A pilot and feasibility study evaluating the mechanisms and outcomes of neurofeedback-assisted mindfulness meditation training

by

Jeremy M. Viczko
B.Sc., Honors, University of Alberta, 2013
M.Sc., University of Western Ontario, 2016

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We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

SUPERVISORY COMMITTEE

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Abstract

Background: Neurofeedback (NF) has been used for cognitive optimization in non-clinical populations and for therapeutic and rehabilitative purposes in clinical populations, as have mindfulness meditation (MM) training programs. Recent commercial and clinical applications include using NF to help support novice mindfulness meditators in their meditative training. The premise is that NF may help novices learn to meditate more quickly and effectively by providing objective feedback on their brain state during practice. The untested assumption is that novice meditators will therefore also gain desirable cognitive, emotional, and health benefits associated with MM training more quickly, effectively, or perhaps even more robustly. Both NF and MM techniques centrally involve training attention and self-regulation abilities, suggesting some neural mechanistic overlap that could be capitalized on in their combination. However, which aspects of training benefit from, or otherwise interact with the addition of NF with MM practice, and through what psychological (e.g., motivation, expectancy, training experiences) or neurocognitive (e.g., attention, meta-awareness, executive functions) mechanisms, are important questions yet to be investigated by well-controlled studies.

Objectives: Broad aims of this dissertation project were to: (1) create a feasible MM+NF training protocol to evaluate against MM alone, (2) evaluate which neurocognitive domains of function involved in MM training are enhanced (or interfered with) by adjunctive NF, and (3) understand the psychological or neural mechanisms driving any additional improvements in skill or well-being resulting from MM+NF training compared to MM alone.

Methods: A sample of emerging adults (n = 28) with no prior meditation experience were randomly assigned to either a *MM-Only*, *MM+NF*, or *MM+Sham* NF in-lab training condition. The meditation training was for 8 consecutive days, alternating in days between in-lab experimentally assigned meditation condition and at-home practice of a 20-minute breath-focused concentrative mindfulness meditation. A multimethod approach was employed for evaluating participant experiences and outcomes that involved electroencephalographic (EEG) recordings, neurocognitive tests, and self-report measures.

Results: Training conditions were highly comparable across all key efficacy, mechanism, and experiential outcome measures. All groups similarly improved in self-reported psychological wellness and cognitive outcomes across training, with effects sustained at a 10-day follow-up. For neurocognitive testing, groups were also comparable in performance. All training conditions showed increased speed and accuracy, concomitant with higher intraindividual variability of reaction times post-training. No EEG changes were found in pre/post resting state recordings or for in-lab meditations recorded across training.

Conclusion*:* Results support feasibility of the study design and acceptability of the training procedures. MM training was not significantly improved or worsened with the integration of real and sham NF. However, the final sample size was underpowered to adequately delineate medium-to-small effect sizes for primary efficacy and mechanistic measures. The strengths and limitations of this study offer guidance and recommendations for future work aimed at studying or developing NF-assisted meditation training procedures and protocols.

Keywords: Meditation, Mindfulness, Neurofeedback, EEG, Attention, Self-Regulation, Alpha, Contemplative Neuroscience

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INTRODUCTION

An impressive and growing body of scientific evidence continues to document wide-ranging effects beneficial of meditation on many aspects of brain, body, and behavior (Brown & Ryan, 2003; Fox et al., 2014, 2016; Fountain-Zaragoza & Prakash, 2017; Smart, 2019). Clinical interventions that incorporate weekly mindfulness meditation are consistently found to be effective for the treatment of depression, pain conditions, smoking, and addiction disorders (Goldberg et al., 2018). The benefits derived from meditation training relate to total length of daily and long-term practice (Valentine & Sweet, 1999; Chan &Woollacott, 2007; Pagnoni & Cekic, 2007; Parsons et al., 2017), although as of yet, no exact dose-response relationship has been established. Hypothetically, increasing initiation, engagement and maintenance of meditation practices will make the health and well-being benefits more accessible and achievable to those interested in this approach to self-improvement or clinical recovery. Continuing to develop understanding of the mechanisms that underlie the biological, psychological and social effects of meditation is of paramount scientific and public health importance, as is the pursuit of increasing the availability and effectiveness of meditation-based interventions and training.

Another type of mental self-regulation training with purportedly wide-ranging benefits is neurofeedback (NF). NF is a biofeedback technique where brain signals are measured in real time by devices that are used to monitor and provide moment-to-moment information to the trainee about their physiological brain activity. The data is processed and relayed back to the individual using auditory or visual cues to train that the NF user can use to learn to willfully modulate characteristics of their own brain activity (and/or related psychophysiological responsiveness), typically for the purpose of improving cognitive functioning and mental health (Egner & Gruzelier, 2004; Vernon et al., 2003; Norris, Lee, Burshteyn, & Cea-Aravena, 2008; Raymond et al. 2005; Moore, 2000). NF can be conducted with functional magnetic resonance imaging (fMRI), functional near-infrared spectroscopy (fNIRS), magnetoencephalography (MEG), and electroencephalographic (EEG) imaging methods, the latter being the most widely studied and applied due to historical, cost, and accessibility factors (Markiewicz, 2017; Niv, 2013).

Research on the effects of various NF interventions on healthy adults has demonstrated positive outcomes in attention (Egner & Gruzelier, 2004; Vernon et al., 2003), physiological arousal (Fragedakis & Toriello, 2014), anxiety (Moore, 2000), mood (Raymond et al. 2005), and cognitive functioning (Norris, Lee, Burshteyn, & Cea-Aravena, 2008; Hosseini, Pritchard-Berman, Sosa, Ceja, & Kesler, 2016). Notably, these outcomes run parallel to those commonly reported in mindfulness literature, resulting from MM practice and related interventions (Sedlmeier et al., 2012; van den Hurk et al., 2010). However, there are ongoing debates concerning whether the myriad of outcomes observed with NF protocols are primarily the result of training specific neurocognitive abilities (and underlying neural substrates), physiological flexibility (e.g., relaxation control), or whether effects are largely driven by non-specific psychological mechanisms such as placebo/expectancy or general learning effects (Micoulaud-Franchi & Fovet, 2018; Schabus, 2018; Thibault, Lifshitz, & Raz, 2018; Thibault & Raz, 2017, 2018; Witte, Kober, & Wood, 2018).

Recently there has been an intriguing convergence of these two methods of mental training, a field primed for further scientific investigation. A variety of accessible, affordable physiological monitoring and NF technologies are becoming increasingly available for commercial, home, and clinical use, at speeds outpacing research into the effects and mechanisms of available applications. As a result, the effectiveness and cost-benefit consequences of such products and services for clinical and non-clinical use are not well addressed by current literature (Albert et al, 2017; Wexler & Thibault, 2019). One example of this is EEG-based NF to assist in meditation training. The premise is that learning to meditate can be difficult. Individuals interested in meditation training may be dissuaded by concerns of whether they are meditating “right” or not, which may interfere with their engagement with continued practice, and feedback received by NF may help this sticking point. Furthermore, it has been suggested NF may enhance meditation training directly (e.g., initiation, depth, and/or duration of meditative states), and boost the acquisition of the skills and benefits associated with meditation proficiency. Here, the premise is that adding NF monitoring and feedback assists the meditator to develop the awareness of mental-physiological states congruent or incongruent (e.g., mind-wandering, anxious rumination) with various meditative states, thereby enhancing the practice of self-regulating mental-physiological states. A unique benefit of this approach is that NF can provide objective mental state cues and personalized feedback in every session, which is not something achievable with traditional training approaches.

Whether adjunctive NF significantly enhances meditative training and proficiency remains to be demonstrated by cognitive or behavioral data coming from well-controlled studies. It is unclear which aspects of meditation training or neuropsychological functions would benefit from the addition of NF. What specific neural and psychological mechanisms operate across various types of meditation and NF protocols are areas of ongoing research. Attention training has been suggested to be a primary driver, directly or indirectly, of the other wide spread cognitive and psychological benefits for both methods (Chiesa, Calati, & Serretti, 2011; Guendelman, Medeiros, & Rampes, 2017; Jensen et al., 2012). One of many interesting questions that can be explored by evaluating combinations of NF protocols and different meditation techniques is how endogenous (self-cued, as in meditation) and exogenous (externally cued, as in NF) attention and self-monitoring regulation systems interact. How might the combination of these two training methods result in better outcomes than from either training system independently? Alternatively, does the combination of these training systems result in competition or switching costs (e.g., dual tasking) that hinders achieving the benefits otherwise associated with each training method independently? Meditation practices and NF protocols also have unique psychological and procedural components which need to be considered in the effective implementation and evaluation of combined training systems.

Scope and Aims of this Dissertation

Research into the specific ways that NF may help or hinder different aspects of traditional or secular meditation training programs is needed, particularly because NF assisted meditation products and services are widely sold and distributed in commercial and clinical settings. If, and how, integrating these different mental training methods enhances cognitive and emotional self-regulation remains to be tested with strategically developed protocols and measurements tightly coupled to mechanistic conceptualizations. On this background, the purpose of this dissertation was to create and contrast a short-term meditation program, with and without NF integrated into daily meditation practices, to critically evaluate what neural, cognitive, and experiential aspects of meditation training are affected by incorporating NF into meditation training.

A challenge in studying meditation and NF interactivity is that meditation techniques vary in aims, scope, difficulty, and recruitment of brain regions (Travis & Shear, 2010; Brewer et al., 2011; Lee et al., 2012; Fox et al. 2014; Amihai & Kozhevnikov, 2015). There is no generic “meditation” practice. In fact, there is considerable variation in the mental faculties recruited across various meditation practices (e.g., attention, feeling, reasoning, visualization, memory, bodily awareness), the objects to which these faculties are directed (e.g., thoughts, images, concepts, internal energy, aspects of the body, love, God or Deity figures), and the ultimate goals of practice (e.g., enlightenment, wellbeing) (Cahn & Polich, 2006; Fox et al., 2014). There are also a countless NF protocols options, which could also vary considerably in the psychological factors and neural substrates implicated in training. That said, compared to the scientific literature on meditation, the field of NF literature has lagged in both the organization and adoption of field-wide scientific frameworks that might ultimately promote more effective and coherent research movement (Micoulaud-Franchi & Fovet, 2018, Ros et al, 2020). Our research team similarly found stark contrasts in the theoretical and empirical quality of research in evaluating the efficacy of MM-based interventions versus NF-based interventions in a contrast of independent studies (Ali, Viczko, Smart, 2020; Smart, Ali, Viczko, & Silveira, 2022).

To narrow the scope, this dissertation is focused on Mindfulness Meditation (MM) as opposed to other forms or traditions of meditation training. Four reasons were considered for this decision: (1) MM is amongst the most widely studied contemplative practice, and thus there is a substantial body of existing and developing scientific research to draw on (Van Dam et al., 2018); (2) MM is currently one of the most widely practiced forms of meditation in North America, and serves as an entry point into further meditation training and exploration for many people (Walsh & Shapiro, 2006); (3) numerous MM-oriented products and applications already exist (mobile apps like “Calm,” NF devices like the “Muse” meditation headband etc.; Bhayee et al., 2016; Mani et al., 2015; Viczko, Tarrant, & Jackson, 2021), which attests to a broad interest and desire for assistance with MM training, and; (4) preliminary research suggests at least partial overlap between NF and MM in terms of underlying neural mechanisms and outcomes (e.g., Brandmeyer & Delorme, 2013; Chow et al., 2016; Tan et al., 2014). This is particularly the case for a specific type of MM concentrative meditation practice – Focused Attention – that is widely regarded as foundational, and taught prior to other practices in most MM-based programs (Lutz, Slagter, Dunne, & Davidson, 2008). This narrowed focus provides the best grounds to begin systematic development and evaluations of NF-assisted meditation training systems.

Accordingly, this dissertation is organized according to the following sections. Chapter 1 provides a literature review of processes and protocols involved in MM and NF training. This is done to set the theoretical and empirical foundations for the research study that is the primary contribution of this doctoral dissertation. Chapter 2 dives deeper into neuroscientific literature and mechanistic theory that supports the notion that NF can be effectively integrated into MM training. A model framework and a set of competing hypotheses are provided based on the reviewed findings, which are used to inform the measurement, design, and interpretation of the empirical study at the core of the dissertation. Chapter 3 provides a detailed account of the design, methods, and procedures of the experimental study. Chapter 4 reports results related to the overall design and implementation of the meditation training, discussed in term of current and future experimental and applied feasibility considerations. Chapter 5 reports the pre- and post-training outcomes on psychological, cognitive-behavioural, and electrophysiological measure between experimental training conditions. Chapter 6 provides an overall summary and discussion of the results contextualized the broader scope of the scientific literature, including study strengths, limitations, and research recommendations.

CHAPTER ONE

A Comparative Review of Relevant Mindfulness Meditation and Neurofeedback Literature

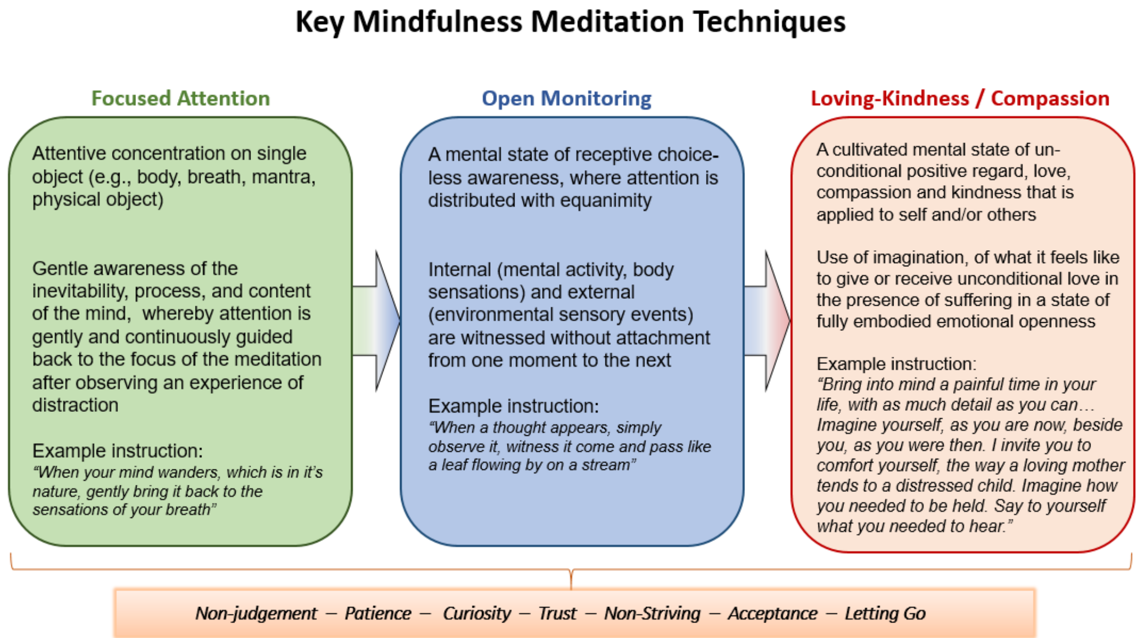
Mindfulness meditations (MM) are a subgroup of meditation practices that originated from a traditional Buddhist context. In the West, MM training practices are presented in secularized formats and are often oriented towards individuals who are new or relatively unfamiliar with meditation practice. Common to the most popular standardized mindfulness meditation programs (e.g., Kabat-Zinn, 1994; Segal, Williams, & Teasdale, 2002), a frequently cited definition of mindfulness is the "awareness that arises through paying attention, on purpose, in the present moment, non-judgmentally" in the service of self-understanding and wisdom (Kabat-Zinn, 1990). In the context of many MM programs, increased state and trait mindfulness is achieved through routinely dedicated time spent in formal practice (e.g., sitting meditations) practicing techniques that aim to strengthen the skills, abilities, and frame of mind considered associated with mindful states and traits. With ongoing formal practice to develop and hone of these skills and attributes, these abilities and characteristics become more effortlessly transferrable and integrated into daily life outside of formal practice, and result in improved self-regulation, resilience, wellness and functioning (Seidlmeier et al., 202; Tang, Holzel, & Posner, 2015).

MM training typically involves scaffolded programming of different meditative techniques bound by underlying principles that foster mindfulness in terms of formal practices and also in daily life. This multicomponent complexity provides a scientific challenge to the study and understanding of the processes and mechanisms involved in these training programs, particularly in terms of what elements are driving specific cognitive, emotional, and behavioural changes. Different MM practices emphasize different aspects of cognitive and emotional self-regulation (Tang et al., 2012). However, in the broadest terms, MM practices are intended to facilitate the trainee's ability to "make space" for new relationships and actions, breaking psychological habits and behavioural automaticity to engage with life in a more flexible, present, and enriched mode of being. In the therapeutic literature, one of the key skills developed throughout MM practice is known as "de-centering" (Segal, Williams, & Teasdale, 2002; Kabat-Zinn, 1994). De-centering (also sometimes referred to as defusion; Hayes et al., 2013) is a meta-cognitive ability where a person is able to separate themselves from their mental content, and take a "third-person" mindful observer role. This de-centered self-awareness, as opposed to being continuously enmeshed in reactive and habit-based "first-person" experiential mode, is thought to underlie many of the positive outcomes resulting from MM training in both clinical and non-clinical studies (Abbott et al., 2014; Eberth and Sedlmeier, 2012; Goldberg et al., 2019, 2018; Sedlmeier et al., 2012; Simpson et al., 2014; Smart, 2019; Zeidan & Vago, 2016).

Figure 1 presents some qualitative differences between the three of the most common and overarching categories of techniques and ordered according to a sequence common MM training program. Often concentrative techniques are taught first, beginning with Focused Attention (FA) types of meditation (inclusive of both body scan and breath focused techniques), before moving onto other techniques such as Open Monitoring (OM) and Loving-Kindness/Compassion meditations (LKC). This training sequence is intended to cultivate and strengthen core attention and awareness abilities first such as sustained and then selective and divided attention, as these remain fundamental to effectively practice more difficult meditation techniques later in training. Crucially, attitudes such as patience, acceptance, non-judgment, and non-striving are folded into all MM practices, although they may be more emphasized in some techniques more than others. Already a variety of stand-alone NF protocols have been used to help support training in these and similar MM techniques (e.g., Antle, Chesick, Sridharan, & Cramer, 2018; Bhayee et al., 2016; Sas & Chopra, 2015; Tarrant, 2016; Tarrant, Viczko, & Cope, 2018). However, scientific investigation has not been conducted in a cohesive or systematic way, particularly with respect to the mechanistic and structural components of the evidence-based MM training programs. It is unclear the extent to which NF augments specific MM skills (e.g., de-centering) or practices (e.g., FA, OM, LKC), or affects other cognitive abilities and neural substrates that underpin MM training experiences and outcomes in a broader sense (Brandmeyer & Delorme, 2013; Brewer et al, 2011). A sequential approach investigating how NF integrates into MM techniques, starting with FA practices, is a good starting place to begin to systematically evaluate the feasibility and incremental cost versus value of NF integrated MM training.

