Table 34) to determine intervention related changes in MTG and BTG. A significant main effect of *Time* was observed, indicating that RTs, pooled across groups and conditions, reduced from T1 to T2 (776 vs 754ms). A strong main effect of *Condition* was observed and was caused by the incongruent condition producing slower RTs across time points than each of the other three conditions [pairwise comparisons all Bonferroni adjusted p <.001], confirming the robustness of the executive behavioural manipulation. The remaining three conditions produced similar RTs.

Table 34: Summary of Mixed ANOVA (*Time* (2) x *Condition* (4) x *Group* (2)) results for RTs

Effect	Statistical Values		
Time	F(1,42) = 11.009,	p = .002	
Group x Time	F(1,42) = 6.263,	p = .016	r = .360
Group	F(1,42) = .212,	p = .647	
Condition	F(1.74,73.22*) = 126.523,	p < .001	
Condition x Group	F(1.74,73.22*) = 1.990,	p = .150	
Time x Condition x Group	F(3,126) = .403,	p = .759	
Time x Condition	F(3,126) = .350,	p = .789	

* Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity

A significant *Group* x *Time* interaction indicated that MTG and BTG modulated RTs differently from T1 to T2 whilst the non-significant *Time x Condition x Group* confirmed that this between groups difference was not caused by a difference between

[40] Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of condition, x^2 (5) = 88.696, p <.001, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .474)

MTG and BTG on any one condition. Thus further analyses were only conducted on RTs pooled across conditions. Paired samples t-tests revealed that the MTG significantly reduced RTs from T1 to T2 [T1: 776, T2: 738; $t(21)= 4.407$, $p <.001$], whilst BTG RTs did not change significantly from baseline [T1: 776, T2: 770; $t(21)= .535$, $p =.598$]. This between groups difference can be seen clearly in Figure 41.

The fact that the MTG improved RTs across conditions suggests that MT may have resulted in improved executive control and a general improvement in attentional monitoring, two proposed functions of the ACC. Together such improvements may have enabled the MTG participants to bias attentional processing to goal directed aspects of the stimulus array (number of words presented), enabling RTs to be improved across conditions regardless of the words semantic meaning. This assertion is discussed further in Chapter 14.

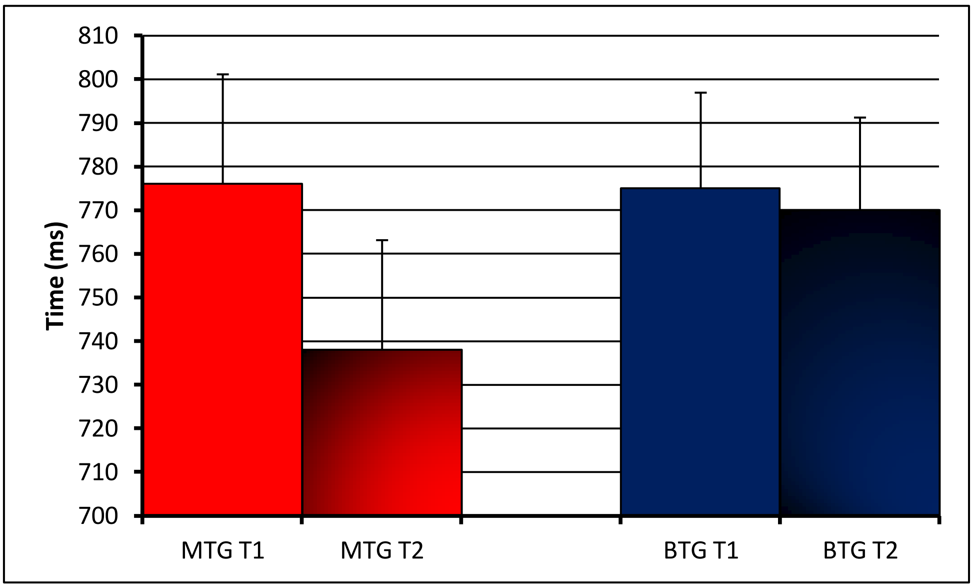

Figure 41: RT differences from T1 to T2 for the MTG and BTG. Error bars depict standard error of the mean.

Accuracy

HRs were subjected to a *Time* (2) x *Condition* (4) x *Group* (2) Mixed ANOVA (Table 35) which revealed main effects of *Time* and *Condition* and a significant *Time* x *Condition* interaction.

Table 35: Summary of Mixed ANOVA (time (2) x Condition (4) x Group (2)) results for HRs (%)

Effect	Statistical Values	
Time	F(1,42) = 5.907,	p = .019
Group x Time	F(1,42) = .680,	p = .414
Group	F(1,42) = 3.663,	p = .062
Condition	F(1.29,54.10*) = 13.633,	p < .001
Condition x Group	F(1.29,54.10*) = 2.587,	p = .105
Time x Condition x Group	F(2.51,105.53*) = 1.820,	p = .157
Time x Condition	F(2.51,105.53*) = 4.542,	p = .008

* Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity

The significant main effect of *Time* was driven by an increase in HRs across conditions from T1 to T2 (97.1 vs 97.8%). The main effect of *Condition* is driven by a lower HR for the incongruent condition as compared the other three conditions [pairwise comparisons all Bonferroni adjusted p<.01] across time points and is further evidence of the difficulty in ignoring the pre-potent response of word reading. The significant *Time* x *Condition* interaction confirmed that the observed increase in HRs was not consistent across all four conditions. Paired samples t-tests were conducted for each condition to explore this interaction and demonstrated that significant increases occurred across groups for the incongruent [t(43)= -3.140, p =.003] and negative [t(43)= -2.087, p =.043] conditions but not for the positive [t(43)= -.488, p=.628] or neutral [t(43)= -.768, p=.447] conditions. These differences are depicted in Figure 43. The non-significant *Group x Time* interaction confirms that there were no between group differences in HRs following training.

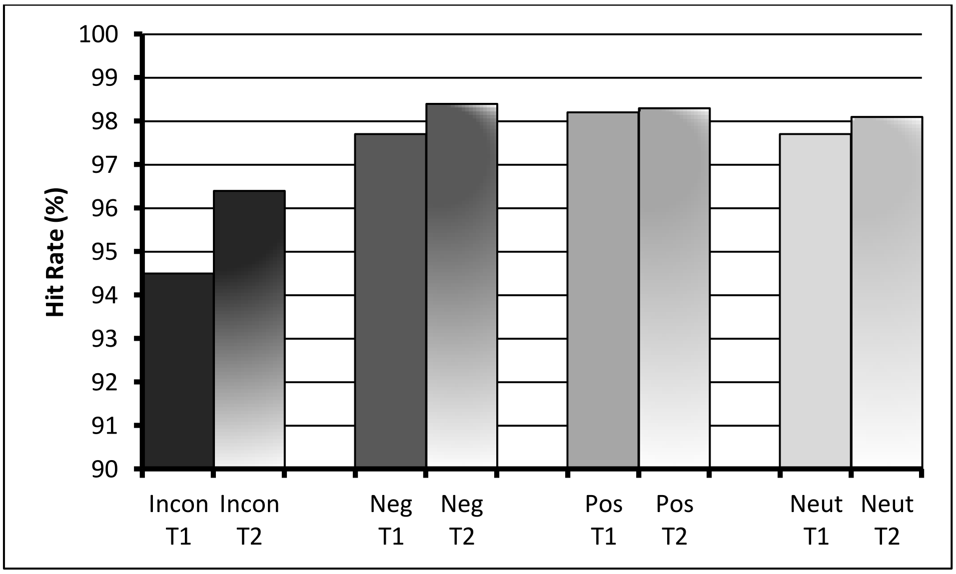

Figure 43: Differences in HRs across groups from T1 to T2 for each of the 4 ECStroop conditions

12.3.2 ERP analyses

As displayed in Table 36 there were no baseline differences between the groups in any of the analysed ERP components across all four conditions.

Table 36: Summary of tests for baseline differences in ECStroop ERP components, with mean values (standard deviations) and respective statistical values for the comparison between MTG and BTG (all 2 tailed)

	MTG (N=18)	BTG (N=18)	Statistical Values	
N2 FCz Incongruent (μV)	-1.52 (2.31)	-1.80 (2.44)	$t(34) = .347$,	$p = .731$
N2 FCz Negative (μV)	-1.79 (2.38)	-1.83 (2.80)	$t(34) = .051$,	$p = .960$
N2 FCz Positive (μV)	-1.80 (2.10)	-1.66 (2.88)	$t(34) = -.166$,	$p = .869$
N2 FCz Neutral (μV)	-1.76 (2.60)	-1.44 (2.80)	$t(34) = -.352$,	$p = .722$
P3 Pz Incongruent (μV)	2.42 (2.10)	2.35 (2.44)	$t(34) = .101$,	$p = .920$
P3 Pz Negative (μV)	2.86 (1.69)	3.23 (2.12)	$t(34) = -.577$,	$p = .568$
P3 Pz Positive (μV)	2.41 (1.81)	2.56 (2.04)	$t(34) = -.228$,	$p = .821$
P3 Pz Neutral (μV)	2.55 (2.34)	2.69 (2.16)	$t(34) = -.183$,	$p = .856$

Fronto-central N2 ERP component

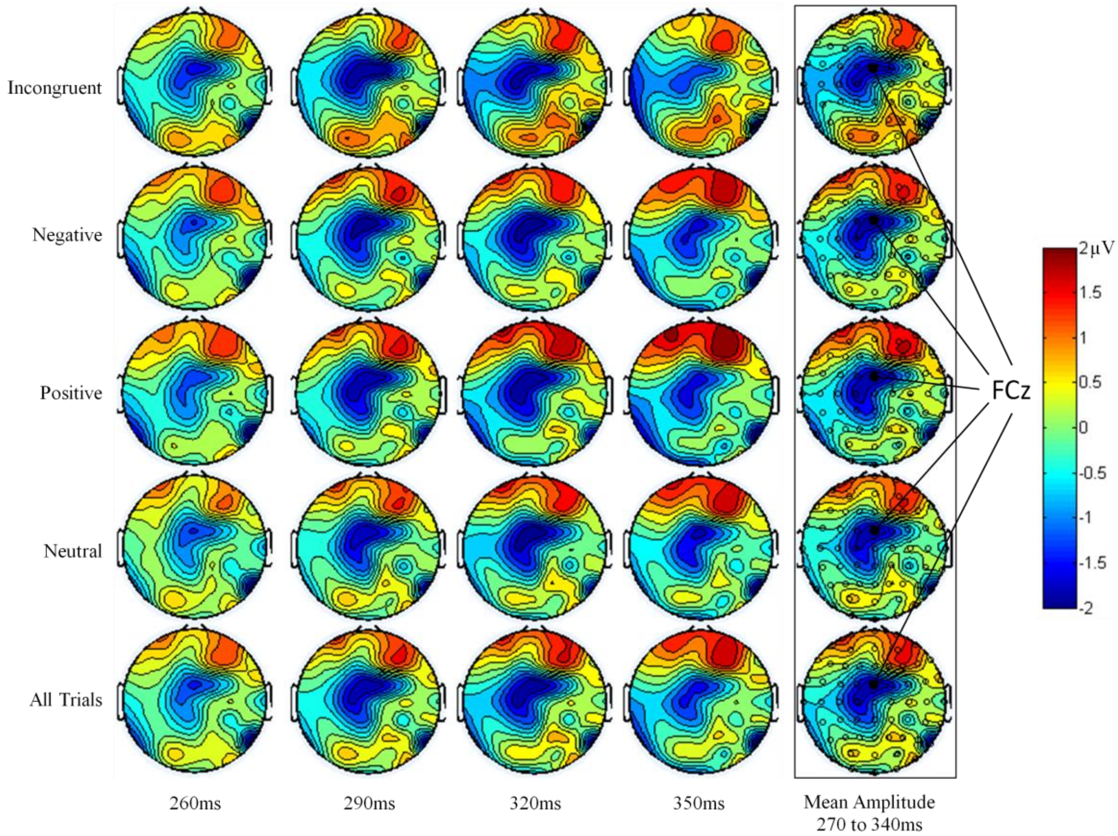

Figure 44: Pooled T1 data (N=43). A time lapse topographical view of the Fronto-central N2 ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 260ms to 350ms (30ms steps from left to right) for all four conditions individually and all trials combined. Mean Amplitude spherical spline interpolated scalp topography is included for the Fronto-central N2 time window (270 to 340ms).

Figure 44 displays the time course and topography of the fronto-central N2 ERP component across all four conditions, and for all trials combined, using pooled T1 data (N=43). As shown in Figure 45, the maxima of the fronto-central N2 was best captured by a time window of 270 to 340ms at FCz. Interestingly, using the pooled T1 data it was found that higher fronto-central N2 mean amplitude was related to lower RTs [r =.304, p =.024, 1 tailed]. This finding confirms the importance of fronto-central N2 mean amplitude to task performance and justifies its position as the main focus of the ERP analysis.

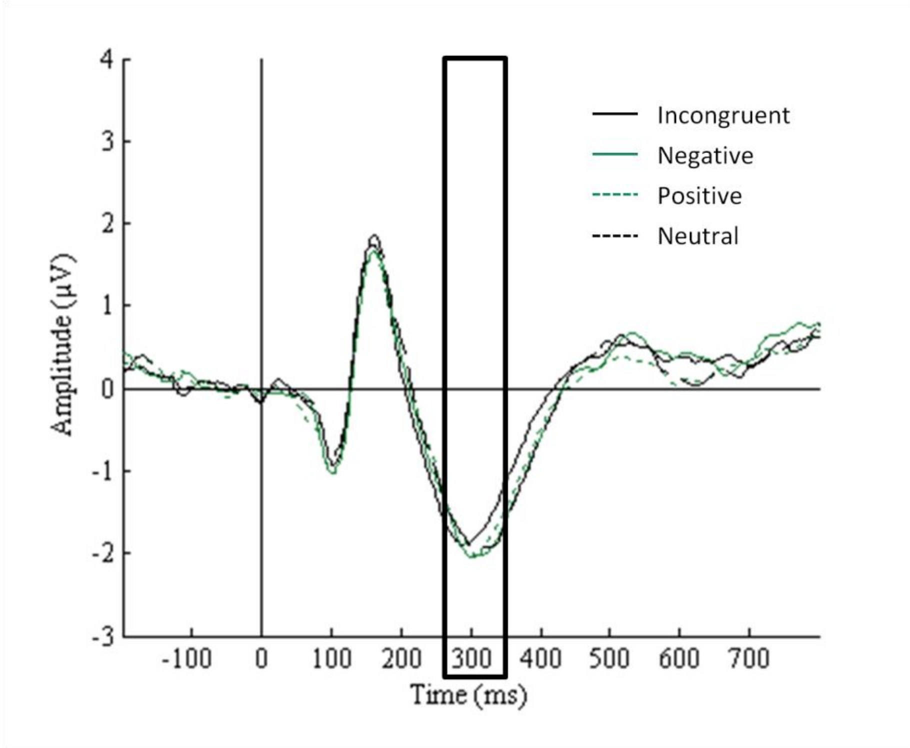

Figure 45: Grand mean evoked potential for all four conditions at FCz, from pooled T1 data (N=43). N2 (270-340ms) is highlighted.

Fronto-central N2 mean amplitude was subjected to a *Time* (2) x *Condition* (4) x *Group* (2) Mixed ANOVA (Table 37), revealing a significant *Group* x *Time* interaction which indicated that MTG and BTG modulated fronto-central N2 mean amplitude differently from T1 to T2.

Table 37: Summary of Mixed ANOVA (*Time* (2) x *Condition* (4) x *Group* (2)) results for fronto-central N2 mean amplitude

Effect	**Statistical Values**		
Time	F(1,34) = 2.940,	*p* = .096	
Group x Time	F(1,34) = 6.989,	*p* = .012	*r* = .413
Group	F(1,34) = .532,	*p* = .471	
Condition	F(3,102) = .439,	*p* = .726	
Condition x Group	F(3,102) = .331,	*p* = .803	
Time x Condition x Group	F(3,102) = 1.292,	*p* = .281	
Time x Condition	F(3,102) = 1.139,	*p* = .337	

Paired samples t-tests revealed a highly significant increase in fronto-central N2 mean amplitude for the MTG across conditions (T1= -1.72, T2= -2.60; $t(17)= 2.81$, $p = .012$) whereas no significant changes were revealed for the BTG (T1= -1.68, T2 = -1.50; $t(17)= -0.75$, $p = .465$). Figure 46 illustrates the differences in the ERP waveforms of each group, clearly demonstrating an increased N2 for MTG as compared a relative decrease for BTG.

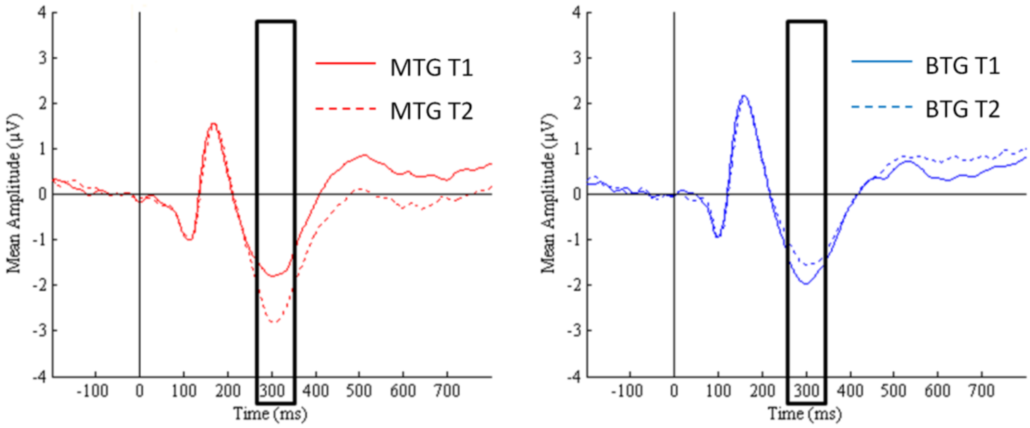

Figure 46: Differences in Fronto-Central N2 (pooled across all four conditions) for MTG and BTG at FCz from T1 to T2

Interestingly, when the fronto-central N2 data were pooled across conditions and groups, T1 to T2 changes (T1minusT2) in RTs and fronto-central N2 mean amplitude were significantly positively correlated [$r = .281$, $p =.049$], further suggesting that fronto-central N2 mean amplitude plays a critical role in task performance. This assertion is consistent with the significant negative correlation between RTs and fronto-central N2 mean amplitude that was found by pooling the T1 data across conditions. As the N2 effect was not specific to the incongruent condition the MT related increase in N2 across conditions may reflect a general improvement in executive control (goal directed attention) and attentional monitoring. Thus this finding is consistent with the RT findings and other findings discussed in this thesis. The implications of this result are discussed in Chapter 14.

P3b ERP component

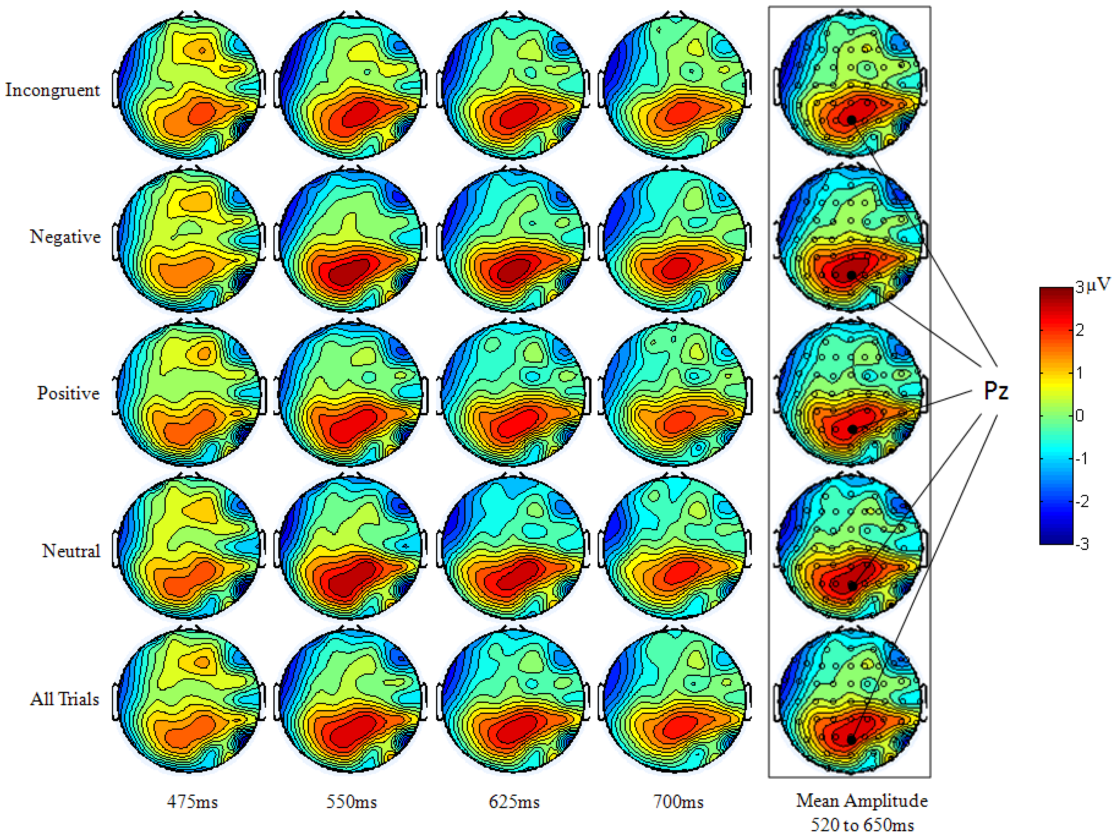

Figure 48: Pooled T1 data (N=43). A time lapse topographical view of the P3b ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 475ms to 700ms (75ms steps from left to right) for all four conditions and for all trials combined. Mean Amplitude spherical spline interpolated scalp topography is included for the P3 time window (520 to 650ms).

Figure 48 displays the time course and topography of the P3b ERP component across all 4 conditions using pooled T1 data (N=43). As shown in Figure 49, the maxima of the P3b was best captured by a time window of 520 to 650ms at Pz.

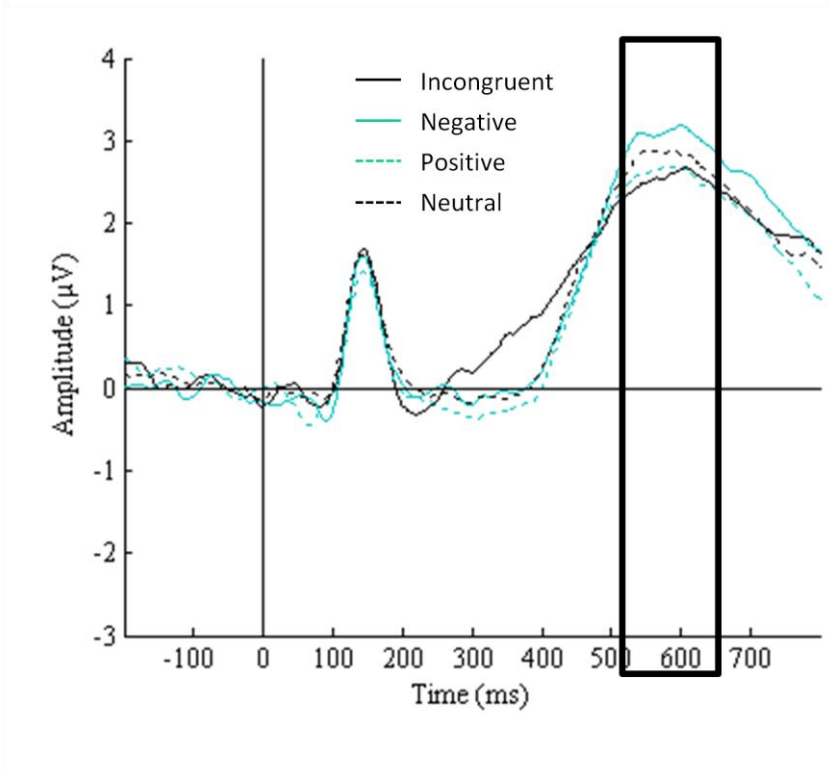

Figure 49: Grand mean evoked potential for all four conditions at Pz, from pooled T1 data (N=43). The selected P3b time window (520-650ms) is highlighted.

P3b mean amplitude was subjected to a *Time* (2) x *Condition* (4) x *Group* (2) Mixed ANOVA (Table 37) to determine intervention related changes in MTG and BTG. The main effect of *Condition* suggested that P3b was modulated by semantic category. Post hoc analyses revealed that across groups and time points the negative condition (3.18µV) produced significantly higher P3b mean amplitudes than both the positive (2.63µV) and incongruent (2.61 µV) conditions (both pairwise comparisons Bonferroni adjusted p <.01), but not the neutral condition (2.86µV). This finding is consistent with the earlier mentioned studies that observed significant modulations of P3b for stimuli of negative valence (Bernat et al., 2001; Carretie et al., 2001; Ito et al., 1998; Junghofer et al., 2001) and confirms that the P3b produced by the ECStroop task was sensitive to the processing of emotional stimuli. However, no further significant main or interaction effects were observed, suggesting that this effect remained robust over time and that neither MT nor BT enabled participants to modulate the processing of emotional stimuli. Thus, no further exploratory analyses of P3b were performed.