Bearing these considerations in mind, the author of this dissertation developed a NF-assisted guided meditation protocol and tested it against MM-only (i.e., NF-absent) and sham-NF MM training conditions. The MM+NF protocol that was developed and implemented in this study took care to not to sacrifice MM instructions to achieve a highly integrated MM+NF training experience. This is an important feature distinguishing this from other NF-based meditation protocols and applications, which on the spectrum of MM-to-NF practice tend to lean toward the latter. An FA-MM technique was chosen for several reasons: first, because of its foundational role in MM training programs; second, it is among the first techniques that trainee's practice; and third, it trains sustained attention which, according to neuropsychological theory, is a foundational attentional skill (Smart, 2019; Sohlberg & Mateer, 2001). Thus, the development and testing of a theoretically grounded FA+NF protocol constitutes a logical starting point to explore dynamics of MM+NF integrated training. There are compelling similarities and differences between the procedures, mechanisms, and outcomes associated with FA and NF practices, many of which, at least theoretically, could be construed to favor their combination for an enhanced approach to training experiences and outcomes. The following sections provide background literature that discusses some shared and unique aspects of FA/MM and NF methods. This sets the stage for translating these theoretical and empirical considerations into a fully operationalized research study.

Figure 1. *Key Mindfulness Meditation Techniques*



Note. Three of the core techniques in mindfulness meditation are Focused Attention, Open Monitoring, and Loving-Kindness/Compassion. The exact instructions and form may vary across training programs, and even by instructor, but described here are some of the central aspects that characterize each technique. Typically, Focused Attention practices are learned and well-practiced before beginning training in Open-Monitoring. Loving-Kindness and Compassion meditations are considered the most advanced, requiring strong attention and emotion regulation skills to conduct. Across all techniques, an important aspect of mindfulness training is to incorporate with intention, the attitudes, and principles of mindfulness (bottom).

Neurofeedback-Assisted Focused Attention Meditation

NF and FA meditations are considered "top-down" approaches to self-regulation training. That is, they both involve the use of higher cortical structures and functions to consciously attend to internal and/or external cues, and volitionally modulate cognitive resources and activities accordingly. Through experience-dependent plasticity, the repeated practice of initiating, sustaining, and shifting mental activity that occurs in training is believed to induce lasting structural and functional changes that make these cognitive and psychological abilities require less effort and become more deployable in and outside of training sessions (Kleim & Jones, 2008). Crucially, the effects of each "top-down" intervention are also associated with reciprocal changes in how "bottom-up" processes are experienced and handled (Farb et al., 2015; Kerr et al., 2011; Kluetsch et al., 2014; Ros et al., 2016). Both MM and NF affect the neural dynamics and functional integration of subcortical networks and processes associated with physiological and emotional responses. Adaptive changes in the integration of these systems are believed to facilitate improvements in both cognitive and emotional self-regulatory abilities.

Mechanistic conceptualizations of MM vary. However, they tend to centralize attention control and self-awareness (meta-cognition) as core cognitive functions that become enhanced through MM practice, and open up a host of wider-spread beneficial abilities and outcomes (Bishop et al., 2004; Chambers, Lo, & Allen, 2008; Dahl, Lutz, & Davidson, 2015; Lutz et al., 2008). Understanding the similarities and differences between attention control and self-awareness as they developed through MM and NF provides a measure of insight into how to go about developing and testing effective NF-integrated MM training protocols.

Although FA meditation and NF are different techniques of attention and self-regulation training, many areas of neural, cognitive, behavioural, and phenomenological overlap in ways provide compelling grounds to hypothesize additive, multiplicative, or subtractive effects in combination. A question of interest is whether “doubling down” on overlapping mechanisms speeds up learning and experience-dependent plasticity in neural systems core to the beneficial outcomes associated with MM, or whether some other complimentary or interfering interactivity occurs. A major practical and theoretical concern is whether combined training results in “dual-tasking” interference. This refers to the detrimental effects on learning or performance caused by incomplete allocation of cognitive resources and mental switching costs when attention is split between competing information sources to achieve distinct goals simultaneously. This might the case if trainees experience combined MM+NF training as having to juggle both MM and NF as competing or poorly integrated training tasks. However, theoretically this could be mitigated if the NF is properly instructionally integrated within the context of MM training, although this remains to be tested and as such is one focus of this study (Chapter 4).

This speaks to another salient issue currently not well addressed in the literature. It is not always clear to what extent NF is being practiced over MM in existing MM+NF applications, academically, commercially, or clinically. This is of concern because more is known about MM regarding mechanisms and outcomes in comparison to NF (Ali, Viczko, & Smart, 2022). Based on this, there is stronger empirical support for MM's health-related benefits and effective tailoring for clinical and non-clinical populations as well, in line with having a clearer picture of its therapeutic mechanisms and tailoring to psychiatric symptoms or pathologies. At least at first glance, many NF-based meditation protocols skew towards the practice of NF-based regulation more so than practicing MM, *per se* (Antle et al. 2018; Bhayee et al., 2016; Viczko, Tarrant & Ray 2021). For example, the popular Muse meditation headband (InterAxon Inc, 2021) begins its training session with concentrative breathing as might be typical for an FA practice. However, the rest of the sessions is then spent with only background NF stimuli guiding the meditation. This NF-centered approach may yoke or dampen core elements of MM training, including the mindfulness-based strategies and skills acquired through MM that are linked to mental health and well-being improvements, as well as the endogenous control of attention that is a focus of the practice.

To illustrate this point with a contrived hypothetical, it could be that a dedicated expert NF-meditator learns only to master their attentional and self-regulatory control of a particular EEG component, and nothing else. The time spent in NF meditation then would not effectively generalize into other cognitive, behavioural, or emotional regulatory abilities that might otherwise have been gained by spending the same amount of time with conventional MM practice. Research is needed to understand how NF and MM training systems transfer or interact at the level of both basic and applied science. The following sections review what relevant theoretical and empirical findings currently exist in the literature, highlighting overlapping processes involved in FA (MM) and NF across procedural, neurocognitive, and psychological levels of analysis.

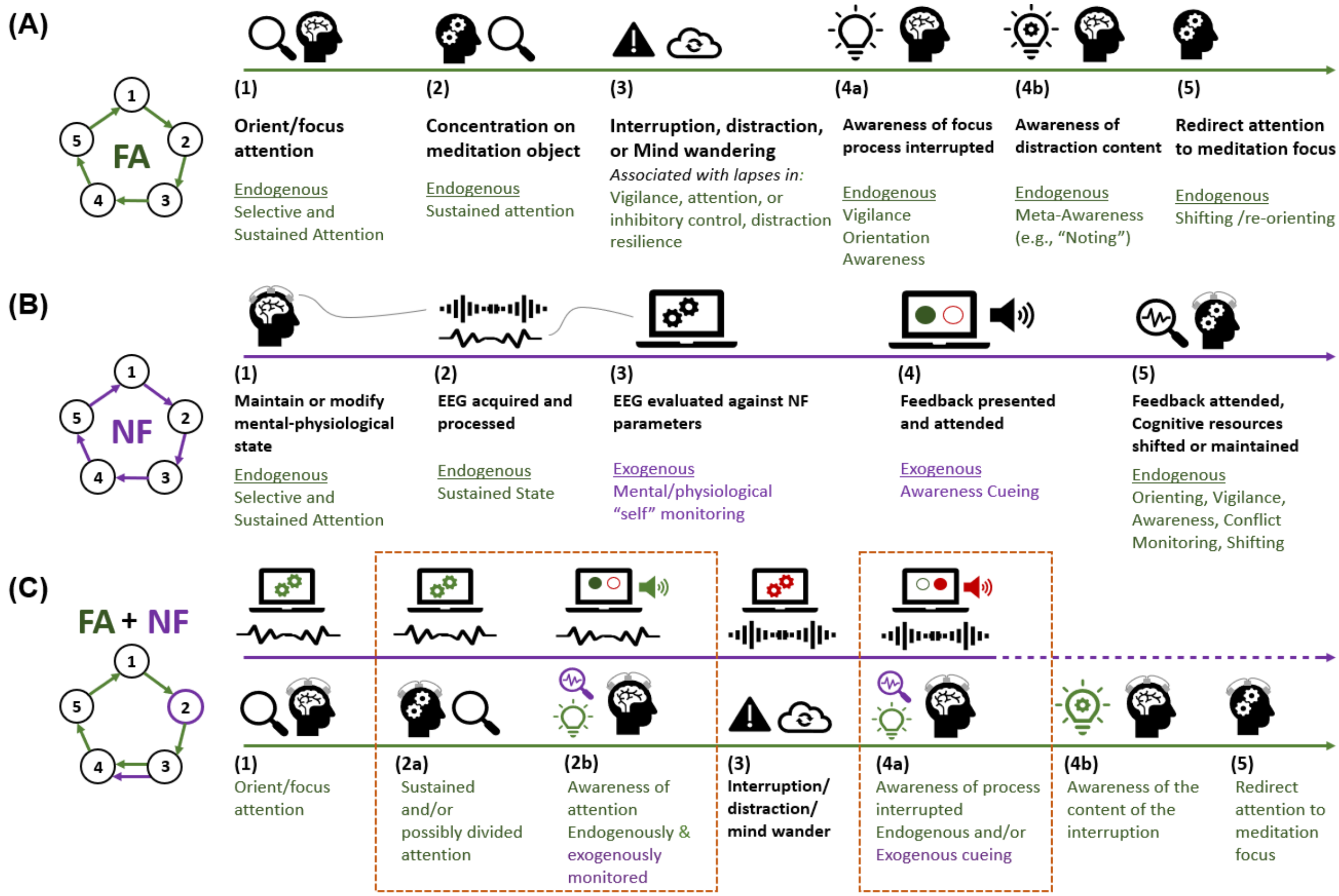
Procedural Similarities and Differences

Figure 2 illustrates the basic steps and psychological processes of FA meditation presented alongside those involved in NF. Both involve initiating a concentrative state of attention, then and modulating mental and/or physiological states based on internal (MM) or external (NF) monitoring information. In FA techniques, the object of attention is often the sensation of breath at a particular point in the body (e.g., tip of nose, or lower belly). For NF techniques it is often auditory or visual feedback cues. In FA it is up to the trainee to learn to self-monitor for "incongruent" mental-cortical activity states such as mind wandering or other internal or external environmental distractions from the intended focus of the meditation (i.e., endogenous control of attention). In NF, an external computing program monitors for protocol "incongruent" mental-cortical states, which the trainee uses as a cue and guide for shifting their underlying neuromodulatory activity (i.e., exogenous control of attention).

Although the process of repeatedly sustaining and redirecting mental-physiological states is common to both FA and NF, and likely central to self-regulatory skill building, the training instructions and approach drastically differ. In MM training programs, psychoeducational components are typically offered beforehand to familiarize the trainee with the attitudes, intentions, and principles of mindfulness that they are encouraged to adopt in their formal practice as well as in daily life. Specific instructions are given in guided FA meditations on how to focus as well as handle distractions, in ways that cultivate and promote trait mindfulness (e.g., to approach the practice with patience, non-striving, etc.). In contrast, NF trainees start off relatively "blind." The trainee is not provided with declarative instructions or strategies to perform NF effectively. They must rely on implicit learning through trial and error. The high levels of (near) real-time brain-contingent feedback that uniquely characterizes NF training effectively drives the skill learning process. Taken together, both training procedures can be characterised by cognitive feedback loops requiring selective and sustained attention to mental events and activities. The end goal of training in of both methods being enhanced self-regulatory control that generalizes to increased self-awareness and self-control outside of the training sessions, in an increasing effortless and enduring way with cumulative practice.

However, there are key differences in the role and development of self-awareness between MM and NF training systems. In MM, including FA, there are explicit verbal instructions that are declaratively learned strategies, cues, and directions to help trainees cultivate and regulate mindful states. Repeated practice with guided instructions that are eventually internalized and hones the ability to self-monitor and regulate these states with increasing ease and with less reliance on explicit instruction. The eventual goal being independent self-guided practice (the maxim, "be your own meditation instructor"). In contrast, for NF, trainees are told in general what feedback cues indicate, but are typically instructed to "feel out" what results in maximized the positive feedback and/or reducing negative feedback stimuli. Thus, for NF, a trainee must largely rely on an implicit learning process and must put in a relatively long amount of time in practice before declarative awareness of working strategies or skills are likely to emerge (Diekelmann, Wilhelm, & Born, 2009). A caveat to this approach is there may be considerable differences between individuals in terms of the strategies or skills used to gain control over the NF signal – in other words, divergent mechanisms of action to reach the same end-goal of top-down self-regulation of attention and awareness. In theory, like MM training, the goal of NF learned self-regulation is also to be able to masterfully deploy self-regulatory skills outside of training (i.e., so-called "transfer of training"). However, relative to MM training, it is unclear what NF training "dose" might be needed to create an enduring and generalizable self-regulatory skillset, and how tightly coupled EEG control is to other cognitive and behavioural outcomes.

Figure 2. *Procedures and Processes Involved in Training Methods*



Note. Steps and corresponding processes involved in focused attention (FA) meditation, neurofeedback (NF) and combined. FA+NF training methods. (A) Outline of the basic process of focused attention meditation. The stages are of NF are sequentially repeated through across a training session. (B) Outline of the basic EEG-NF process. (C) Outline of the basic process of focused attention meditation with neurofeedback. Cognitive and computational processes are listed underneath (grey text) and noted as either exogenously (external) or endogenously (internal) occurring. Areas of presumed interaction are highlighted in (C).

Neither guided MM, nor NF training, involves purely internal or external self-monitoring. In MM guided audio recordings, instructors often offer "external cuing" ("If you have noticed your mind has wandered…"), albeit not delivered with personalized contingency with trainee's ongoing, real-time, internal mental activities as occurs with NF. However, with NF, trainees may also internally come to sense that they are distracted, unfocused, or in an otherwise undesirable mental state in sessions, with or without information about a particular brain signal being relayed back to them. So, while MM may involve more endogenous control and NF more exogenous control, this is not absolute in either case. That internal and external monitoring natively occurs in each method suggests compatibility, and an opportunity to leverage the unique strengths and limitations of each approach to create a highly integrated combined learning/training system. However, effectively realizing this potential relies on understanding the interactivity of the neural and cognitive mechanisms subsumed in combined MM+NF training versus MM or NF training alone.

The available literature directly evaluating MM and NF interactivity is presently sparse. The next section provides a neuroscientific overview of common and complimentary findings associated with the training of attention, meta-cognition, and phenomenological aspects of MM and NF. These areas of focus are to build support for the notion that NF can be combined effectively with meditation practice, in ways that support or compliment core meditation processes. The theoretical and empirical discussion covered is translated to informed research design and measurement in the following chapter. This then bridges into the methods, results, and discussion of findings across remaining chapters.

Attention Regulation

Both methods centrally involve components of attention regulation, particularly abilities of orienting, selecting, and sustaining attention. Unsurprisingly, the most common outcomes reported in FA and NF research studies are increased performances on attention tasks (Chiesa, Calati, & Serretti, 2011; Guendelman, Medeiros, & Rampes, 2017; Jensen et al., 2012), and changes in the neural networks that underpin attention regulation abilities (Fox et al., 2014; Fox et al., 2016; Chow et al., 2016; , Engelbregt et al., 2016). Tang et al., (2020) have shown as few as ten hours training in their MM-based program related in structural, functional, and metabolic changes in the anterior cingulate cortex (ACC), believed to be associated with increased self-control capacities. Expert meditators at rest and during various meditations show increased activation in premotor cortical regions and dorsal/mid-ACC areas, with deactivations in the posterior cingulate cortex (PCC) and inferior parietal lobe regions (Fox et al., 2016). Morphometric differences in meditators versus non-meditators include findings of increased grey matter in premotor and cingulate cortical areas. These differences are thought to be associated with increased attention and self-regulation abilities reported for experienced meditators (Fox et al., 2014). This same-meta-analysis also revealed increased grey matter in insular and somatosensory cortical regions in meditators, the difference in these areas is thought to be associated with heightened interoceptive abilities, emotional awareness, and control.

Despite some attempts, no equivalent comprehensive meta-analyses have been conducted on NF. This is due to longstanding limitations in the scientific rigor and quality of evidence in NF literature, as well as the considerable diversity across types of protocols, cognitive targets, and participant populations included in studies (Ali, Viczko, & Smart, 2020; Thibault & Raz, 2016; Viviani & Vallesi, 2021). Individual neuroimaging studies have indicated that the initial stage of EEG Brain-Computer Interface (BCI)-learning (such as NF) is associated with activations in prefrontal, premotor, as well as parietal cortex areas (Wander et al., 2013; Neumann and Kotchoubey, 2004), and depend on plasticity of cortico-striatal circuits (Koralek, Costa, & Carmena, 2013). These are large, distributed, and highly interconnected functional networks, recruited to some degree for a large variety of mental and behavioural processes, including attention and executive functions.

Along these lines, Ghaziri et al. (2013) conducted a MRI study with diffusion tensor imagining and voxel-based morphometry methods to determine whether 13.5 weeks (40 sessions) of beta-NF training, designed to improve sustained attention, might induce structural changes in white matter pathways associated with attention abilities. The study was a randomized controlled trial with a non-clinical sample of university students that were assigned to real-NF, sham-NF and no-NF training groups. Among their findings, they observed white matter change, indicated by increased fractional anisotropy, in the cingulate bundle – a tract that connects the anterior cingulate cortex with the dorsolateral prefrontal cortex and the posterior portion of the parietal cortical areas. They found a positive correlation between visual attention task improvements and increases in fractional anisotropy in the left superior longitudinal fasciculus and the left anterior limb of the internal capsule. Neither of the control conditions showed significant white matter change. In terms of sustained attention testing, the real-NF group showed significant improvement pre-to-post training on both the auditory and visual components of a continuous performance test. The no-NF group showed no attention improvements. Interestingly, the sham-NF also showed improvements, but only for visual sustained attention, and with a different pattern of grey matter findings compared to the real-NF training group.

In clinical contexts, both NF (Arns, Heinrich, & Strehl, 2014; Bakhsayesh et al., 2011;Baumeister et al., 2018; Niv, 2013) and MM-based interventions (Cairncross & Miller, 2020; Jiaming, Yun, & Ying, 2019; Poissant et al., 2019) have been considered efficacious for the treatment of ADHD; the quintessential disorder of dysregulated attention. However, effect sizes for NF on attention, inhibitory control, and other neuropsychological (e.g., executive function) and symptomatic measures (e.g., impulsivity) are notably reduced in blinded and active-control randomized control trials. This has resulted in researchers and clinicians questioning strength and clarity of empirical support for NF as a specific and efficacious ADHD treatment (Albert et al., 2017; Schönenberg et al., 2017).

An interesting example of attentional skill transfer between MM and NF comes from Tan, Dienes, Jansari, and Goh (2014). In their study, participants were assigned to MM training, a music training, or inactive control group across a 12-week period. MM and music groups endorsed similarly high expectations their assigned training would transfer to improved ability to control an EEG brain-computer interface (BCI) that would allow them to control letter selections on a computer. Only those who completed the MM program demonstrated improved control of EEG-BCI device compared to the music and no training control conditions. Thus, MM seems to lend itself to BCI skill development, with

NF falling under the umbrella of BCI. However, it is not clear if this relationship exists in the other direction (NF facilitates MM), or whether it was MM-enhanced attention control versus self-awareness/monitoring skills that led to better BCI control when tested post-training.

Taken together, there is evidence that both MM and NF lead to neurocognitive improvements in attention abilities. The evidence reviewed suggests that the neural substrates and regions that underpin attention regulation might similarly be trained in FA-MM and NF, and potentially facilitate the development of regulation across other cognitive and behavioural domains. However, the extent to which specific neural mechanisms of NF and MM might overlap or interact is unknown. Additionally, and critically, attentional control is not the only component of MM, including FA, that is believed to be play a core role in enhanced self-regulatory skill.

Awareness, Monitoring, and Meta-Cognition

Attentional control is fundamental to adaptive functioning (Solberg & Mateer, 1989; Lezak et al., 2012). However, it is impossible to be a master of self-regulation without some degree of self-awareness folded in. In both FA and NF, breaks in concentration are expected as eventually everyone succumbs to internal and external attentional distractions. Where FA and NF appear to diverge substantially is in what happens after the concentrative state is interrupted. The approach to deal with distraction in all MM practices involves self-monitoring for moments of lost focus *as well as* taking the extra step of explicitly noting the nature of the distracted mind in terms of both process and content[1]. This is done in a patient, curious, non-judgmental and accepting way (Kabat-Zinn, 1990). It is thought that this process leads to increased levels of mindful self-awareness of one's patterns of thinking and feeling, a highly adaptive and flexible form of meta-cognitive awareness. This ability as it is acquired through formal

[1] The deployment of attention control versus meta-awareness is emphasized differently across MM practices. FA practices primarily emphasize focused selective attentional control, but also include aspects of meta-cognitive skill development which are bridged into, and further develop, in OM practices. OM meditations are characterized by a state of non-selective distributed attentional awareness that lends itself more strongly to the practice of non-attached, mindful, self-observation.

MM is then extendable into “real-world” awareness of mental habits, alongside the practiced skill of controlled disengagement from them if so desired (Kristeller & Rikhye, 2008; Lutz et al., 2008; Sedlmeier et al., 2012). In contrast, in NF training explicit strategies are generally not provided for developing awareness. The NF trainee user must “feel out” what works versus what does not and slowly build self-awareness of the relationship between themselves and the feedback signal. So, in NF awareness of “something” is cued by the external NF monitoring system, and it is left to the trainee to discover what this is and how to control it; a far slower ambiguous approach but one that can effectively lead to both increased control and awareness none-the-less. The “noting” step, thought to improve meta-awareness in MM, is not as certain and is perhaps unlikely in NF learning (unless the NF trainee is trained in this skill) because there are no explicit instructions to do so to do so. It is therefore less clear whether NF promotes the same capacity and skillset as mindfulness-based self-awareness, or what the time course to develop explicit levels of self-awareness, knowledge, and ultimately self-regulatory proficiency with NF training alone is.

Despite heavy reliance on implicit learning processes, explicit awareness can still develop out of implicit learning process that characterises NF reinforcement learning. Davelaar (2018) proposed a computational neuroscience-based model positing that NF involves an endogenously driven process of trial-and-error, where meta-representation of one’s mental-physical states are being “noted” in a neural representation sense (i.e., implicitly as opposed to declaratively). This meta-representation is compared to the external NF cues, and iteratively and volitionally modified by the trainee to achieve, and increasingly maintain, a mental-physiological that satisfies the goal state programmed define by the NF protocol (this describes a Bayesian learning process). The process of comparing and updating the mental-physical “snapshots” occurs continuously and implicitly, supported by fronto-parietal and thalamocortical networks, and centrally mediated by the striatum. As these distributed networks acquire more state data of what is “correct” versus “incorrect,” it becomes possible to recognize and experiment with different strategies at a conscious level, which improves expertise greatly in terms of both task knowledge and performative skill. This concept was demonstrated by the author with implicit motor-sequence learning tasks, similarly dependant on the striatum, where a subset of learners became explicitly aware of a hidden pattern after a short duration of implicit learning trails (Viczko et al., 2020). Interestingly, once explicit awareness emerged, even partially, task performances improved an order of magnitude above that of participants whose sequence memory remained implicit (but also showed slower course improvements over time). Those with explicit awareness of the pattern/strategy procured additional sleep-dependent enhancements of pattern knowledge and skill proficiency (presumed to be hippocampally mediated), where those with pure implicit knowledge did not.

A meta-analysis of fMRI-NF findings conducted by Emmert et al. (2016) revealed that both the striatum and the anterior insula were non-target regions consistently activated during NF learning across various protocols. They suggested the existence an NF “regulating network,” where the striatum and the anterior insula contribute to reward-based learning and self-awareness processes, respectively. The anterior insula has been linked to interoception (awareness of the body’s internal/visceral states: Craig, 2009; Critchley et al., 2004). It also implicated in emotion recognition (Craig, 2004) and meta-cognitive awareness (Fleming & Dolan, 2012), leading some researchers to point to it as the gateway substrate of conscious experiences writ large (Huang et al., 2021). Notably, the anterior insula has been found to be significantly recruited in nearly all meditation techniques, including all MM practices (Fox et al., 2016), with morphometric differences in this region associated with long term meditation practice (Fox et al., 2014). Thus, the anterior insula appears to be an important neural substrate involved in both NF and MM training and of interest as a potential hotspot of interactivity for FA+NF combined training. NF training alone may not lead to the same type of metacognitive skills as MM, insofar as de-centering is concerned, but it may still result in highly attuned self-awareness of mental and physical states given similar requisite structures are involved.

Taken together, the literature reviewed indicates that both MM and NF recruit common neural structures that support physiological, cognitive, and emotional awareness – albeit NF learning appears to depend more on subcortical learning pathways, that may make learned skills and strategies less accessible to conscious awareness until late into training. Skill acquisition and mastery still relies on procedural learning through extended practice in both training methods. In MM this is substantially aided by declarative strategies used to develop increased awareness and attentional control in practices. In NF a uniquely high degree of continuous feedback implicitly reinforces the development and honing of attentional self-control, and with self-awareness capacities also eventually emergent in this process (at training timescales not known). Tasks rich in both implicit and explicit sources of information for learning, such as it might be in NF integrated MM training systems, could foreseeably enhance the facilitation of skill learning and knowledge acquisition. Much of the similarities discussed suggest some degree of immediate or eventual convergence in attention and awareness development despite apparent differences in these training systems. If they have more in common than not, experiential reports should also reflect how these methods might converge or diverge in terms of synergistical potential.

Neurophenomenological Convergence

Neurophenomenology refers to a methodological approach intended to bridge the so-called "explanatory gap" in understanding of how to integrate first-person subjective experiences of phenomena with the third-person objectively measurable physiological features of the mind (Berkovich-Ohana et al., 2020; Varela, 1996). It involves measuring both the neural markers associated with states of consciousness, while also probing for qualitative aspects of the experience ("qualia") at an individual level. This is typically achieved through trained introspection or guided interviewing techniques. This approach has been considered necessary in the field of contemplative neuroscience, where conventional multi-method approaches fall short of capturing adequate depth and subtlety of the inner experiences associated with different meditative traditions and level of expertise. To understand at the deepest level what is going on in meditation, you must be able to integrate not only brain activation but also first-person experiences that are occurring. Expert and long-term meditators, including those with extensive training in MM (e.g., Dor-Ziderman et al., 2016) have been considered ideal candidates for neurophenomenological research into consciousness because of heightened introspective and interoceptive capacities. With its own merit, NF is considered to be an exceptionally useful tool for neurophenomenological investigations in meditator and non-meditator research programs (Bagdasaryan & Quyen, 2013; Prestel et al., 2019). Results from neurophenomenological investigations offer unique knowledge into how MM and NF practices might converge and diverge. They provide valuable information toward understanding whether and how NF and MM could be combined effectively.

As mentioned, part of FA MM training involves gently “noting” the process and content of the mental interruption (e.g., mind wandering) before re-directing attention back to focus of meditation. Ideally, in the MM approach, this is done in line with the principles of mindfulness, including a non-striving attitude, letting go of the idea that getting distracted is non-achieving. Here again there may be a departure from the mindset of NF training, which may tend to over-stress goal (feedback) achievement. Interestingly, however, is that effortful striving is associated with increased high beta activity (Olbrich et al., 2011). In practice, most meditation/relaxation-based NF protocols often directly or indirectly reinforce against this activity (Hammond, 2007). As such, many NF protocols may coincidentally lead to the adoption and practice of non-striving state of mind, despite no explicit instruction to do so.

In support of this, Davelaar et al. (2018) conducted a quantitative and qualitative investigation of participants learning to regulate frontal-central alpha in a brief, single NF session. They were able to classify learners (those who succeeded in enhancing their alpha across training) from non-learners (those who were not) in terms of their use of "trying" versus "sensing" strategies. Non-learners reported investing mental effort and exerting deliberate attentional focus to receive feedback ("*trying* to relax"). Learners reported adopting a non-attached awareness to sensory internal and external (NF feedback) events, which ultimately proved to be highly successful for NF performance. This was consistent with an earlier study by Nowlis and Kamiya (1970), who found that participants successfully modulating posterior alpha reported using mental strategies that embraced awareness, relaxation, reduced focus, and letting go. Thus, incidentally, successful NF may implicitly train users to adopt mindsets similar to those explicitly coached in MM practice.

This suggests an intriguing degree of potential processual-experiential overlap. Another relevant research finding to this point comes from a study of expert meditators participating in an fMRI-NF task. Garrison et al. (2013) obtained verbal reports from ten highly experienced meditators after each of three meditation sessions and one neurofeedback session in the fMRI scanner. Two sessions were meditation sessions, followed by a third session that required ongoing meditation plus noticing associations between moment-to-moment subjective experiences while they viewed the NF display. The NF target was BOLD signal in the PCC, a structural hub of the Default Mode Network (DMN) that is typically activated in idle mind wandering or other self-referential, non-task oriented mental activity. The final session required the meditators to direct manipulation of the feedback display while in the fMRI, by increasing PCC activation (although they were not told this was the NF target). Participants were asked how well the feedback corresponded with their experience and their strategy for manipulating the feedback signal. They observed that PCC activation was associated with "distracted awareness" and "controlling," whereas PCC deactivation was associated with "undistracted awareness" and "effortless doing." PCC deactivation has also been linked to increased alpha in midline and posterior areas. Thus, PCC and related DMN intrinsic network deactivation, is marked by increased alpha in both alpha-NF and MM practices, with similar phenomenological and physiological effects.

These findings are interesting as they bridge psychophysiological with experiential aspects of each method, both elements are highly relevant to the current study and training protocol. MM and NF are more than relaxation techniques, despite calm and focused states commonly resulting in practice (Jain et al., 2007; Marzbani, Marateb & Mansourian, 2016). In both cases, "getting out of your own way" to reach a calm, present, and not effortfully attached frame of mind appears to lead to positive sessional experiences. One of the most widely studied electrophysiological markers linked with these described mental-physiological states is alpha activity.

Alpha Activity: A Keystone?

Alpha activity is conventionally defined as cortical oscillatory activity in the 8-12 Hz frequency bin. Separating broadband alpha into lower alpha (7-10 Hz) and upper alpha (10-13 Hz) sub-bands is also commonplace, as some research indicates these to be functionally distinct (Klimesch, 1999). Some researchers extend this to the 7-13 Hz range, which more broadly encompasses sub-band peak alpha frequency ranges across individuals. The neurobiological basis of alpha oscillations involves thalamicortical-synaptic loops of excitation and inhibition to synchronize (or desynchronize) cortical pyramidal firing; which among other functions influences top-down perceptual control, and facilitates resource allocation between competing neural network processes (Klimesch, 1996; Hughes & Crunelli, 2005; Scheeringa et al., 2012). Research into the neural properties and cognitive functions related to alpha activity is ongoing (Klimesch, 2012; Mathewson et al., 2012; Sadaghiani et al., 2010; Wilken et al, 2023).

Increased alpha activity is one of the earliest and most reliable markers of meditation proficiency in novice meditators (Kakumanu et al., 2018; Lomas, Ivtzan, & Fu, 2015). Alpha oscillations occur more robustly in experienced meditators during non-meditative rest, compared to non-meditators, suggesting a transfer of neural effects that continue to be present “off the cushion” (Cahn & Polich, 2006; Chiesa & Serretti, 2010). Alpha activity in meditators is proposed to be a marker improved neural and cognitive system efficiency (Kerr et al., 2013; Ros et al., 2016). According to Kerr et al. (2013) the practice of MM is thought to modify cortical alpha rhythmicity in ways that both reflect and result in better information processing and transfer between cortical and subcortical networks. Kerr et al. (2013) highlight the connection between breath and body focused meditations, interoception, and the fine-tuning of thalamocortical filtering of relevant and non-relevant information into the cortex (and conscious awareness). Their model predicts that practicing MM leads to top-down alpha modulation, which enhances the effectiveness of somatosensory processing, and the deployment of task-relevant attention and working memory abilities. Notably, this MM theory shares much in common with neurophysiological mechanistic accounts of NF (Bagdasaryan & Quyen, 2013; Nicholson et al., 2016; Ros, Baars, Lanius, & Vuilleumier, 2014).

Similar support for this notion in the NF literature is provided by Escolano et al. (2014). They demonstrated increased processing speed and working memory performance after eight sessions of upregulating alpha-NF in a sample of patients with major depressive disorder relative to a no treatment control. Support from MM literature is provided by Moore et al. (2012). They conducted an event-related potential (ERP) study with sample of meditation-naïve adults. The study was a randomized waitlist control design, with the active group completing a 10-minute mindful-breathing (FA) meditation practiced daily across a period of 16 weeks. In addition to increased self-reported mindfulness, the FA training resulted in altered N2 and P3 ERPs on a Stroop task, source localized to regions known to support attention-related processes. Their interpretation of this was that MM practice altered the efficiency cognitive resource allocation, secondarily leading to improved self-regulation of attention.

Lower alpha, in particular, is strongly anti-correlated with elaborative or effortful thinking processes such as mind wandering and problem solving, and appears to be a useful meditative marker across MM techniques (Rodriguez-Larios & Alaerts, 2020; Rodriguez-Larios, Faber, Achermann, Tei, & Alaerts, 2020). Two studies used a probe caught sampling method to evaluate the markers of meditative versus non-meditative experiences with samples of novice and experienced meditators conducting FA (Rodriguez-Larios & Alaerts, 2020) and OM (Faber, Achermann, Tei, & Alaerts, 2020) meditations, respectively. In both studies, reports of immersive meditative states co-occurred with EEG power in the alpha and theta bands converging to peak in the upper theta/lower alpha band range (7–9 Hz). EEG activity in mind wandering episodes, as well as during a mental arithmetic task, co-occurred with the meditative low alpha peak separating, shifting power concentrations into lower theta and higher alpha frequency in a phase-locked harmonic arrangement[2]. These harmonic coupling events occurred with most frequency when meditators were engaged in a mental arithmetic task, followed by baseline rest, and occurred with least frequency during meditation (Rodriguez-Larios, Faber, et al., 2020). The authors of these studies came to the conclusion that lower alpha might be an ideal candidate for NF protocols aimed at meditation support.

A variety of alpha NF protocols have previously been research tested in the context of meditation training (Hinterberger, 2011; Sas & Chopra, 2015; Tarrant, 2016). In a sample of university students, Chow et al. (2016) demonstrated that a single session of alpha-NF had comparable psychophysiological and psychological effects to that of an equally long FA mindfulness meditation. In a longer intervention, Antle et al. (2018) used commercially available EEG headsets to train schoolgirls in an impoverished

[2] Harmonic phase-locking refers to when the phase of a higher (e.g., alpha) and lower (e.g., theta) frequency achieve resonance. For example, a cross-coupling theta power peak of 6 Hz co-occurring alpha peak at 12 Hz with phase locking would constitute a 1:2 harmonic. This type of harmonized activity is thought to reflect interaction between the memory and executive components of cognition (i.e., working memory); enabling dynamic synchronous communication between the neural networks involved in producing these rhythmic arrangements.

area of Nepal to improve self-regulation of attention and anxiety. Their field study employed a pre/post waitlist control design with a 2-month follow-up and included surveys and interview assessments from multiple informants focused on anxiety and attention regulation as ecological measures of NF skill transfer. The NF program ("Mind-Full") was based on Eastern mindfulness practices aimed at fostering calm and attentive states. After an initial coaching session, each child completed sessions 3-4 times a week for 6 weeks, 10 min a session, across three game modes, two of which focused on sustaining increased alpha, the other on beta. After training children showed clinically meaningful transfer of heightened self-regulation skills into the classroom and playground, that were maintained at follow-up. Their success is notable as proof of principle that even demographic groups with low literacy and elevated behavioural concerns can respond beneficially to combined MM+NF training.

Taken together, the reviewed studies provide compelling support for the notion that alpha activity, particularly in the low alpha range, plays a significant role in reflecting state and trait changes involved in MM and NF training. Alpha activity may broadly reflect neural network efficiency, which augments the deployment of a variety of other neurocognitive abilities. The exact correlative versus causative nature of alpha in relation to various cognitive abilities remains to be clarified in the context of MM and NF training applications, as well as a broader focus of neuroscientific and psychological inquiry.

Chapter Summary

MM and NF interventions are both used for cognitive optimization in non-clinical populations and for therapeutic and rehabilitative purposes in clinical populations. Recent commercial and clinical applications have implemented NF technology to help train novice meditators in their meditative practice. MM and NF training methods are both designed to increase a trainee's capacity for mental and physiological self-regulation. Both require and lead to increased development of self-awareness and attentional control abilities, although to different extents. The literature reviewed highlights that neural, cognitive, and phenomenological harmonies exist despite learning and procedural differences emphasized by each approach. In fact, it is these differences that suggest space for compatible integration. MM provides cognitive strategies for guiding self-regulation skill practice, and NF offers to lend a high degree of monitoring and feedback to test and hone these MM-based self-regulatory skills and strategies. It is not known how NF actually integrates into MM learning and practice, in terms of its ability to directly or indirectly support MM-related skills and abilities. NF could increase pace of neuroplastic changes in underlying neural substrates that serve attention control or awareness development, as there appears to be overlap in recruitment of the common structures NF and MM practiced separately. Or perhaps the addition of technology and NF monitoring influences the training experience itself, resulting in dual-tasking, or by increasing or decreasing interest or engagement levels of trainees, within practices or across programs of training at different stages.

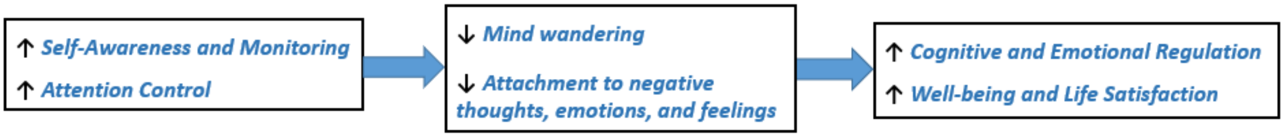
What is needed is an effective framework to facilitate theoretically informed empirical investigations into the mechanisms of NF interactively with meditation training, and in general. Limited knowledge in this area makes it difficult understand the efficacy and suitability of NF applications, including for its utility in meditation training. The next chapter provides a theoretically informed, empirically testable working model for research; one that specifies putative neurocognitive mechanisms and processes that could interact when NF is integrated effectively into MM training and provides an initial roadmap for teasing apart the relationships between mechanisms and outcomes of combined MM+NF training.