Table 38: Summary of Mixed ANOVA results (*Time* (2) x *Condition* (4) x *Group* (2)) for P3b mean amplitude

Effect	**Statistical Values**	
Time	$F(1,34) = 1.952$,	$p = .171$
Group x Time	$F(1,34) = .001$,	$p = .974$
Group	$F(1,34) = .063$,	$p = .803$
Condition	$F(3,102) = 5.916$,	$p = .001$
Condition x Group	$F(3,102) = .187$,	$p = .905$
Time x Condition x Group	$F(3,102) = 1.230$,	$p = .303$
Time x Condition	$F(3,102) = .244$,	$p = .865$

The overall pattern of results for ECStroop suggests that whilst MT resulted in improved executive function and attentional resource allocation a concurrent improvement in the processing of emotional stimuli was not found. This suggests that improvements in attention regulation may precede improvements in emotion regulation. The implications of this finding are discussed in Chapter 14.

Chapter 13. Mindfulness Training, Ageing and Temporal Attentional Resource Allocation: Attentional Blink Task

13.1 Theoretical Background

Chapter 13 details the use of an attentional blink paradigm which was utilised to assess whether the temporal dynamics of attentional processing may be modulated in older adults following MT. The Chapter discusses the reasons for using the ABtask, the tasks design, its associated outcome measures and specific hypotheses and the presentation of the detailed ABtask results and analysis.

The Attentional Blink, Ageing and Mindfulness Training

The ABtask assesses the temporal allocation of attentional resources. During the ABtask participants are asked to identify two targets embedded in a rapid serial visual presentation (RSVP[41]). If the two targets are presented within 200-500ms of one another the second target is often missed (Raymond, Shapiro, & Arnell, 1992; Ward, Duncan, & Shapiro, 1996). As this impairment is considered analogous to someone blinking after the first target (tar1) and consequently missing the second target (tar2), it has been labelled the ‘attentional blink’ (AB; Raymond, Shapiro, & Arnell, 1992). It is important to note that tar2 is not always missed. The so called ‘AB effect’ expresses the performance difference between tar2 stimuli that are temporally close to tar1 (<500ms) and tar2 stimuli that are temporally disparate (>500ms). Herein, the utilised ABtask included both a short lag tar2 (appearing 316ms post tar1) and a long lag tar2 (appearing 632ms post tar1) in order to assess said AB effect.

Most interpretations of the AB suggest that it occurs due to limitations of working memory consolidation processes (Giesbrecht & Di Lollo, 1998; Vogel & Luck, 2002). A number of studies have demonstrated that tar2 is fully perceived (e.g. Vogel, Luck, & Shapiro, 1998), but because the consolidation process is relatively slow tar1 may still be undergoing consolidation when tar2 is presented, causing the subsequent non-target stimuli to overwrite tar2 before it can also be consolidated. Giesbrecht and Di Lollo (1998) utilised two task conditions to test this interpretation 1) tar2 was the last

[41] In a RSVP stimuli are presented briefly, at the same location and in rapid succession.

stimuli in the RSVP and 2) tar2 was followed by a non-target stimulus, finding that performance was improved in the former condition. Further, using similar task conditions Vogel and Luck (2002) found that the P3 ERP component, utilised as a measure of attentional resource allocation, was completely suppressed in the later condition but merely delayed in the former. Further, Kranczioch, Debener, and Engel (2003) analysed the P3 evoked by tar2 stimuli that were correctly identified compared to tar2 that were missed, finding that missed tar2 did not evoke a P3 whereas correctly identified tar2 did produce a P3, even when tar2 had appeared in the AB time window. Thus, with the majority of the limited amount of available attentional resources being taken up by consolidation processes for tar1, the non-target stimuli may overwrite tar2 before it can also be consolidated. Isaak, Shapiro, and Martin (1999) provided a similar interpretation, concluding that the AB effect may reflect competition/interference among multiple RSVP items for attentional resources that are already engaged by the preceding item. However, as tar2 is not always missed when it is presented in the AB time window, some control over the allocation of attentional resources to facilitate consolidation processes across targets may be possible.

As was briefly introduced in Chapter 9, ABtask performance typically declines with age (Georgiou-Karistianis et al., 2007; Lahar, Isaak, & McArthur, 2001; Maciokas & Crognale, 2003; van Leeuwen et al., 2009) with older participants both missing tar2 more frequently and missing it for longer periods of time following detection of tar1. One plausible explanation for these observed findings concerns the proposed reduction in attentional resource capacity in older adults. A reduction in the amount of available attentional resources would mean that less resources were available for processing tar2 whilst tar1 is still being processed, leading to the observed increase in AB. A second plausible explanation concerns the inhibitory deficit hypothesis (e.g. Hasher et al., 1999) discussed in Chapter 9. In line with this hypothesis a number of researchers have suggested that the increased AB in older adults may be caused by reduced inhibitory control (Georgiou-Karistianis et al., 2007; Lahar et al., 2001). Said inhibitory deficit is likely to increase the difficulty of inhibiting the processing of non-target stimuli, thus taking up additional attentional resources that were required for tar2 consolidation, which in turn leads to the observed pattern of poorer performance. Thus it is feasible to suggest that gaining greater control over the allocation of attentional resources for consolidation processes and strengthening inhibition related processes would enhance

ABtask performance in older adults. As MT was shown to modulate the allocation of attentional resources in LS1 and in a number of studies discussed in this thesis (e.g. Slagter, Lutz, et al., 2007), and expert mindfulness meditators have shown enhanced functional activation in attention related brain regions (e.g. Teper & Inzlicht, 2013), a strong case can be made for assessing whether MT may improve ABtask performance in older adults.

Two previous studies have examined the impact of MT on ABtask performance. As these findings have already been discussed in previous Chapters they are only briefly summarised herein. In short, using both behavioural and electrophysiological methods Slagter, Lutz, et al. (2007) found that a 3 month mindfulness retreat resulted in a reduced AB and that said reduction was related to a decrease in P3b mean amplitude to tar1[42], whilst in a purely behavioural study van Leeuwen et al. (2009) found that older mindfulness meditators were able to outperform both age-matched and younger controls on the ABtask. Although these findings offer encouragement, they do not provide information regarding how MT may improve attentional resource allocation in a non-meditating sample as both of these studies utilised expert meditator samples and Slagter et al. data were collected following an intensive retreat with 8hrs+ of daily practice. Further, as discussed in Chapter 3 such studies inherently include a number of confounds (e.g. non-mindfulness components, lasting state induced changes from large amount of daily practice, multiple meditations) that make direct attribution of improvements to a specific MT difficult. Thus research that assesses the effects of a singular MT technique on ABtask performance is required to confirm said previous findings and to determine if MT may modulate the temporal allocation of attentional resources in older adults. Therefore, the ABtask was employed in LS2 to meet this need, providing the first longitudinal examination of ABtask performance and MT in older adults.

[42] The reduction in P3b to tar1 was interpreted as a reduction in the allocation of attentional resources to tar1, thus leaving more resources available to consolidate the latterly presented tar2 which in turn lead to an increase in tar2 detection rates and a reduced AB.

Electrophysiological and Behavioural Outcome Measures and Hypotheses.

The ERP component identification procedure detailed in section 4.4 resulted in the identification of two ERP components of interest. For consistency with Slagter, Lutz, et al. (2007) study, the analyses herein utilised epochs time-locked to tar1 and were focused on the P3b ERP component which is considered to represent attentional resource allocation to tar1 processing and consolidation.

The P3b ERP component was observed in the 420 to 550ms time window, peaking at FCz (see Figure 51 and Figure 52). An additional positive ERP component, peaking at FCz in the 650 to 780ms time window was also observed. However, Sergent, Baillet, and Dehaene (2005) have shown that the conscious perception of tar2 can influence ERP components occurring as little as 270ms after the appearance of tar2. This suggests that in the paradigm utilised herein, whereby tar2 was presented either 316ms or 632ms after tar1, the latter time window may include activity related to tar2. Using the pooled T1 data (N=46), the mean amplitude to both short and long lag conditions were subjected to separate Paired Samples t-tests for both the 420 to 550 and the 650 to 780ms time windows, finding a significant difference for the latter time window only [$t(45)= 2.566$, $p = .014$]. This finding suggests that the conscious perception of tar2 overlaps with ongoing processing of tar1 and modulates the second of the identified positive ERP components. This finding is in line with the literature discussed in this chapter that suggests that tar2 processing begins before tar1 has been consolidated and that the AB is caused by attentional resources being taken up by tar1 processing. In line with Slagter et al. study, the objective herein was to determine if attentional resources allocated to tar1 processing may be modulated to facilitate tar2 processing. Thus the focus was on the appropriation of attentional resources to tar1. Accordingly, the later ERP component which was modulated by processing of tar2 was not analysed further.

No RTs were recorded during ABtask completion. Accordingly, the focus of the behavioural analyses was on HRs to tar2. Tar2 responses were only analysed if tar1 had also been reported correctly to ensure that only responses in instances where attentional resources had been successfully allocated for tar1 consolidation were included.

As van Leeuwen et al. (2009) found that older mindfulness meditators had a reduced AB compared to age matched and younger controls and Slagter, Lutz, et al. (2007) found that a 3month meditation retreat could lead to a reduction in P3b mean amplitude to tar1, and that this reduction correlated with a reduced attentional blink size, it was hypothesised herein that MT would lead to a reduced P3b ERP component and that this reduction would be concurrent to an improvement in tar2 accuracy.

13.2 Task Design and Stimuli

Stimuli consisted of 2 numbers (targets) and 18 letters (non-targets) presented in a RSVP. Letters were randomly drawn from the alphabet with the exception of letters that could be easily mistaken for numbers (B, I, O, S, Z). The target stimuli were the numbers 2 to 9. Stimuli were presented in black on a grey background, with the exception of tar1 which was presented in red to facilitate the capture of attention. This was expected to increase the number of trials available for analysis given that HRs were only analysed for instances in which tar1 had been correctly identified. Each trial began with a fixation cross displayed for 1500ms followed by a 250ms blank screen. RSVP then commenced and the 20 stimuli were each shown for 66ms followed by a blank of 13ms. The first target could appear at either position 7 or 10 in the stream. Tar1 and tar2 were separated by either 4 or 8 letters with tar2 appearing at either position 11 or 15, 14 or 18 accordingly, meaning there was always at least 2 further stimuli presented after tar2. The temporal distance between tar1 and tar2 was either 316ms (Short Lag) or 632ms (Long Lag). Only 2 target conditions were utilised herein for a number of reasons. Firstly, redundancy is typically seen for tar2 presented at lags of 2,3,4,5 letters following tar1 i.e. similar performance is seen for each of these lags as they all appear within the AB time window, thus additional lags were deemed unnecessary. Secondly, as 50-60 trials were needed for each lag in order to generate an appropriate ERP for analysis, increasing the number of lags would significantly increase the number of trials in the task, producing an increased task duration and burden on participants. Lastly, the use of only a short and long lag allowed for an easier comparison between results obtained herein and those obtained by Slagter, Lutz, et al. (2007) who similarly only used 2 target conditions.

Participants completed 120 trials overall, 60 each from the short and long lag conditions. They were given two practice blocks of 8 trials each. The first block of 8 trials was presented at a reduced speed to facilitate task understanding and the second block was at full speed to mirror task conditions. Participants were instructed that there would be 2 targets per trial, that the first target would always be red and that they should refrain from responding until the screen was blank in order to avoid missing tar2. Participants responded to the targets they had seen by pressing the appropriate number keys of a standard QWERTY keyboard. Participants were instructed not to guess if they had missed 1 or both targets. However, they were to respond if they had 2 numbers in their head as it was likely they had seen both targets but were not confident due to the speed of presentation. RTs were not recorded.

13.3 Results

An a priori decision was taken to exclude participants from both electrophysiological and behavioural longitudinal analyses if they had a hit rate below 50% to tar1 (at either T1 or T2) as this would indicate poor task understanding and limit the number of trials available for analysis. Seven participants failed to meet this criterion and were removed from the longitudinal analyses accordingly.

13.3.1 Behavioural Analyses (Accuracy)

HRs to tar2 were calculated based only upon trials for which tar1 had been correctly identified. The efficacy of the task manipulation was confirmed by subjecting the pooled T1 data (N=51)[43] to a Paired Samples t-test, revealing a highly significant difference between the short (76.3%) and long (87.4%) lag [$t(50) = -4.433$, $p < .001$] conditions. Direct comparisons at T1 revealed no significant difference between the MTG and BTG in either the short [$t(41) = .720$, $p = .476$] or long [$t(41) = 1.625$, $p = .112$] lag conditions.

To assess whether MT or BT caused improvements in ABtask performance HRs were subjected to a *Time* (2) x *Lag* (2) x *Group* (2) Mixed ANOVA (Table 39), revealing significant main effects of *Time* and of *Lag*.

[43] Only 5 participants had <50% accuracy to tar1 at T1.

Table 39: Summary of Mixed ANOVA (Time (2) x Lag (2) x Group (2)) results for HRs

Effect	**Statistical Values**		
Time	F(1,41) = 13.771,	*p* = .001	*r* = .501
Group x Time	F(1,41) = .768,	*p* = .386	
Group	F(1,41) = 1.371,	*p* = .248	
Lag	F(1,41) = 17.282,	*p* < .001	
Lag x Group	F(1,41) = .030,	*p* = .863	
Time x Lag x Group	F(1,41) = 1.509,	*p* = .226	
Time x Lag	F(1,41) = .796,	*p* = .377	

The main effect of *Lag* was caused by a significant difference in HRs between the short and long lag conditions across groups and time points (79.6 vs 88.9%), confirming that the behavioural task manipulation was successful and that the AB effect (HR difference between short and long lag) remained robust throughout. The highly significant main effect of *Time* and non-significant *Group x Time* interaction suggested that both groups had similarly improved performance from T1 to T2. The non significant *Time x Lag* interaction suggests that improvements were not limited to either the short or long lag conditions, further confirming that the AB effect remained robust. Pooling the data across groups and lags there was a significant increase in HRs from T1 to T2 (82.2 vs 86.3%), confirming that overall performance improved over time.

Table 40: Summary of means (standard deviations) for MTG, BTG and overall

	MTG (N=21)	**BTG (N=22)**	**Overall (N=43)**
Hit Rate (%)			
Short Lag	T1: 79.3 (22.9)	T1: 74.9 (17.4)	T1: 77.0 (20.2)
	T2: 84.7 (16.7)	T2: 79.6 (16.5)	T2: 82.1 (16.6)
Long Lag	T1: 90.5 (6.9)	T1: 84.2 (16.5)	T1: 87.3 (13.0)
	T2: 91.3 (7.7)	T2: 89.6 (10.0)	T2: 90.4 (8.9)

As performance improved across groups and lags (Figure 50), practice effects rather than a general effect of cognitive training are the most likely cause. Thus the hypothesis that MT would lead to improved performance is not supported as performance was not improved beyond the level of improvement gained from repeated administration of the task. The implications of this finding are discussed in Chapter 14.

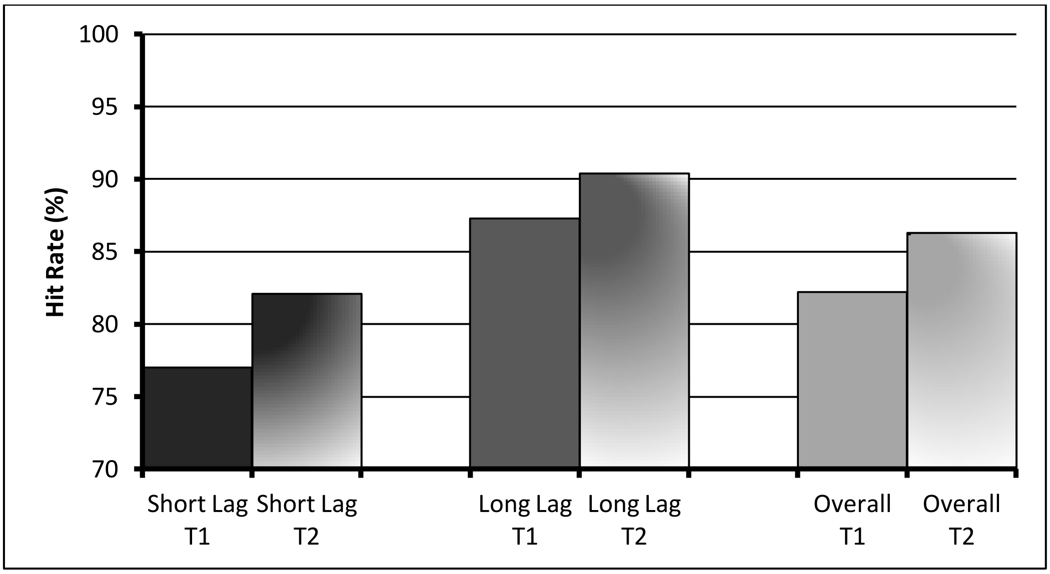

Figure 50: T1 to T2 differences in HRs, pooled across groups, for the short and long lag conditions and overall pooled across lags

13.3.2 ERP analyses

<u>P3b ERP component</u>

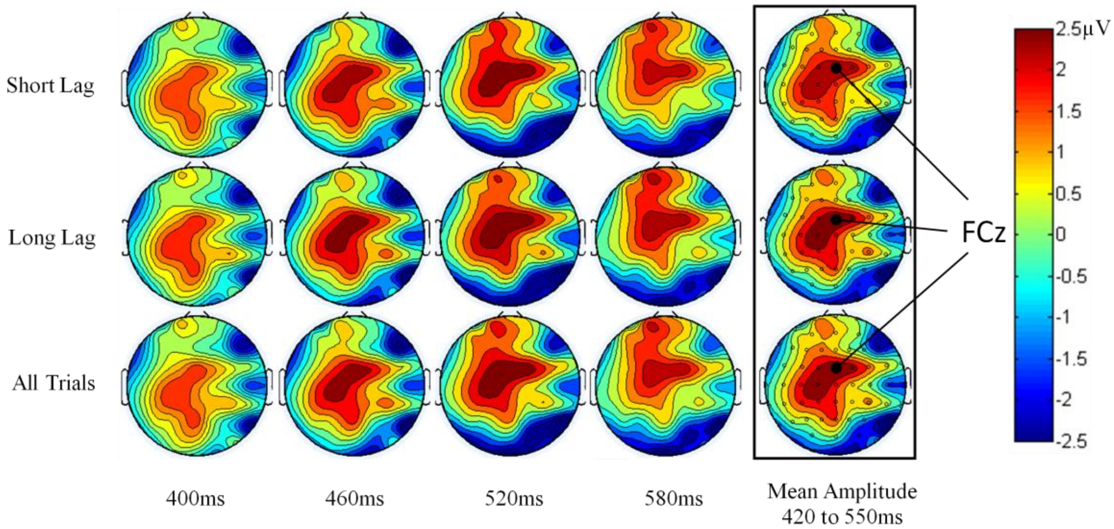

Figure 51: Pooled T1 data (N=46). A time lapse topographical view of the P3b ERP component displayed using instantaneous amplitude spherical spline interpolated scalp topographies from 400ms to 580ms (60ms steps from left to right) for the short and long lag conditions and for all trials combined. Mean Amplitude spherical spline interpolated scalp topography is included for the P3b time window (420 to 550ms)

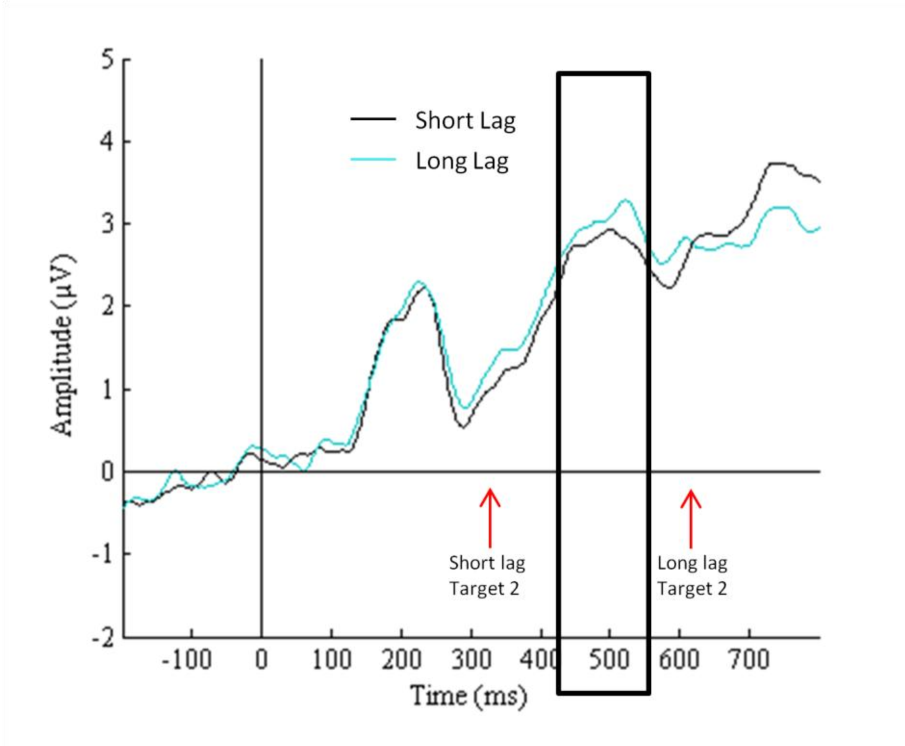

Figure 52: Grand mean evoked potential for tar1 at FCz for both the short and long lag conditions, from pooled T1 data (N=46). P3b time window (420 to 550ms) is highlighted.

Figure 51 displays the time course and topography of the P3b ERP component for both short lag and long lag conditions using pooled T1 data (N=46). As shown in Figure 52, the maxima of P3b was best captured by a time window of 420 to 550ms at FCz. Direct comparisons at T1 revealed no between group differences in P3b mean amplitude in either the short [$t(34) = 1.375$, $p = .178$] or long [$t(34) = 1.827$, $p = .076$] lag conditions.

Table 41: Summary of Mixed ANOVA (*Time* (2) *x Lag* (2) *x Group* (2)) results for P3b mean amplitude at FCz

Effect	**Statistical Values**		
Time	$F(1,34) = 8.763$,	$p = .006$	$r = .453$
Group x Time	$F(1, 34) = 1.072$,	$p = .308$	
Group	$F(1, 34) = 1.862$,	$p = .181$	
Lag	$F(1, 34) = 2.276$,	$p = .141$	
Lag x Group	$F(1, 34) = .000$,	$p = .991$	
Time x Lag x Group	$F(1, 34) = .208$,	$p = .651$	
Time x Lag	$F(1, 34) = .905$,	$p = .348$	

P3b mean amplitude was subjected to a *Time* (2) x *Lag* (2) x *Group* (2) Mixed ANOVA (Table 41) to determine intervention related changes in MTG and BTG, revealing only a main effect of *Time*. This effect was caused by a reduction (see Figure 53) in P3b mean amplitude across groups and lags from T1 to T2 (2.71 vs 1.84 µV). The concurrent decrease in P3b and increase in behavioural performance observed herein are in line with Slagter, Lutz, et al. (2007) finding of reduced P3b amplitude resulting in improved performance. However, the *Group x Time* interaction was non-significant suggesting that both groups had similarly reduced P3b following training. Thus in line with the behavioural results there appears to be no specific effect of MT.

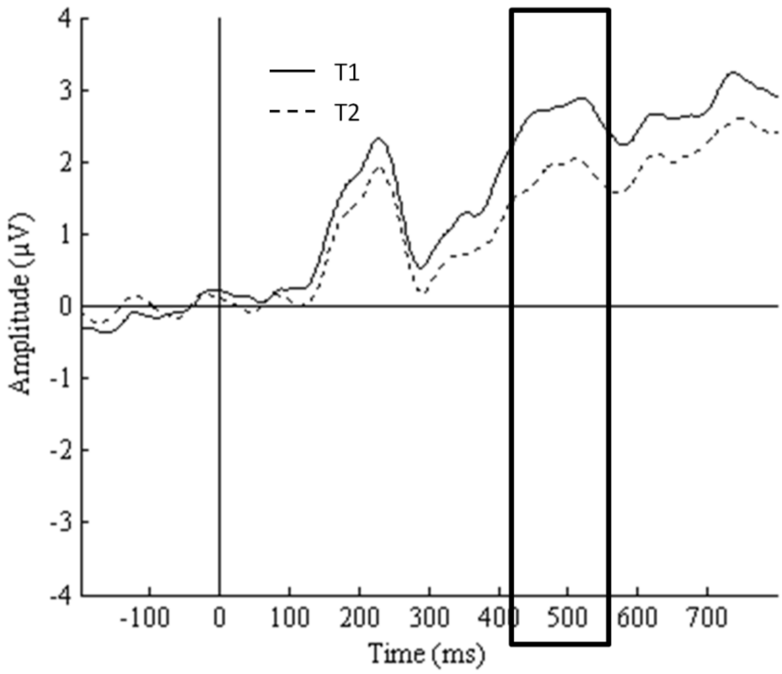

Figure 53: Differences in P3b at FCz, pooled across lags and groups, from T1 to T2.

However, inspection of the individual groups ERP waveforms (Figure 54) suggests a larger decrease for the MTG as compared the BTG. Thus, as a purely exploratory step, paired samples t-tests were run for each group, pooled across lags (total) to ascertain how each group modulated P3b from T1 to T2 (Table 42).

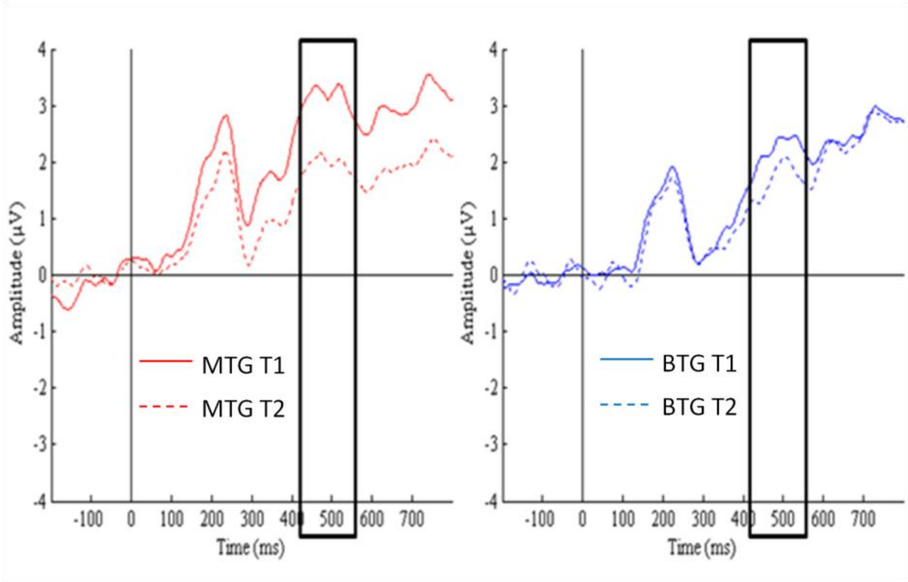

Figure 54: Differences in P3b at FCz, pooled across lags, for the MTG and BTG from T1 to T2

The Paired Samples T-test's demonstrate that only MTG significantly modulated P3b from T1 to T2, with a significant decrease observed when P3b was pooled across conditions. Whilst these findings intimate that MT caused the largest reduction in P3b amplitude, the non-significant *Group x Time* interaction means that it must still be concluded that MT did not significantly modulate P3b as compared BT. The implications of this result are discussed in Chapter 14.

Table 42: Summary of means (standard deviations) and paired samples t-tests displaying P3b mean amplitude (µV) differences at FCz from T1 to T2 for MTG and BTG

	MTG (N=18)	**BTG (N=18)**
Short Lag	T1: 3.01 (1.80)	T1: 2.16 (1.89)
	T2: 1.97 (1.88)	T2: 1.65 (1.35)
Long Lag	T1: 3.31 (1.52)	T1: 2.38 (1.55)
	T2: 2.00 (1.67)	T2: 1.76 (1.19)
Overall	T1: 3.16 (1.62)	T1: 2.27 (1.67)
	T2: 1.98 (1.71)	T2: 1.71 (1.22)
Paired Samples T-test	$t(17)= 2.415$, $p=.027$	$t(17)= 1.720$, $p=.104$

Chapter 14: Implications of Longitudinal Study 2

For LS2, three tasks of attention were administered to older adults before and after MT or BT in order to provide a comprehensive assessment of training related modulations of executive and sustained attention functions and the neural mechanisms that subserve them. This chapter contains a discussion of the implications of LS2. A discussion of the findings of LS2 in relation to the overall implications of this thesis is contained in Chapter 15.

14.1 The Positive Effect of Mindfulness Training on Core Attentional Functions and the Neural Mechanisms that Subserve them in Older Adults

A number of positive results emerged from the analysis of the CPT data. As hypothesised, the MTG improved RTs and concurrently increased the no-go P3 ERP component whereas no such modulations were observed for BTG. The reduction in RTs observed for MTG following MT suggests that MT may improve sustained attention and strengthen executive attentional functions related to inhibitory control in older adults given that said skills were required during task completion to enable consistent, prompt and accurate responses whilst concurrently inhibiting responses to no-go stimuli. Herein, higher no-go P3 was significantly correlated with faster RTs at T1 and increases in no-go P3 from T1 to T2 were correlated with improvements in RTs. This suggests that the ability to inhibit responses in the no-go condition is strongly related to the speed at which responses can be made in the go condition. A number of studies discussed in Chapter 9 similarly demonstrated that older participants who are able to allocate the most neural resources during task completion typically perform better (e.g. Cabeza et al., 2002; Vallesi, 2011; Vallesi et al., 2011). Thus 8 weeks MT may produce positive modulations in the allocation of task related neural resources which in turn facilitated improvements in RTs.

Interestingly, an exploratory analysis which incorporated *site* as an additional variable suggested that the MTG increase in no-go P3 was consistent with an increase in activity in fronto central electrode sites over the right hemisphere (see Figure 34). Successful inhibition has previously been associated with enhanced activity in right prefrontal cortex (Boecker et al., 2007; Rubia et al., 2003). Thus, the enhanced activation observed in right frontal sites at T2 for MTG may reflect enhanced activation of the primary inhibitory network, rather than the recruitment of an additional compensatory network. Recently, enhanced activity in these regions has also been seen for old vs. young participants during successful inhibition (Heilbronner & Munte, 2013). This suggests that enhanced activation of regions implicated in inhibitory control is an age associated compensatory response. Sebastian, Baldermann, et al. (2013) similarly found that older adults increasingly recruit brain regions involved in inhibitory control until inhibitory load exceeds compensatory capacity. Herein inhibitory load was low due to the low difficulty of the utilised CPT, thus compensatory capacity was unlikely to be exceeded. Given that increases in no-go P3 in the right hemisphere were significantly correlated with improved performance, the enhancement of no-go P3 and concurrent reduction in RTs for MTG suggests that MT facilitated an adaptive and compensatory increase in the appropriation of attentional resources for inhibitory control. However, it must be acknowledged that because source localisation techniques were not utilised herein it is not possible to state with certainty the exact brain regions that may be producing the observed pattern of enhanced activation for the MTG. Thus it is unclear whether an increase in right frontal regions produces the observed pattern of activity recorded at the scalp level herein. Nevertheless, previous research utilising such techniques has implicated the ACC as a potential generator site for the no-go P3 (Beste et al., 2008; Bokura et al., 2002; Schmajuk et al., 2006) and has confirmed that the ACC is activated during the completion of tasks involving inhibition such as Go/No-go tasks (e.g. Langenecker & Nielson, 2003; Nielson et al., 2002) and the Simon task (Sebastian et al., 2013). Thus the observed pattern of results for the MTG following MT may relate to enhanced activation in regions implicated in attentional control such as the ACC. As the ECStroop task findings presented in Chapter 12 appear to be in line with this assertion, the potential mechanisms by which MT may produce positive effects across tasks are discussed after a brief discussion of the ECStroop findings below.

Similar to the CPT, positive behavioural and electrophysiological findings were observed for the MTG following analysis of the ECStroop data. As hypothesised, the MTG improved RTs and increased fronto-central N2 mean amplitude across conditions following 8 weeks MT, whereas no significant changes were observed for the BTG. The reduction in RTs suggest that MT may have resulted in improvements to executive/attentional control and conflict monitoring given that both of these functions are required for successful ECStroop task completion. Of note, change in fronto-central

N2 mean amplitude, across groups, was significantly correlated with change in RTs, with increases in N2 related to faster RTs. Thus MT again appears to have produced positive modulations in the allocation of task related neural resources which in turn facilitated improvements in RTs. As with the no-go P3 discussed above, source localisation techniques have implicated the ACC as a generator for the fronto-central N2 (e.g. Bekker et al., 2004, 2005; Liotti et al., 2000; Nieuwenhuis et al., 2003; Van Veen & Carter, 2002). Further, the original cStroop task (Bush et al., 1998), upon which the paradigm utilised herein was based, was designed and observed to activate the ACC. Thus although source localisation was not conducted herein it may be speculated that MT produced modulations in task related neural activity associated with regions implicated in core attentional functions.

Interestingly, the MT related enhancement of fronto-central N2 and improvements in RTs were seen across conditions on the ECStroop. This suggests that MT may have produced a more general improvement in attentional monitoring rather than an improvement limited to instances when conflict was present. Recent findings have begun to suggest that the ACC, which is a key structure in the executive attention network and its salience subsection, plays a more general attentional monitoring role and that it is not restricted to conflict monitoring (Mansouri, Tanaka, & Buckley, 2009). This assertion is backed up by studies that observed increased ACC activation even when tasks involving negligible conflict were employed (Mohanty et al., 2007; Schulz et al., 2011). A recent review (Gasquoine, 2013) concluded that the ACC contributes to behaviour by modifying responses especially in reaction to challenging cognitive and physical states that require additional effortful cognitive control. Thus the ACC is very much involved in top-down attention and supports the process of monitoring current behaviour in relation to a desired goal (Kerns et al., 2004), whilst the exact goal does not necessarily need to include conflicting information. Thus improvements in attentional functions and task related neural activity related to the ACC may account for the pattern of results observed across tasks herein.

The observed pattern of results across tasks is particularly encouraging given that age related declines in regions such as the ACC have been observed. A recent MRI study (Mann et al., 2011) observed age related declines in grey matter volume across the cingulate cortex as a whole and specifically for the ventral ACC which is a region that is thought to be involved in the aforementioned function of attentional monitoring. Pardo et al. (2007) have also found that metabolism in the ACC declines with age and that this decline is correlated with declining cognitive function. In the ongoing moment to moment competition for limited attentional resources top-down attentional control processes play a fundamental role in selecting relevant from irrelevant sensory information. Thus, appropriating an adequate amount of resources for current goals may become more challenging, and more necessary, for older adults given that the amount of available attentional resources appears to be reduced with older age. The studies discussed in Chapter 9 that observed enhanced and bilateralised activation patterns for older adults in regions implicated in attentional control are likely to evince an age related requirement for additional top-down attentional regulation across paradigms. In line with this assertion, a number of recent studies have demonstrated that older adults recruit a more frontally distributed attention network during the completion of a variety of tasks (Li et al., 2013; O'Connell et al., 2012; West, Schwarb, & Johnson, 2010). Li et al. (2013) found that older adults recruit a more frontal attentional network, associated with top down attentional control, during task conditions that were designed to induce both automatic bottom up (pop out) and effortful top down search behaviours. Further, by simultaneously recording both fMRI and EEG O'Connell et al. (2012) observed that older adults had higher P3a ERP component mean amplitudes in frontal regions than younger adults and that these old vs. young differences were driven by increased activation of regions implicated in attentional control such as the cingulate cortex, whilst a decrease was observed in inferior parietal cortex. Taken together Li et al. (2013) and O'Connell et al. (2012) findings suggest an increased reliance on frontal top down attentional control structures for older adults. The results obtained across the CPT and ECStroop suggest that 8 weeks MT may strengthen top down attentional control structures and their associated functions. Thus MT may be particularly useful as a cognitive training intervention for strengthening said structures and functions in older adults with the potential to positively influence age related declines in attentional functions. The wider implications of these findings and the potential use of MT as a strategy to modulate cognitive decline are discussed in Chapter 15. First it is important to discuss why MT may have produced the pattern of results observed across the CPT and ECStroop.

As proposed in Chapter 9, MT may be particularly useful as a cognitive training intervention for strengthening top down attentional control mechanisms in older adults as it involves the repeated use of core attentional functions and repeated activation of attention related brain regions during practice (Baron Short et al., 2007; Brefczynski-Lewis et al., 2007; Hasenkamp et al., 2012; Hölzel et al., 2007). Chapters 3 and 9 detailed that attentional processes become more efficient through training (e.g. Newman et al., 2007; N. B. Sarter et al., 2007; Slagter, Giesbrecht, et al., 2007; Vidnyanszky & Sohn, 2005) and that the repeated activation of a brain region may result in increased grey matter (Ilg et al., 2008; A. May et al., 2007). Thus it is feasible to suggest that 8 weeks of MT may have increased the allocation of attentional resources and improved attentional performance by increasing the capacity of available neural substrate. This assertion is consistent with previous cross sectional evidence which suggests that long term engagement in MT may lead to enhanced grey matter density (Hölzel et al., 2008; Luders et al., 2009; Pagnoni & Cekic, 2007) and increased cortical thickness (Lazar et al., 2005) in attention related brain regions. Further, increases in available neural substrate may be possible after only 8 weeks MT given that previous research has found that a similar duration of MT increased grey matter density (Hölzel, Carmody, et al., 2011) and improvements in white matter integrity in the ACC have been found after only 11hrs of IMBT (Tang et al., 2010).

An alternative explanation for the observed pattern of results is that 8 weeks MT resulted in improvements in the allocation of already available attentional resources without an increase in the capacity of available neural substrate. Consistent with modern conceptualisations of mindfulness (e.g., Bishop et al., 2004; Chiesa & Malinowski, 2011; Malinowski, 2008, 2013; Shapiro et al., 2006), the MT utilised herein emphasised that arising endogenous and exogenous stimuli that appear during moment to moment experience should simply be *observed* with the individual maintaining a curious, non-elaborating attitude toward them, and returning attention back to the breath when drifts of attention are noticed. If such arising endogenous and exogenous stimuli were passed on for higher order processing, they would inherently take up attentional resources. Thus participation in this form of MT over an extended period is likely to strengthen goal directed attention and simultaneously reduce the processing of non-goal relevant extraneous stimuli. In particular, the MTG increase in no-go P3 suggests that MT resulted in a greater allocation of resources to the goal at hand and neural inhibition/suppression of extraneous neuronal activity given that Polich (2007) proposed that such ERP components may reflect neural inhibition/suppression of extraneous neuronal activity to facilitate task related attentional processing. This interpretation for the observed pattern of results is supported by the findings of a recent longitudinal study (Mrazek et al., 2013) which found that a 2 week MT course[44], with only 10minutes of daily practice, resulted in a reduction in the occurrence of distracting thoughts during operation span task completion and that improvements in task performance were mediated by reduced mind wandering among participants who were prone to distraction at pretesting. A number of other studies have similarly found that MT may produce a reduction in rumination (Anderson et al., 2007; Chambers et al., 2007; Jain et al., 2007; Ramel et al., 2004; Shapiro, Brown, & Biegel, 2007) and mind wandering (Brewer et al., 2011). Thus a more efficient allocation of available attentional resources is a plausible explanation for the pattern of results observed herein.

Importantly, the abovementioned potential mechanisms are likely to be complimentary. MT may have both increased attentional *capacity*, making more attentional resources available for task completion, and increased the *efficiency* of neural mechanisms involved in the appropriation of existing resources by reducing non-goal related extraneous processing. Theories of cognitive reserve propose that brain networks that are more efficient and have greater capacity are likely to cope better with the disruption caused by brain pathology. According to Steffener and Stern (2012) recently extended model of CR, the increases in task performance and task related neural activity observed herein may be explained by MT related increases in CR, which in turn improved task performance by enhancing task related neural activity. Thus, MT may have great utility as a strategy for increasing CR. The implication of these findings and recommendations for future research are discussed in detail in Chapter 15.

[44] The mindfulness course involved the following: 45 min group sessions, four times a week for 2 weeks with each session involving 10-20mins of mindfulness practice. Participants were also required to meditate for 10minutes per day out of class. Mindfulness exercises included FA to the sensations of breathing, to tastes of a fruit or to sounds of an audio recording. Participants were also given instruction on distinguishing between naturally arising thoughts and elaborative thinking.

14.2 Mindfulness Training and the Attentional Processing of Emotional Stimuli

It was hypothesised herein that P3b mean amplitude may be reduced following MT for both the negative and positive conditions of the ECStroop task as the MT instruction given to the MTG emphasised a non-judgmental, non- reactive attentional state to arising thoughts and emotions. Surprisingly, there was no change in the processing of emotional stimuli for either group following cognitive training. Given that there was a significant difference in P3b mean amplitude between the positive and negative conditions, the utilised ECStroop task does appear sensitive to the emotional valence of word meaning. However, this difference remained robust following training, suggesting that the attentional processing of emotional stimuli was not modulated. Thus the pattern of results observed herein was that of improvements in attentional functions and associated neural activity with no concurrent improvement in the processing of emotional stimuli.

The ECStroop emotional findings are not necessarily negative. In fact, the observed pattern of results herein is in line with modern conceptualisations of MT that suggest FA must first be trained in order for an individual to remain in the present moment and to consistently engage a non-reactive and non-judgmental OM state (Lutz et al., 2008; Malinowski, 2013; Wallace & Shapiro, 2006), thus attentional improvements are likely to be seen before improvements in emotion regulation. Thus, the observed pattern of improved attentional performance and enhanced attentional resource allocation across the CPT and ECStroop may evince a strengthening of present moment FA whilst the null findings from the emotional conditions indicate that the administered dose of MT was not sufficient to enhance emotional processing.

As introduced in Chapter 12, Allen et al. (2012) did find that 6 weeks of MT was able to produce a positive improvement in attentional functions and a concurrent improvement in the processing of affective stimuli with negative valence. However, despite being 2 weeks shorter than the MT employed herein, the amount of daily MT (20 vs 10-15minutes) and group instruction (6 x 2h weekly meetings vs 4 x 1.5h meetings) administered by Allen et al. was substantially higher, which suggest that the total amount of time that participants engaged in MT will have been approximately 30% higher over the course of their study, as compared to that administered herein. Thus additional MT experience is a plausible cause of the disparate results obtained by Allen et al. and those obtained herein. This conclusion is backed up by Allen et al. finding that only those participants who engaged in the most MT had a reduction in blood oxygenated level-dependent signals to affective stimuli of negative valence.

A further difference between Allen et al. (2012) study and LS2 was that the MT participants in the former study were given an additional ‘heart practice’ aimed at developing fullness of feeling and empathy (Risom, 2010) and also included a meditative practice involving compassion. Together these additional elements may account for why changes in emotional processing were seen following short term MT. Such additional instruction or counselling regarding emotion regulation are also typically seen in MBIs such as MBSR and MBCT and may provide crucial instruction for participants on how to process transient arising emotional stimuli. Thus, the lack of extensive and detailed instruction regarding how to regulate emotional processing herein may account for the null between-groups effects. Therefore, it may be proposed that whilst a singular breath awareness MT may be sufficient to provide attentional improvements upon which improvements in emotion regulation may be built, further instruction/counselling or additional MT with emotional elements may be necessary to facilitate improvements in emotional regulation following short term MT. However, it is feasible to suggest that a singular breath awareness MT which includes instruction regarding a non-judgmental, and accepting attitude, administered over a longer period may produce improvements in emotional regulation without the need for additional instruction or counselling. Repeated practice would be expected to enable practitioners to interrupt pre-potent and automatic responses both in and outside of the meditative state once the practitioner is able to consistently and successfully engage in mindfulness state that is characterised by a non-judgmental, accepting attitude and a non-reactive attentional state. The amount of MT administered herein may simply have been too low a dose to observe such change. The implications of the observed pattern of results and recommendations for MBIs and future research are discussed in Chapter 15.

14.3 Mindfulness Training and the Attentional Blink Effect

The two hypotheses relating to the ABtask were both unsupported as there were no between groups differences in tar2 HR nor in the T1 to T2 modulation of the P3b ERP component. However, HRs pooled across lags and groups were improved and P3b mean amplitude was reduced across groups and lags from T1 to T2. The large effect sizes observed for these modulations suggest a robust change. Two feasible explanations may be proposed for this observed pattern of results: 1) cognitive training in general improves both behavioural performance and reduces attentional resource allocation to tar1 or 2) repeated administrations of the ABtask may produce practice effects.

The latter explanation appears to be the most plausible. Perceptual learning (Fahle, 2005), through repeated practice, may enable participants to detect the target stimuli more easily and/or participants may have become better at predicting the timing of the target stimuli in the stream. A recent study (Choi et al. (2012) found that the AB effect may be eliminated following 1 hour of training with a modified ABtask, wherein a short lag tar2 was presented in a salient colour. Further, this effect was maintained up to a month later. These findings certainly suggest that the ABtask may be susceptible to practice related effects following repeated administrations. However, in a follow up experiment in which the training involved repeated administration of the original ABtask, the AB effect was not modulated during the post training administration of the task. Thus practice effects may not fully explain the null between group effects.

An alternative explanation for the observed pattern of results concerns the presentation of tar1 in the paradigm utilised in LS2. Herein tar1 was coloured red in order that it may be more readily identified, thus ensuring that an appropriate number of trials were available for analysis given that tar2 accuracy calculations were based only on cases in which tar1 was correctly identified. Other authors have similarly used this technique (Georgiou-Karistianis et al., 2007; Maciokas & Crognale, 2003; van Leeuwen et al., 2009). However, each of these previous studies utilised a cross-sectional design meaning that participants only encountered the task once. Thus it is feasible that repeated administration of the task, with tar1 in red, may reduce the amount of attentional resources required to process it as participants become familiar with its timing, leading to a reduction in P3b mean amplitude to tar1. This would feasibly lead to more attentional resources being available for tar2 processing and would explain why an improvement in HRs across lags and groups was observed for tar2. However, this explanation cannot account for why previous studies have observed a reduction in the AB effect (difference between HRs for short and long lag conditions) following MT (Slagter, Lutz, et al., 2007).

A specific effect of mindfulness retreats or longer exposure to MT may explain why Slagter, Lutz, et al. (2007) observed a reduction in the AB effect post retreat. Similar to the results observed herein, participants in both the retreat group and matched control group (age, gender and education) significantly improved HRs for short and long lag tar2 stimuli when they encountered the AB task for a second time in Slagter et al. study. However, the difference in performance between the short and long lag conditions, and thus the AB effect, only reduced for the retreat group and this reduction was correlated with a reduction in tar1 P3b. Thus MT administered via an intensive 3 month retreat was able to improve AB performance above and beyond practice effects with the observed improvement related to more efficient attentional resource allocation. However, given that the retreat group were already expert meditators at baseline and that no between groups differences were found when the experts and meditation naïve participants encountered the task for the first time, it is feasible to suggest that specific effects of retreat participation, rather than MT in general or length of exposure to MT, may modulate AB performance.

Spending 3months in an intensive mindfulness retreat with daily practice of over 8hours is likely to produce transient changes in ones attentional state that are likely to influence task performance. For example, despite instruction to the contrary it would be difficult to not utilise a mindfulness state during the completion of a task that requires FA, such as the ABtask, having spent 8hours per day for the past 3months engaging in MT that includes elements of FA. Completing the ABtask without the induction of such a state was likely to be much easier for the MTG herein as they only completed 10-15 minutes of MT daily. The findings of a number of other studies further suggest that changes in attentional state may produce modulations of the AB effect. For example, Olivers and Nieuwenhuis (2005) found that the AB effect was reduced by having participants concurrently listen to music and thus creating a distributed attentional state, a state previously described to account for MT related attentional improvements (Jha et al., 2007). Further, C. J. May et al. (2011) found that whilst 8weeks of loving kindness meditation did not reduce the AB effect, engaging in this form of meditation immediately before task completion did result in a significant reduction. Thus changes in attentional state during task completion may play a more crucial role in reducing the AB effect than mindfulness related trait attentional change. Engaging in 1hour of training in ABtask completion (Choi et al., 2012) may similarly produce changes in ones attentional state. Changes in attentional state specific to retreat participation would account for why between groups differences were observed by Slagter, Lutz, et al. (2007) and not herein. In conclusion, the ABtask may be more sensitive to state induced changes in attention than to trait related attentional change following MT, of which there is clear evidence following MT herein. An important question that may be answered by future research is whether a singular MT, completed over a brief period, may enable individuals to evoke an attentional state that can modulate the AB effect if they were in fact given explicit instruction to evoke such an attentional state.

14.4 Mindfulness Training and Self Report Measures of Mindfulness in Older Adults

A somewhat surprising finding of LS2 was that MT did not produce a significant increase in self reported mindfulness for the MTG. As an increase was seen in LS1 following MT for the MTG, the administered MT appears to have utility in increasing self reported mindfulness. A logical explanation for the observed difference between LS1 and LS2 concerns the different ages of the participant samples. A previous study conducted by Splevins, Smith, and Simpson (2009) which utilised the Kentucky Inventory of Mindfulness Skills (KIMS; Baer, Smith, & Allen, 2004), an earlier iteration of the FFMQ utilised herein, found that a sample of older adults (mean age = 65years) reported higher scores for the *observe* (FFMQ-O herein) and acting with awareness (FFMQ-A) facets of mindfulness than has previously been found in other studies utilising younger samples (Baer et al., 2008; Carmody & Baer, 2008). Thus ageing may be associated with increased levels of self reported mindfulness and a ceiling effect may have prevented the MTG in LS2 from increasing mindfulness following MT.

In order to test the hypothesis that age is related to increased self reported mindfulness the baseline data from 3 studies for which we have utilised the FFMQ in our lab were pooled (N=151) and the correlation co-efficient of FFMQ total score vs. age was calculated. As predicted, FFMQ-total was significantly positively correlated with age (r = .209, p =.005), with increasing age related to higher self reported mindfulness. As in Splevins et al. (2009), this relationship was also found for FFMQ-O (r = .191, p =.010) and FFMQ-A (r = .235, p =.002) but not for FFMQ-NJ (r = .074, *p* =.183) or FFMQ-D (*r* = .027, *p* =.372). Incidentally, the FFMQ-NR scale which is not included in the KIMS was also correlated with age (*r* = .177, *p* =.015).