CHAPTER TWO

Theoretical Framework and Hypotheses

The previous chapter brought attention to theoretical and empirical research findings spanning neural, cognitive, methodological, and even phenomenological similarities between mindfulness meditation (MM) and neurofeedback (NF) training practices. MM training is comprised of multiple meditative techniques, and each meditative technique is itself multifaceted and dynamic. Focused attention (FA) meditations, such as mindful concentrative breathing, are considered foundational in the development and acquisition of attention and awareness skills that required to be effective in other MM practices and become more mindfully aware and in control in daily life. Figure 3 outlines a basic psychological model of how FA MM training could lead to some of the broadest desirable outcomes associated with MM training. Attention control and self-aware monitoring (so called “meta-cogntive” abilities) are hypothesized to be core mechanistic abilities that ultimately leading to a variety of desirable “downsteam” outcomes in MM (Bishop et al., 2004; Jankowski & Holas, 2014; Tang, Hölzel, & Posnter, 2015). Increased capacities in these domains, brought about by MM training, are believed to directly contribute to better self-regulation of automatic or unhelpful cognitive, emotional, and behavioural patterns. This includes being able to reduce time spent in mind wandering, that otherwise may habitually detract engagement from positive and productive moments in daily life (Killingsworth & Gilbert, 2010).

Figure 3. *Cognitive and Behavioural Model of Mindfulness Meditation*

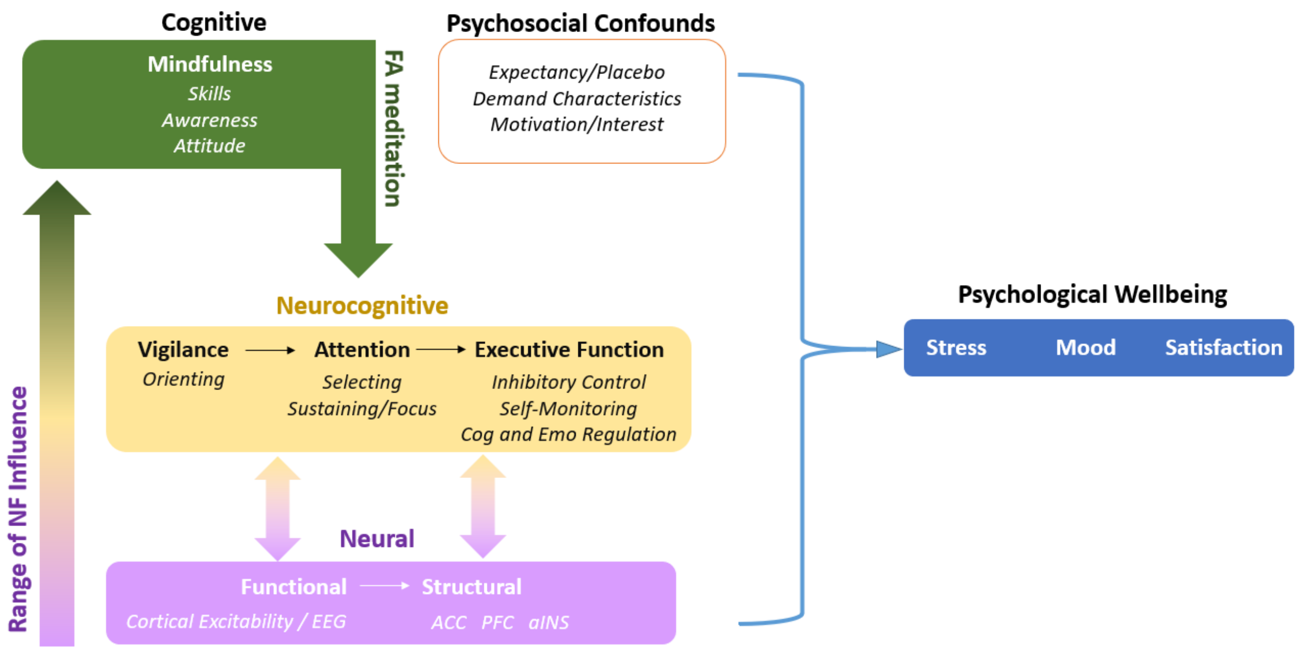


Note. A basic cognitive and behavioural model how training in mindulfness meditation is believed to lead to therapeutic outcomes. Foundational neurocognitive abilites related to attention and self-monitoring are both recruited and further improved through practice of mindfulness meditation skills related to control and attachment to other mental activities. With enough training these skills and capacities increasingly generalize into improved self-regulation abilities in daily life, that may also lead to a myriad of other mental health and functional benefits.

What remains to be addressed is what an effective MM+NF training system would look like based on what is known about cognitive processes involved in MM training. That is, what would an effective training protocol entail, how long would it take to for desirable and generalizable effects to emerge, and by what additional complimentary process or mechanisms would results be achieved. If EEG feedback significantly augments core components of MM training, then significant improvements in the skills, abilities, and other outcomes that are associated with MM training can also reasonably be predicted. The gains made from MM+NF should be greater or acquired faster than those acquired through conventional MM practices. If the addition of NF is does not benefit MM training, no difference across mechanism or outcome measurements would be observed. Even a benign result such as this holds practical value in terms of the cost-benefit implication to potential consumers of meditation-NF technologies. As a worst case, it is possible that NF could interfere with fundamental aspects and experiences of traditional MM training. This would negatively impact the acquisition of fundamental skills and benefits typically associated with MM training. Each is outcome is possible, so it important to conduct research that can decipher these effects from a dismantling and mechanism focused approach.

Identifying mechanistic pathways helps pinpoint which components are causally related to improvements (or deteriorations) from those that might be spuriously driving outcomes. Research into what interactions are responsible for driving observeable change across multiple levels of analysis is critical for the development and refinement of mental training and treatment applications (Kazdin, 2005). There are several factors at neural, cognitive, and psychosocial levels of analyses that can be examined across the course of MM training, including and beyond what outlined in Figure 3. Figure 4 provides an expanded model of FA training components and effects, across various interrelated levels of processes, functions, and abilities. This working model provides a framework for empirically investigating the centrality and interplay of relevant neural, cognitive, and psychological factors involved in MM+NF training.

Figure 4. *Framework for Neurofeedback Range of Influence on Mindfulness Meditation Training*



Note. When combined to help support focused attention (FA) meditation, it is unclear what range of influence neurofeedback (NF) will have on various components and processes. It is also unknown NF interactions improve or impede the various capacities, skills, and outcomes gained from FA practices without NF. Other factors, unrelated to direct neural or cognitive effects of NF, may also influence outcomes. Acronyms: Anterior cingulate cortex (ACC), prefrontal cortex (PFC), anterior insula (aINS), focused attention (FA), neurofeedback (NF).

Neural Factors

According to neuropsychological theory backed by decades of research, many neurocognitive functions are hierarchically arranged (Solberg & Mateer, 1989; Lezak et al., 2012). General cortical arousal supporting attentional vigilance are the basic foundations for higher order attentional and executive processes (Posner, 2008). Sustained attention and selective attention are reliant on the abilities to filter, orient, and attend to internal and external information, and be resistant to distraction through inhibitory control (Raz & Buhle, 2006; Miyake & Friedman, 2012). This relies in part on subcortical structures (e.g., reticular activation, thalamic gating), as well as on frontal-parietal networks that function in "top-down" prioritization, initiation, and follow-through of actions (Peterson & Posner, 2012). As reviewed earlier, functional and structural changes have been documented in these regions as associated with extended meditation practice.

Neural influences can occur in a less localized fashion as well (Ros et al., 2016; Tang & Posner, 2009). If functional communication within and between neural networks is less "noisy" – that is extraneous processes are limited, and information processing at cellular and network system levels are highly tuned - then neurocognitive processes should benefit from this efficiency and be deployed more effectively behaviourally. Endogenous alpha activity has been suggested to be a marker of "top-down" and "bottom-up" efficiency, a reflection of how effective resource allocation and signaling is occurring within and between large distributed brain networks (Kerr et al., 2013; Ros et al., 2016). Research focused on MM and NF interventions has reliably document state and trait changes in endogenous alpha activity (Cahn & Polich, 2006; Niv, 2013). However, observed changes in alpha activity have yet to be definitively linked to neural and cognitive outcomes. It remains unclear whether alpha is merely an epiphenomenon of entering a relaxed-but-vigilant state, as often occurs during concentrative practices, or whether it is a phenomenon that more directly facilitates increased neurocognitive capacities in broad or localized functions. Thus, from a mechanistic standpoint, alpha activity is important factor to measure to help decipher state and trait effects of MM and NF training.

Structurally and functionally, the neural regions most often implicated in MM training – particularly FA-MM – are the same substrates that support executive attention control. These include structures such as the ACC (anterior, mid, and dorsal areas) and prefrontal cortex (medial and dorsolateral areas), but also the insula and somatosensory cortices (related to interoceptive attention and awareness) (Fox et al., 2014; Fox et al., 2016; Tang, Holzel, & Posner, 2015). Functional neuroimaging of these regions using MRI-based methods is one way to identify the neural regions recruited or affected by MM+NF training. However, neuroimaging findings do not necessarily translate into functional differences observable at the cognitive or behavioural level. Fortunately, many cognitive, behavioural, and neuropsychological tasks have been well-researched in terms of what specific neural regions and structures their performances depend on, and thus can offer an indirect, but reasonable degree of insight into the areas of structural and functional neural regions affected by training. Additionally, they offer the benefit of being able to quantify meaningful changes in abilities that are presumed to factor most strongly into the outcomes related to MM training with and without NF. Thus, this approach was preferred for the present study versus relying on more intensive and costly imaging methods.

Neurocognitive Factors

A variety of cognitive skills, capacities, and dispositional components are implicated in MM practices. Many of which are reliant on and develop in tandem with an increased capacity for self-awareness and attention control. These are believed to be two of the most important neurocognitive mechanisms involved in MM training that lead to a variety of other desirable outcomes related to improved cognitive and emotional self-regulation (Bishop et al., 2004; Jankowski & Holas, 2014). As Figure 4 illustrates, these abilities are multifaceted, inter-related processes and constructs – and their development is tightly coupled to the structural and functional neural substrates that support these and other cognitive skills and functions. The term “neurocognitive” captures the bridging role of these abilities/constructs.

On the basis of the literature reviewed, it is reasonable to hypothesize that NF could affect the following neurocognitive processes involved in FA-MM: (1) improved selective and sustained attention control, potentially related to improved physiological and psychological vigilance capacities augmented by the addition of NF, (2) improved executive attention abilities, such as attentional switching and inhibitory control, associated with the resistance to distractors and the ability to more efficiently re-direct focus when lost assisted by NF monitoring signals, (3) the development of enhanced self-monitoring, related to increasing the frequency and self-awareness of mind wandering and distraction detection also associated with the additional monitoring offered by adjunctive NF.

A selection of cognitive and behavioural tasks was chosen specifically to help decipher the specificity of NF influence across these core neurocognitive MM abilities. Where applicable, psychometrically validated self-report scales were included to assess whether any improvements in these domains also meaningfully translated into using these enhanced abilities more effectively in daily life. These are detailed in the following chapter.

Psychosocial Factors

Careful experimental design is necessary to clearly decipher contributions of different mechanistic factors serving as potential drivers of observed outcomes. One of the most effective approaches to parse out so-called “non-specific” psychosocial factors, such as placebo/expectancy effects, from that of other mechanisms of influence, is to include yoked or sham conditions. A lack of these experimental control arms in NF literature has been the subject of pointed scrutiny (Thibault & Raz, 2017). However, all variety of health-related interventions are influenced by placebo effects to varying degrees, including a number of other non-specific psychosocial factors that co-occur with treatment delivery (Benedetti, 2005; Wager & Atlas, 2015). The question then is not a matter of whether these influences occur, but rather to what degree are they occurring in comparison to the “active ingredient” contributions on measured outcomes (Burke et al., 2019). MM and NF interventions are no exception, and steps need to be taken to account for the influence of non-specific psychosocial factors (Prätzlich et al., 2016; Davies, et al., 2020). This is particularly important for the present study because neural mechanisms underlying placebo effects have been found to be the same as or similar to mechanisms implicated in MM, NF, and MM+NF training (e.g. thalamus, anterior insula, dlPFC, ACC, mPFC, amygdala; Wager & Atlas, 2015).

The most effective way to account for placebo influences is to tease them out at the level of experimental design. Typically, this means including a closely matched active control group or placebo condition (Kazdin 2005). Sham conditions are recommended as a gold standard method to control for technological placebo and expectation effects in NF research (Ros et al., 2020). A typical example of a sham control is to prep and setup participants to the NF machine and provide the same instructions as the real NF participants have, but then provide the sham group with the auditory or visual feedback signals that are not contingent on their brain activity (as would otherwise be the case in the true NF condition). This is typically done without sham NF participants being aware their feedback is not “real”. Thus, the sham condition involves the same procedural and psychosocial experiences (e.g., expectancy, characteristic demands, researcher contact) but lacks the specific core intervention element of the NF training. An additional approach for handling psychosocial confounds, aimed at the individual level of control, is to obtain self-report measures. For the present study these include measurements of attitude, engagement, and motivation, at baseline and across the study. Both group and individual difference measurement approaches are incorporated in the present study to control and quantify the role of potentially influential psychosocial factors on neural, physiological, and psychological outcomes and experiences associated with adding NF into MM training.

Research Approach and Hypotheses

If NF can be integrated in way that directly or indirectly influences core neural or cognitive components of FA training, then measurable changes should occur in those domains as well as in "downstream" skills and abilities they support. This line of reasoning and the model provided in Figure 4 can be used as a guide for uncovering the most relevant factors, mechanisms, and outcomes as they potentially unfold in FA-NF interactivity. This is what the current study seeks to achieve, alongside initial feasibility evaluation of the protocols and designs informed by the literature reviewed but designed and tested for the first time in this study.

This dissertation employed a multi-method, active control, repeated-measures design. Young adults were assigned to one of three conditions: (1) FA-MM training without NF (*MM-only*); (2) FA-MM training with alpha-NF integrated into guided meditation (*MM+NF*), and; (3) FA-MM training with Sham-NF (*MM+Sham*). Previous research has suggested that daily MM training in as few as five days in length can result in measurable physiological, cognitive and behavioural changes (Hwang et al., 2018; Short et al., 2015; Tang et al., 2017; Zeidan et al., 2010). The length of the training program designed for this study was 8 sessions, alternating between four in-lab and four at-home practices. Depending on assigned training condition, trainees either received of veritable-NF, no-NF, or sham-NF during in-lab MM practice sessions. Thus, even in the *MM+NF* condition, trainees completed four "regular" (at-home, no NF) FA-MM sessions, plus four sessions with NF integrated (in-lab). This alternation allowed both within- and between-group comparisons of training experiences and outcomes to ensure even the NF groups are acquiring some MM competency and practice, to increase the detection of NF interactivity effects on the ongoing development of core MM components. The cumulative duration of training with each method was believed to be sufficient to reveal the magnitude and direction of NF effects across variables, in relation to training without NF (e.g., Tang et al., 2017).

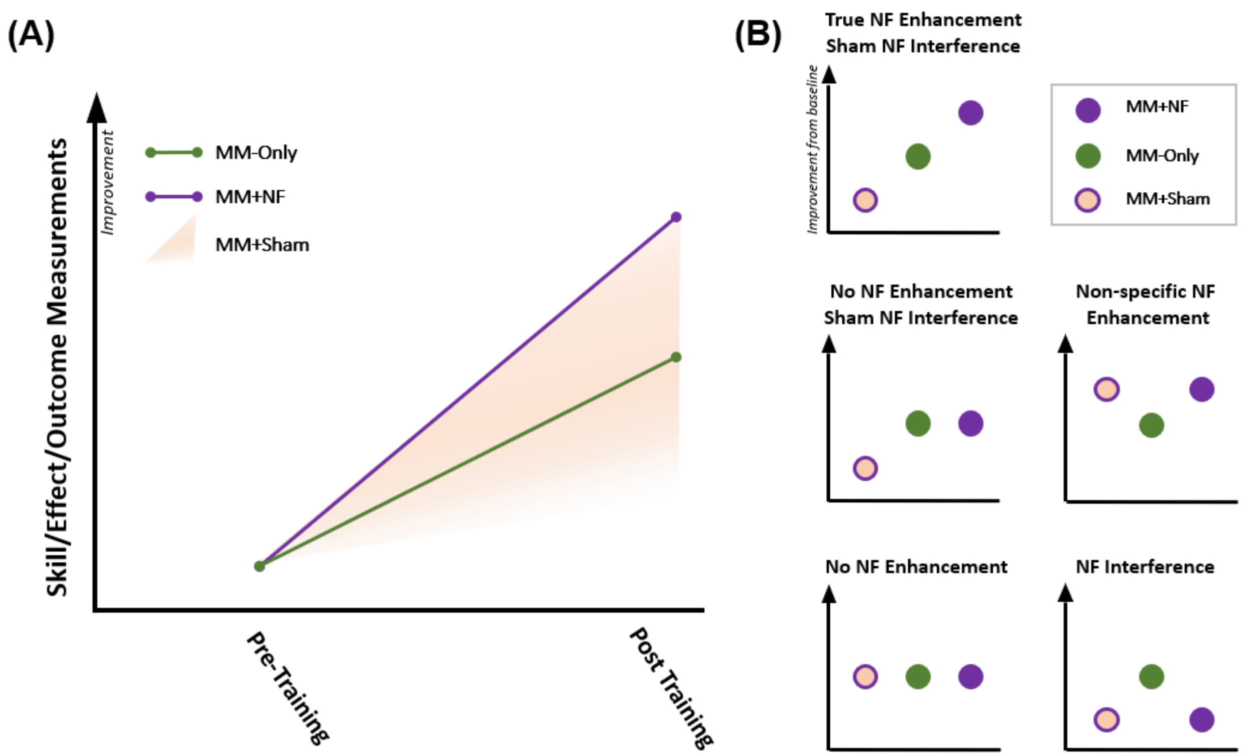
Healthy young adults were believed to be ideal sample demographic to begin to explore the mechanism and outcomes of a brief MM+NF training program with, specifically those that fell within the “emerging adulthood” neurodevelopmental age range (Arnett, 2000). Emerging adulthood describes the prolonged transition between adolescent into adulthood up to the third decade of life (Reifman Niehuis, 2023), and is characterized by ongoing development and integration of the prefrontal and limbic systems that support cognitive and emotional regulation (Taber-Thomas & Pérez-Edgar 2014). It is appreciated as a sensitive period, neurologically and psychologically, where new psychopathological vulnerabilities or resiliencies can form (Kessler, 2005; Schulenberg & Zarrett, 2006). Given the neural substrates and cognitive functions therapeutically targeted by MM training, this demographic group was anticipated to be highly responsive to the self-regulation training program deployed in this study and seemed likely to benefit from introduction and beginner practice of self-regulation skills during a sensitive and critical period of early adult life.