Splevins et al. (2009) propose that mindfulness may be an extension of the developmental process. Further, they propose that FFMQ-O and FFMQ-A, facets which largely concern the observation of external stimuli, may be enhanced in older adults as many older adults have more free time. It was proposed that this reduced demand on available time would mean that attention may be given fully to the task at hand, rather than being divided, and thus make observation of external stimuli in the ongoing train of experience much easier. As noted by Splevins et al. further research is required to explore the relationship between age and the ability to observe and act with awareness in older adults to clarify whether these skills are age-related or whether socio-demographic factors and/or experience related factors may play some role in this relationship.

14.5 Summary

LS2 is the first fully randomised, active control group study to assess the effects of MT on attentional functions in older adults, providing a unique contribution to the ever expanding body of research concerning the potential positive effects of MT. Carrying out a simple mindfulness based breath awareness meditation, which involved elements of FA and OM, for just 8 weeks improved both behavioural and electrophysiological markers of attentional functions and attentional resource allocation in a sample of older adults. Importantly, the observed behavioural and electrophysiological results were complimentary, with enhanced attentional resource allocation related to improved behavioural performance across both the CPT and ECStroop tasks. However, the previous finding of a reduced AB effect following an intense 3 month mindfulness retreat (Slagter, Lutz, et al., 2007) was not replicated, with retreat specific modulations of the attentional state proposed as the most likely reason for the disparate results obtained herein.

The results obtained from the CPT and ECStroop tasks are indicative of improvements in core attentional functions that are subserved by an attentional control network which includes the ACC, a key structure which has previously been shown to have reduced grey matter volume (Mann et al., 2011) and metabolism (Pardo et al.,

2007) in older adults. Based on the observed pattern of results it is proposed that MT may strengthen executive attentional functions in older adults through two potential mechanisms. Firstly, repeated activation of executive functions, and the neural mechanisms that subserve them, during MT may lead to an increase in available attentional resource *capacity* given that previous research has found that short term MT can lead to both increased grey matter density (Hölzel, Carmody, et al., 2011) and white matter integrity (Tang et al., 2010) in attention related brain regions. Secondly, the MT administered herein instructed individuals to remain in the present moment (focussed on the breath), to reduce elaborative thinking, rumination and mind wandering, and to maintain awareness of the present moment unfiltered by expectations. Thus a strengthening of goal directed attention and a reduction in non-goal related extraneous processing may be achieved as a result of the interplay between the FA and OM components of the administered MT. In turn, this may be expected to lead to an increase in the *efficiency* with which available attentional resources may be appropriated for current goals, with or without an increase in overall resource *capacity*. Together these mechanisms are complimentary and may account for why older expert meditators have previously been found to have enhanced grey matter density in attention related brain regions (Hölzel et al., 2008; Luders et al., 2009; Pagnoni & Cekic, 2007) and enhanced behavioural performance compared to age matched meditation naïve individuals (van Leeuwen et al., 2009). With respect to the CR literature reviewed in Chapter 9, the observed results suggest that MT may capitalise on CR mechanisms and may have great utility in promoting cognitive and neural functioning in older adults. Recommendations for future research and the potential uses for MT in older adults are discussed in Chapter 15.

Interestingly, the overall pattern of results obtained from LS2 was that of improvements in attentional functions, with no concurrent improvement in the processing of emotional stimuli. Rather than being negative, this pattern of results is in line with conceptualisations of MT that suggest FA must first be trained in order for an individual to remain in the present moment and to consistently engage a non-reactive and non-judgmental OM state (Lutz et al., 2008; Malinowski, 2013; Wallace & Shapiro, 2006), with improvements in these core components of MT likely to facilitate subsequent improvements in emotion regulation. The dose of MT administered in LS2 appears to have been too small to allow the clearly observed attentional improvements to influence emotion regulation processes. Further, these results suggest that the additional counselling and instruction related to the processing of emotions that are often given in MBIs, but were not given herein, may play a crucial role in improving emotion regulation following short term MT. The implications of this finding for MBIs are discussed in Chapter 15.

The randomised active control group design of LS2, along with the administered self report questionnaires and the baseline tasks (Speed of Processing task and SSTM) enabled a large range of variables to be controlled between groups, including group contact time (social interaction), group session content, daily exercise time, experimenter contact and motivation, learning, participants' intention and motivation, cognitive training environment, age, dispositional mindfulness, computer ability, years spent in education, self reported health, self efficacy, mental well being, ongoing/current cognitive and physical activity, baseline processing speed, and working memory capacity. Further, the use of EEG recordings and the ERP technique enabled links to be drawn between the overt responses measured behaviourally and the attentional processing and attentional resource allocation that produce said responses. Thus the methodological design allows for confidence that the observed improvements in task performance and electrophysiological markers of attentional resource allocation were a direct result of the administered MT. Thus the findings of both LS1 and LS2 make a unique contribution to the extant literature by drawing direct links between engagement in MT and improvements in attention. Future studies must maintain this level of methodological rigor in order to further advance the field of mindfulness research.

Chapter 15: General Discussion

Table 43: Overview of main findings

	Variable type	**MT Vs. Comparison group (LS1= WCG; LS2 = BTG)**		**Relationship to previous findings**
Longitudinal Study 1				
Stroop Task	ERP	N2 @ Pos Right and Pos Left	⇧	These results build upon recent longitudinal findings which have demonstrated that MT leads to improved attentional functions (e.g. Jha et al., 2007).
		Increase in N2 correlated with decrease in P3 (incongruent condition)		
		P3 @ POz	⇩	
ANT	Behavioural	Reaction Times	⇩	
Longitudinal Study 2				
CPT	ERP	NoGo P3 @ FCz	⇧	1st longitudinal evidence of MT related improvements in sustained attention and inhibition related processing in older adults.
	Increases in NoGo P3 ERP correlated with decreases in reaction times			
	Behavioural	Reaction Times	⇩	
ECStroop	ERP	Fronto-central N2 @ FCz	⇧	1st longitudinal evidence of MT related improvements in executive/attentional control and conflict monitoring in older adults.
	Increases in fronto-central N2 correlated with decreases in reaction times			
	Behavioural	Reaction Times	⇩	
AB Task	ERP	P3b @ FCz	=	Slagter et al. (2007) findings not replicated. No support for van Leeuwen et al. (2009) findings of greater AB task performance for aged meditators.
	Behavioural	Accuracy	=	

The two primary objectives of this thesis were met; confirming that a fundamental MT, a simple breath awareness meditation, may modulate behavioural and electrophysiological markers of core attentional functions and that MT modulates these markers in older adults. The findings of this thesis may be briefly summarised as follows (see Table 43 for overview of main findings). Albeit in samples of different ages, both LS1 and LS2 found that short term MT modulates behavioural and electrophysiological markers of core attentional functions. LS1 revealed MT related improvements to earlier stages of stimulus processing in terms of improvements in goal directed allocation of attentional resources (N2 increase in the Stroop Task; RT decrease in the ANT) and more efficient perceptual discrimination and conflict resolution processes (P3 reduction, Stroop Task), with increases in the former correlated with decreases in the latter. For LS2, MT related increases in task related neural activity (fronto-central N2 increase, ECStroop; no-go P3 increase, CPT) were observed on both the CPT and ECStroop. Given that the ACC, a key structure involved in top-down attentional control that supports the process of monitoring current behaviour in relation to a desired goal (Kerns et al., 2004), has been implicated as a generator of these ERP components in previous studies (see Chapter 14) it was proposed that MT increased the allocation of attentional resources during task completion. Further, MT related improvements in RTs were observed on the CPT and ECStroop, with said improvements related to increases of task related neural activity across these tasks (both fronto-central N2 and no-go P3 increases were related to RT decreases), suggesting that the MT related increase in attentional resource allocation was adaptive and compensatory. The findings of LS2 are particularly encouraging given that old age is typically associated with slower RTs and that the aforementioned ERP components are typically diminished on these tasks. Of note, short term MT did not modulate the attentional processing of stimuli of emotional valence and a previously found MT related reduction in AB was not observed herein.

As discussed in Chapter 3, most modern conceptions position attention as a core component of mindfulness (Bishop et al., 2004; Hölzel, Lazar, et al., 2011; Malinowski, 2013; Shapiro et al., 2006; Wallace & Shapiro, 2006) and the development of attentional skills is considered a central part of MT (Hölzel, Carmody, et al., 2011; Lutz et al., 2008; Tang & Posner, 2009; Wallace & Shapiro, 2006). However, methodological limitations (see Chapter 3) have meant that an unequivocal link between MT and improvements in attention has previously remained elusive. Thus, the longitudinal studies detailed in this thesis provide a novel contribution to the ever expanding pool of mindfulness research by directly linking a specific, fundamental form of MT to both behavioural and electrophysiological modulations of core attentional functions. The implications of these findings are relevant to discussions in two main areas of ongoing research. First, given that MT resulted in adaptive and compensatory modulations of attentional functions in older adults, it is important to assess to what extent MT may be utilised as a cognitive training technique to enhance CR, with CR thought to play a key role in how older adults are able to deal with age related and/or disease related brain pathology. Second, as MT has been shown to modulate attention in LS1 and LS2, it is important to assess what role attentional modulations may play in the observed salutary effects of MT, an ongoing discussion which may have implications for modern MBIs. The following sections bring together the findings of LS1 and LS2 and all of the information presented herein to discuss current theory in these key areas of ongoing research. Recommendations for future research are outlined.

15.1 Mindfulness Training as a Strategy to Increase Cognitive Reserve in Older Adults

As identified in Chapter 9, a key ongoing aim for researchers is to identify methods of increasing CR in order to find ways of ameliorating the effects of cognitive decline in ageing. The findings of LS2 are particularly promising as they represent the first empirical evidence that MT improves core attentional functions and increases attentional resource allocation in older adults, demonstrating that MT may have the potential to utilise neuro-protective CR mechanisms to improve attentional functions in older adults. Whilst these findings are clearly a first step for research in this direction, and require replication and confirmation across further samples and paradigms, they do allow for some speculative conclusions to be drawn regarding their potential wider reaching implications. The following discussion will detail the potential mechanisms by which CR may modulate the relationship between MT, task related neural activity and task performance. Additionally, the discussion will also detail why MT may have wide reaching utility in older adults, including the potential implications for cognitive training interventions designed for the prevention/treatment of MCIs and AD, the benefits of introducing MT during retirement, and recommendations for future research in this area.

Mechanisms by Which Mindfulness Training May Increase Cognitive Reserve and Recommendations for Future Research

It is important to start this discussion by reiterating and expanding on why MT may be a valuable form of cognitive training for increasing CR. As stated in Chapter 9, evidence for crossover effects of cognitive training is limited, with cognitive training typically improving performance on the specific tasks trained without crossover of improvements into other tasks (e.g. Ball et al., 2002). Slagter et al. (2011) proposed that MT may produce such crossover effects due to their utility in improving core cognitive processes that are called upon during various other tasks. The findings of both LS1 and LS2 clearly demonstrate that MT improves such processes and that they generalise from the specific task of meditation to performance on a variety of attentional tasks that call upon these trained core cognitive skills but do not require meditation. The increased allocation of attentional resources in ERPs linked to the ACC that were observed across tasks following MT in LS2 is a particularly important finding as it is indicative of modulations in primary attentional networks. Such modulations of neural activity at the level of brain networks imply increases in CR (Stern, 2009) and suggest that MT may capitalise on the remaining neuro-plasticity[45] of the aging brain to facilitate adaptive and compensatory change.

Since the conception and completion of LS2, Stern and colleagues (Steffener & Stern, 2012) have recently extended their model of CR in ageing following a review of their groups studies examining the neural basis for CR. Although LS2 was simply conducted to determine if MT may modulate markers of attentional functions in older adults rather than to assess any extant model, the observed pattern of results do fit Stern and colleagues extended model despite pre-dating it. The model details a number of ways by which CR may mediate the relationship between age related pathology, task related neural activity and task performance/clinical outcomes. Firstly, increased CR may modulate or decrease the effect of age or disease related pathology on task performance/clinical outcomes, e.g. if two AD patients had similar underlying

[45] The term neuro-plasticity refers to the capacity of the brain to change physical structure (i.e., reorganization of neuronal networks) and function in response to environmental attributes or factors.

pathology the individual with the highest CR would be expected to have better task performance. This suggests that higher CR enables an individual to tolerate more pathology. Secondly, CR may modulate task related neural activity which in turn facilitates improved task performance/clinical outcomes, e.g. CR may increase the capacity of primary neural networks and/or enable additional compensatory resources to become available through neural compensation, which separately or together enable additional neural resources to be allocated during task completion, leading to improved performance. Lastly, CR may have a direct impact on task performance, irrespective of task related neural activity, if CR utilises its own network, e.g. increased activity from a generalised CR network may modulate task performance irrespective of modulations of task related neural activity. This model provides potential pathways by which MT related increases in CR may modulate task performance and these will be discussed below. However, it is important to state at this juncture that further research is ongoing and necessary to validate Steffener and Stern model thus the discussed mechanisms are necessarily speculative at this stage despite being in line with current theory.

Increases in task related neural activity and related improvements in task performance were clearly observed following MT in LS2. In line with Steffener and Stern (2012) extended model, this suggests that MT may increase CR which in turn improves task performance by enhancing task related neural activity. However, the exact ways in which MT increases CR requires further study. In Chapter 14 it was speculated that MT may modulate CR in two complimentary ways, by increasing available attentional resource capacity through repeated activation of attentional functions during MT and/or by improving the efficiency with which available attentional resources are allocated through a reduction of extraneous neural activity. It is feasible to suggest that each of these mechanisms may be accounted for by MT related increases in neural reserve. However, the lack of spatial precision afforded by the ERP technique means neural compensation cannot be ruled out. It is unclear whether or not the increased availability of attentional resources was caused by 1) an increase in attentional resource capacity of primary networks, 2) an increase in the efficiency of the primary networks in allocating attentional resources by limiting extraneous activity, 3) the use of additional compensatory resources via neural compensation or 4) a combination of any of these 3 potential causes. In line with the abovementioned mechanisms, increases in the capacity and efficiency of primary networks are certainly feasible explanations for the pattern of results observed herein given that the ERP components modulated following MT in LS2 have previously been linked to ACC functions and activation. Recent research certainly shows that both long term (e.g. Hölzel et al., 2008; Luders et al., 2009; Pagnoni & Cekic, 2007) and short term (Hölzel, Carmody, et al., 2011; Tang et al., 2010) MT can alter the structure of brain regions implicated in attentional functions, suggesting that MT may capitalise on the neuro-plasticity of neural networks, and that the findings observed herein may result from such modulation. However, each of these previous studies utilised samples of young to middle aged adults, meaning that these results require replication in an older sample before strong conclusions may be drawn. Regardless of whether the observed results were resultant from increased neural reserve or enhanced neural compensation, the results are positive and it can be concluded that the findings of LS2 suggest that neuro-plasticity may be capitalised upon in older adults to produce improvements in task performance. A number of recommendations for future research may be made that would help researchers to better understand the relationship between MT, neural reserve and neural compensation.

Longitudinal examinations that include functional and/or structural neuro-imaging techniques, with their excellent spatial resolution, would help to pinpoint specific brain regions that may be functionally or structurally modulated following short term MT in older adults. Said techniques have the potential to unravel the roles that neural reserve, neural compensation and the intrinsically linked brain reserve may play in MT related modulations of neural networks. However, such studies are notoriously costly and thus further behavioural and electrophysiological examinations may be required before such studies are justified.

In order to gain further insights into MT related modulations of attentional resource capacity and efficiency future studies may examine how such modulations impact the brains ability to cope with increased task difficulty and/or time on task. As LS2 was the first study of its kind, task duration and difficulty were purposefully kept at a minimum to keep the overall task burden low (even then approximately 2.5-3.0 hours were still spent in the lab for each testing session) in order to simply assess if MT related modulations were possible in older adults. Extending the time spent on task in future studies may provide valuable insight into MT related modulations in attentional resource capacity. For example, using a sustained attention task (e.g. a CPT) with extended task duration would allow for an assessment of vigilance decrements over time, with reduced vigilance decrements being a potential marker for increases in attentional resource capacity (see Chapter 9 for more info regarding vigilance decrements). ERPs may also be recorded to assess if attentional resource allocation and behavioural performance decline in tandem with time on task. Said analysis was not carried out herein as the utilised CPT was only 7 minutes in duration and such a short duration is likely to be insufficient to significantly deplete attentional resources on a task of this difficulty. Manipulating task difficulty in future studies, within or across tasks may concurrently provide valuable insight into the efficiency with which attentional resources are allocated and regarding the availability of compensatory resources. Steffener & Stern, 2012) proposed that more efficient neural networks would require less of an increase in neural activity when task demand was increased. Thus if MT increased the efficiency of neural networks increases in task demand may require less of an increase in task related neural activity to maintain performance. Further, Sebastian, Baldermann, et al. (2013) demonstrated that older adults increasingly recruit additional compensatory resources as task difficulty increases until demand exceeds compensatory capacity. Therefore, if MT facilitates neural compensation in older adults then the threshold at which demand exceeds compensatory capacity may be increased and thus performance levels and/or task related neural activity may be maintained compared to controls despite increasing task difficulty.

Examining the links between MT, attention and WM in older adults may be a particularly interesting avenue for future research. Interestingly, the word mindfulness derives from the Pāli word *sati* which is related to the verb *sarati*, meaning to remember or keep in mind (Analayo, 2006). A link between mindfulness and memory may be somewhat surprising given that throughout this thesis present moment awareness is emphasised as being a crucial aspect of mindfulness. However, Analayo (2006) suggested that if examined within the context of the Pāli discourses, what is meant is that once sati/mindfulness is present, memory will function well. As briefly introduced in section 10.3.7 a number of recent studies have suggested that MT may modulate WM (Chambers et al., 2007; Jha et al., 2010) and selective attention influences WM at multiple stages of processing. Given that it is well established that WM declines with age (Craik & Salthouse, 2000), a case can be made for assessing whether MT related improvements in attentional functions may modulate WM in older adults. Of note, no change was observed in WM capacity (SSTM) following MT herein. However, future studies which are explicitly designed to assess this relationship may incorporate a full WM task battery which will be more sensitive to MT related modulations in WM over time.

<<<Stephen whitmarsh method, include details regarding questionnaire methods struggling to underpin mindfulness and that neurocognitive methods such as whitmarsh may provide a window into an important element of mindfulness, metacognitive monitoring>>>

Finally, including appropriate follow up periods may further strengthen longitudinal studies of MT. A key limitation of LS1, LS2 and previous longitudinal examinations of MT in general is that they lack follow up examinations to test if the effects of MT on attentional functions still remain weeks, months or even years after the administered intervention. Follow up examinations were not included herein as the timeframe of this thesis did not afford enough time to conduct them. Further, there are a number of potential confounds which make the inclusion of adequate follow up examinations difficult. For example, repeated task administration in longitudinal studies can lead to practice and ceiling effects that can obscure between groups differences, as was seen for the Stroop task in LS1, thus adding additional follow up examinations which utilise the same tasks included in the pre and post intervention testing sessions may exacerbate this issue. Fortunately, as in LS1, modulations of different stages of attentional processing can still be observed using ERPs, and studies that utilised structural imaging techniques such as MRI would be unaffected by this issue, though the problem remains for purely behavioural studies. Follow up examinations that use different tasks for which performance has previously been shown to be highly significantly correlated with the outcome measures used during the study period may provide a way to get around this issue. A further issue concerns whether or not participants continue MT in the interim before the follow up examination as previous studies have shown that ongoing MT may be as or more important than prior experience (e.g. Chan & Woollacott, 2007). Post study feedback across LS1 and LS2 suggested that the vast majority of participants intended to continue meditating despite the end of the study period. Thus asking the participants to stop meditating in the interim period before follow up, in order to assess if MT related effects remain following the cessation of practice, may be particularly difficult and somewhat unethical given that research is increasingly supporting the potential benefits of MT. Tackling these tricky issues in future research will provide further insight into the longevity of the effects of MT but not all kinds of studies may be suitable for including follow up examinations.

Future research that builds upon these recommendations is much needed and warranted and has the potential to provide valuable insights into the utility of MT for older adults, and possibly more importantly how MT may impact both age and disease related brain pathology. The final section of this discussion introduces why MT may have utility in delaying AD symptoms and compressing their associated cognitive morbidity and why MT may be recommended as an ideal cognitive activity to take up following occupational retirement.

Mindfulness Training, Cognitive Reserve and Age Related Pathology and Disease

In addition to helping older adults deal with the typical age related pathology that accompanies growing old, interventions that increase CR such as MT may also enable individuals to better cope with disease related pathology, such as in AD. As of the time of writing this thesis there is no consensus regarding the treatment of AD and no drug treatments available that prevent it. A number of critical issues are yet to be resolved regarding AD diagnosis and treatment, not least that current guidance inherently limits diagnosis of AD to a stage at which patients present with dementia symptoms despite the fact that the underlying anatomical and pathophysiological changes in AD may have begun many years before clinical symptoms manifest. The food and drug administration in the USA has recently released draft guidance (Food and Drug Administration, 2013) to enable pharmaceutical companies to better identify patients in pre dementia stages of AD with the eventual aim of enrolling such patients into clinical trials to assess new treatments. However, until pharmaceutical treatments that can prevent or slow down the progression of AD become available a key achievable clinical outcome is to reduce or ameliorate symptoms and/or reduce the time a patient spends symptomatic, with non-pharmacological treatments that increase CR likely to play a crucial role.

As introduced in Chapter 9, a growing body of research suggests that increases in CR fostered through mental activity can enable individuals to better cope with brain pathology and a number of small clinical trials have begun to demonstrate that cognitive training may slow the progression of symptoms in MCI (Cipriani et al., 2006; Rozzini et al., 2007; Talassi et al., 2007) and AD (Galante et al., 2007; Tarraga et al., 2006). In addition to the well established memory dysfunction that is considered the hallmark of AD, attentional deficits are also thought to manifest early in the diseases progression. For example, studies have observed that MCI and AD patients have impairments in focused attention (Levinoff, Saumier, & Chertkow, 2005) and a deficiency in the ability to disengage attention and utilise alerting cues (Tales et al., 2005), suggesting deficits to core attentional functions. Such deficits are thought to play a key role in patients struggling to undertake everyday tasks (e.g. planning and cooking a meal) early in the diseases progression (Perry & Hodges, 1999). Difficulty completing such seemingly simple tasks is likely to severely impact a patients’ quality of life and independence, thus interventions that can delay or limit the time spent symptomatic are much needed.

Recent observational evidence has shown that engaging in mental activity can compress the cognitive morbidity associated with AD, i.e. less time spent symptomatic, and reduce the rate of cognitive decline prior to dementia onset (R. S. Wilson et al., 2010). Despite further investigations being required to better understand the relationship between MT and CR, it may be expected that MT would produce a similar effect. The findings from LS2 allow for the speculative hypothesis that MT may be useful as a method of increasing CR and strengthening core attentional functions to better deal with pathology, by increasing task related neural activity and thus moderating the relationship between pathology and performance. MT would most likely be best utilised as a preventative measure, building up CR to delay symptoms or reduce time spent symptomatic, rather than as a rehabilitation strategy as pre-existing deficits in attentional functions may increase the difficulty of undertaking MT given that MT relies heavily upon attentional functions to facilitate focussed attention even in its early stages. As the symptoms that accompany AD pathology are potentially life changing and AD prevalence is likely to increase, any treatment that can delay symptoms or compress the time spent symptomatic may provide valuable assistance to healthcare providers and patients alike. Thus, if future research is able to confirm the efficacy of MT to increase CR, neural reserve and/or neural compensation, MT may at the very least provide a potentially efficacious low cost non-pharmacological adjunct to the ever evolving pharmaceutical battery, with the added benefits of being minimally time consuming, having no known side effects and not interfering with other medications.

Mindfulness Training During Retirement

To round off this discussion it is important to discuss the potential efficacy of MT for healthy older adults following occupational retirement. Occupational retirement is a particularly important and potentially challenging landmark in the ageing process which is typically accompanied by a reduced amount of mental activity due to the inevitable changes associated with ceasing employment. As stated in Chapter 9 a number of recent reviews (Bonsang et al., 2012; Mazzonna & Peracchi, 2010; Rohwedder & Willis, 2010) have proposed that this retirement related reduction in mental activity may exacerbate cognitive declines. Additionally, older adults often do not expect to control cognitive outcomes (Hess et al., 2003), often because of habitually negative thoughts and cultural stereotypes, to the extent that they may withdraw from cognitively challenging situations (Stine-Morrow, 2007). In turn this may cause a somewhat self deprecating cycle of reduced cognitively demanding activity leading to reduced cognitive ability, which in turn weakens confidence in cognitive outcomes to the extent that it may cause an individual to further withdraw from cognitively demanding activity. There are a number of key reasons why MT may be particularly useful for retired individuals and play a crucial role in breaking this cycle. Firstly, MT itself is a cognitively demanding activity and thus engaging in MT inherently increases the amount of cognitive activity being undertaken. Secondly, as MT may strengthen core attentional functions it is likely to give back a sense of control over cognitive outcomes which may have the additional benefit of facilitating engagement with other cognitively demanding activities as well. Lastly, MT teaches one to experience the present moment free from habitual thoughts and cultural stereotypes which may cause individuals to withdraw from mental activity. Thus MT may be recommended as a low cost, minimally time consuming mental activity that has potential to positively influence cognitive ageing in retired individuals. This is not to say that MT should only be started upon retirement. To the contrary, engaging in mental activity prior to retirement is likely to increase the amount of CR with which one enters retirement. As emerging evidence continues to suggest that the ageing brain retains neuro-plastic properties it is important to stress that it is never too late to exert some control over our own cognitive trajectories by engaging in activities that may increase our chances of ageing well. MT may be seen as a particularly promising way of doing just that.

15.2 The Role of Attentional Modulation in MT Related Salutary Effects

In recent times the interest in mindfulness as a means to treat a variety of physical and psychological conditions has risen sharply (Chiesa & Serretti, 2010; Ludwig & Kabat-Zinn, 2008) and a number of randomised control studies have provided evidence for the efficacy of MBIs in such conditions. MBSR has been found to reduce pain, stress and psychological problems in healthy individuals and patients with chronic pain and cancer (Chiesa & Serretti, 2011a; Ledesma & Kumano, 2009; Shennan, Payne, & Fenlon, 2011), whilst MBCT has been successfully utilised as an intervention for currently depressed patients and for the prevention of depression relapse in patients with three or more prior episodes (Chiesa, Mandelli, & Serretti, 2012; Chiesa & Serretti, 2011b; Manicavasgar, Parker, & Perich, 2011; Piet & Hougaard, 2011). However, as discussed in Chapter 3, the mechanisms by which MBIs produce such clinical outcomes are unclear given that they typically include a range of experiential, didactic and group elements that may separately or together produce positive outcomes.

Using MBSR as an example, a typical 8 week MBSR course includes a variety of elements as follows: a) *Experiential* elements include a variety of meditation practices such as awareness of breathing, body scanning, sitting meditation, mindful movement meditations that may incorporate yoga and/or qigong[46], and other walking meditations. Meditations that include compassion and empathy are also typically included. B) *Didactic* elements include lectures and discussions with participants learning about mindfulness, and more importantly about how habitual reactions to stress create anxiety, depression, and illness. C) *Group* elements include group discussions that provide group support and afford the opportunity for participants to share and discuss daily practice. In addition participants are often asked to perform weekly reflection and diarising exercises. Given this wide variety of potentially active ingredients it is unclear what is producing the observed salutary effects of MBSR.

Herein, additional meditation practices and the didactic content were stripped away in order to observe the effects of a specific, fundamental, breath awareness MT on

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[46] Qigong is an ancient Chinese system of postures, exercises, breathing techniques, and meditations. Its techniques are designed to improve and enhance the body's *qi*. According to traditional Chinese philosophy, qi is the fundamental life energy responsible for health and vitality.

core attentional functions in samples of younger and older meditation naïve individuals. Importantly, the results of this thesis clearly demonstrate that in said samples short term engagement in this fundamental MT can lead to observable behavioural and electrophysiological improvements in core attentional functions. Thus, improvements in attentional functions observed in previous studies (e.g. Gaden Jensen et al., 2012; Jha et al., 2007) that have utilised similar MT techniques as part of wider interventions, such as MBSR, may at least be partially explained by engagement in such fundamental meditation practices. This suggests that improvements in attention fostered by engagement in MT may play a key role in the salutary effects of MBIs. However, whether improvements in attention have a direct or indirect effect on the observed salutary effects of MBIs requires further study. Examining the mechanisms by which MBIs exert salutary effects was beyond the scope of this thesis as it first needed to be established that there was a definitive link between specific meditations and improved attentional functioning, a need fulfilled by LS1 and LS2. However, taking together the observed pattern of results herein and the findings of a number of recently published studies and reviews some tentative conclusions may now be drawn and recommendations for further research can be made.

A number of recent review papers have attempted to explain how MT may exert its salutary effects (Chiesa et al., 2013; Heeren & Philippot, 2010; Hölzel, Lazar, et al., 2011). Hölzel, Lazar, et al. (2011) attempted to explain the mechanisms of MT at both the conceptual and neural level, proposing that there are four key components that may influence how MT exerts its effects: 1) attention regulation, 2) body awareness, 3) emotion regulation and 4) change in perspective on the self. Importantly, the authors note that these components are likely to interact and may ultimately lead to improvements in self regulation[47], which may in turn foster MT related effects. A further consideration is that different MBIs and MT's may utilise these components to differing degrees. As noted and discussed throughout this thesis the training and refining of attentional skills is a central part to most psychological and Buddhist conceptualisations of mindfulness practices (e.g. Lutz et al., 2008), thus an important question to ask is whether improvements in attention regulation may precede

[47] Self regulation may be broadly defined as the ability to monitor and modulate cognition, emotion and behaviour, to accomplish one's goal and/or to adapt to the cognitive and social demands of specific situations (Berger et al., 2007).

improvements in the other three proposed mechanisms? The focus for this discussion is on the relationship between attention regulation and emotion regulation as the emerging pattern of results suggests that the former may indeed precede the later. Thus the improvements to core attentional functions observed herein may play a crucial role in the observed positive effects of MT.

For the purpose of this discussion emotion regulation is simply considered the ability to regulate ones emotions and emotional responses (see Gross, 1998a, 1998b). Deficits in emotion regulation cause difficulty in monitoring, evaluating and modifying emotions and emotional reactions. Said deficits have been implicated in a wide range of conditions including depression, borderline personality disorder, substance use-disorders, eating disorders and other psychopathological symptoms (see Berking et al., 2012 for recent review). This suggests that improvements in emotion regulation, whether directly or fostered by improvements in attention regulation, may play a key role in the observed positive effects of MT on mental health. Indeed recent findings suggest that improvements in emotion regulation may underlie the positive effect of MT on stress reduction (Garland, Gaylord, & Fredrickson, 2011) and the reduction of depressive symptoms (Shahar et al., 2010).

Attention regulation and executive attentional functions in particular are thought to play a key role in emotion regulation (see Berger et al., 2007 for review). Given that executive attention is the basis for inhibitory control, problem solving and self monitoring it is feasible to suggest that these core attentional functions allow attention regulation to strongly influence affective experience by filtering and analysing emotional and mental information, both automatically and consciously (Calvo & Nummenmaa, 2007). Furthermore, Wadlinger and Isaacowitz (2011) proposed that improving attention regulation through training may be a particularly useful way of improving emotion regulation and concluded that meditation techniques such as MT provide a means to improve attention regulation.

Herein the general pattern of results was of improvements in core attentional functions without concurrent changes in the processing of emotional stimuli (ECStroop). Taken with the findings from Allen et al. (2012; discussed Chapter 14), who observed MT related increases in regions implicated in top down attention mechanisms (DLPFC) but only found increased recruitment of regions implicated in emotional processing (dorsal ACC, medial PFC and right anterior insula) for individuals who engaged in the most MT over their 6 week study, the emerging pattern of results suggests that improvements in emotion regulation may be dependent on the dose of MT and that they may be reliant on improvements in attention regulation occurring first. In line with the abovementioned papers, it is feasible to suggest that the strengthening of core attentional functions, such as those responsible for response inhibition, attentional monitoring and sustained attention, may foster the development of attentional stability, clarity, and awareness of the current mental state, i.e. present moment awareness. In turn such changes are likely to provide the platform upon which improvements in emotion regulation are built. Sahdra et al. (2011) similarly concluded that improvements in socio-emotional functioning may be fostered through improvements in core attentional skills, response inhibition in their study, following MT. It is important to note that MBIs such as MBSR acknowledge the need to first train attentional skills by starting with meditations that focus on strengthening FA before moving onto OM meditations later on in the program (typically in week 5 of 8). Similarly, emerging interventions that include mindfulness continue to acknowledge the need to first train attentional stability. For example, cognitive-based compassion training, which has recently been shown to enhance empathic accuracy (Mascaro et al., 2013), acknowledges the need to first develop attention and stability of mind by including shamatha and vipassana practices in the first weeks of training whilst the cultivation of self-compassion and compassion for others is addressed later in the course.

However, the results of a recent study suggest that the relationship between attention regulation, emotion regulation and MT may not be so clear cut. Teper and Inzlicht (2013) recorded ERN amplitudes during the completion of the Stroop task and found that expert meditators had higher ERN amplitudes and higher emotional acceptance (measured using the emotional acceptance subscale of the Philadelphia Mindfulness Scale; Cardaciotto et al., 2008) compared to controls. The results of mediation analyses led the authors to conclude that meditation related increases in executive control, evinced by higher ERN, may be accounted for by heightened emotional acceptance. However, the cross sectional nature of the study does not allow for strong conclusions to be made regarding directionality of the relationship between attention and emotion regulation. Further, the opposite pattern observed herein (attention regulation precedes emotion regulation) and by Allen et al. (2012) may be accounted for by the fact that participants were meditation naïve at baseline in these studies whereas Teper and Inzlicht findings may reflect the fact that the relationship between emotion regulation and attention may manifest differently in expert meditators.

Following a review of neuro-imaging studies investigating MT within the context of emotion regulation Chiesa et al. (2013) proposed that differing levels of experience with MT may indeed result in different ways in which mindfulness may result in emotion regulation being employed. They suggested that MT may be associated with top down regulation strategies in short term meditators and bottom up regulation strategies in long term meditators. In terms of bottom up strategies it was suggested that MT be described as an increased attention to the present moment in experience with a non-judgmental attitude and no attempt to cognitively reappraise emotionally salient stimuli. On the other hand, top down strategies were said to describe MT as facilitating positive reappraisal, and thus modulating emotional outcomes as opposed to simply observing arising emotions. Hölzel, Lazar, et al. (2011) similarly speculated that bringing mindful awareness to emotional responses might initially require some top down cognitive control, in order to overcome habitual ways of internally reacting to one's emotions. Importantly, a number of the 'short term' studies included in Chiesa et al. review involved MBSR, thus participants will have been exposed to didactic elements that will have included instruction regarding how to recognise and modulate habitual patterns of thoughts and emotions, and additional meditations that are likely to have involved instruction with affective content. Therefore, participants may have been more inclined to engage top down regulation strategies to modulate emotional outcomes. This may account for why changes in emotional processing have been seen in studies employing MBSR (e.g. Farb et al., 2010; Farb et al., 2007; Goldin & Gross, 2010) but not herein. Of note, an increase in FFMQ-O scores was observed following MT in both LS1 and LS2, suggesting that MT resulted in greater awareness of thoughts, bodily sensations and emotions. However, despite being a short term intervention the MT utilised herein would better fit in with a bottom up description of emotion regulation as practitioners were instructed to simply observe arising emotions and to disengage from them (to return focus to the breath) without modulating the content in anyway. Importantly then, it may be concluded that the way in which mindfulness is taught, conceptualised or packaged (as in MBIs) may play a more important role in which emotion regulation strategy is utilised than the length of experience of the meditator. Thus didactic elements and meditations that include components of affect are likely to play a crucial role in MBIs. For example, Gaden Jensen et al. (2012) recently demonstrated that MBSR produced reductions in perceived and physiological stress and a concurrent increase in mindfulness (measured using the MAAS) whilst a none mindfulness based stress reduction intervention did not, supporting the crucial role of the additional mindfulness instruction and meditations used in MBSR. Future research must endeavour to tease out the effects of the experiential and didactic elements of MBIs in order that their mechanisms are better understood and that interventions may be tailored to treat specific conditions. Comparing a singular MT without didactic elements to MBSR in a longitudinal study may provide valuable insights into this relationship, especially if both cognitive and affective paradigms with electrophysiological or neuro-imaging techniques are utilised.

It is important to state that improvements in attention regulation may also have a more direct effect on MT related positive outcomes. For example, the repeated disengagement from ruminative and/or distracting thoughts during MT may improve attention regulation in a way that reduces maladaptive rumination, and said reduction is thought to be a further mechanism by which MT may exert positive effects (see Heeren & Philippot, 2010 for review). Further, irrespective of its influence on emotion regulation and other potential mechanisms of MT related effects, the fact that MT has been shown to directly influence core attentional processes herein may have implications for a number of conditions that are caused or confounded by attentional dysfunction. For example, as MT strengthens core attentional functions, enhances attentional resource allocation and increased grey matter density in attention related cortical areas (Grant et al., 2010; Hölzel et al., 2008; Luders et al., 2009; Pagnoni & Cekic, 2007), it has been proposed that MT may ameliorate the symptoms of ADHD (Grant et al., 2013), which is characterized by inattention, under recruitment of attention related brain regions (Dickstein et al., 2006) and reduced cortical thickness in populations of both adults and children (Seidman, Valera, & Makris, 2005; P. Shaw & Rabin, 2009). Importantly, this direct effect of improvements in attention regulation is likely to have utility in older populations wherein attentional deficits are likely to become increasingly prevalent in coming years.

15.3 Methodological Issues in Longitudinal Mindfulness Research

The systematic literature reviews and longitudinal studies conducted as part of this thesis have identified a number of methodological issues that researchers must tackle and strive to overcome in future research. A number of key issues are briefly discussed below.

Measuring adherence

How to measure adherence is an important methodological consideration for any longitudinal study that is designed to measure the effect of an experimental manipulation or treatment. Herein there was no intention to analyse the relationship between dose of MT and any outcome measure, thus a simple weekly diary was utilised to enable participants to record the amount of MT they undertook. As the available evidence discussed in section 15.2 suggests that there may be a dose related effect of MT on emotion regulation it is important that future examinations that seek to examine this relationship utilise methods that are able to closely monitor adherence. If the experimenter was satisfied with adherence being recorded by the participant, the increasingly prevalent use of smart phones may afford an appropriate way to monitor adherence on a daily basis via a customised application. This would enable the experimenter to monitor the amounts of MT the participants were completing daily and prompts could be given when participants fell below the recommended dose. However, self reports are inherently reliant on the honesty of the participant and in a study involving a self administered intervention such as MT there is always a possibility that the participant would fail to report non-adherence. If an experimenter needed to be more certain regarding compliance they could use a smart phone app such as skype which would enable participants to complete their daily dose of MT via video link. Nevertheless, if a large number of participants were involved the logistics of conducting such a study would be burdensome and unfeasible. Further, such additional experimenter contact via video link is an additional confounding variable that would need to be controlled across groups. Thus experimenters will need to judge whether the additional information the use of technology may provide is of sufficient value given the additional confounds and time they may involve.

Use of covariates in longitudinal research

Randomisation is a standard methodological procedure for longitudinal studies wherein the objective is to assess the efficacy of an experimental manipulation. Such randomisation prevents a selection bias from causing systematic differences between an experimental and control group at baseline. To test that randomisation has been successful an experimenter will typically test for baseline differences between groups by using data obtained before the intervention begins. Herein, independent t-tests confirmed that no significant baseline differences existed between groups on any of the outcomes that were of interest to the longitudinal examination. However, when using such tests any judgment regarding whether a between group difference is important is based on the somewhat arbitrary cut off of a p value of .05 and it is debatable whether a group difference at the .06 would be any less important. If a significant or almost significant between groups difference had occurred at baseline in a primary outcome variable it would have been necessary to include baseline performance as a covariate in the analysis. The use of covariates may be particularly important if such instances occur in longitudinal examinations that include outcome measures such as RTs and HRs because inter-individual differences in task performance at baseline could mean that one group has more room for improvement than the other and this could critically influence baseline to end of study differences. For example, within the field of mindfulness research longitudinal examinations of expert meditators and control subjects may require the use of baseline data as covariates because long term meditation practice may be expected to produce a baseline difference between groups on a primary outcome measure such as RT or HR.

Measuring Mindfulness

Currently used self report measures of mindfulness continue to receive criticism and it is debatable whether an appropriate self report measure of mindfulness can be developed due to the great difficulty involved in operationalising mindfulness. In the future, electrophysiological and neuro-imaging techniques may provide an objective way of measuring mindfulness. For example, in his recent PhD thesis Stephen Whitmarsh (2013) investigated the neural correlates of meta-cognition, a core component of mindfulness, by using a novel task[48] that required participant's to report their meta-cognitive awareness of somatosensory attention while their brain activity was recorded with MEG. Such novel paradigms provide insights into the neuronal substrate that may be involved in a person's ability to report on one's own attentional focus, i.e. a person's meta-cognitive awareness, and thus may provide a more objective measure of such core components of mindfulness. Such methods warrant further investigation as the field of mindfulness research continues to advance in the future.

15.4 Closing Remarks

The field of mindfulness research is no longer in its infancy following two decades of investigations. Support for MT related improvements in core attentional functions has increased and the methodological rigour of studies is improving. The longitudinal studies included in this thesis have a number of key strengths that should serve as a benchmark for future studies, including random group allocation, an active control condition (in LS2), meditation naïve participants, behavioural and electrophysiological dependent variables which enable us to see beyond an overt response, and a well defined MT.

In conclusion, this thesis makes a unique and novel contribution to the growing understanding of mindfulness by demonstrating that MT may have a significant positive influence on core attentional functions and capitalise on the neuro-plasticity of neural networks to modulate task related neural activity in both young and more importantly older adults. The emerging pattern of results suggests that such attentional modulations play a crucial role in fostering the wide range of MT related positive effects that have been observed. Said results open up a number of exciting avenues for future research for which recommendations are made herein. The potential for MT to positively modulate core attentional functions in older adults and to potentially impact cognitive ageing demands further investigation. It is hoped that the positive findings obtained herein act as a springboard to further research that seeks to investigate the probable relationship between MT, CR and positive cognitive outcomes using similarly robust randomised active control group trials.

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[48] In response to auditory cues participants maintained somatosensory attention to either their left or right hand for intervals varying randomly between 5 and 32 seconds. Trials were terminated by a probe sound, to which they reported their level of attention on the cued hand right before probe-onset.

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Appendix A: Overview of cognitive tasks introduced throughout this thesis.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Attentional Blink Task (AB task)	Choi et al. (2012); Georgiou-Karistianis et al., 2007; Giesbrecht & Di Lollo, 1998; Isaak et al. 1999; Jha et al., 2007; Kranczioch et al. 2003; Lahar et al., 2001; Maciokas & Crognale, 2003; May et al., 2010; Olivers & Nieuwenhuis, 2005; Raymond, Shapiro & Arnell, 1992; Slagter et al., 2007; van Leeuwen et al., 2009; Vogel & Luck, 2002; Vogel, Luck & Shapiro, 1998; Ward, Duncan & Shapiro, 1996.	3	Sustained Attention, Selective Attention, Working Memory, Temporal Attentional Processing.	The ABtask requires participants to sustain focus to a rapidly presented stream of visual stimuli in order that 2 temporally close target stimuli may be identified.
Stroop Task	Andrés et al., 2008; Chan & Woollacott, 2007; Cohn, Dustman, & Bradford, 1984; Gaden Jensen et al., 2012; Hanslmayr et al., 2008; Kozasa et al., 2012; Laguë-Beauvais et al., 2013; Langenecker et al., 2004; Liotti et al., 2000; Mager et al., 2007; Mayas et al., 2011; Milham et al., 2002; Moore & Malinowski 2009; Moore & Malinowski, 2012; Panek, Rush, & Slade, 1984; Polak, 2009; Roelofs et al., 2006; Teper and Inzlicht, 2013; Van der Elst et al., 2006; Volkow et al., 1998; West and Alain, 2000; West and Bell, 1997; West & Moore, 2005.	3	Executive Inhibition, Conflict Monitoring, Selective Attention.	During the Stroop task participants are asked to name the colour in which words are presented. As word reading is highly automatic in proficient readers, participants' responses are significantly slower and less accurate when the colour in which the word is presented is incongruent to the words semantic meaning, e.g. BLUE.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Attention Network Test (ANT)	Bish et al., 2005; Bush, Luu, & Posner, 2000; Fan et al., 2002; Fan et al., 2003; Fan et al., 2005; Fan, Kolster et al., 2007; Fan, Byrne et al., 2007; Fernandez-Duque & Black, 2006; Jha et al., 2007; Klein, 2003; Kratz et al., 2011; Mezzacappa, 2004; Neuhaus et al., 2010; Polak, 2009; Posner et al., 2002; Rueda et al., 2004; Sobin et al., 2004; Tang et al., 2007; Wang et al., 2005; Zhou et al., 2011.	3	Executive Attention, Conflict Monitoring, Attention Shifting /Orienting, Sustained attention/ Alerting.	Stimuli consist of a row of 5 visually presented horizontal black lines, with arrowheads pointing left or right. The target is a left or right arrowhead at the centre. To introduce a conflict-resolution component the central arrow is ‘‘flanked’’ on either side by 2 arrows in the same direction (congruent condition) or the opposite direction (incongruent condition). To introduce attentional orienting and alerting components to the task, the row of 5 arrows are presented in 1 of 2 locations, above or below fixation, and 3 possible warning cue conditions, a centre cue, no cue, and a spatial cue, are utilised.
Emotional Stroop e.g. Emotional Counting Stroop (ECStroop Task)	Emotional Stroop: Allen et al., 2012; Anderson et al., 2007; Bernat et al., 2001; Carretie et al., 2001; Foa et al., 1993; Hope et al., 1990; Ito et al., 1998; Johnston et al., 1986; Junghofer et al., 2001; Mathews & MacLeod 1985; McNally et al., 1990; McNally et al., 1992; Thomas et al., 2007; Watts et al., 1986; Williams et al., 1996. ECStroop: Whalen et al., 1998	3	Executive Attention, Conflict Monitoring, Inhibition, Attentional Processing of Affective Stimuli.	In a typical emotional Stroop paradigm participants are presented with colour words of negative and/or positive valence. Emotional Stroop stimuli are typically used in patient samples. When patients are presented with colour words relevant to their current concerns or condition automatic processing of the words meaning delays naming of the word’s colour. The pre-potent word meaning causes emotional conflict which leads to an increase in RTs. However, increased response latency is not typically seen in normal healthy adults. The ECStroop has been shown to activate the affective subdivision of the ACC.
The d2-test of attention	Gaden Jensen et al., 2012; Moore & Malinowski, 2009; Friese et al., 2011	3	Attentional Control, Inhibitory Control, Selective Attention.	The d2 test is a paper pencil test. The participants task is to scroll through rows of targets and non-targets, striking through targets when they are found. The targets and non-targets are very similar meaning that selective attention and inhibitory control are both needed in order to discriminate which items are targets.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
The Wilkins Counting Task	Valentine & Sweet, 1999	3	Sustained attention.	The Wilkins Counting Test requires participants to attend to and count a series of auditory bleeps that are presented at a set frequency (e.g. 0.25 Hz, 1 bleep every 4 seconds).
Posner Cuing Paradigm	Hodgins & Adair, 2010	3	Selective attention, Orienting.	The Posner cuing paradigm utilises spatial cues to direct attention to where a target will appear. Responses are faster when valid spatial cues are given and delayed for invalid cues.
Global to local task	van Leeuwen et al., 2012	3	Selective attention.	When attending to the global shape of an object, such as a tree, there is less attention available to attend to the fine grained detail, such as the leaves, and redirecting attention between levels – from the global shape to the local details or vice versa – is known to be inherently slow. In psychophysical tests subjects are typically much faster in detecting the global pattern than the local detail; this phenomenon is known as the "global precedence effect." The task utilised by van Leeuwen et al, displayed numbers arranged in a pattern so that they made a larger number at the global level.
The Controlled Oral Word Association Test	Zeidan et al., 2010	3	Verbal Fluency.	The Controlled Oral Word Association Test (Benton, 1989) is a measure of verbal fluency in which subjects are asked to say as many words as they can think of beginning with the letters ''F, A, and S", or ''C, F, and L" within one minute. The dependent measure is the total number of words produced.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
The Symbol Digit Modalities Test	Zeidan et al., 2010	3	Working Memory.	The Symbol Digit Modalities Test (Smith, 1982), written version, is a measure of complex visual tracking and working memory that requires decoding of a series of numbers listed on paper according to a corresponding template of visual symbols. With the use of a reference key, participants are given 90 s to accurately match numbers with corresponding geometric figures. The dependent measure is number of symbols coded minus errors.
N-back task	Zeidan et al., 2010	3	Working Memory, Attention, Speed of Processing.	In a typical N-back task participants view a sequence of letters and indicate whether or not a probe letter is the ‘‘same” or ‘‘different” as the stimulus item presented ‘N’ items back.
Dual Attention to Response Task (DART)	Gaden Jensen et al., 2012	3	Sustained Attention, Vigilance.	In the DART white and grey digits are presented sequentially in cycles. Participants are instructed to monitor the digit colour, Responding with different keys for white and grey digits but to always withhold the response after the digit *3*.
Spatial and Temporal Attention Network (SPAN)	Gaden Jensen et al., 2012	3	Orienting, Spatial Attention	In the SPAN task a cue is presented centrally on the screen, flanked by 2 boxes inside of which a target will appear. Both spatial (pointing at either box) and temporal cues (detailing when in time a target will appear) can be used. Valid, invalid and neutral spatial and temporal cues can be used.
CombiTVA paradigm	Gaden Jensen et al., 2012	3	Visual attention, Working Memory.	Stimuli are presented in 6 possible locations on an imaginary circle. The stimuli are in 2 different colours and the participants’ task is to report all of the stimuli that were observed in the target colour. The number of targets and length of mask between stimulus presentation and response is varied.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Water Jug Task	Greenberg et al., 2012	3	Executive Attention, Cognitive Rigidity	Participants viewed 3 jars onscreen marked A, B, and C with numbers indicating their size, and a target cup indicating the goal to obtain. Participants are instructed to obtain the goal amount of water by adding or subtracting the jars given in each problem, while applying the simplest and shortest solution.
Object Detection Task	Anderson et al., 2007	3	Selective Attention.	This task required participants to report the presence/absence of a named object as quickly as possible when it was presented in consistent or inconsistent scenes (e.g. a chicken in a barnyard vs. a classroom). Consistency effects are evident as an increased reaction time being needed to identify targets in inconsistent vs. consistent scenes.
Dichotic Listening Task	Lutz et al., 2009	3	Selective Attention.	In a typical dichotic listening task participants are instructed to attend to and report the occurrence of tones in one ear although tones are actually presented in to both ears. Distracting tones are typically used.
Internal Switching Task	Chambers et al., 2007	3	Sustained Attention, Task Switching.	Participants switched between a neutral and affective task. In the neutral task participants were presented with words that were from 2 semantic categories, food and household items. The task was to keep a mental count of the number of items presented in each category. For the affective task, negative and positively valenced words were presented and the task was to assess the valence of the word and to keep a mental count of how many words from each category were presented.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Digit Span backward subscale of Wechsler Adult Intelligence Scale	Chambers et al., 2007	3	Working Memory.	Participants must recall digits they have just been presented with. In the backward subscale they must recall these digits backwards, from the last digit presented to the first.
Choice Reaction Time Task	van den Hurk et al., 2010	8	Executive Attention, Selective Attention.	In this choice reaction time task participants had to move their head to face and select a stimulus presented on either the left or right hand side of a screen. Warning cues were utilised to warn the participant of an upcoming spatial cue which in turn gave information regarding the upcoming location of the target stimuli.
Auditory Oddball Task	Cahn & Polich, 2009	8	Executive Attention, Inhibitory Control.	In a typical auditory oddball task, target, distracter and oddball tones are presented. The oddball tone will typically elicit a higher P3 ERP component as it is infrequent and novel compared to the more frequent target and distracter stimuli.
Digit Discrimination Task	Deaton & Parasuraman, 1993.	9	Sustained Attention, Vigilance.	Digit discrimination tasks typically require participants to respond only to the appearance of one digit out of a number of potential digits that are displayed over the course of the task. For example, participants may randomly be presented with the digits 0-9 and should only respond when they see the 0.
Simulated Air Traffic Control Task	Thackray & Touchstone, 1981.	9	Sustained Attention, Vigilance.	2- h simulated air traffic control task with alphanumeric symbols.
Continuous Performance Task (CPT)	Davies & Davies, 1975; Hammerer et al., 2010; Mani et al., 2005.	9	Sustained Attention, Vigilance, Executive Inhibition.	CPT's typically require attention to be sustained over extended periods of time in order that participants are able to respond to *rarely* presented stimuli.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Digit Cancelation Task	Filley & Callum 1994.	9	Sustained Attention, Vigilance.	In a digit cancellation task participants are typically given a list of digits with the instruction to strike through 1 or more digits as they make their way through the list.
Mackworth Clock Test	Giambra & Quilter, 1988; Surwillo & Quilter, 1964.	9	Sustained Attention, Vigilance.	The Mackworth Clock test typically involves a red dot moving around a circle in a pattern similar to the seconds hand of a clock, with 1 space moved every 1 second. At infrequent and irregular intervals the dot makes a double jump and the participant's task is to identify when these occur.
Sensory Vigilance Task	Giambra, 1997.	9	Sustained Attention, Vigilance.	Detection of 17 mm × 17 mm squares among 20 mm ×20 mm neutral squares
Go/No-go tasks e.g. SART	Bekker et al., 2004; Beste et al., 2008; Bokura, 2002; Bruin and Wijers, 2002; Carriere et al., 2010; Fallgatter et al., 1997; Fallgatter and Strik, 1999; Heilbronner et al., 2013; Jackson & Balota, 2011; Jodo and Inoue, 1990; Jodo and Kayama, 1992; Kok, 1986; Langenecker et al., 2003; McAvinue et al., 2012; Nielson et al., 2002; Nieuwenhuis et al., 2003; Pfefferbaum et al., 1985; Roberts et al., 1994; Schmajuk et al., 2006; Sebastian et al., 2013; Smith et al., 2006; Smith et al., 2007; Vallesi et al., 2009; Vallesi et al., 2011; Vallesi, McIntosh & Stuss, 2011; Van't Ent and Apkarian, 1999.	9	Sustained Attention, Vigilance, Executive Inhibition.	Go/No-go tasks typically involve a large number of responses and rare non-target stimuli which require the participant to inhibit a pre-potent response. During a typical SART, digits are presented 1 at a time in the centre of a computer screen, e.g. the numbers 1-9 and the participants task is to respond to all numbers except for a non-target stimulus, e.g the number 3.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Stop-signal Task	Andrés et al., 2008; Boecker, 2007; Hu et al., 2012; Rubia et al., 2003; Sebastian et al., 2013; Williams et al., 1999.	9	Sustained Attention, Vigilance, Executive Inhibition.	In a typical stop signal task participants have to execute a choice reaction time task in response to a target (Go condition), except in those trials where, at variable stimulus onset asynchronies, a tone stopping signal (No-go condition) follows the target. Thus the participant must inhibit an already prepared response, i.e. cancel a planned action.
Simon Task	Kubo-Kawai & Kawai, 2010; Lubbe & Verleger, 2002; Maylor et al., 2011; van der Sebastian et al., 2013; West & Alain, 2000.	9	Sustained Attention, Vigilance, Executive Inhibition.	Stimuli in a typical Simon task may be a right facing arrow presented on the left hand side of a computer screen, with the participants' task being to ignore the location of the arrow and respond to the direction it is pointing. Thus interference inhibition is required as the stimuli create a conflict in response selection by co-activating response tendencies due to incompatible stimulus dimensions.
Eriksen Flanker Task	Endrass et al., 2012; Waszak et al., 2010.	9	Executive Attention, Conflict Monitoring	A typical Eriksen Flanker paradigm consists of a row of 5 stimuli, with the target stimuli in the middle flanked by 2 stimuli on either side. For incongruent trials the flanking stimuli conflict with the target stimuli on a task related stimulus dimension. For example, the stimuli may be 5 arrows and in an incongruent trial the flanking stimuli would be pointing in the opposite direction to the target stimuli. This incongruence typically leads to slower RTs and poorer accuracy.