Hypotheses

This study was designed to investigate the outcomes and mechanisms of neurofeedback-assisted mindfulness meditation training. This is a complex, multi-faceted topic of investigation. However, in its barest form the research questions were: (1) Does NF enhance MM training, and (2) if so, how? The main hypothesis to test was whether integrating NF into MM training would in fact significant enhance MM training in a way that would result in better skill acquisition and cognitive/self-report outcomes than MM training without NF. This is the implied or stated claim of existing clinical and commercial NF-mediation applications, despite a lack of independent, high-quality, and well-controlled research studies in of support these assertions. However, it is also plausible that NF adds no significant benefit (additively or interactivity), detracts from benefits, or has a more complicated pattern of influence across the various mechanisms and outcomes involved in MM training. This experiment was designed appreciate and evaluate these reasonable and alternative hypotheses. By including MM-only and sham-

NF control conditions, sets of competing hypotheses become more clearly testable. This approach helps quantify and distinguish the efficacy and specificity of NF influences across MM training components and outcomes in multiple directions of effect. Figure 5 provides offers an interpretive framework for evaluating training related changes across neural (e.g., EEG/alpha), neurocognitive (e.g., attention), and psychological (e.g., mindfulness, well-being etc.) variables.

Figure 5. *Hypothetical Outcomes Across Training Conditions*



Note. (A) illustrates anticipated pre-to-post differences between MM training outcomes with and without neurofeedback integrated into training, in line with the hypothesis that the addition of veritable NF enhances the skills, effects, or outcomes natively acquired in MM training without NF. The magnitudes of change shown are purely illustrative. The *MM+Sham* condition is less specified than the *MM-only* and *MM+NF* conditions to highlight the wide range of outcomes it could produce with vastly different interpretations depending on its relativity to post-training outcomes in the other two conditions. (B) illustrates some of these hypothetical patterns of results as they might occur between groups, and possible interpretations.

In line with existing literature, it is expected that MM group will show improvements in neural markers of meditation proficiency (e.g., alpha) as well as the on the cognitive, behavioural, and self-report measures that reflect core neurocognitive abilities believe to be trained by MM practice. The pre/post results of the *MM-Only* group provide a bench marker for teasing out how NF might influence the mechanisms and outcomes associated with MM training in terms of positive, negative or neutral impacts relative to the other conditions (i.e., an efficacy indicator). The *MM+Sham* condition, and its pattern of pre/post-training when results compared to the other groups, reveals the extent to which non-specific and psychosocial aspects of adjunctive NF influence mechanisms and outcomes of training (i.e., an indicator of mechanistic specificity). The level of hypothetical specificity and granularity required to make accurate predictions of NFs potential influence for each component, across every level of measurement, for each condition goes beyond what the current state of literature and theory can confidently support. Established neuropsychological theories and existing MM and NF literature offer interpretive scaffolding to predict different how different cognitive abilities and neural substrates could be affected and interplay across different experimental training conditions. The framework of well-established theory, measurement, and design incorporated in this study set up conditions of high interpretability across a variety of potential patterns of outcomes. How the pattern of results resolves provide insight into the comparative efficacy and specificity of NF-related effects on MM training. With these consideration in mind, the results are expected to fall into one of four conditional hypotheses:

Hypothesis 1. *NF enhances MM training through neurocognitive mechanisms of change.* This hypothesis is supported if the *MM+NF* condition shows significant improvements post-training on objective neural, neurocognitive, and cognitive measurements beyond those observed in the *MM-only* and *MM+Sham* groups. Improvements in self-reports measures would be expected alongside and associated with self-reported improvements in functioning and wellbeing. These results would provide strong support that *MM+NF* acts specifically and efficaciously to enhance MM training.

Hypothesis 2. *NF enhances MM training through non-specific psychosocial mechanisms of change.* This hypothesis is supported if both the *MM+NF* and *MM+Sham* conditions show a comparable pattern of results in outperforming the *MM-Only* condition. Self-reported outcomes for these groups are expected to be higher than those in the *MM-Only* group post-training, potentially without significant improvements above the *MM-Only* group on objective neurocognitive measures. These results would support the notion that NF's predominant influence is through expectancy or other psychosocial effects, as opposed to target neural or cognitive training effects.

Hypothesis 3. *NF interferes with MM training*. This hypothesis is supported if the *MM+NF* training shows educed benefits of training on self-report or neurocognitive measures compared to *MM-Only* training. This pattern of results suggests the addition of NF is disruptive to some aspect of training at the experiential level (difficulty, engagement, motivation to train) or at a neural/cognitive mechanistic level (competitive interference of strategies or neurocognitive processes). If only the *MM+Sham* group shows deficits, this suggests that sham-feedback, but not veritable feedback, somehow interferes with MM training.

Hypothesis 4. *No Major NF Influence.* This hypothesis is supported if the addition of NF does not result in meaningful differences across primary outcome and mechanistic variables relative to those acquired by the *MM-Only* group. If this null hypothesis plays out across all measurements, interpretation from a basic science perspective is difficult. However, this constitutes a meaningful pattern of result in terms of cost-benefit implications for pursuing MM training with versus without NF technology. If this plays out for some mechanism or outcome measures but not others, such results would still be valuable contribution in understanding the specificity or limits of NF MM interactivity across the multiple components and pathways involved in MM training.

The experimental conditions are designed to discover the relationship between mechanisms and outcomes of MM training with and without NF. The overall pattern of results that the *MM+NF* group demonstrates across targeted MM measures, in comparison to *MM-Only* and *MM+Sham* training, was aimed to generate the knowledge required to support or reject hypotheses, in ways that allow meaningful interpretations for each category of hypothetical result. This is the focus of Chapter 5.

However, necessitating the possibility for any meaningful interpretation entails evaluating whether, at the broadest level, the procedures and protocols were reasonably actualized in operation, many of which were designed specifically for this study. An evaluation of the study design and protocol feasibility bears important implications for the findings of the current study and helping inform the methods and designs for closely related future studies. This is the focus of Chapter 4, which evaluates daily meditation ratings spanning motivational levels, distractibility, and mood, overall and between groups and by setting (in versus out of lab sessions), adverse affects, dropouts, sham believability, and other indices of effective or ineffective procedures.

The results of this study will deepen our collective understanding of the relationship between neurocognitive functions involved in MM, NF, and other related forms of self-regulation training. Ultimately, the findings of this study are intended to be used to understand and develop more effective evidence-based health and wellness training programs. At its most basic level, this dissertation promises to generate valuable knowledge to help inform consumers, practitioners, and other researchers about the strengths and limitations of NF-integrated training systems and programs.

CHAPTER THREE

Experimental Design Methods and Procedures

Participants

This study was approved by The Human Research Ethics Board of the University of Victoria. All participants gave informed consent after being provided with detailed information regarding the background of the study, potential risks and discomforts, and confidentiality. All participants were allowed to withdraw from the study at any time during the duration of the study and were free to withdraw their data should they wish to.

Participants were prospectively recruited for participation through (i) local community and University of Victoria campus print and social media, and (ii) the University of Victoria online SONA system for administering research studies to undergraduate participants. Participants recruited from SONA were compensated for their participation with course credit, whereas community and student participants recruited outside of SONA were compensated financially.

Inclusion criteria included being an adult between ages 20-30 and no prior extensive and/or recent experience with meditation or neurofeedback (NF) training. Extensive experience was conservatively defined as having a consistent practice averaging 30 min per week (or more) for a duration of more than 1 year (or cumulatively estimated 26 hours of training). Participants were excluded if they had practiced any meditation or NF within the last 6 months. These criteria also applied to contemplative movement meditation practices such as yoga, tai chi, qi gong, or conscious dance. They were also asked to refrain from engaging in meditation (apps or other modalities) other than the meditation training involved in this study for the duration of the study. Exclusion criteria included a diagnosis of any psychiatric disorder (e.g., bipolar disorder, panic disorder, ADHD, PTSD), a history of head trauma, presence of medical devices inserted in the heart or head, visual impairment, or visual field defect, serious medical or neurological illness, or currently taking psychotropic or psychostimulant medications.

Participants were screened for eligibility based on inclusion and exclusion criteria, and if they reported being able to complete the training and testing timelines. All eligible participants were given a unique password and ID which provided them access to a secure website portal designed for the study (via the Brightspace platform), which contained information and resources for participating in the study. The website included information on the study design and protocols (without highlighting different experimental conditions), orientation to the principles and practices of mindfulness including an FAQ for optimizing their training experience. The research portal also included the links to the daily home practice recordings and daily post-meditation survey links. This platform also allowed the research team to verify that daily meditation links were accessed only once on the days they were scheduled to complete their at-home meditations. Research assistants worked with each participant to identify times of day that might be consistently best to complete their in-lab testing sessions and meditation training sessions based on circadian preferences and weekly schedules.

Experimental Design

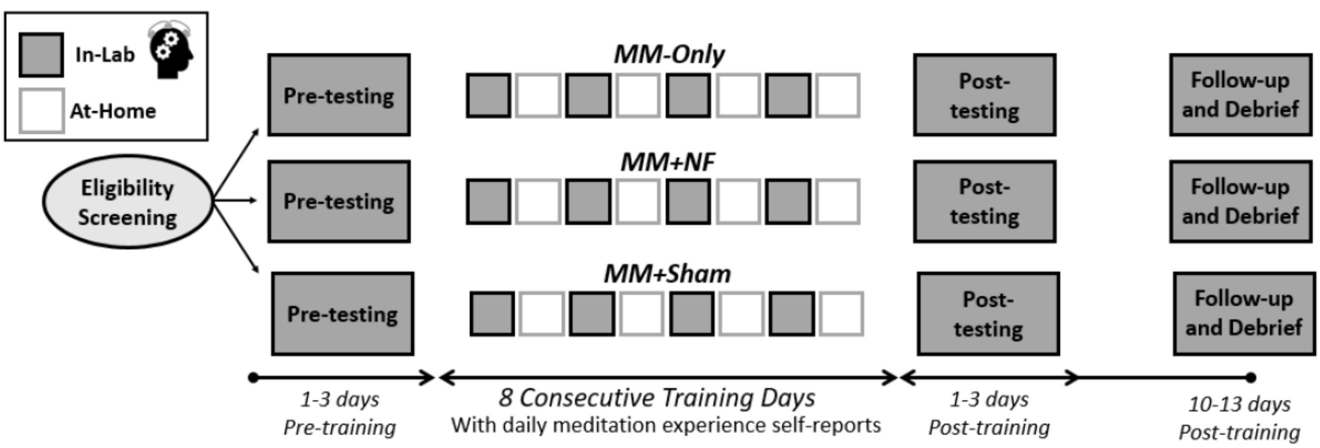
This study employed a randomized control intervention design, with multimodal repeated measures taken pre-training, post-training and at 10-day follow-up intervals. Figure 6 illustrates the experimental design. Participants completed a battery of self-report, cognitive, behavioural, and electrophysiological measures before and after training. The test battery took approximately 2 hours per participant. A subset of questionnaires was administered again at a follow-up and debrief session. Cognitive-behavioural and electrophysiological measurements were not administered at follow-up. Participants were asked to get a good sleep and abstain from substance use (alcohol, caffeine, cannabis) in the 24 hours before testing days, as well as minimally across the training period. They were queried during in-lab sessions to account for these potential confounding effects. Participants also provided ratings on various cognitive and experiential aspects of their daily meditations after each in-lab and at-home meditations across training. Electrophysiological recordings were taken for each of the four in lab meditation sessions.

Participants were randomly assigned to either a *mindful meditation (MM)-Only*, *MM+NF*, or *MM+Sham* NF training condition. All participants were trained on the same 19 minute and 49 second audio-guided meditation daily for eight consecutive days, alternating between in-lab and at-home practice. For participants in the *MM+NF* and *MM+Sham* conditions, additional instructions were given just prior to their meditation that oriented them to the neurofeedback sounds and how to incorporate it into the practice intervals in-between meditation instructions. These instructions were added or modified to give explicit direction to participants in the *MM+NF* and *MM+Sham* conditions during in-lab sessions on how to incorporate the neurofeedback, in ways consistent with the approach and principles of mindfulness. The meditation transcript and additional instructions are contained in Appendix A.

Participants in all three groups were setup with identical EEG montages. EEG data was actively acquired for a 2-minute baseline calibration task and throughout the meditation. *MM-only* were not given any NF guidance with their online acquired EEG signal. Only the *MM+NF* underwent true EEG-NF provided to them during the intervals of non-instruction in the MM recording. In contrast, participants in the *MM+Sham* group were played recordings acquired from the *MM+NF* under the false assumption that they were receiving personalized brain-contingent feedback during their in-lab sessions. All participants were debriefed at a follow-up, at which time the details of the experimental conditions and their scientific purpose were disclosed. Participants assigned to *MM+NF* and *MM+Sham* training conditions were then asked in retrospect which of the two NF training conditions they believed they had been assigned to and assign a confidence rating to their belief. True group assignment was revealed afterward. All participants were given time to share thoughts, ask questions, and reaffirm if they consented for their data to be used for analyses after full disclosure of experimental conditions.

COVID-19 Procedures. Data collection for this study began in the spring of 2022 when COVID19 provincial and institutional restrictions were changed to allow for in-person research contact. However, the conditions for in-person research necessitated the use of masks for all research team members and participants during all face-to-face contact. Mask removal was allowed for participants in the privacy of the testing room once research team members left the room. All participants chose to remove their masks for the testing and breath focused meditation sessions in the laboratory test room, and thus the impact of mask wearing was not believed to have impacted the data collection or meditation training. All equipment and surfaces were sanitized between participant sessions.

Figure 6. *Experimental Design*



Note. Participants screened eligible were randomly assigned to one of three training conditions. Training alternated between in-lab meditations with EEG recorded, and at-home practice without EEG. For the in-lab sessions, for the *MM+NF* group only, the EEG was used to provide participants with low alpha contingent neurofeedback during intervals in the meditation. In-lab, the *NF+Sham* group received auditory feedback from participants in the *MM+NF* that was unrelated to their own EEG activity. The *MM+Only* group was not given any neurofeedback, real or sham. The At-Home sessions were identical across groups, and had participants access and follow the same guided meditation audio file through an online platform that provided the training materials and daily meditation self-report questions. Pre- and post-training cognitive, behavioural, and self-report measures administered in the few days preceding and following the 8-day meditation training program. Participants returned to the lab for follow-up self-report measures and a debrief approximately 10 days after completing the post-training testing session.

Guided Meditation

The meditation instructions developed were in line with the psychological conceptualization of MM that emphasizes the development of attentional abilities combined with a specific, non-judgmental attitude toward the different mental experiences that may arise during MM (Slagter et al, 2011; Lutz, et al., 2008). The meditation was designed, scripted, and recorded by the dissertation author JV under the guidance and review of his primary supervisor CS. CS has extensive personal, clinical, and academic experience teaching and researching traditional Buddhist and mindfulness-based meditation practices and their neuroscientific bases. JV has supervised experience in facilitating guided MM practices in clinical, community, and academic settings, and upkeeps a personal meditation practice.

The guided meditation delivered in this study was a breath-focused (FA) MM of approximately 20 minutes in duration. The first few minutes provided instructions to help participants settle into their environment and their body. This was followed by a short set of instructions adopting a posture and frame of mind to support them in their MM. The next ten minutes guided participants to focus their attention on the sensation of their breathing at their nostrils. They were asked to refrain from manipulating their breathing in any form, and instead to allow their natural breathing rhythm to occur. They were instructed that, whenever they became aware that their attention had wandered from being focused on breathing sensations, to note the contents of their mind and after doing so gentle redirect their attention back to the sensations of their breath. In addition to focusing their attention on their breath, participants were instructed to observe any distracting thoughts, feelings, or sensations without judging, evaluating, or elaborating on them. Only for the *MM+NF* and *MM+Sham* group in-lab meditations, a subset of instructions was given providing guidance on how to incorporate the NF soundscape into the meditation as aligned with principles of mindfulness (i.e., to be peripherally aware of and use the feedback as needed, without becoming overly attached to it). Appendix A contains the meditation transcript (A.1), the specific instructions given to NF groups (A.2), and other training resources provided to participants (e.g., educational material on principles and attitudes to cultivate and support their MM practice; A.3).

Self-report Questionnaires

Several empirically validated self-report questionnaires were selected for this study based on psychological and neuropsychology-informed theories on the process and effects of training in mindfulness meditation. All self-report forms are contained in Appendix B.

Demographic Questionnaire

This was a form created in lab to account for participant age, assigned sex at birth, gender identity, ethnic background, prior meditation experiences that did not meet exclusion criteria, years of education, employment status, patterns of legal substance use (alcohol, nicotine, cannabis), typical sleep patterns, and handedness. Interest in learning meditation and perceived ability to learn meditation relative to peers were two areas also probed initially in the demographic questionnaire. Interest ("*How interested are you in learning and practicing meditation*") was queried with a 5-point Likert response anchored at 0 ("*Would prefer not to*") and 4 ("*Very interested*"). Perceived ability to learn meditation relative to peers was queried with participants viewing a normal curve distribution, with a short description of percentile ratings. The prompt was "*How skilled do you believe you will be at meditation, currently and relative to 100 other peers?*", that they provided their perceived percentile rank in response to. Notably, interest and perceived proficiency in meditation was also re-assessed at re-assessed at the follow-up/debrief session, post-training.

Five Factor Mindfulness Questionnaire-15 (FFMQ-15)

The FFMQ-15 (Baer et al., 2006) was used to detect and differences in trait mindfulness at baseline, pre-intervention, that might have occurred despite group randomization. The FFMQ consists of 15-items that factor load onto the following five subscales as the full 39-item FFMQ: (1) Non-reactivity ("*Usually when I have distressing thoughts or images, I step back and am aware of the thought or image* *without getting take over by it*"), (2) Observing ("*I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing*"), (3) Describing ("*I'm good at finding words to describe my feelings*"), (4) Acting with Awareness ("*I rush through activities without being really attentive to them*"), and (5) Non-judging ("*I tend to evaluate whether my perceptions are wrong or right*"). Although some studies have used the FFMQ and FFMQ-15 to evaluate intervention related changes to mindfulness, other researchers have suggested that is not a robustly stable or sensitive measure for these purposes (Gu et al., 2016). Previous studies suggest that the five-factor structure of the FFMQ is robust across various samples, displaying adequate to good internal consistency with α = .75-.91.

Attitude and Affinity for Technology

Participants' attitude and affinity for technology were measured with a multi-item and single item scale from Edison and Geissler (2003). The Affinity for Technology Scale is comprised of 10 items, with statements ("I am comfortable learning new technology") rated on a five-point Likert scale, anchored at 1 ("*Strongly disagree*") and 5 ("*Strongly Agree*"). Internal consistency for this scale was acceptably high (α = .88). The single factor construct of Technological Affinity measured by this scale was found to be positively associated with dispositional optimism (r = 0.29), draw to cognitively challenging tasks (r = 0.44), and self-efficacy (r = 0.21). A significant but small negative correlation was found for technological affinity and age (r = -.11). Another stand-alone item was borrowed from Edison and Geissler (2003) that reflects negative attitudes to technology, however psychometric properties were not reported for this item. Like the FFMQ-15, the attitude and affinity for technology measures were only administered once, at pre-training. These measures were used to evaluate the potential influence that participants baseline attitude and affinity for technology might have in relation to their NF technology-supplemented MM training.