Task	Papers	Chapter Introduced	Functions Tested	Task Overview
Spatial Short Term Memory (SSTM)	Lewandowsky et al., 2010	10	Spatial Short Term Memory, Working Memory.	The SSTM consists of trials wherein 1-6 dots are consecutively displayed into cells of a 10x10 grid, with only 1 dot appearing on the screen at a time. Participants are instructed to remember the spatial relations between dots and to reproduce the overall pattern of dots into a blank grid following a brief mask at the end of the stimulus presentation.
Counting Stroop Task (cStroop Task)	Barrós-Loscertales et al., 2011; Bush et al., 1998; Bush et al., 1999; Roth et al., 2006; Strakowski et al., 2005; Tlustos et al., 2011.	11	Executive Attention, Conflict Monitoring, Inhibition.	Similar to the original Stroop task (Stroop, 1935) the cStroop produces cognitive interference by pitting 2 competing information processing operations against each other. Whereas word reading and colour naming are in competition in the classic Stroop, the cStroop utilises word reading and counting processes to create conflict. A typical cStroop trial will involve the presentation of 1-4 words on the screen and in an incongruent trial the word will be a number word and the amount of numbers will be incongruent with the meaning of the word, e.g. ONE presented 3 times. Congruent conditions wherein the word and number presented match and neutral trials wherein the word meaning does not related to the task (e.g. chair presented 3 times) are also typically included.
Operation Span Task	Mrazek et al., 2013.	14	Working Memory	In this complex span task, presentations of to-be-remembered stimuli are alternated with an unrelated processing task (e.g. to verify the accuracy of presented equations). In each of 15 trials, the to-be-remembered items were sets of 3 to 7 letters chosen from a pool of 12 letters and presented for 250 ms each. At the end of each trial, participants selected the presented items in the order in which they had appeared.

Appendix B: Summary of details for a representative sample of longitudinal MT studies

Study	Area of study	Type of MT	Comparison Group
Anderson et al., 2007	Attention	MBSR	Waitlist control
Chambers et al., 2008	Attention, working memory	Vipassana	No practice
Cusens et al., 2010	Chronic pain (pain management study)	Breathworks (including mindful breathing, moving and body scan)	Treatment as usual
Davidson et al., 2003	Brain and immune function	MBSR	Waitlist control
Gaden Jensen et al., 2012	Attention	MBSR	1. Non-mindfulness based stress reduction. 2. No practice.
Greenberg et al., 2012	Attention	MBCT	Waitlist control
Goldin et al., 2013	Attention	MBSR	Aerobic exercise
Hargus et al., 2010	Meta-awareness, memory specificity	MBCT	Waitlist control
Heeren et al., 2009	Memory	MBCT	Waitlist control
Hőlzel et al., 2011	Structural changes in brain networks	MBSR	No practice
Jain et al., 2007	Stress	MBSR based	1. Somatic Relaxation 2. No practice
Jha et al., 2007	Attention	1. MBSR 2. Intense Vipassana retreat	Waitlist control
Jha et al., 2010	Working Memory	Mindfulness Based Mind Fitness Training (MBMFT)	No Treatment
Kilpatrick et al., 2011	Attention	MBSR	Waitlist control

Study	Area of study	Type of MT	Comparison Group
Kuyken et al., 2010	Depression	MBCT	Maintenance anti depressive medication
Ortner et al., 2007 (Study 2)	Emotional interference on a cognitive task	Mindfulness meditation	1. Relaxation meditation course: included visualization, breathing, progressive muscle relaxation, spin breathing, body scans and discussion. 2. Waitlist control
Polak, 2007	Attention	Mindfulness based breath awareness meditation	1) Progressive Relaxation Training 2) Neutral task, e.g. make a list of places visited yesterday.
Semple, 2010	Attention	Mindfulness meditation (no further detail given)	1. Muscle relaxation, to control for physical relaxation effects on attention 2. Wait list
Slagter et al., 2007	Attention	Vipassana Retreat	No practice
Splevins et al., 2009	Emotional Distress	MBCT	None
Tang et al., 2007	Attention	Integrative mind body training	5 days of relaxation training, involved relaxation of body parts.
van Leeuwen et al., 2012	Attention	Open monitoring meditation retreat	No practice
VanVugt, 2010	Working Memory	Intensive retreat based on Sathipattana Sutra	No practice
Wenk-Somaz, 2005	Attention	Mindfulness based breath awareness meditation	1. Learning task, learning a list through mneumonics 2. Rest, mind wandering
Zeidan et al., 2010	Verbal fluency, working memory, visual coding	Mindfulness based breath awareness meditation	Story listening

Appendix C: Cognitive and Physical Activity Scale

Please indicate how often you perform the following activities by ticking the appropriate option.						
	Daily	**Several days per week**	**Once weekly**	**Monthly**	**Occasionally**	**Never**
1. Reading books or newspapers						
2. Writing for pleasure						
3. Doing crossword puzzles						
4. Playing board games or cards						
5. Participating in organised group discussions						
6.Playing musical instruments						
7. Playing tennis						
8. Playing golf						
9. Swimming						
10. Bicycling						
11. Dancing						
12.Participating in group exercises						
13. Playing team games such as bowling						
14.Walking for exercise						
15. Climbing more than two flights of stairs						
16. Babysitting						

	Daily	Several days per week	Once weekly	Monthly	Occasionally	Never
17. Doing housework						
18. Critical thinking						
19. Problem solving						
20. Dealing with novel/new situations						
21. Multi-tasking						
22. Performing calculations or using mathematical skills						
23.Spending more than 30 minutes a day moving around at work						
24. Using a computer						
25. Creative thinking/ generating new ideas						
26. Spending more than an hour a day on your feet at work						
27. Lifting and carrying						
28. Climbing stairs						
29. Typing						

Appendix D: Peer Reviewed Publication for Improvements in Electrophysiological Markers of Attentional Control Following Regular, Brief Mindfulness Practice

frontiers in
HUMAN NEUROSCIENCE

ORIGINAL RESEARCH ARTICLE
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Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control

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Mindfulness-based meditation practices involve various attentional skills, including the ability to sustain and focus ones attention. During a simple mindful breathing practice, sustained attention is required to maintain focus on the breath while cognitive control is required to detect mind wandering. We thus hypothesized that regular, brief mindfulness training would result in improvements in the self-regulation of attention and foster changes in neuronal activity related to attentional control. A longitudinal randomized control group EEG study was conducted. At baseline (T1), 40 meditation naïve participants were randomized into a wait list group and a meditation group, who received three hours mindfulness meditation training. Twenty-eight participants remained in the final analysis. At T1, after eight weeks (T2) and after 16 weeks (T3), all participants performed a computerized Stroop task (a measure of attentional control) while the 64-channel EEG was recorded. Between T1 and T3 the meditators were requested to meditate daily for 10 min. Event-related potential (ERP) analysis highlighted two between group effects that developed over the course of the 16-week mindfulness training. An early effect at left and right posterior sites 160–240 ms post-stimulus indicated that meditation practice improved the focusing of attentional resources. A second effect at central posterior sites 310–380 ms post-stimulus reflects that meditation practice reduced the recruitment of resources during object recognition processes, especially for incongruent stimuli. Scalp topographies and source analyses (Variable Resolution Electromagnetic Tomography, VARETA) indicate relevant changes in neural sources, pertaining to left medial and lateral occipitotemporal areas for the early effect and right lateral occipitotemporal and inferior temporal areas for the later effect. The results suggest that mindfulness meditation may alter the efficiency of allocating cognitive resources, leading to improved self-regulation of attention.

Keywords: meditation, mindfulness, cognitive control, EEG, Stroop, interference, attention

INTRODUCTION

During the last decade the scientific interest in the effects of meditation and mindfulness practice has experienced an unprecedented surge. A growing number of studies are confirming benefits of mindfulness practices in a broad range of psychologically relevant domains (Grossman et al., 2004; Chiesa and Serretti, 2009, 2011). After an initial phase of demonstrating general benefits, research is increasingly zooming in on more detailed questions regarding the underlying mechanisms that contribute to the observed changes.

Mindfulness meditation practices are considered to entail at least two central components: the training of attentional skills and the development of an equanimous, non-judgmental attitude toward one's own experiences, toward sensations, thoughts and feelings, where arising experiences are acknowledged without elaboration or reaction (e.g., Kabat-Zinn, 1990, 2003; Bishop et al., 2004; Malinowski, 2008). Although conceptualizations may differ in some specific details, as for instance the inclusion of additional components such as the intention to practice (Shapiro et al., 2006), or the provision of a more fine-grained classification of contributing factors (Dorjee, 2010), the development of attentional skills is included as a fundamental factor throughout (Lutz et al., 2008). The basic training of attentional skills is thought to underpin other changes that lead to positive health outcomes and well-being (Chiesa and Malinowski, 2011; Malinowski, 2012). Most importantly, attentional stability, clarity, and flexibility are thought to be prerequisites for maintaining a non-judgmental attitude toward one's experiences. In a first approximation these two components of mindfulness practice have been described in cognitive terms as focused attention and open monitoring (Lutz et al., 2008), which, depending on the particular meditation system, may be practiced selectively or in a combined fashion.

As the development and refinement of attentional skills appears fundamental to all forms of mindfulness meditation practice, it is not surprising that a major line of investigation focuses on revealing how meditation practice influences various aspects of attentional performance and the underlying brain mechanisms (e.g., Valentine and Sweet, 1999; Lutz et al., 2004; Wenk-Sormaz, 2005; Anderson et al., 2007; Brefczynski-Lewis et al., 2007; Jha et al., 2007; Chambers et al., 2008; van Leeuwen et al., 2009; Hodgins and Adair, 2010; van den Hurk et al., 2010; Zeidan et al., 2010). Chiesa et al. (2011) provide a systematic review of studies into this topic that were published until May 2010. So far, the findings suggest that meditation practice may increase the efficiency of attention networks (Corbetta and Shulman, 2002; Raz and Buhle, 2006; Posner and Rothbart, 2007), where executive control functions that comprise of mental set shifting, the updating and monitoring of information and, crucially, the inhibition of prepotent responses play a central role (Miyake et al., 2000).

However, extant research varies greatly regarding study design, levels of meditation experience, and various other aspects, meaning that straightforward conclusions regarding possible causation are difficult. For instance, the majority of studies only used a cross-sectional approach, which does not answer the question whether meditation practice is *causally* involved in observed differences between meditators and non-meditators. Other studies investigated meditators with rather varied meditation experience or from different meditation traditions, and a number of other studies employ intervention packages like the mindfulness-based stress reduction program (MBSR; Kabat-Zinn et al., 1985, 1987, 1992), which entails other aspects like yoga exercises and psychoeducative components. While all of these studies are worthwhile and make important contributions to our understanding as to how mindfulness practice influences attentional functions (Williams, 2010), it is important to complement these findings with studies that directly investigate the effects of meditation practice over time, while keeping additional aspects that may influence the results to a minimum.

In studies that focused on investigating a specific meditation practice rather than employing more comprehensive intervention programs like MBSR the time period and the amount of daily meditation practices varied considerably. At the lower end are studies that used only very brief periods, as for instance Polak (2009), who investigated the effect of only two 15 min meditation sessions or a study by Wenk-Sormaz (2005), where participants completed three times 20 min of meditation practice. At the upper end changes resulting from meditation retreats, where participants are withdrawn from ordinary life for longer periods of time, were investigated. Chambers and co-workers (2008) investigated the effects of a 10-day meditation retreat, Jha et al. (2007) and van Vugt and Jha (2011) studied the effects of one-month mindfulness meditation retreats while other studies investigated the effects of different three month meditation retreats (Slagter et al., 2007; Lutz et al., 2009; MacLean et al., 2010; Jacobs et al., 2011; Sahdra et al., 2011). Between these endpoints a few further studies used dosages of meditation practice that can more easily be integrated into ones daily routines. In a study by Semple (2010) participants were asked to practice mindfulness meditation for 20 min twice per day over a period of one month. Tang et al. (2009) employed 20 min of daily integrative mind-body training (IBMT) over a period of five days and another study by Tang et al. (2010) asked participants to practice IBMT for a period of one month, for 30 min daily, five days per week. As this brief overview shows, there is little coherence regarding the amount or dosage of meditation practice. It is thus difficult, if not impossible, to find any guidance regarding the "right" amount and duration of practice. As has been pointed out recently, this issue has not yet been addressed systematically (Slagter et al., 2011).

The present study was designed to address our primary interest of investigating the effects of meditation practice that can easily be integrated into one's life, without requiring major changes in daily routines or life style. A related secondary aim was to study lower boundaries of meditation practice. We were curious to find out whether a rather modest dosage would yield any benefits in terms of cognitive processing. It was thought that 10–15 min of daily meditation practice would be a minimum time period allowing participants to settle in the meditation practice and develop some attentional stability. An additional question was what time period would be required for any changes to appear. Due to the low daily meditation dose, we considered that practice effects might require longer time to emerge. Balancing resources, the required commitment of participants and avoiding interference through breaks due to summer vacations, we settled for a total meditation period of 16 weeks. To get some indication regarding the time course of the changes, an intermediate testing session was included halfway through the study, after eight weeks. To reduce the possible influence of group dynamics that would make unequivocal interpretations of our results more difficult, we furthermore opted for an approach that includes only 3 h of group contact time in groups of three to six participants, early on in the study.

In line with our aim of investigating elementary aspects of mindfulness meditation, a meditation practice was chosen that is common to many forms of mindfulness training. For instance, the mindful breathing practice that was employed here is an integral part of MBSR (Kabat-Zinn, 1990) and MBCT (Segal et al., 2002), is the starting point in contemporary meditation programs as for instance the shamatha training composed by Alan Wallace or of mindfulness practice as explained by Gunaratana (1992). At the same time it is a basic component of different traditional buddhist meditation systems, ranging from early buddhist sources like the Anāpānasati Sutta or the Satipatthāna Sutta (Bhikkhu Bodhi, 1995) to classical Tibetan buddhist instructions (Karmapa Wangchug Dorje, 2009). Thus, the mindful breathing exercises used in this study bear relevance to a large variety of mindfulness approaches and practices.

As we were particularly interested in the effects of meditation practice on executive functions, we employed the Stroop Word-Color Task (Stroop, 1935; MacLeod, 1991), which in a previous study in our lab has revealed large differences between meditators and non-meditators (Moore and Malinowski, 2009). Central to the Stroop task is that the automatized reading of words leads to performance decrements if the semantics of a color word conflicts with naming/indicating the color this word is printed in (e.g., "BLUE" presented in red). Good performance on this task would be indicative of good cognitive control and relatively low automaticity or impulsivity of one's responses. Because the actual meditation training is very different to the Stroop task itself, improvements in the Stroop task would be of interest regarding the question, whether abilities trained in meditation generalize to other tasks and domains beyond the training itself. Thus, although the training consists of merely directing and redirecting one's attention to breathing-related sensations and to disengage from or non-engage with arising thoughts and emotions, changes in the automaticity of reading that is part and parcel of the congruency effect in the Stroop task would be remarkable. As skill learning is usually very task-specific and does not easily generalize beyond the specific tasks, stimuli, or contents (Green and Bavelier, 2008), such changes would furthermore highlight the possibility that mindfulness practice leads to changes of underlying processes rather than specific content (Slagter et al., 2011). Furthermore, such changes could be an indication of improved impulse control or even a fundamental change as to how individuals relate to their experiences, possibly having relevance beyond the cognitive domain itself (Chambers et al., 2009).

To get a precise estimation as to how meditation practice may change the involved neuronal processes, we employed 64-channel EEG recordings, while the participants engaged in a computerized version of the Stroop task. We hypothesized that, compared to a non-meditating, wait list control group, engagement in a regular, brief meditation practice would lead to improvements in attentional performance as indexed by the behavioral Stroop interference effect, which would also be reflected in changes in several electrophysiological parameters. As previous studies found that this Stroop effect is reflected in a late negativity (LN) that typically starts around 350–400 ms after stimulus onset, we expected to find meditation-related changes in this event-related potential (ERP) component (e.g., Liotti et al., 2000; Hanslmayr et al., 2008). First electrophysiological investigations of attention effects in mindfulness meditators furthermore report a reduction of a slightly earlier positivity—the P3 component—in response to a distracter sound (e.g., Cahn and Polich, 2009) and as an indicator of improved resource allocation in the attentional blink task (Slagter et al., 2007), which requires the temporal allocation of selective attention. Accordingly, we also considered this component. As for some other types of meditation also changes in a negative deflection occurring before the P3 in a time range starting from around 150 ms after stimulus onset were reported (Cahn and Polich, 2006), and this earlier negative component (N2) has been implicated in attentional processes (Folstein and van Petten, 2008), it was considered as well. As both the N2 and the P3 have been shown to reflect attentional control mechanisms, while the LN is considered to be an indicator of the Stroop interference effect, we expected that mindfulness practice would influence some or all of these ERP components.

To sum up, the aim of the current research was to investigate whether a simple, brief meditation practice carried out regularly for 16 weeks will lead to detectable changes in cognitive performance and associated neural processes. To reduce the possible influence of some of the factors that made unequivocal interpretations of previous results difficult, we opted for an approach that includes only a minimum of group contact time (3 h) and a limited amount of daily meditation practice (10 min), thus allowing participants to carry on with their daily routines without much change or disruption. Furthermore, this "ten-minutes-per-day" approach that we employed may be a more viable option, for people who may consider integrating mindfulness practice into daily life.

METHODS

PARTICIPANTS

Forty healthy adults (13 males; mean age 35.4 years) were recruited via a combination of online advertisements and from a psychology participant panel maintained at Liverpool John Moores University (LJMU). To be included in the study participants had to be meditation naïve (no previous meditation experience), have normal or corrected-to-normal visual acuity, confirm they have no ongoing or recent mental health problems or neurological disorders (e.g., epilepsy) and confirm they are not receiving any psychopharmacological treatments. Thirty-eight participants described themselves as "White" or "White/British," one as "White/Irish" and one as "White/Caribbean." Fifteen participants classed their religious background as Christian (Christian, Roman Catholic, Church of England), one as Atheist, one as Agnostic. The remaining participants stated no religion. Three students took part in the study. Most of the participants were in full-time or part-time employment or in voluntary work. The majority of participants were educated at least to undergraduate level, with 11 participants with postgraduate qualifications. Due to the nature of the design the participants were aware of the general aims of the study, but no specific hypotheses were explained to them.

The study was carried out in line with the ethics guidelines of the British Psychological Society and was approved by the LJMU Research Ethics Committee. All participants provided written, informed consent and were reimbursed with £10/h for attending the six testing sessions.

Participants were randomly allocated to the meditation group or the waitlist control group, with the restriction that age and gender composition were matched across groups. **Figure 1** summarizes the flow of participants through the study. Twelve participants in the meditation group and 16 in the control group were included in the final analysis of the EEG data. As far as could be ascertained, drop-outs in the meditation group were motivated by personal or health reasons not related to the study itself.

Initial tests of baseline (Time 1) measures are presented in **Table 1** and confirm that the two groups did not differ significantly with respect to age, gender, the different self report measures, or performance measures on the Stroop task.

SELF-REPORT MEASURES

Global well-being

The Subjective Happiness Scale (SHS, Lyubomirsky and Lepper, 1999) was used to assess the global, subjective assessment of participants' own happiness and well-being. The SHS is a brief four-item questionnaire scored on a seven-point Likert scale and includes items like "In general I consider myself a very happy person." High total scores reflect high levels of global well-being/happiness. The SHS has been successfully used in different community-based and college-student samples, showing Cronbach's alpha values between 0.79 and 0.94 (Lyubomirsky and Tucker, 1998; Lyubomirsky and Lepper, 1999).