Mindfulness Self-Efficacy Scale - Revised (MSES-R)

The MSES-R is a measure of the self-efficacy to deploy effective mindfulness skills and attitudes in day-to-day life. The MSES-R (Cayoun, 2012) is a 22-item, shortened and validated version, developed from the 37 items of the original MSES (Kasselis, Cayoun, & Skilbeck, 2011). The MSES-R scale uses a five-point Likert-scale, anchoring at 0 ("*Not at all*") to 5 ("*Completely*"). In addition to a total score the MSES-R included six factor analysis verified subscales: (1) Emotional Regulation ("*When I feel overwhelmed by emotion it takes a long time for it to pass*"), Equanimity ("*I can face my thoughts even if they are unpleasant*"); (2) Social Skills ("*I try to avoid uncomfortable situations even when they are really important*"), Distress Tolerance ("*When I have unpleasant feelings in my body, I prefer to push them away*"), Taking Responsibility ("*My actions are often controlled by other people or circumstances*"), and Interpersonal Effectiveness. Higher scores indicate higher self-efficacy in each respective domain. The internal consistency (α = .86) and test-retest reliability (r = .88) of this scale were found to be good. This measure has also demonstrated convergent validity with other mindfulness scales (e.g., MAAS, FFMQ, FMI), an inverse relationship with scores on depression and anxiety self-report scales (e.g., Depression Anxiety and Stress Short Form), and MSES-R scores changes have been observed in response to brief MM interventions (Allred, 2016).

Experiences Questionnaire – Decentering (EQ-D)

The EQ-D (Fresco et al., 2007) an 11-item measure of decentering guided by a mindfulness-based cognitive therapy (MBCT) framework. The EQ-D is a factor analysis validated subscale of the full EQ (the other factor being rumination). The EQ-D is designed to measure the ability to step back (i.e., "decenter") from negative thoughts. This is a core metacognitive skill believed to be developed through MM practice. Higher scores indicate better decentering ability. EQ-D scores have been shown to improve after MM-based interventions as short as ten sessions (Soler et al., 2014), and have demonstrated a predictive relationship with symptoms of distress, depression, anxiety, and well-being

(Bieling et al., 2012; Fresco, Segal, et al., 2007). Fresco and colleagues (2007) reported acceptably high internal consistencies of EQ scales (α = .81–.84). Information on EQ-D test-retest reliability was not found after a pointed literature search.

Attentional Control Scale (ACS)

The ACS (Derryberry & Reed, 2002) is a 20-item self-report measure that measures attentional control. Participants rated how frequently each item statement capture their recent experiences over the past week. The response format was a 4-point Likert-scale anchored at 1 ("*Almost never*") and 4 ("*Always*"). Some items are reverse-scored, and with higher scale scores indicating better attention control. In addition to a total attention control score, a 9-item measure of attentional focusing ("*My concentration is good even if there is music in the room around me"*) and an 11-item measure of attentional shifting ("*It is easy for me to alternate between two different tasks*") can be calculated. The total score of the scale is internally consistent with reliability estimates ranging from α = 0.71–0.88 (Gyurak & Ayduk, 2007; Verwoerd, de Jong, & Wessel, 2008). ACS scores show negative correlations to measures of distraction resistance (Judah et al, 2013) and anxiety (Derryberry & Reed, 2002). The Focusing and Shifting subscales were validated by independent factor analysis studies and found to be moderately correlated (Ólafsson et al., 2011). Information on ACS test-retest reliability was not found after a pointed literature search.

Executive Function Index (EFI)

The EFI (Spinella, 2005) is a consists of 27 questions that assess an individual's executive functioning in daily life. The format is a five-point Likert-scale rating of how much each item statement describes the participant, anchored at 1 ("*Not at all*") and 5 ("*Very much*"). In addition to a total score, the EFI also includes five factored subscales: (1) Motivational Drive ("*I have a lot of motivation to do things*"), (2) Organization ("*I sometimes I lose track of what I'm doing*"), (3) Strategic Planning ("*I use strategies to remember things*"), (4) Impulse Control ("*I lose my temper when I get upset*"), and (5)

Empathy ("*People who are foolish enough to be taken advantage of deserve it*"). Internal consistency for the total score was α = .82, and subscales *ranged between* α = .69-.76 in the initial community validation sample. Further factor analysis showed the EFI scales corresponded to functions associated with the three principal neuropsychologically relevant regions responsible for executive functioning: (1) the orbitofrontal prefrontal cortex (Impulse Control and Empathy scales); (2) the dorsolateral prefrontal cortex (Strategic Planning and Organization Subscales), and (3) the medial prefrontal cortex (Motivational Drive scale). EFI test-retest reliability was not found after a pointed literature search.

Multidimensional Assessment of Interoceptive Awareness - Version 2 (MAIA-2)

The MAIA-2 (Mehling, 2018) is an 8-scale state-trait questionnaire with 37 items to measure multiple dimensions of interoceptive awareness by self-report. Interoception has been defined as the process by which the nervous system senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the body's internal landscape across *conscious and unconscious* levels (Mehling 2012). The original MAIA (Mehling, 2012), and the slightly modified MAIA-2 (2018), were developed to assess the conscious level of interception. The MAIA and MAIA-2 have scales developed to distinguish between anxiety-driven and mindful modes of body awareness, which make it a unique and highly appropriate choice for measuring awareness of bodily symptoms in this study. Participants rate how often each statement applies to them in general daily life along a six-point Likert-scale anchored at 0 ("Never") and 5 ("Always").

Like the original, the MAIA-2 includes a total interoceptive awareness score, as well as six factor analysis validated scales, labelled: (1) Noticing ("*I notice changes in my breathing, such as when it slows down and speeds up*"), (2) Not-Distracting ("*I try to ignore pain*"), (3) Not-Worrying ("*I start to worry if something is wrong if I feel any discomfort*"), (4) Attention Regulation ("*I am able to focus on my body as a whole*"), (5) Emotional Awareness ("When something is wrong in my life I can feel it in my body"), (6) Self-Regulation ("*When I feel overwhelmed I can find a calm place inside*"), (7) Body

Listening ("*I listen for information from my body about my emotional state*"), and (8) Trust ("I feel my body is a safe place"). Some items are reverse scores. Higher scores indicate higher interoceptive awareness for each scale. The MAIA-2 differs from the MAIA by the addition of items to the Not Worrying and Noticing Scales to increase the internal consistency of these scales. The internal consistencies across scales ranged from α = .64-.83. The authors note that the Not-Distracting and Not Worrying scales have increased internal reliability estimates in samples high in mind-body training acquired through therapy, meditation, or other body awareness training experiences. Test-retest reliabilities for the English version of the MAIA or MAIA-2 were not found upon a pointed literature search. However, the 2-week test–retest reliability of a Japanese translated version ranged from adequate to high across scales, ICC = 0.76–0.85 (78 young adult students; Fujino, 2019).

Regarding convergent validity, in the initial validation study (Mehling, 2012) the MAIA scales were most highly and positively correlated with aspects of mindful attention and body awareness, particularly with the FFMQ-Observing scale, and Body Responsiveness Questionnaire's (Daubenmier, 2005). A moderate relationship between the MAIA and emotion regulation measured by the Emotional Attention Control Scale and Difficulty in Emotion Regulation Scale (DERS) were moderately to highly negatively correlated with Trait scale scores of the State-Trait Anxiety Inventory (Spielberger, 1983).

Mind Wandering Scale (MWS)

The MWS (Mrazek et al., 2013) is a tool designed to quickly assess trait levels of inattentive mind wandering. The scale is comprised of five items that capture day-to-day task-focus interruptions caused by task-unrelated thoughts ("*I find myself listening with one ear, thinking about something else at the same time*"). Items were informed by, and convergent with well-researched attention and mindfulness scales. The scale is a six-point Likert-scale anchored at 1 ("*Almost never*") and 6 ("*Almost always*"). Each of the five scale items had a high loading on a single mind wandering factor (.71 – .84). The internal consistency of the scale in a young adult student sample was acceptably high (*α* = .85). Information on MWS test-retest reliability was not found after a pointed literature search.

Profile of Mood Survey - Short Form (POMS-SF)

The Profile of Mood States (POMS; McNair et al, 1981) is a widely used 65-item measure of psychological distress in clinical and research settings (Nyenhuis et al., 2021; Petrowski et al., 2021). This study used a shortened 37-item version (POMS-SF; Shacham, 1983; McNair et al., 1992). Participants were asked to rate how much mood items describe them "…*over the past week including today*", rated on five-point scale anchored at 1 ("*Not at all*") and 5 ("*Extremely*"). Like the full POMS, the POMS-SF measures six different dimensions of mood across a period of time. These include: (1) Tension-Anxiety, (2) Anger-Hostility, (3) Vigor-Activity, (4) Fatigue-Inertia, (5) Depression-Dejection, and (6) Confusion-Bewilderment, as well as a Total Mood Disturbance scale. Administered to a sample of non-clinical adults (DiLorenzo et al., 1999) the internal consistencies for all of the POMS-SF scales yielded *α's* ≥ 0.90, with the exception of the Confusion-Bewilderment subscale (*α* = 0.73). Curran et al. (1995) produced comparable results, which indicated the POMS-SF had equivalent or stronger psychometric properties than the original POMS. POMS test-retest reliability in an older adult sample of 100 with a one-week retest interval produces (*r*'s > .75; except for confusion, *r* = .68). Information on the test-retest reliability for the short form could not be found.

Perceived Stress Scale (PSS)

The PSS (Cohen et al., 1983) is a widely used psychological instrument for measuring the perception of stress. Items were designed to tap how unpredictable, uncontrollable, and overloaded respondents find their lives. It is a measure of the degree to which situations in one's life are appraised as stressful. The scale is comprised of 10 items that are direct queries of current levels of experienced stress. Participants were asked to rate how often they felt or thought a certain way over the previous 10 days on a 5-point Likert-Scale anchored at 0 ("*Never*") and 4 ("*Very Often*"). Lee (2012) found the several translations of PSS demonstrated decreasing but still satisfactory test-retest reliability between two days and four weeks. Two-week test-retest reliability in with a validated Spanish equivalent form (Remor et al., 2006) yielded and r = .77 (α = .83).

Psychological Wellbeing Scale (PWS)

The PWS (Ryff & Keyes, 1995) is an 18-item self-report questionnaire that is comprised of six dimensions of wellness, specifically: Autonomy, Environmental Mastery, Personal Growth, Positive Relations with Others, Purpose in Life, Self-Acceptance. Confirmatory factor analysis provided support for the proposed six-factor model, with a single second-order super factor. Ryff and Keyes (1995) note moderate-to-low levels of internal consistency across subscales related to low item numbers for each scale. All scales are negatively correlated with multiple indicators of depression (strongest for Self-Acceptance and Environmental Mastery), and positively correlated with other measures of happiness and life satisfaction. Negatively phrased items are included on the scales that are reversed scored. For each item, participants choose from six statements ranging from ‘completely disagree’ (1) to ‘completely agree’ (7). Higher scores mean higher levels of psychological well-being for each scale.

Daily Meditation Experience Ratings

Immediately after each meditation session participants rated ten items on 5-point Likert scale that probed various aspects related to their daily meditation, including: motivation, difficulty/ease, satisfaction, mood, focus, energy, tension/relaxation, and distractibility from mind wandering, internal/body and external/environmental sources. *MM+NF and MM+Sham* participants were additionally asked three questions related to the helpfulness, perceived accuracy, and attention paid to the neurofeedback audio cues after their in-lab meditation sessions. A selection of questions related to participant’s attitude, motivation, and continued intention to practice meditation were asked prior to the debrief, during the final in-lab follow-up session. Additionally, questions inquiring about both pleasant and unpleasant/adverse experiences perceived to be directly related to their meditation practice were asked, as advised by other contemplative science researchers (Schlosser et al, 2019).

Self-Efficacy for Mindfulness Meditation Practice Scale (SEMMP)

The SEMMP (Birdee et al., 2020) was designed to inform research on adoption of mindfulness meditation practice as a health behavior, developed through a process of expert consensus, cognitive interviewing, and evaluation among MM practitioners. Whereas the MSES assesses the resulting skills and implementation of mindfulness in daily life, the SEMMP assesses the ability to perform mindfulness meditation within practice sessions. Participants rate the frequency of each state according to the prompt "*During my meditation practice…*", on a nine-point Likert Scale anchored at 0 ("*Never*") and 9 ("*Often*"). It's comprised of 9-items that factor unidimensionally, and across three subconstruct scales: (1) Attention ("*I am able to notice thoughts as they arise*"), (2) Self-kindness ("*I am able to be compassionate with myself when my mind wanders*"), and (3) Emotion ("*I am able to notice emotions as they arise*"). Higher scores indicate higher efficacy of MM ability within practice sessions. Internal consistency was found to be high with (α = .89), with an acceptable two-week test–retest reliability (ICC = 0.85). SEMMP scores positively correlate with health self-efficacy, and mental health-related quality of life, and with the five facets of mindfulness from the FFMQ. The authors also noted a correlation with social desirability effects. The SEMMP was administered digitally on both the second and final day of the training program, after participants at-home meditation practice, to evaluate the change in meditation ability for each of the three training conditions.

Cognitive and Behavioural Tests

Several computer-based cognitive tests were administered. The consideration for planning the cognitive and behavioural test battery was to include tasks that could provide reliable indices of processing speed, vigilance, sustained attention, and attentional control (shifting and resistance to distraction). Though considered distinct neuropsychological functions, these processes are functionally interrelated, particularly in terms of supporting “higher-order” cognitive and emotional regulation processes, including many of the constructs assessed with the questionnaire measures (e.g., attention, executive function, and interoceptive awareness). Tasks were administered in a sound dampened room using the Psychtoolbox extension (Version 3) with MATLAB R2021 (Mathworks; Natick, U.S.A) on a LCD laptop with a 35 x 19-centimeter display. For all three tests, measures of accuracy (correct versus incorrect key hits and omissions), speed (median reaction time), and consistency (intraindividual variability of mean reaction times) were extracted analysis. Participants were instructed to use their dominant hand for all tests at each measurement session. Median reaction time was the primary speed measure as it is a better estimate of central tendency in skewed data, such as is often the case with reaction time-based tests. Intraindividual variability was computed as a coefficient of variation metric, calculated by dividing the mean by the standard deviation and multiplying by 100.

Go/No-Go Task

The Go/No-Go task quickly presents highly frequent visual stimuli which participants are instructed to respond to (Go trials), setting up a prepotent response tendency, mixed in with infrequently occurring stimuli to which participants are instructed to withhold a response to (No-Go trials). This task engages conflict monitoring to allocate neural resources between the two competing processes (response and non-response), keeping track of the alignment between behaviour (or potential behaviour) and the goals held by participants. The Go/No-Go task also requires sustaining attention to keep track of stimuli, potential conflicts, and engage response inhibition processes to actively prevent a habitual or prepotent responding. Experienced MM practitioners showed higher accuracy on Go and No-Go trials, compared to age-matched non-meditators in at least one study (Bailey et al. 2019). This was associated with a frontally shifted distribution of neural activity during the P3 in both Go and No-Go trials, interpreted as being the result of alterations to global attentional processes rather than specifically to inhibitory control.

The version of the task used in this study presented participants with a series of circles colored gray (frequent “Go”; 70% of trials), yellow (rare “Go”; 10) and blue (“No-Go”; 20%) with 241 trials total. The circles were presented center screen for a duration of 500ms followed by a blank screen for 250ms. Participants had up to1250ms to respond with a spacebar press before the next trial began. Intertrial intervals were randomly jittered between 250ms-750ms. Participants were instructed to have their palm resting on the laptop with there fingers in contact with the spacebar at all times to reduce variability in response making distance. Reaction times as well as accuracy of hits and omissions were recorded. This task lasted approximately 10 minutes without breaks. It was always given last in order maximally leverage any attentional fatigue that might have accumulated from completing the preceding computer tasks and increase sensitivity to vigilance and inhibitory control lapses.

Multi-Source Interference Test (MSIT)

The MSIT (Bush, Shin, Holmes, Rosen, & Vogt, 2003) is a theory-driven computerized neuropsychological test that involves directed and selective attention in the context of conflicting or incongruent cues. It is a speed and accuracy task that involves Stroop (Stroop, 1935), Erickson flanker (Eriksen & Eriksen, 1974), and Simon effects of cognitive interference (Simon & Berbaum, 1990). In clinical and non-clinical samples, individuals with lower directed attention abilities perform poorer when there are non-matched (incongruent) trials (Bush, 2009). The cognitive interference delay in reaction time-MSIT interference trials is significantly larger than Stroop or flanker tasks alone (Jung et al., 2018). Importantly, this task has been demonstrated to activate the dorsal anterior cingulate cortex (dACC), a structure that is centrally involved in decision-making, target detection, novelty detection, error detection, response selection, and stimulus/response competition. Additional networks and regions that the MSIT has been shown to recruit include the dorsal anterior midcingulate cortex (daMCC), the dorsolateral prefrontal cortex (dlPFC), the premotor and primary motor cortex (responsible for planning and execution of non-automatic tasks), the inferior temporal gyrus, and the superior parietal lobule

(Bush and Shin 2006). MSIT has been found to deactivate the perigenual anterior cingulate cortex (pACC), involved in emotional processing (Bush, 2003). Frontal and midline theta ERPs responses are reliably detected during interference trials (Roberston et al., 2014), with power reductions in posterior alpha having also been observed during MSIT (González-Villar & Carrillo-de-la-Peña, 2017).

Participants were instructed that three numbers (1, 2, or 3) would appear in the center of the screen every few seconds. The target number would always be different from the other two numbers. Participants were instructed to select the target number that was different from rest. They used a response keypad to indicate their answer, with the index, middle, and ring finger corresponding to response options 1, 2, and 3, respectively. In the control condition, the different number was always located in the congruent position (relative to the response key/finger) and the distractors are ‘x’s (i.e., 1xx, x2x, or xx3). In the interference condition, the different number were always located in an incongruent location and the distractors are other numbers (1, 2, or 3; e.g., 322, 221, or 131). Participants were instructed to respond as quickly and accurately as possible. Participants completed 15 practice control and interference trials first. They had to perform with accuracy ≥80% (12 correct) on the practice trials, or another practice block was performed. The MSIT testing consisted of 200 trials (100 per condition), divided into five blocks of 20 control and 20 interference trials. The control condition was always presented first. Each trial involved presentation of the stimuli for 900ms followed by a black screen interval that randomly lasted between 1,500-2,000ms. After each block a 15 second break was given. Total administration time was approximately 10 minutes.