Mindfulness

The *Five Facet Mindfulness Questionnaire* (FFMQ) was used to assess different aspects of mindfulness that were expected to be

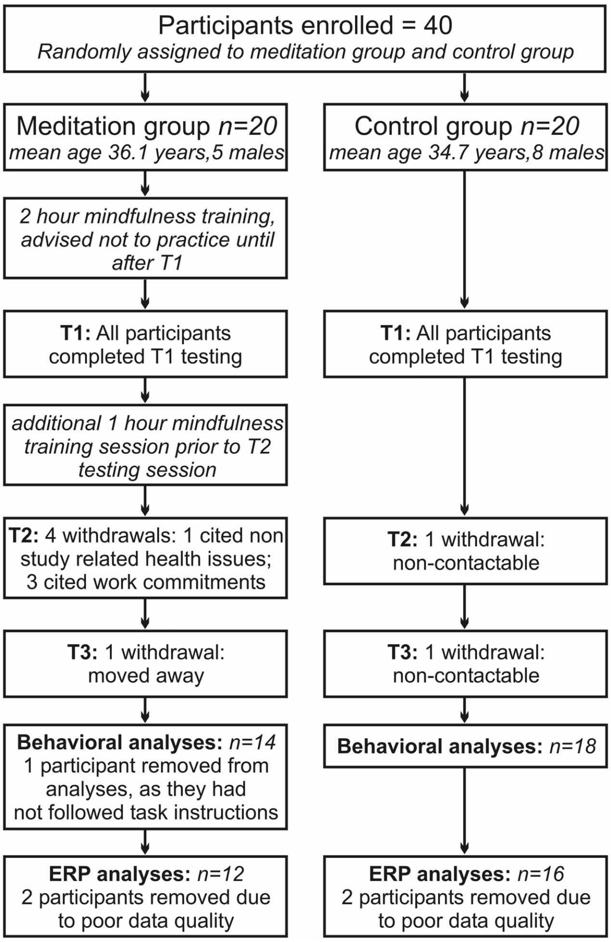

FIGURE 1 | Flow of participants through the study. From randomly allocating 20 participants to each group, for the final analysis 12 participants remained in the meditation group and 16 in the control group.

influenced by mindfulness practice. This 39-item-questionnaire was derived from an exploratory factor analysis of six existing self-report measures of dispositional mindfulness (Baer et al., 2006). Validation on two samples (Baer et al., 2006, 2008) suggests a five factor structure: (1) *Non-reactivity* to inner experience (FFMQ-NR; seven items), e.g., "I watch my feelings without getting lost in them"; (2) *Observing* internal and external sensations including thoughts, emotions, sights, sounds, and smells (FFMQ-O; eight items) e.g., "I intentionally stay aware of my feelings"; (3) *Acting with awareness* describes attending to one's actions in the present moment and can be contrasted with automatic, impulsive, or habitual behaving (FFMQ-A; eight items), e.g., "It seems I am running on automatic without much awareness of what I'm doing"; (4) *Describing* involves labeling internal experiences with words (FFMQ-D; eight items), e.g., "When I have a sensation in my body, it's hard for me to describe it because I can't find the right words"; (5) *Non-judging of experience* means refraining from value judgments or self-criticism (FFMQ-NJ; eight items) "I tend to evaluate whether my perceptions are right or wrong." The response format comprises a five-point Likert scale (1 = never or very rarely true, rarely true, sometimes true, often true, and 5 = very often or always true). After reversing the scores for the 19 negatively worded items, scores between 1 and 5 are summed to produce totals for each subscale and a total scale score (range: 39–195). The FFMQ has been shown to have good internal consistency and significant relationships in the predicted directions with a variety of constructs related to mindfulness. The internal consistencies (Cronbach α) for these facets have been reported as 0.75 for FFMQ-NR, 0.83 for FFMQ-O, 0.87 for FFMQ-A, 0.91 for FFMQ-D, and 0.87 for FFMQ-NJ (Baer et al., 2006).

Meditation log

On a weekly basis participants in the meditation group completed a brief meditation diary (online or paper-pencil version), which recorded how often they meditated in a given week and the average length of the meditation sessions.

PROCEDURES

Potential participants received detailed information regarding the study, completed a screening questionnaire, signed a consent form, and were then randomly allocated to the meditation or control group.

Over the course of approximately 16 weeks, participants were tested at three time points (T1, T2, T3; 8–10 weeks apart). At each time point participants first completed the self-report questionnaires and then performed the experimental task, while the EEG was recorded. Two testing sessions of approximately 90 min length were conducted at each time point, as several other tests were carried out that are not reported in this paper. Around T1, the meditation group received introductory 2 h mindfulness training, in groups of three to six participants. In order to obtain accurate baseline data the meditators were instructed not to begin practicing meditation until after their first testing sessions. A follow up 1 h meditation training session was given to them prior to T2 and throughout the study the participants were able to contact the meditation teacher to answer questions or give further instruction.

MEDITATION INSTRUCTION

Participants in the meditation group were introduced to a simple mindful breathing meditation by a meditation teacher with more than 15 years of teaching experience. In this meditation the meditator is required to focus their attention on the sensations accompanying their breathing, either attending to the experience at the nostrils, around the diaphragm or the movement of the abdomen when in- and exhaling, without manipulating the breath in any form. Whenever the attention would slip or wander off, the task would be to become aware of it and, without further elaboration, to redirect the focus of attention to the sensation of breathing. In addition to this focusing of attention, participants were instructed to observe other mental experiences, arising thoughts, feelings or sensation, trying not to judge or evaluate them, and maintain a curious, non-elaborating attitude toward them. This meditation instruction is in line with common psychological mindfulness conceptualizations that emphasize the development of attentional abilities combined with a specific, non-evaluative attitude toward the different mental experiences that may arise (e.g., Bishop, 2002;

Table 1 | Summary of tests for baseline differences, with mean values, standard deviations (in brackets), and respective statistical values for the comparison between meditation group and control group.

	Meditation group	Control group	Statistical values
Age (years)	36.9 (12.1)	34.6 (11.4)	$t(26) = 0.53$, $p = 0.60$
FFMQ-total	126.9 (15.6)	136.8 (12.6)	$t(26) = -1.86$, $p = 0.08$
SHS	22.0 (2.9)	21.3 (3.4)	$t(26) = 0.62$, $p = 0.54$
RT all trials (ms)	789.3 (102.7)	738.6 (127.9)	$t(26) = 1.13$, $p = 0.27$
RT congruent (ms)	741.0 (102.5)	683.3 (117.6)	$t(26) = 1.35$, $p = 0.19$
RT incongruent (ms)	840.2 (110.7)	798.0 (148.9)	$t(26) = 0.82$, $p = 0.42$
Accuracy all trials (%)	95.9 (2.9)	95.6 (4.7)	$t(26) = 0.23$, $p = 0.82$
Accuracy congruent (%)	98.0 (2.4)	98.0 (2.8)	$t(26) = -0.14$, $p = 0.89$
Accuracy incongruent (%)	94.0 (4.1)	93.0 (7.6)	$t(26) = 0.41$, $p = 0.68$
RT variance all trials (ms)	186.2 (33.4)	181.6 (46.2)	$t(26) = 0.29$, $p = 0.77$
RT variance congruent (ms)	169.4 (35.7)	159.5 (51.6)	$t(26) = 0.57$, $p = 0.57$
RT variance incongruent (ms)	185.7 (37.1)	179.9 (43.5)	$t(26) = 0.37$, $p = 0.71$
Inverse efficiency all trials	8.3 (1.3)	7.8 (1.7)	$t(26) = 0.77$, $p = 0.45$
Inverse efficiency congruent	7.6 (1.2)	7.0 (1.4)	$t(26) = 1.21$, $p = 0.24$
Inverse efficiency incongruent	9.0 (1.5)	8.8 (2.4)	$t(26) = 0.30$, $p = 0.77$

Shapiro et al., 2006; Malinowski, 2008; Chiesa and Malinowski, 2011; Malinowski, 2012). For the period between T1 and T3 (16 weeks) participants were asked to meditate regularly for a minimum of 10 min per day, at least five days per week and to record frequency and duration in their meditation log on a weekly basis. The participants did not receive any particular instructions regarding the body posture beyond the emphasis of trying to sit in an upright, relaxed position with a straight back. They had the liberty to meditate on a chair, meditation stool, or cushion. Given the relatively small sample size and low dosage of meditation we did not expect the specific meditation posture to have a discernable effect and thus did not record these details.

TASK DESIGN AND STIMULI

Stimuli in the Stroop task were the four color words RED, BLUE, GREEN, and YELLOW, presented in the same color as the written word in congruent trials (e.g., RED presented in red) and in different colors (e.g., RED presented blue) in incongruent trials. The task was presented on a 21-inch CRT-monitor (100 Hz vertical refresh rate, 1024 × 768 resolution) and was controlled by the Cogent 2000 toolbox (v1.25) running in the Matlab environment (Mathworks, http://www.mathworks.com). Words were presented in the Arial Font (font size 48 pt), viewed at a distance of approximately 90 cm. Each incongruent stimulus appeared in each of the three other colors with equal frequency. Participants were instructed to respond as fast and accurately as possible and to indicate the color each word was presented in, while ignoring the semantic meaning of the word. Four keys on a standard QWERTY keyboard were used to enter their responses, using the keys "a" (red, left middle finger), "." (blue, left index finger), "x" (green, right index finger), and " ' " (yellow, right middle finger). The keys were color-coded and chosen to provide optimum comfort for the participant whilst responding.

At the beginning of each trial a fixation cross was presented for 500 ms, followed by the color word, which remained on the screen for 1500 ms. The trial concluded with a variable inter-trial interval of between 850 and 1100 ms. The stimulus always appeared centrally on the screen, replacing the fixation cross. The experiment began with a color-to-key acquisition phase which consisted of 48 trials that were similar to those used in the experimental blocks. During this phase, mistakes were highlighted by an audible tone and accuracy and reaction time feedback was given following completion of this phase. The experimental phase consisted of three blocks of 48 trials (50% congruent, 50% incongruent trials) for a total of 144 trials and 72 trials per condition. Each trial block lasted approximately 3 min and was followed by a 20 s break before the subsequent block.

ELECTROPHYSIOLOGICAL RECORDINGS

EEG was recorded continuously from 64 Ag/AgCl electrodes with a BioSemi Active-Two amplifier system (BioSemi, Amsterdam, Netherlands). For monitoring eye movements and blinks the horizontal and vertical electrooculogram (EOG) was recorded with supra- and infraorbital electrodes on the left eye and two electrodes placed next to the external canthi. EEG and EOG were sampled at 512 Hz. Two additional electrodes (Common Mode Sense [CMS] and Driven Right Leg [DRL]) were used as reference and ground (see www.biosemi.com/faq/cms&drl.htm for details). For further off-line analysis, the average reference was used.

EEG was segmented to obtain epochs starting 200 ms prior and 800 ms following stimulus onset. Pre-processing of data was performed in EEGLAB version 9.03 (Delorme and Makeig, 2004). The *Fully Automated Statistical Thresholding for EEG artifact Rejection* procedure (FASTER, Nolan et al., 2010) was employed for removing artifacts from the data. Using a predefined z-score threshold of ±3 for each parameter, artifacts were detected and corrected regarding single channels, epochs, independent components (based on the infomax algorithm, Bell and Sejnowski, 1995) and single-channel single-epochs. Remaining artifactual independent components and epochs containing artifacts were removed after visual inspection. Data were filtered offline with a

1Hz high pass filter. A pre-stimulus baseline from –60 ms to 0 ms was applied.

No between group differences existed regarding the number of trials available for analysis (Meditation group: 129.0, 132.3, and 131.8 Control group: 131.2, 131.7, and 130.3 for T1, T2, and T3, respectively) or the amount of independent components that were removed from the data (Meditation group: 9.3, 10.2, and 8.8; Control group: 11.4, 8.8, and 9.3 for T1, T2, and T3, respectively).

DATA ANALYSIS

Analysis of behavioral and self-report data

For analyzing the behavioral and self-report data we conducted mixed ANOVAs with *Group* × *Time* × *Congruency* as factors for response times (RTs), response variability, and response accuracy and *Group* × *Time* for the self-report measures. As an estimate for the variability of responses over time we used the standard deviation of the RTs of all correct trials in each condition. To account for possible criterion shifts or influences of speed-accuracy tradeoffs, we furthermore analyzed the inverse efficiency scores, derived by dividing the mean RT by the proportion of correct responses, calculated separately for each condition and each participant (Akhtar and Enns, 1989; Christie and Klein, 1995).

Whenever the sphericity assumption (equality of variances) had been violated (Mauchly's test), Greenhouse-Geisser estimates of sphericity were employed to adjust the respective degrees of freedom.

All analyses of behavioral and self-report data were carried out twice, once including all participants that completed the study (14 meditators, 18 controls) and once limited to those participants that were included in the final analysis of EEG data (12 meditators, 16 controls). For consistency we will subsequently only report the latter, because the pattern of relevant results was identical for both approaches.

Analysis of event-related potentials (ERP) — electrode space

A 16 Hz low pass filter was applied prior to all ERP analysis. Based on the grand mean evoked potential (see **Figure 2**), three ERP components of interest were defined: N2 (160–240 ms), P3 (310–380 ms) and a late negative deflection (LN; 400–600 ms) for incongruent stimuli, typical for the Stroop task (e.g., Liotti et al., 2000). Mean amplitudes averaged across the respective time window were calculated for the amplitude maxima identified in the scalp topographies of each component and were subjected to *Group* × *Time* × *Congruency* mixed ANOVAs. Of particular interest for this study were interaction effects that included the factors *Group* and *Time*, as they would indicate that the respective ERP amplitudes were influenced differentially by meditation practice. Accordingly, the analysis primarily focuses on these interactions. As an estimate of the strength of the effect we calculated the effect size *r* for these interactions.

As for the behavioral and self-report data, whenever the assumption of variance equality had been violated we employed the Greenhouse-Geisser procedure to adjust the respective degrees of freedom.

Analysis of event-related potentials (ERP) — source space

To get a general indication of brain areas that may be selectively influenced by meditation practice, we applied Variable Resolution Electromagnetic Tomography (VARETA; Bosch-Bayard et al., 2001) to localize the cortical generators of the relevant ERP components that were identified in the electrode-space ERP analysis. This procedure was applied separately for each factorial combination of *Group, Time,* and *Congruency*. The VARETA approach provides the spatially smoothest intracranial distribution of current densities in source space which is most compatible with the amplitude distribution in electrode space (Gruber et al., 2006). The inverse solution consisted of 3244 grid points ("voxels") of a 3D-grid (7 mm grid spacing). This grid and the arrangement of 64 electrodes were placed in registration with the average probabilistic MRI brain atlas ("average brain") produced by the Montreal Neurological Institute (MNI; Evans et al., 1993). To localize the activation difference between T1 and T3 for each component and congruency condition, statistical comparisons were carried out by means of paired *t*-tests for the meditation group and control group. Activation threshold corrections accounting for spatial dependencies between voxels were calculated by means of false discovery rates (Benjamini and Hochberg, 1995). All statistical parametric maps were thresholded at a significance level of $p < 0.001$.

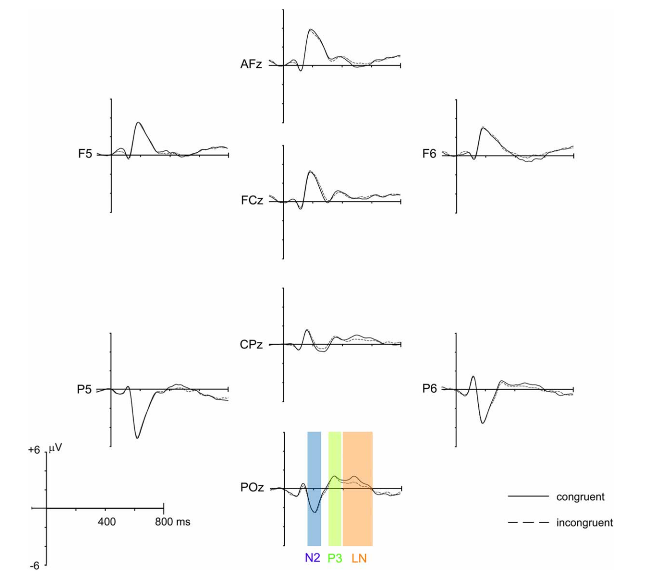

FIGURE 2 | Grand mean average ERPs of all 28 participants for congruent and incongruent stimuli, averaged over Group (meditation, control) and Time (T1, T2, T3). ERPs from eight representative electrodes (out of 64 scalp electrodes) are shown. The three analysis time windows (N2: 160–240 ms, P3: 310–380 ms, and LN: 400–600 ms) are indicated at electrode POz.

RESULTS

TEST FOR GROUP DIFFERENCES AT BASELINE

Group × *Congruency* ANOVAs for RT, accuracy, RT-variability, and inverse efficiencies did not yield any significant main effects for *Group* nor significant *Group* × *Congruency* interactions (all $p > 0.28$) at T1. As summarized in **Table 1**, no significant differences between meditation group and control group were present when direct comparisons at T1 (*t*-tests) were calculated.

BEHAVIORAL DATA AND SELF-REPORT MEASURES

Response times

For RTs significant main effects of *Time* [$F(1.60,41.48) = 4.953$, $p = 0.018$] and *Congruency* [$F(1,26) = 110.554$, $p < 0.001$] were observed, indicating that overall the mean RTs decreased throughout the experiment (T1: 760 ms, T2: 732 ms, T3: 732 ms) and that responses to congruent stimuli were faster (689 ms) than to incongruent stimuli (797 ms). There were no other significant effects. Importantly, neither the *Group* × *Time* interaction nor the *Group* × *Time* × *Congruency* interaction were significant ($p = 0.39$ and $p = 0.15$, respectively).

Response time variability

For the variability of RTs a significant main effect of *Congruency* [$F(1,26) = 43.609$, $p < 0.001$] was observed, reflecting that there was a lower RT variability for congruent (SD = 154 ms) than for incongruent (SD = 181 ms) conditions. Again, no effect that would reflect differential changes in meditation group and control group were present and the respective interaction effects were far from being significant (both $p > 0.56$).

Response accuracy

Only the main effect of *Congruency* was significant [$F(1,26) = 33.604$, $p < 0.001$, congruent: 98.3%, incongruent: 95.1%] and no indication of differential changes between the groups emerged (both $p > 0.26$).

Inverse efficiency

There were significant main effects of *Time* [$F(1,26) = 4.408$, $p = 0.008$] and of *Congruency* [$F(1,26) = 85.224$, $p < 0.001$] but no further significant effects that would indicate differential changes between groups (both $p > 0.14$).

Overall, the analyses of the behavioral results confirm that the task manipulation was effective, reflected by the influence of *Congruency* on task performance. Regarding possible training effects, only an initial speeding up of responses from T1 to T2 was observed, which is also reflected in improved efficiency scores. Beyond that, the data show that behavioral performance did not change differentially for meditation and control group and did not improve after T2.

Mindfulness

For the total mindfulness score, which combines the scores on the five FFMQ subscales, a significant main effect of *Time* [$F(1.640,42.645) = 5.832$, $p = 0.009$] was observed, indicating that overall the mindfulness scores increased from T1 (132.6) to T3 (138.3). This effect was further qualified by a significant interaction between *Group* and *Time* [$F(1.640,42.645) = 5.077$, $p = 0.015$]. As **Figure 3** shows, the increase of mindfulness from T1 to T3 is more pronounced in the meditation group (T3–T1: 11.8 points, $p = 0.015$) than in the control group (T3–T1: 1.1 points, $p = 0.650$). Although the figure appears to suggest a difference between meditation and control group at T1, testing for baseline differences (**Table 1**) showed that these differences were not significant ($p = 0.08$) and may just be an effect of random group allocation.

The analysis of the FFMQ subscales revealed a stronger increase in the meditation group than in the control group for the *observing* (FFMQ-O) subscale [$F(2,52) = 4.300$, $p = 0.019$] and the *non-reacting* (FFMQ-NR) subscale [$F(2,52) = 3.771$, $p = 0.030$]. No other significant effects emerged from the analysis of the FFMQ subscales.

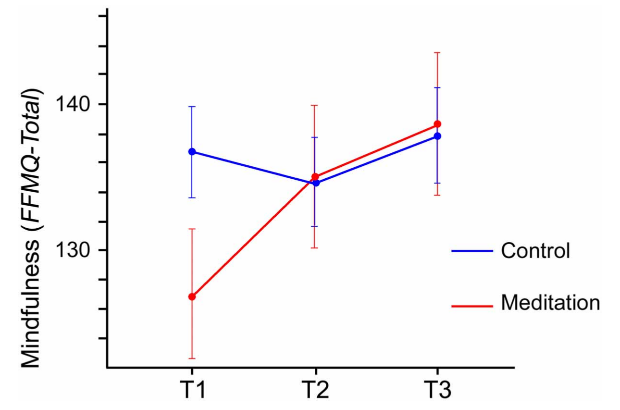

FIGURE 3 | Total mindfulness scores (FFMQ-total, possible range 39–195) for meditation group and control group from T1 to T3. The figure depicts the significant interaction between Group and Time. Error bars show the standard error of the mean.

Meditation time

In general, the participants in the meditation group managed to adhere to the required meditation schedule. Based on the meditation logs, the mean time spent meditating during each session was 11.3 min (range: 6.2–21.5 min) and the average number of meditations per week was 5.0 sessions (range: 2.6–8.7).

Mindfulness and meditation time

To analyze whether the amount of meditation practice would predict the increase in self-reported mindfulness, we calculated the Pearson correlation between the total time spent meditating over the 16 weeks and the changes in mindfulness scores from T1 to T3 in the meditation group. As **Table 2** shows, increases in the total mindfulness score correlated highly with total meditation time. Similarly, changes in three of the five FFMQ subscales (*observing*, *acting with awareness*, *non-judging*) correlated significantly with the total meditation time. None of the other behavioral measures correlated with total meditation time.

Table 2 | Pearson coefficients for the correlations between total amount of time spent meditating between T1 and T3 and increase in mindfulness (FFMQ scores) from T1 to T3.

	Total meditation time
FFMQ-total	0.771 (0.002)
FFMQ-O	0.592 (0.021)
FFMQ-A	0.577 (0.025)
FFMQ-D	0.009 (0.489)
FFMQ-NJ	0.805 (0.001)
FFMQ-NR	0.474 (0.060)

Values in brackets indicate one-tailed significance levels (N = 12).

ERP DATA

Plausibility check

Before investigating the specific effects of meditation training and related between group differences, we confirmed that the resulting ERPs are in line with the typical patterns of electrical activity observed for the Stroop paradigm. **Figure 2** depicts the grand mean ERPs averaged over *Group* (meditation, control) and *Time* (T1, T2, T3) of eight representative electrodes distributed over the whole scalp. The ERP deflections resemble the pattern usually found with the Stroop paradigm. Also the typical late negative deflection (LN) for incongruent trials, considered to be a robust reflection of the Stroop effect, is present in the data (e.g., Liotti et al., 2000).

N2 component

Maxima of the N2 were best captured by small clusters of left occipito-parietal (PO7, PO3, O1) and right occipitoparietal electrodes (PO8, PO4, O2). *Group* × *Time* × *Congruency* ANOVAs revealed significant *Group* × *Time* interaction for the left [$F(2,52) = 3.862$, $p = 0.027$, $r = 0.263$] and for the right [$F(2,52) = 4.273$, $p = 0.019$, $r = 0.276$] electrode cluster. Planned *Group* × *Time* contrasts indicated that this effect reflects relatively higher amplitudes at T3 in the meditation group than in the control group. The relative increase of the N2 amplitude from T1 to T3 in the meditation group contrasted with an amplitude decrease in the control group for left and right clusters [$F(1,26) = 6.421$, $p = 0.018$, $r = 0.445$ and $F(1,26) = 4.987$, $p = 0.034$, $r = 0.401$]. **Figure 4(A)** shows the changes in the ERPs of the two electrode clusters from T1 to T3. The grand mean spherical-spline interpolated T3–T1 topographical difference maps in **Figure 4(C)** show that the N2 amplitudes at left and right posterior sites tend to develop in opposite directions for meditation and control group. **Figure 4(D)** depicts the neuronal sources where the differences from T1 to T3 developed. In the meditation group significant decreases in source strength (salmon-colored) from T1 to T3 for congruent stimuli were observed in the left middle and superior frontal gyri, the left medial and lateral occipitotemporal gyri, and the left middle temporal gyrus. In comparison, an increase of source strength (green color) in the left medial and lateral occipitotemporal gyri was observed in the meditation group. For incongruent stimuli, the control group showed a decrease in source strength in the left lateral occipitotemporal and left inferior temporal gyri, whereas no significant changes were present in the meditation group.