Distractor n-Back

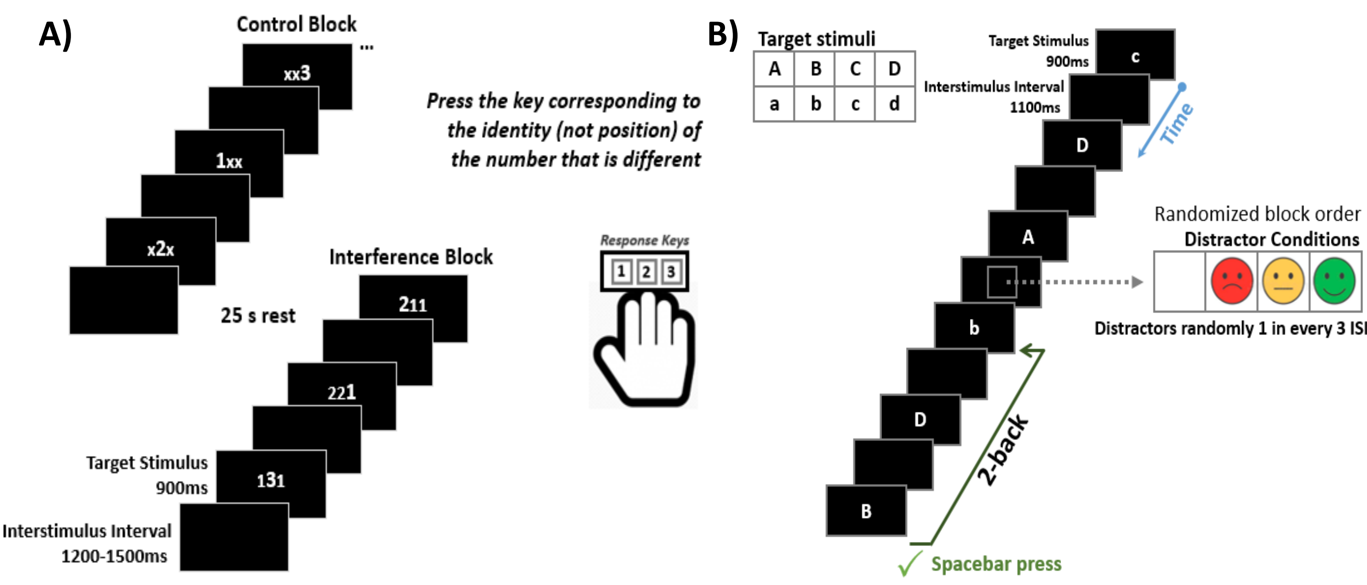
This working memory task requires participants to monitor the identity or location of a series of verbal (letter) stimuli and to indicate when the currently presented stimulus is the same as the one presented n trials previously (Owen et al., 2005). Typically, there are two conditions with increasing difficulty: 2-back, and 3-back. In the 2-back condition, participants indicate via spacebar press, whether the stimulus they just saw was the same as the one they saw 2-back (i.e., the one that appeared two prior). Likewise, a similar instruction is given for the 3-back conditions.

For this study, only a 2-back condition was used. The task difficulty was modulated by having training blocks with and without distractor images interleaved (details below). For all blocks and trials, the target stimuli were the letters A-D, randomly varied as upper- or lower-case to limit reliance on perceptual information. The target letters stimulus duration was 800ms, with 1200ms inter-stimulus interval. Participants were administered 15 practice trials of the basic (no distraction) condition before moving forward in the instructions to introduce the distractor elements as randomly three-out-of-four blocks would occur with these additional stimuli. They also were provided with 15 practice trials of the n-back with emotional stimuli appearing at the same rate as the experimental trials. In both cases participants had to perform with an accuracy ≥70% on the practice trials to ensure understanding and reduce initial learning effects. If they performed below this, another practice trial was administered. Failing that, the task exited into a message to call in the experimenter before proceeding, at which point effort and understanding would be evaluated for continuing testing.

For the "emotional interference" distractor conditions, the inter-stimulus interval between the *n*-back letters contained emotionally evocative pictures. This was done to increase the cognitive demands alongside introducing affective processing; thus, creating a working-memory and implicit emotion regulation measure of cognitive-emotional distraction resilience. The emotional stimuli were selected from the Open Affective Standardized Image Set (OASIS; Kurdi, Lozano & Mahzarin, 2017). OASIS is an open-access online stimulus set containing 900 color images depicting a broad spectrum of themes, including humans, animals, objects, and scenes, along with normative ratings on two affective dimensions: (i) Valence - the degree of affective response that the image evoked on a 7-point Likert-scale (1 Highly Negative, 7 Highly Positive), and (ii) Arousal - the intensity of the affective response that the image evoked, rated on a 7-point Likert-scale (1 Low arousal, 7 High Arousal).

There were four distractor conditions: (1) no distractor (regular *n*-back), (2) neutral distractor (*M* arousal = 2.3, range 1.7 - 3.2; *M* valence = 4.2, range 3.5 - 4.7), (3) positive distractor (*M* arousal = 4.2, range 3.2 -5.1; *M* valence = 5.9, range 4.8 – 6.5), and (4) negative distractor (*M* arousal = 4.3, range 3.3 – 5.3; *M* valence = 2.4, range 1.4 – 3.3). Each block had 60 trials, with a 10 second rest between blocks. There was a maximum number of 21 correct hits, randomly distributed throughout the 60 trials for all conditions. Distractors in the distractor conditions randomly appeared in one-third of the interstimulus intervals. There were a balanced number of themes in each distractor condition. Accuracy, speed, and consistency were recorded for each block. Appendix D contains details of task performance from all participants at BL (including those who dropped out before PT) to verify differences in performance between the distractor conditions. The total time including instructions, practice trials, experimental blocks, and rest pauses was approximately 12 minutes.

Figure 7. *Illustration of MSIT and Emotional Distractor n-Back Tasks*



Note. Panel (A) shows the MSIT, the two block types, stimuli parameters and response keys. Panel (B) shows a graphic representation of the emotional distractor n-back task, stimuli, and parameters.

Electrophysiological Tasks

Participants in all groups completed a resting-state EEG recording within three days before and after their meditation training. A neurofeedback control task was also included to investigate whether MM with or without NF leads to better NF control. The resting state and alpha neurofeedback control task (described below) were administered with the same general EEG recording parameters and setup.

EEG Parameters

To reduce participant and resource burden, a sparse montage was used. This montage was comprised of 3 midline electrodes placed at Fz, Cz, and Pz. Electrodes were also placed on both mastoid sites (M1 and M2), linked to as an online reference. A ground electrode was placed at Fpz. One electrode was affixed to the outer canthus of the left eye (LO1), used to detect eye movements, blinks, and muscle tension which were individually registered for each participant prior to each experimental recording and used to assist in artifact identification and data cleaning post-hoc. All electrodes were Ag/AgCl and placed according to 10-20-system of electrode placement. Prior to electrode placement, skin was prepared with a mild abrasive skin cleaner and conductance enhancer (NuPrep; Weaver and Company, US). Electrodes were then affixed with adhesive conductive paste (Ten20, Weaver and Company, US). EEG was recorded at a rate of 125 samples per second, with an online analog bandpass of 0.016–100 Hz and amplified with a 4-channel Neurobit Optima+ (Neurobit Systems). The frequency bands of experimental interest were defined as Alpha (7-13Hz), Theta (3-7 Hz), Beta (14-30 Hz), and Gamma (30-45 Hz). Additionally, lower alpha activity was broken down into lower (7-10 Hz) and upper (10-13 Hz) frequency sub-bands for analysis. Bandpasses for Fz, Cz, and Pz used Butterworth IIR filtering of the sixth order. LO1 was bandpassed with a third order Butterworth filter for activity in the 0.5-4 Hz range, for detection of eye movements, and a sixth order Butterworth filter for activity in the 45-60 Hz range for detection of jaw and face muscle tension. All electrode impedances were maintained below 8kΩ throughout the recording session, checked before each EEG-based task. BioExplorer software was used in conjunction with the Neurobit amplifier, as together they were compatible for recording EEG and providing real-time neurofeedback with online data acquisition. In all recordings the program exported channel and bandpass filtered data in 1 second epochs of 2 second sliding average windows for analyses. A notable limitation that was discovered into data collection was that the raw signal at original sampling rate was not recoverable after the data recordings finished, and the EEG data for analysis was limited to the 1 second epochs exported when the recordings stopped. This significantly reduced the opportunity for more fine or sophisticated EEG analysis and artifact cleaning, including using ICA-based methods and automated MATLAB-based pipelines used by the author previously.

Instead, artifacts were attended to offline in a series of semi-automated steps that required moving the text-based exported files into Excel-based matrixes of 1-second epoch data, separated into electrode sites and bandpass filters described above. Data registering above 55 µV was removed as activity in this range can be elicited with movement and is unlikely to be cortical in origin. The highest and lowest 2% values of data were then trimmed. The continuous LO1 site 0.9–4 Hz and 45-60 Hz signals were examined from the calibration recording section that instructed blinks, jaw clenching, and eye movements to determine artifact detection and epoch rejections across the midline channels. Epochs where the LO1 .5-4 signal breached the 15^{th} percentile of jaw clench register, or the 15^{th} percentile of the 45-60 Hz of the eye movement register were automatically removed for all electrodes. Epochs were flagged when theta at Fz correlated with EOG (.9 -4 Hz) with $r > 0.8$ for a 1 second epoch as it was noticed in prepiloting spectrogram observations that some eye movements including blinks had visible time-locked spillover into Fz.

All remaining flagged and unflagged data were visually inspected for each recording via scatterplot and spreadsheet viewing. Appendix E provides illustrations and further description of EEG cleaning. Minor adjustments made to rejection thresholds (+/- 1-2mV to cut-offs) and manual epoch rejection to minimize false rejection of EEG data based on the bandpass percentile screening, and as initial rejection parameters tended to be liberal towards rejection with first pass screening. Highly artifact-contaminated channels had all channels removed for the entirety of the session. After cleaning, data from Fz, Cz, and Pz were average according to above mentioned bands for statistical analysis.

Resting State Task

After the calibration recording, participants followed recorded instructions to close their eyes and relax. After four minutes passed, they were instructed to open their eyes and gently gaze at a fixation cross on the computer screen. A total of eight minutes of resting state data was collected (520 epochs of data; 240 epochs for each of eyes closed and open rest, pre-cleaning).

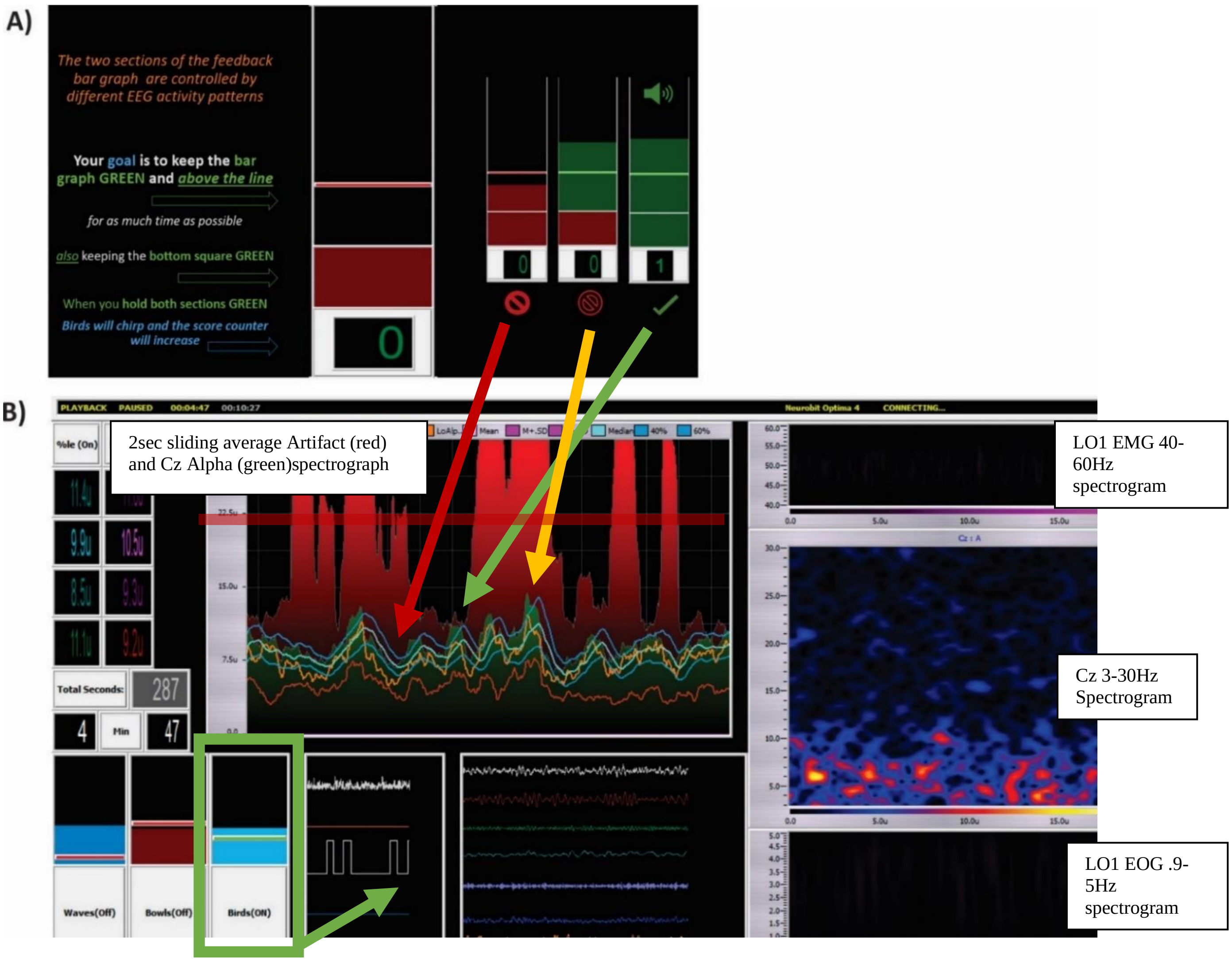
Alpha Neurofeedback Control Task

Immediately after the resting state instructions, the instructional recording requested the participants to continue to gently gaze at the fixation cross but now begin to count backwards in their head from 200 by 7s. They were given 36 seconds to complete this task, before the resting state protocol ended. In the background the software computed the last 100 seconds of alpha and provided the 40% and 60% percentile of average amplitude at Cz. These values were extracted and used to set the auditory and visual feedback thresholds for the subsequent alpha neurofeedback control task. Thus, the eyes-open rest and mental arithmetic conditions were used to create an amalgamated threshold at Cz to program the alpha neurofeedback control task against.

Participants were introduced to the task with the following instruction set: “Now we will have you try a neurofeedback task to see how well you can keep a bar graph green and above a line using your EEG signal. The instructions will appear on the screen so just follow along. This takes about 10 minutes. For the first block the target line is set still. Then, a second block, the target line will move and adapt to your ongoing brain activity.” A short, pre-recorded video played outlining how to use the neurofeedback display shown in Figure 8A. Briefly, the participants had two tasks, which they had to implicitly figure out how to execute. The first was to sustain their alpha amplitude for at least 750ms above the 60th percentile of mean alpha amplitude obtained from their eyes-open rest and mental arithmetic calibration. The second was to keep their muscle and eyeblink artifacts low. This was accomplished by creating a single artifact composite, defined as 2*EMG+EOG, which had to remain below 22uV (parameters and thresholds set based on earlier pilot data). When these two objectives were achieved for 1 second, a "bird" point would be added to the counter along with the sound of a chirping bird (audio recorded courtesy of a local starling nesting on campus).

Participants had a 1-minute warm up to be accustomed to the task without the bird score tallying. Then they completed two experimental 4-minute blocks separated by 30 seconds of rest. In the first block, the threshold line was visible as a stationary bar. In the second block, the threshold for the bird counter and auditory feedback was the same. However, the visual feedback mode changed. In this block the threshold for visual feedback (having the bar graph green and higher than the moving threshold bar) was calculated based on the moving average amplitude of Cz measured continuously across the preceding five seconds, such that the threshold bar would have temporarily been randomly exceeded 65% of the time. This was the sliding threshold that ongoing Cz activity had to be brought above in real time using the main bar graph, which refreshed every 500ms on screen. This ensured that participants were provided a relatively constant level of guidance (feedback) toward the target of increasing alpha amplitudes to the level needed to achieve the goal of 'catching more birds' with the same covert threshold to achieve the set threshold condition. The same EEG parameters were extracted for analysis in both blocks of the task, as well as the participant's total bird count.

Figure 8. *Neurofeedback Controls*



Note. (A) Screenshot of the task display flanked by the instructions that were given in audio-visual recording format; (B) A screenshot of the experimental dashboard invisible to participants that illustrates the NF mechanics. The red, orange and green lines from panel (A) indicate on the spectrograph when this participant might match the no-bird versus bird adding thresholds of sustained Cz alpha (green peaks in spectrogram) in the absence of large eye or muscle artifacts that might otherwise contaminate Fz, Cz, Pz. Participants had to sustain alpha above the baseline-set threshold line (green box) while also keeping the eye and muscle tension lower than the artifact signal thresholds (indicated here with a horizontal red line on the spectrogram; approximately 20uV for all participants). Satisfying of both conditions for a 1-second duration resulted in the auditory feedback of birds chirping and a bird being added to the participant display in real-time for each second. The volume of the bird chirps was set, and not determined by alpha amplitude above threshold. The green box pointing to the NF threshold pass spectrogram shows this occurring. The MM+NF training mechanics, shown beside this box as toggled off, followed a similar mechanic whereby 7-10 Hz amplitudes below the red line in the “Waves” box triggered the sound of a rolling wave and 7-10 Hz sustained above the red line in the “Bowls” box would begin a gently tapered in Tibetan singing bowl. The volume of the waves and bowls were scaled to the distance of ongoing lower alpha levels from the threshold lines.

In-Lab Meditations: EEG and Neurofeedback

In the lab, the meditation recording was identical to the one assigned for home practice, with the procedural differences in being prepared with EEG recording equipment, and brief explanations of the EEG and NF methods. EEG acquisition, montage, and filtering were as previously described. Although EEG was recorded across the entirety of each meditation session, only 6 blocks of breath-focused meditation practice (FA MM) between brief instruction sets were used for data analysis. This resulted in a total of 9 minutes and 30 seconds, in 570 epochs of data for analysis. Intervals of real or sham neurofeedback were provided to the *MM+NF* and *MM+Sham* groups, respectively. Appendix B.1 contains the meditation instructions with recording/neurofeedback blockings embedded.

Immediately prior to the in-lab meditation, all groups completed a 2 minute and 40 second calibration recording comprised of: (1) artifact calibration (35 seconds: blink 6 times, clench jaw for 5 seconds then relax jaw, look up then back, look down then back, look left then back, look right then back, then relax face and gaze), (2) eyes closed rest (45 seconds: “close your eyes, relax, and let your mind go where it goes”), (3) eyes closed mental rehearsal (45 seconds: “with your eyes remaining closed, in as much detail as possible, mentally rehearse the last 12 hours including coming into the lab”). The calibration instructions were given in recorded audio to keep standardization in time-lock fashion to the recording. At the end of the calibration recording, the research assistant documented the 40^{th} and 60^{th} percentile of averaged four second sliding window low alpha activity (7-10Hz) at Cz for the last 90 seconds of the pre-meditation recording. These thresholds were then a composite of state non-mindfulness insofar as the eyes-closed rest, listening to instructions, and effortful mental rehearsal are not in line with states of mindfulness meditation. The 40^{th} and 60^{th} percentile were then manually programmed into each participant’s in-lab meditation session prior to each in-lab meditation, and specifically served as the lower and upper thresholds for providing feedback to the *MM+NF* group. This was also done for the *MM-Only* and *MM+Sham* group participants, although neither of these groups received feedback contingent on their low alpha levels during in-lab meditations. The meditation script and spacing of the FA EEG/NF windows can be found in Appendix A.