P3 component

The analysis of the P3 component focused on the central posterior amplitude maximum at electrode Pz. There was a significant *Group* × *Time* × *Congruency* interaction [$F(2,52) = 4.711$, $p = 0.013$, $r = 0.288$]. Planned contrasts revealed that this interaction was due to a relative decrease in the P3 amplitude in the meditators in the incongruent condition from T1 to T3 compared to the control group, which exhibited an amplitude increase [$F(1,26) = 9.267$, $p = 0.005$, $r = 0.513$]. The ERPs presented in **Figure 5(A)** show these differential changes from T1 to T3. The grand mean spherical-spline interpolated T3–T1 difference maps in **Figure 5(C)** show the topographical distribution of the changes over time, with a maximum decrease over central posterior sites in the meditation group for incongruent trials, contrasted by an increase in the control group. **Figure 5(D)** provides an indication of the brain areas that show differential source strength at T1 and T3. For the congruent condition a slight decrease in left superior and middle temporal gyri was present that was not present in the meditation group. An important contrast appeared for the incongruent condition. Whereas an increase of source strengths was observed for the control group (left medial and lateral occipitotemporal gyri, left inferior temporal gyrus, and right lateral occipitotemporal gyrus) an opposing pattern appeared for the meditation group. Here the right lateral occipitotemporal gyrus and the right inferior temporal gyrus showed a decrease in source strength from T1 to T3.

Late negative component

The broad negative deflection had a central posterior maximum that was best captured with an electrode cluster comprising of Pz, POz, P1, and P2. The only significant effect that emerged from the analysis was a main effect of *Congruency* [$F(1,26) = 8.219$, $p = 0.008$], confirming the typical Stroop interference effect, with the ERP for incongruent stimuli being negatively deflected compared to the congruent condition (see **Figure 2**).

DISCUSSION

Sixteen weeks of regular, brief meditation practice significantly changed neuronal activity related to executive control functions in the Stroop task. These changes were, however, not accompanied by related improvements in behavioral performance and did not pertain to the late negative ERP component (400–600 ms) that typically reflects the behavioral interference effect in the Stroop task (e.g., Liotti et al., 2000; Hanslmayr et al., 2008).

Meditation practice led to a relative increase of lateral posterior N2 amplitudes over both hemispheres, irrespective of stimulus congruency. Estimation of the neural sources (VARETA) suggests that these changes in the meditation group were primarily driven by increased activity in the left medial and lateral occipitotemporal areas for congruent stimuli, contrasted by decreased activity in similar brain areas in the control group. These left-hemispheric areas of the ventral processing stream have previously been identified as being selectively involved in lexical tasks (e.g., Cohen et al., 2002; Cohen and Dehaene, 2004; Shaywitz et al., 2004), with a similar posterior N2 component as observed here (e.g., Adorni and Proverbio, 2009). It thus seems plausible that this effect reflects more successful or consistent attentional amplification, selective to the word stimuli that were used in this task. This interpretation is in line with the time course of enhanced stimulus processing when attending to non-spatial features of a stimulus. Typically, enhanced negative posterior ERP amplitudes appear from around 100 to 150 ms after stimulus onset (Hillyard and Anllo-Vento, 1998; Hillyard et al., 1998). Even more, the posterior N2 is particularly enlarged when attending to the color as compared to the form of a stimulus (Eimer, 1997). Thus, while the control group exhibited a habituation effect over the course of the study (and 3 × 144 trials), which was expressed in a reduction of the ERP amplitudes and the related cortical source strengths, the meditation group showed the opposite

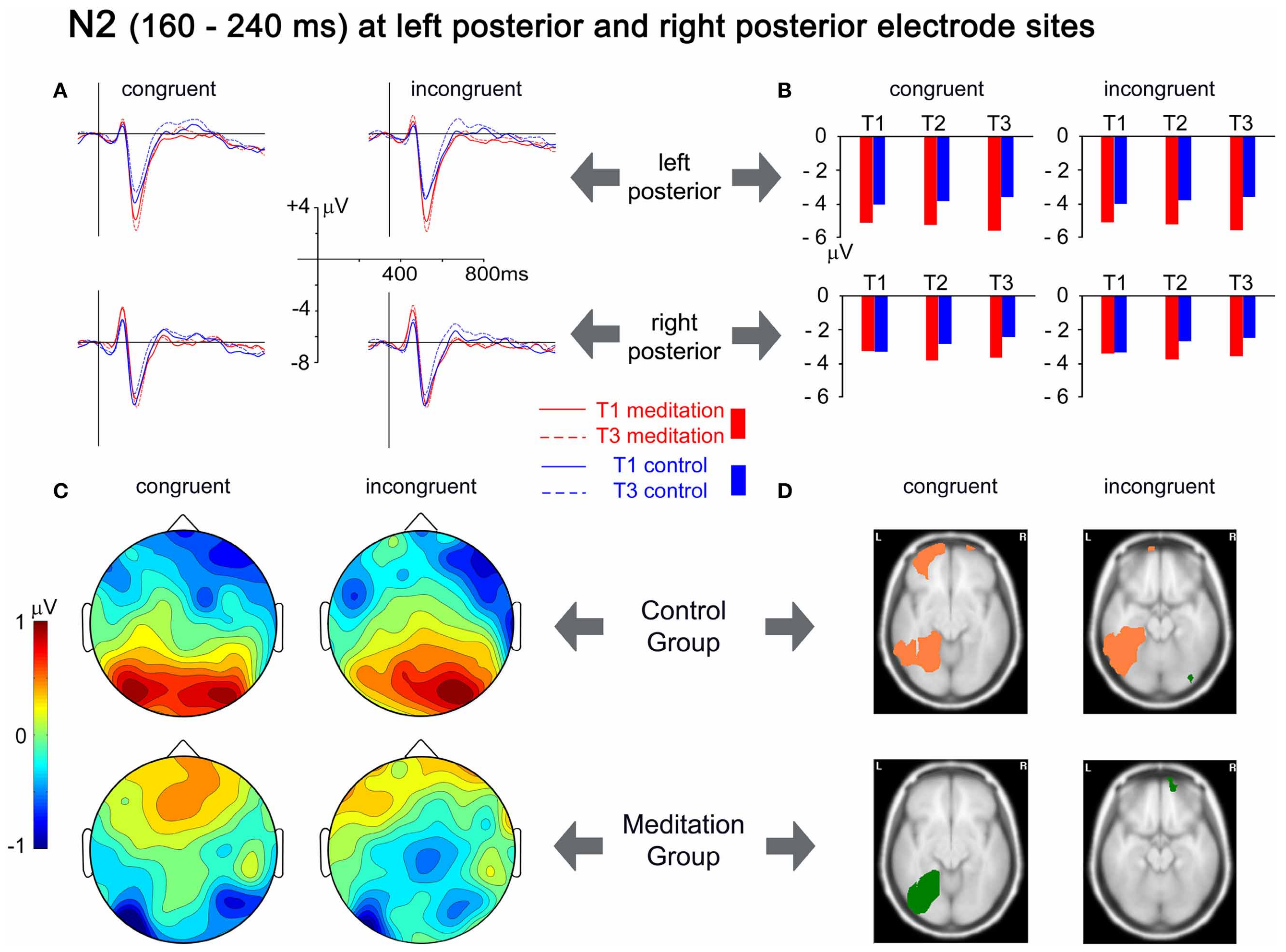

FIGURE 4 | Analysis of the N2 time window, from 160 to 240 ms. **(A)** Grand mean averages for meditation and control group for T1 and T3 averaged over left posterior electrodes (PO7, PO3, O1; upper row) and right posterior electrodes (PO8, PO4, O2; lower row). **(B)** Mean N2 amplitudes from T1 to T3 averaged over the same electrode clusters. **(C)** Spherical spline interpolated scalp topographies of the difference between T1 and T3 (T3–T1) for meditation and control group, separated for congruent and incongruent stimuli. Positive values indicate a decrease in amplitudes; negative values indicate an increase in amplitudes. **(D)** Activation differences between T1 and T3 for each group and congruency, based on the localization of cortical generators with VARETA. Significant differences (threshold $p < 0.001$) are presented for axial MNI slices at $Z = -10$ for congruent stimuli and at $Z = -17$ for incongruent stimuli (centers of gravity of the activation). Salmon-colored areas indicate a decrease in activation and green areas indicate an increase in activation.

pattern, where increased activation of task relevant cortical areas developed with meditation practice.

The second difference between meditators and controls was observed in the P3 component (310–380 ms). The majority of ERP studies of the Stroop task focus on later components starting around 400 ms, as these tend to correlate with behavioral performance (Liotti et al., 2000), whereas the preceding P3 component appears to reflect earlier aspects of stimulus processing that, in themselves, are not the source of the behavioral Stroop interference effect (Ilan and Polich, 1999). Changes of the P3 over the course of the study were primarily observed for incongruent stimuli. While the participants in the control group exhibited an increase of the P3 amplitude for incongruent stimuli, a decrease was observed for the meditation group. The P3 decrease in electrode space was accompanied by significantly decreased signal strength in source space, which comprised lateral occipitotemporal and inferior temporal regions of the right hemisphere. These areas have been implicated in object recognition processes (Schendan and Kutas, 2002; Schendan and Stern, 2007). In addition, the temporal/parietal P3 component is considered to reflect attentional resource activation that is generated when perceptual stimulus discrimination occurs and is linked to related inhibition processes that are required when conflicting stimulus information is present (Polich, 2007). The pattern of results emerging for the P3 component thus suggests that through meditation practice the perceptual processing of incongruent stimuli becomes less resource demanding.

These findings bear similarities to the results from a previous study, where experienced meditators showed a reduced P3 amplitude to a distracter tone during an auditory oddball stimulation while they were meditating (Cahn and Polich, 2009). There are however, noteworthy differences to our study. In Cahn

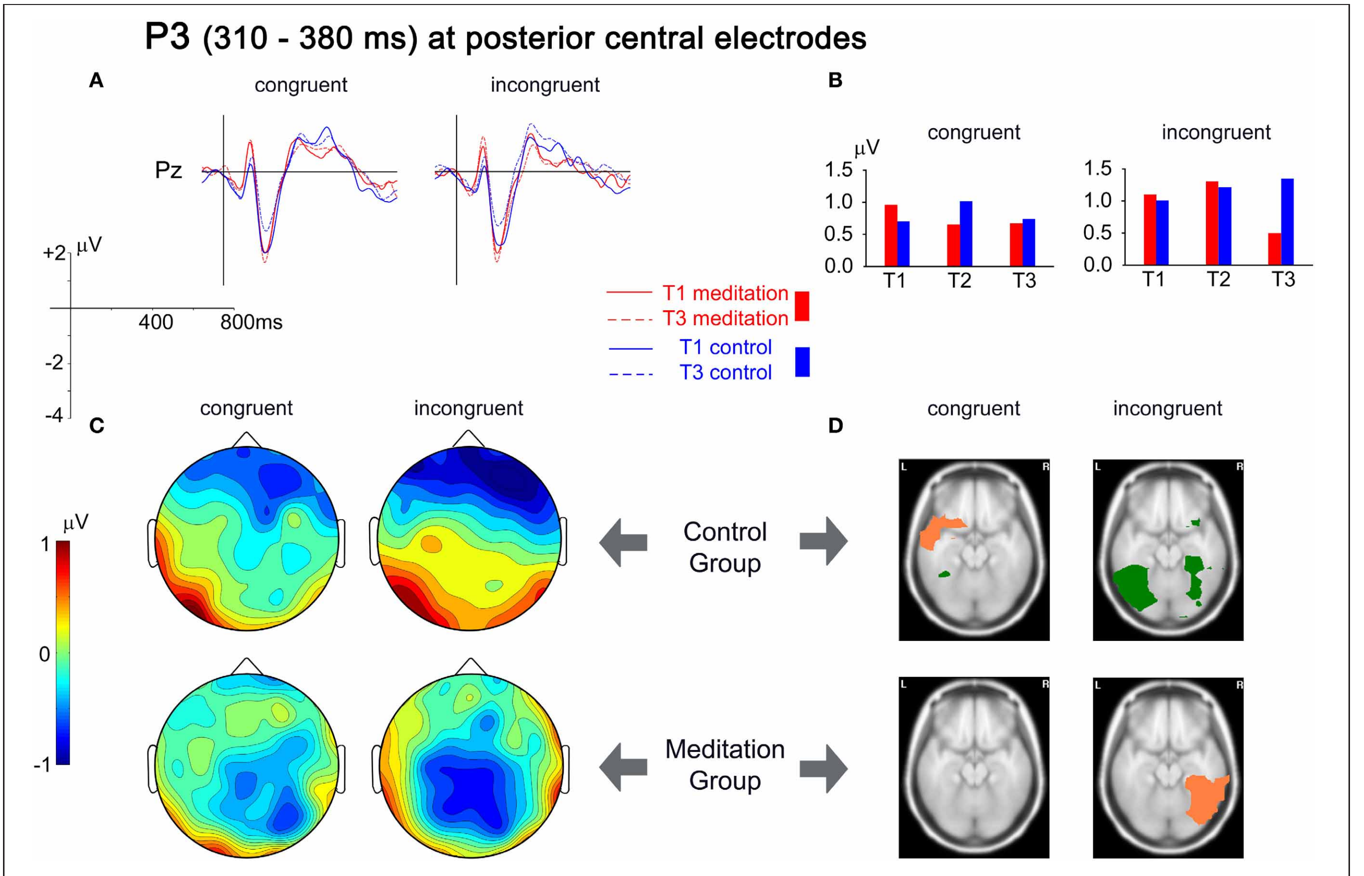

FIGURE 5 | Analysis of the P3 time window, from 310 to 380 ms. **(A)** Grand mean averages for meditation and control group for T1 and T3 for electrode Pz. **(B)** Mean P3 amplitudes from T1 to T3 averaged for the same electrode. **(C)** Spherical spline interpolated scalp topographies of the difference between T1 and T3 (T3–T1) for meditation and control group, separated for congruent and incongruent stimuli. Positive values indicate an increase in amplitudes; negative values indicate a decrease in amplitudes. **(D)** Activation differences between T1 and T3 for each group and congruency, based on the localization of cortical generators with VARETA. Significant differences (threshold $p < 0.001$) are presented for axial MNI slices at $Z = -17$ (center of gravity of the activation). Salmon-colored areas indicate a decrease in activation and green areas indicate an increase in activation.

and Polich's study a meditation state was compared to a neutral thinking state, whereas we studied the effect of meditation in a task that was performed outside of the meditation practice. Furthermore, we investigated changes through meditation practice developing over time, while Cahn and Polich (2009) only tested at one time point and thus do not directly address the question of causal influences of meditation training. The parallels are nevertheless interesting, as they suggest that an ability that developed and is present during meditation practice appears to generalize to a different task performed when not meditating. It may indicate that state effects observed during meditation may translate into trait effects observed outside of meditation (Cahn and Polich, 2006), an assumption that underlies the idea that meditation practice generalizes into daily activities and extends to contexts separate from meditation practice (Hodgins and Adair, 2010; Slagter et al., 2011).

Furthermore, our results are in line with other studies suggesting that meditation practice leads to more effective brain resource allocation (Slagter et al., 2007, 2009). Slagter and co-workers employed the attentional blink paradigm to investigate how a three-month intensive meditation retreat changes the temporal deployment of attention compared to a non-meditating matched control group (Slagter et al., 2007, 2009). During the attentional blink task participants have to attend to a rapidly changing stream of stimuli (e.g., letters) and report the identity of two target stimuli (e.g., digits) after each trial. Performance to the second target in the stream is typically negatively affected if it appears within 500 ms after the first target, the so-called attentional blink effect (Shapiro et al., 1997). After the meditation retreat the meditators showed a reduced attentional blink effect. Furthermore, the P3b amplitude elicited by the first target stimulus was reduced in meditators after the retreat and the participants with the greatest decrease of the P3b amplitude also showed the largest decrease in attentional blink size (Slagter et al., 2007). Interestingly, the additional analysis of the phase of oscillatory theta activity following successfully detected second targets, showed a reduced cross-trial variability, considered to indicate that the deployment of attention was more consistent and that through meditation training attentional resources become more rapidly available to process additional information (Slagter et al., 2009).

The results from a recent fMRI study comparing meditators and matched controls on the Stroop task provide further support for our findings. Compared to a control group, meditators showed reduced activity in various brain areas subserving attention (Kozasa et al., 2012). The authors interpret their overall pattern of findings as evidence of enhanced efficiency in meditators that may result from improved sustained attention and impulse control.

When considering our results of enhanced N2 and decreased P3 amplitudes and source strengths in light of the reviewed findings, a possible interpretation emerges. We surmise that the more successful attentional amplification of the color word stimuli evidenced by increased N2 amplitudes/source strengths had the subsequent effect that fewer resources needed to be invested during object recognition processes, especially when incongruent stimulus information was processed, indexed by the decrease in P3 amplitudes/source strengths.

Confining the meditation training to a very simple, but fundamental, mindful breathing meditation, which often constitutes the first step into a more elaborate path of different meditation practices, gives confidence that the observed changes indeed stem from the meditation practice itself. Having kept the group sessions to a bare minimum (a total of 3 h), makes it furthermore unlikely that unspecific group effects account for the changes. The fact that participants only meditated for very brief periods each day speaks against an explanation that life style changes could explain the observed differences, an influence that may well be relevant when studying the effects of longer daily meditation practices, of meditation retreats or when studying highly experienced meditators.

As meditation effects were compared to effects in a non-active waitlist control group, an alternative explanation might be that the observed effects merely result from the fact that the meditators were engaged in a novel regular activity per se, rather than being specific to the meditation practice. The current design cannot fully rule this out, but given that the observed effects are in line with results from several other studies into similar meditation practices, it appears likely that the effects are more specific. However, the general weakness of waitlist controlled designs in this respect needs to be acknowledged. The study tells us that engaging in 10 min of daily meditation practice for the given period has specific effects. It can, however, not be concluded that these effects are completely unique to meditation practice in general or to this specific type of mindfulness meditation in particular. While the mindfulness training had these effects, other practices or activities may have as well. Future studies will have to face up to the challenge of addressing the question how specific changes associated with meditation training actually are. Toward this end, control conditions that are matched with respect to somatic, mental, and cognitive demands but without actually being meditation practice will be required.

In this study the participants were required to record frequency and amount of meditation practice themselves. As the experimenters appeared to have a good rapport with the participants and it was emphasized that it is more important to provide accurate information than to fulfill a specific regime, we have no specific reason to doubt the honesty and accuracy of these records. We are, however, in no position to objectively confirm this. The fact that we found a positive relationship between mindfulness (FFMQ) and amount of meditation practice might be taken as a positive indicator, but as both are self-report measures they may be prone to similar distortions. Future studies may want to control actual meditation time more objectively. One needs to be aware, though, that this is only possible to a certain extent, because even if, for example, actigraphic measures of rest and activity cycles were available or sensors were integrated into meditation stools or cushions, we have to rely on participant reports whether during a period of physical rest they actually engaged in meditation practice.

An unexpected result of the study was that no differences in behavioral measures between meditation and control group appeared. This finding goes hand in hand with the lack of an effect of meditation practice on the LN, but is at odds with results from several other studies, which tended to show better performance of meditators over controls in similar measures of executive attention and conflict resolution (Chan and Woollacott, 2007; Jha et al., 2007; Moore and Malinowski, 2009). One important difference between such cross-sectional data and the study presented here is that a longitudinal design requires the repeated administration of the same experimental task. In the current study 144 trials of the Stroop task were administered at each time point (to a total of 432 trials). The fact that overall RTs did not improve after T2 (T2: 632 ms, T3 632 ms) and that accuracy was above 95% for incongruent trials, suggests that a performance ceiling might have been reached. A further difference to the cross-sectional study that showed the clearest performance differences between mindfulness meditators and a control group (Moore and Malinowski, 2009) was, that a verbal paper-pencil version of the Stroop task was used, whereas here a computerized version with manual button presses was employed. Several authors have highlighted that the way of administering the Stroop task has an influence on behavioral results and the interference effects in particular (Kindt et al., 1996; Salo et al., 2001). Liotti and co-workers (2000) furthermore showed that different response formats in the Stroop task (verbal, covert, or button press responses) yield differential scalp distributions of the ERPs. Variations in task administration, trial repetition, and related ceiling effects or the type and duration of the investigated meditation practice may have contributed to some diversity in outcomes observed in different studies (Chiesa et al., 2011).

An additional explanation is suggested by new evidence regarding the involvement of the anterior cingulate cortex (ACC) in Stroop-like tasks. The ACC has been shown to be the generator of the LN and to be involved in performance monitoring and response selection (Liotti et al., 2000; Hanslmayr et al., 2008). However, two recent event-related fMRI studies suggest that the role of the ACC is more related to anticipatory regulation of attention rather than the specific selection of responses itself (Roelofs et al., 2006; Aarts et al., 2008). The lack of differential effects in the LN might thus reflect that with extended exposure to the Stroop task anticipatory regulation was perfected in both groups, resulting in the observed ceiling effect. The meditation practice, it seems, has improved earlier stages of processing (indexed by N2 and P3 changes) that reflect more fundamental changes in attentional processing and are less amenable to simple task repetition effects. Although speculative, this would also explain why clear behavioral differences are found when meditators encounter the Stroop tasks for the first time (Chan and Woollacott, 2007; Jha et al., 2007; Moore and Malinowski, 2009), while they tend not to develop on repeated presentation of the same task as was observed here and also reported before (Anderson et al., 2007).

Our results also appear at odds with findings from a longitudinal study carried out by Lutz and co-workers, who found a reduction in RT variability (Lutz et al., 2009) that was not present in out data. There are, however, noteworthy differences to our study in that Lutz et al. investigated changes after much more intensive meditation training (a three-month retreat) and studied the response to rare targets in an auditory task. It might well be that a combination of the already mentioned ceiling effect and the considerable difference in the amount of training accounts for the different outcome.

Despite the lacking evidence of behavioral effects of the meditation practice, significant differences on self-reported mindfulness levels were evident and the increase in mindfulness (FFMQ-total) was correlated with the amount of time participants invested in their meditation practice, suggesting that the time invested in meditation directly translates into recognizable increases in mindfulness. Considering the sample size of $N = 12$ for this analysis, one needs to be cautious, though, to not over-interpret the results of this correlation.

This study focused on the effects of meditation practice on mechanisms of attentional control as indexed by performance and ERP measures related to the Stroop task. However, we do assume that also other aspects of attention may have been influenced by the meditation practice. A recent paper provides an excellent theoretical account, arguing that mindfulness meditation training, developed over longer periods of time, should lead to the enhancement of cognitive core processes including the sustained monitoring of one's own mental states, the ability to disengage from distracting objects and the skill to redirect attention back to the chosen focus (Slagter et al., 2011). We suggest that the observed changes in the N2 and P3 partially reflect the enhancement of such core processes. In line with this view of more wide-ranging changes, our study also included various other measures, results of which we aim to report elsewhere. These pertain to sustained attention and alertness and the orienting of attention without interfering or conflicting stimuli. In addition, these data will allow us to investigate brain dynamics during rest and meditation practice, where we are particularly interested in global brain states, indexed by oscillating neural activity. Several recent studies suggest that there might be differences between meditators and non-meditators (e.g., Lutz et al., 2004; Tei et al., 2009; Cahn et al., 2010) and between different types of meditation (Travis and Shear, 2010) in this respect. Although not directly related to the methodological approach we were using, it is also worth noting that several studies comparing meditators and non-meditators found differences in brain structure (cortical thickness or gray matter), often in brain areas involved in attentional functions (Lazar et al., 2005; Hölzel et al., 2008; Luders et al., 2009; Grant et al., 2010) and first longitudinal studies show such structural changes in gray and white matter even after relatively brief periods of meditation practice (Tang et al., 2010; Hölzel et al., 2011).

CONCLUSION

This study adds to the growing body of research indicating the positive effects of meditation training on the neural systems involved in attentional processes. It is one of only a few studies that investigate such changes in a longitudinal fashion and makes several unique contributions. First of all, we showed that a relatively low dose of only 10 min of practice per day, employed over the course of 16-weeks, significantly changes underlying brain processes that are related to the processing of conflicting stimulus material.

Carrying out a simple mindful breathing meditation for an average of only 10 min per day for a period of 16-weeks improved neural functioning that is indicative of enhanced focused attentional processing (N2) and less resource intensive object recognition processes (P3), suggesting improvements of neural processing related to attentional core processes. These improvements seem to generalize from the specific situation of a meditation exercise (i.e., focusing on breathing related sensations and maintaining a non-responsive attitude to all arising experiences) to the processing of visually presented stimuli and to the disambiguation of conflicting information present in the stimuli. Based on such generalizations we may speculate that meditation practice addresses very fundamental processes of selective and executive attention that may exhibit its beneficial effects in a variety of domains and situations.

The lack of meditation-specific improvements in behavioral performance may be a result of a too low dose of meditation practice, as several studies with experienced meditators show clearly superior performance. An alternative explanation is that the repeated administration of the same task resulted in performance optimization for all participants, beyond which also the meditators were not able to improve. As the present study cannot distinguish between these explanations, it is advisable to choose the tasks of future longitudinal studies carefully and to limit trial repetition as much as possible, in order to avoid possible ceiling effects.

In sum, these findings provide a positive message to everybody who considers taking up mindfulness meditation practice. Even short, regular meditation practice may hone our attentional systems in a useful fashion.

At the end of the study one of the participants expressed how employing the meditation regime influenced their work performance: "*I am completing routine reports in a shorter time period. Also whilst undertaking new tasks I feel that I have a better grasp of understanding complex issues due to improved attention and concentration. (...) It has opened up my train of thought and has led me to think outside the box.*" Such subjective accounts highlight the relevance of the meditation training beyond the laboratory situation and indicate beneficial effects of meditation practices that do not require any life style changes, some of which we aim to capture by employing cognitive neuroscience methodologies.

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