MM+NF neurofeedback protocol. Only the *MM+NF* group's EEG was used in real-time to provide them with true NF meditative guidance (valid and ongoing brainwave feedback received throughout the sessions). The protocol was such that, for each block of FA instruction practice, when participants low alpha dropped below the lower calibrated cutoff (40^{th} percentile, as described above) the sound of a wave rolling on a rocky beach would taper in, and if they sustained low alpha above the upper calibrated threshold (60^{th} percentile, as described above) the sound of Tibetan singing bowl would be tapered in. In classic behavourist terms, the sound of singing bowls would be termed positive reinforcement signal and the rolling waves positive punishment. However, the instructions given to the *MM+NF* (and *MM+Sham*) prior to participants on how to interpret and use this feedback was couched in different language and operationalized in a way believed to be more conducive to NF and MM integrated practice. The specific instructions, read verbatim by research assistants after the calibration recording, prior to starting their EEG recorded meditation, was the following:

> *"During some stretches in the middle sections of the meditation, you will have the addition of EEG neurofeedback come on in the background to help support you. As you continue to meditate according to the meditation instructions, I invite you to be peripherally aware of its guiding sounds when they turn on, with the sound of rolling waves suggesting you may have fallen out of a relaxed and focused mindset, perhaps reflecting mind wandering or mental or physiological tension. Gently note and see if there are mental or physical things to let go of while returning to be with the breath if you find you are getting lots of this feedback. In contrast, there will also be the sound of a singing bowl, with the volume of it tied to when your mind has continuously held a calm, gentle, or deeper-focused state."*

The meditation audio and feedback sounds were played from the laptop speakers, at a consistent level determined to be clearly audible but not loud informal piloting surveys. NF volumes were set to 5-30% of the meditation audio volume, in such a way that the increasing difference of mean lower alpha amplitudes below and above the aforementioned lower 40th percentile threshold and above the 60th percentile threshold respectively increased the volume of the wave and bowl feedback. The max volume of the waves (30% meditation instructions) was anchored at 1 μV, and the max volume of the singing bowls (also 30% meditation instructions) was anchored to 40 μV; so that volume increases were scaled linearly from passing thresholds to these volume-amplitude anchor points.

The sound of a rolling wave was triggered and ran to completion when a participant's lower alpha remained below threshold for 2 seconds. The wave sound lasted 4 seconds with minimally a 2 second gap before a second wave could be triggered. In contrast, the singing bowl feedback required that lower alpha activity be sustained above the higher lower alpha amplitude for 3 seconds. This stimulus involved a more continuous contingency of a tapered loop of a Tibetan singing bowl .mp3 file (total track length 53 seconds), reset to begin from the tapered start of the track after each drop back below its threshold. The real-time user generated lower alpha signal was the average of the preceding four-seconds of activity, which was done to provide a highly smoothed signal for processing and feedback.

MM+Sham. Participants in the *MM+Sham* group underwent procedures identical to the *MM+NF* group, except for that NF audio output they would have actually been receiving with their true EEG was muted. Instead, and unbeknownst to the *MM+Sham* participants, a pre-recorded audio track of the waves and singing bowls neurofeedback generated by a *MM+NF* participant. Each *MM+Sham* participant was matched solely to one *MM+NF* participant. Prior to participant arrival, the sham audio track was uploaded into the protocol. Sham audio files were played for MM+Sham participants in the same order they were generated by their MM+NF match. Thus, *MM+Sham* participants heard identical performance feedback as the *MM+NF* participants, within and across training sessions.

MM-Only. The *MM-Only* participants were told the electrodes were just for recording brain activity while meditating in the lab, with no NF reference or instructions. They were not provided with any EEG feedback, real or sham. However, the data acquisition and exporting included the amount of NF each *MM-Only* participant would have received based on their low alpha activity relative to their premeditation calibration percentiles according to the NF parameters set for the *MM+NF* group.

Statistical Analysis

Repeated-measures ANOVAs (RM-ANOVAs) were used to test for interactions and main effects. For the questionnaire measures, which were administered at three time points, a 3x3 Group (*MM-only, MM+NF, MM+Sham*) x Test Session (BL, PT, FU) RM ANOVA was used. Meditation experiences across training days were averaged then analyzed with 3x2 RM ANOVA Group x Training Half (First half sessions 1-4, Second half sessions 5-8), as well as with 3x2 Group x Setting (in-lab, at home) RM ANOVA. The Go/No-Go, MSIT, n-Back, resting state EEG and the alpha neurofeedback control task measures were all analyzed with a 3 x 2 Group x Test Session (BL, PT), as well as the SEMMP, which was given only on the first and last day of home practice.

For RM-ANOVA tests, sphericity was assessed with Mauchly's Test of Sphericity. In cases where sphericity violations were found, a Huynh-Feldt correction to degrees of freedom was applied. Testing for assumptions of equality of variance of normality were tested with Levene's test for homogeneity of variance (α = .05). The majority of measures met this assumption. Violations of inequality of variance and outliers was approached by examining for measures with skewness values outside of -2.5 to +2.5 range, kurtosis values outside of the -7 to +7 range and visual inspection of Q-Q residual plots, which lead to the identification of one MSIT outlier, and some EEG files that required extra cleaning by removing large segments of high frequency artifact contaminated sessions that seemed related to loose reference electrodes. The measurements that violated equality of variance included EFI at BL and PT. Correction of type I error from multiple measurement was done using the Holm-Bonferroni method of stepwise adjustment for critical values was used to correct for family-wise ANOVA and for post hoc comparisons with alpha of 0.05.

Missing Data. The data sets for the two participants who each dropped out before completing their third session of training were removed from the final analysis. The remaining questionnaire dataset was complete for all participants except for a *MM+Sham* follow-up (FU) PWS and a *MM-Only* second SEMMP. For daily post-meditation ratings, training days 7, 8, and 9 were never completed for a *MM+Sham*, MM-Only, and a different *MM+Sham* participant, respectively. However, the impacts of this were minimized as data was averaged according to first versus second half of training for comparison, and thus all participants had viable data sets for analysis. Regarding cognitive-behavioural tasks, the MSIT for one participant was an outlier with threefold non-responses and errors compared to the rest of the participants. This participants MSIT data was removed from final analysis, but their Go/No-Go and nBack task data was retained as they remained statistically comparable to other participants' data. Problems with the EEG hardware and software and protocol misadministration resulted in data loss of both baseline (BL) and post training (PT) EEG data for one *MM-Only* participant, a BL session for another *MM-Only* participant, the first training session of a *MM+Sham* participant, and fourth training session for each of a *MM-Only*, *MM+NF*, and *MM+Sham* participant.

CHAPTER FOUR

Study Implementation, Acceptability, and Feasibility

The data recruitment for this study was negatively impacted by, among other time and resource limitations, the COVID-19 pandemic. Specifically, the restriction of in-person activities affected the capacity to pilot and begin the study. Nevertheless, the number of participants who completed the study was ultimately sufficient for evaluating the feasibility, acceptability, and strengths and limitations of this randomized sham-controlled study of focused attention (FA) mindfulness meditation (MM)+ neurofeedback (NF) training, providing guidance and recommendations for future research and applications that might draw from different design and protocol aspects implemented in this study.

The overall implementation and feasibility of the study design and training conditions were determined by analyzing: 1) The extent to which recruited participants were able to complete the study and adhere to the training commitments and participation demands, and 2) investigating patterns of positive versus negative subjective experiences, including examining whether the overall pattern of daily meditation experience ratings was overall in a beneficial direction, with no significant adverse experience reporting. Additionally, additional analyses were conducted that focused specifically on the NF conditions, which aimed to explore: 3) how believable the *MM+Sham* was as a matter of being an adequately blinded control condition, 4) the amount of and type of feedback the MM+NF group received, and how this impacted training experiences, and 5) whether the in-lab EEG meditation recordings reflected reliable spectral changes, particularly in the alpha range which the NF was targeting. Although largely quantitative, some of the data acquired involved more open ended qualitative-oriented feedback, including an optional final feedback survey.

Sample Characteristics

The demographic characteristics for all participants who entered the study are shown in Table 1. Despite the barriers and hesitancies for participating in in-person research post-COVID19, that may have altered group characteristics, the sample here was comparable in demographic and baseline levels of key traits (e.g., mindfulness, meditation self-efficacy) to other young adult, non-clinical samples found in other studies involving brief meditation training procedures (e.g., Chow et al., 2016; Moore & Malinowski, 2009; Tang, Askari, and Choi, 2020). The sample was predominantly post-secondary students in different stages of study. The ratio of female to male participants was 3:2 initially, but two male participants dropped out before the halfway point of training, slightly increasing this skew. The reasons for dropout included one due to illness for one participant assigned to *MM+Sham*. The other participant, assigned to *MM+NF,* was withdrawn from the study after reporting adverse experiences from home practice, detailed below. Table 2 contains the demographic characteristics between groups assigned to the three different experimental training conditions in the final data set for further analysis. Groups were statistically comparable across the demographic characteristics. They were also comparable for trait mindfulness, motivation for learning mindfulness meditation, perceived skillfulness in meditation, and in attitudes and affinity for technology.

Table 1. *Recruited Sample Demographics*

N = 30	M (SD)	Range
Age	23.3 (3.6)	20-30
Years Post-Secondary	3.7 (2.1)	0-11
	Category	Frequency
Sex / Gender[1]	Female	18
	Male	12
Handedness	Left	6
	Right	23
	Ambidextrous	1
Ethnicity	White	18
	Mixed	4
	East Asian	5
	East Indian	2
	African	1
Highest Education	High school	4
	Some post-secondary	16
	Bachelor's degree	4
	In graduate studies	5
	Graduate degree	1
Yearly Income	<25K	23
	25-50K	5
	50-100K	2

Note. [1] Sex at birth and gender identification were asked as separate questions. A all participants reported gender identities that matched their sex at birth.

Table 2. *Demographic Characteristics Between Groups*

	MM-Only	*MM+NF*	*MM+Sham*
n	10	9	9
Age	23.5 *(3.5)*	24.0 *(4.0)*	23.0 *(3.9)*
Trait Mindfulness	50.6 *(7.2)*	50.7 *(7.3)*	49.3 *(6.8)*
Motivation to Train in Meditation	4.5 *(0.2)*	4.3 *(0.7)*	4.1 *(0.6)*
Perceived Meditation Skill	52.6 *(12.7)*	48.0 *(27.0)*	52.8 *(13.4)*
Affinity for Technology	40.2 *(7.5)*	41.4 *(6.0)*	41.7 *(5.4)*
Attitude Towards Technology	3.3 *(0.8)*	3.8 (*0.4)*	3.6 *(0.7)*
Female	7	6	5
Male	3	3	4
Right-Handed	7	6	9
Left-Handed	2	3	0
Ambidextrous	1	0	0
High School	1	1	2
Some Post-Secondary	7	4	4
Bachelor's degree	0	1	2
In Graduate Studies	2	2	1
Graduate Degree	0	1	0

Note. One-way ANOVA and Chi-Square testing indicated comparability between groups across measures. M(SD) are shown for age, mindfulness, motivation, and technology ratings. Frequency is reported for remaining measures.

Adverse Experiences Check

On the final questionnaire administered at follow-up (FU), participants from all groups were asked to indicate if whether they believed they had adverse or unpleasant experiences related to their meditation training. A summary of responses from the final sample of participants by group and for the total sample are displayed in Table 3. There was no statistical difference between groups in frequency of endorsements ($X^2_{4, N = 28} = 1.87$, $p = .760$). Any response other than "no" was followed up on via brief interview to clarify the nature and severity of potential adverse experiences. All four cases of responses other than "no" were related to transitory feelings of mild emotional and/or physical discomfort that associated with some sitting meditation sessions. These were characterized by participants as being mildly unpleasant, non-enduring and not significantly distressful; subjective reports that were entirely in keeping with expected experiences that emerge in meditation practices and are part of skill and self-growth in developing a MM practice (Compson, 2018; Lindahl et al. 2017). Some participants also included the inconvenience of multiple lab trips as being an unpleasant aspect of the meditation training.

The individual whose participation was discontinued after reporting disruptions in sleep quality and routine after the second home practice was assigned to the *MM+NF* condition, but their disruption was not related to their in-lab assigned condition. Rather, the problems described were related to completing their home practices after midnight, then having difficulty falling asleep. Notably, all participants were given basic recommendations to help support home and lab practices during the baseline session, and all were also directed to review the FAQ resource provided to them on the project webpage used to access home recordings and post-meditation experience ratings. This material can be found in Appendix C. Follow-up with the withdrawn participant revealed restoration of usual sleep routine within a couple days of discontinuation of night-time MM practice, and they reported voluntarily continuing occasional MM practice using the recording file from the study to be earlier in the day with noticeable benefits to awareness, mood, and focus.

Table 3. *Frequency of Self-Reported Potentially Adverse Participation Experiences*

Question:	Response options	*MM-Only*	*MM+NF*	*MM+Sham*	Total
"Did you have any particularly unpleasant or adverse experiences that you think might have been related to the meditation training you completed in this study?"	Yes, certainly	0	0	0	0
	Yes, potentially	1	1	1	3
	I don't know	1	0	0	1
	No	8	8	8	24

Note. Data are shown for the final sample, with no significant difference in endorsement distribution between groups. Brief follow-up questioning with participants indicating responses other than “no” revealed all were related to minor physical and emotional discomfort arising intermittently and non-enduring, entirely in-line with normal range of experiences commonly experienced in mindfulness meditation training.

Acceptability of Meditation Training

The total amount of time participants spent in meditation (i.e., the MM "dose" for 8 days of an approximately 20-minute-long meditation) was 158 minutes 32 seconds. This included instructions on finding a comfortable posture, a brief body scan, in addition to the FA instructions and practice intervals as well as a few minutes of guided instructions in closing the daily meditation. Within this, the total amount of time participants spent practicing breath-focused FA, including instructions, was 104 minutes (13min/session). The total amount of breath-focused FA, discounting instructional time was 76 minutes (9min30sec/session). Half of this FA time (38min) occurring in-lab with real-time EEG being recorded for all groups, so this was also the "dose" of neurofeedback session time that *MM+NF* and *MM+Sham* received. Acceptability of the meditation was evaluated with a combination of overall (total training by groups) and group-by-setting (home vs in-lab meditation) evaluation of daily meditation self-report ratings, as well as with qualitative feedback obtained from a voluntary participant feedback survey.

Overall Daily Meditation Experience Ratings

Table 3 shows the average ratings across meditation training for each group and a grand total for all participants. Here the overall rating results are summarized, followed by more detailed group-by-setting (in-lab versus home training rating) statistical analysis. Of note, one participant from each of the *MM-Only* and *MM+Sham* group did not complete their third and fourth home session ratings, and platform log history indicated that neither clicked the portal for those days of practice. Remaining participants had complete ratings data sets and verified home meditation recording access. A one-way ANOVA did not indicate any significant between-group differences (all p's > .10).

Participants in the sample averaged slightly above neutral in terms of their motivation to engage in their daily practice, with ratings ranging from "somewhat unmotivated" to "very motivated." No participant reported being very unmotivated. Importantly, there were no between-group differences in overall (i.e., mean across training) motivation rating levels, suggesting that the NF manipulations did not sway motivation one way or the other significantly. Overall, participants averaged in rating difficulty in the “neither easy nor difficult” range, with the *MM-Only* and *MM+Sham* rating slightly more difficult than *MM+NF*. Regarding the satisfaction participants felt with there daily meditation training, overall ratings tended towards “somewhat satisfied” or better, with no participants rating any session as somewhat unsatisfying or very unsatisfying.

Regarding participant self reported changes in their psychological and physiological state after completing their daily meditations, results were largely in beneficial directions. Participants in all groups rated becoming “somewhat” to “much more” relaxed. For mood ratings, participant groups were highly comparable, overall averaging in the “somewhat better” range, with no participants reporting worse mood after. Participants overall averaged feeling “somewhat more focused,” with ratings also including “much more focused” and “no difference” responses. Overall, participants tended not to feel much change in their energy levels after meditating.

In terms time participants estimated being distracted by internal or external events during sessions, participants averaged reporting about half the session time. No participants indicated being distracted by mind wandering “very minimally” or “nearly all the time,” with those in *MM-Only* reporting slightly more time distracted by mind wandering. The ratings for time distracted by distraction by bodily sensations (e.g., temperature, touch, muscles, visceral sensations) was lower than for mind wandering and were similar between groups. Overall ratings averaged close to the “less than half the time” mark, ranging from “very minimally” from “more than half of the time.” For ratings of environmental distraction during session (e.g., sights, sounds, smells), overall ratings averaged in the “less than half the time” range. *MM-Only* and *MM+Sham* only gave ratings of “very minimally” and “less than half of the time," whereas *MM+NF* additionally included ratings of "about half of the time" and resulting in average ratings of slightly more environmental distractibility than the other groups.

Table 4. *Descriptive Statistics for Daily Meditation Experience Ratings*

Rating	Group	*Mean*	*SD*	*Min*	*Max*
Motivation	*MM-Only*	2.9	.70	2	4
	MM+NF	3.6	.85	2	5
	MM+Sham	3.3	.54	3	4
	Total	3.3	.74	2	5
Difficulty	*MM-Only*	2.7	.64	2	4
	MM+NF	3.1	.62	2	4
	MM+Sham	2.9	.35	2	4
	Total	2.9	.57	2	4
Satisfaction	*MM-Only*	3.3	.37	3	4
	MM+NF	3.6	.65	3	5
	MM+Sham	3.4	.27	3	4
	Total	3.4	.46	3	5
Mood	*MM-Only*	4.0	.28	4	5
	MM+NF	3.9	.52	3	5
	MM+Sham	3.9	.34	4	5
	Total	3.9	.38	3	5
Focus	*MM-Only*	3.8	.25	3	4
	MM+NF	3.9	.66	3	5
	MM+Sham	3.6	.42	3	4
	Total	3.8	.46	3	5
Relaxation	*MM-Only*	4.1	.32	4	5
	MM+NF	4.3	.50	4	5
	MM+Sham	4.2	.48	4	5
	Total	4.2	.43	4	5
Energy	*MM-Only*	3.0	.42	3	4
	MM+NF	3.1	.90	2	4
	MM+Sham	2.9	.47	2	4
	Total	3.0	.61	2	4
Mind Wandering	*MM-Only*	2.8	.53	2	4
	MM+NF	3.0	.77	2	4
	MM+Sham	3.1	.50	3	4
	Total	3.0	.60	2	4
Body Distraction	*MM-Only*	3.6	.86	2	5
	MM+NF	3.9	.73	2	5
	MM+Sham	3.9	.49	3	5
	Total	3.8	.71	2	5

Environmental Distraction	*MM-Only*	4.4	.46	4	5
	MM+NF	3.9	.51	3	5
	MM+Sham	4.2	.31	4	5
	Total	4.2	.46	3	5

Note. Sample sizes were *MM-Only* (n = 10), *MM+NF* (n = 9), *MM+Sham* (n = 9). Ratings were made on a 5-pt Likert scale centered at a neutral point of three, with ratings higher than 3 indicating a positive direction of effect and lower a negative direction of effect. A one-way ANOVA did not reveal group differences in overall ratings across measures (α = .05, p's > .10).

Daily Meditation Experience Ratings by Setting

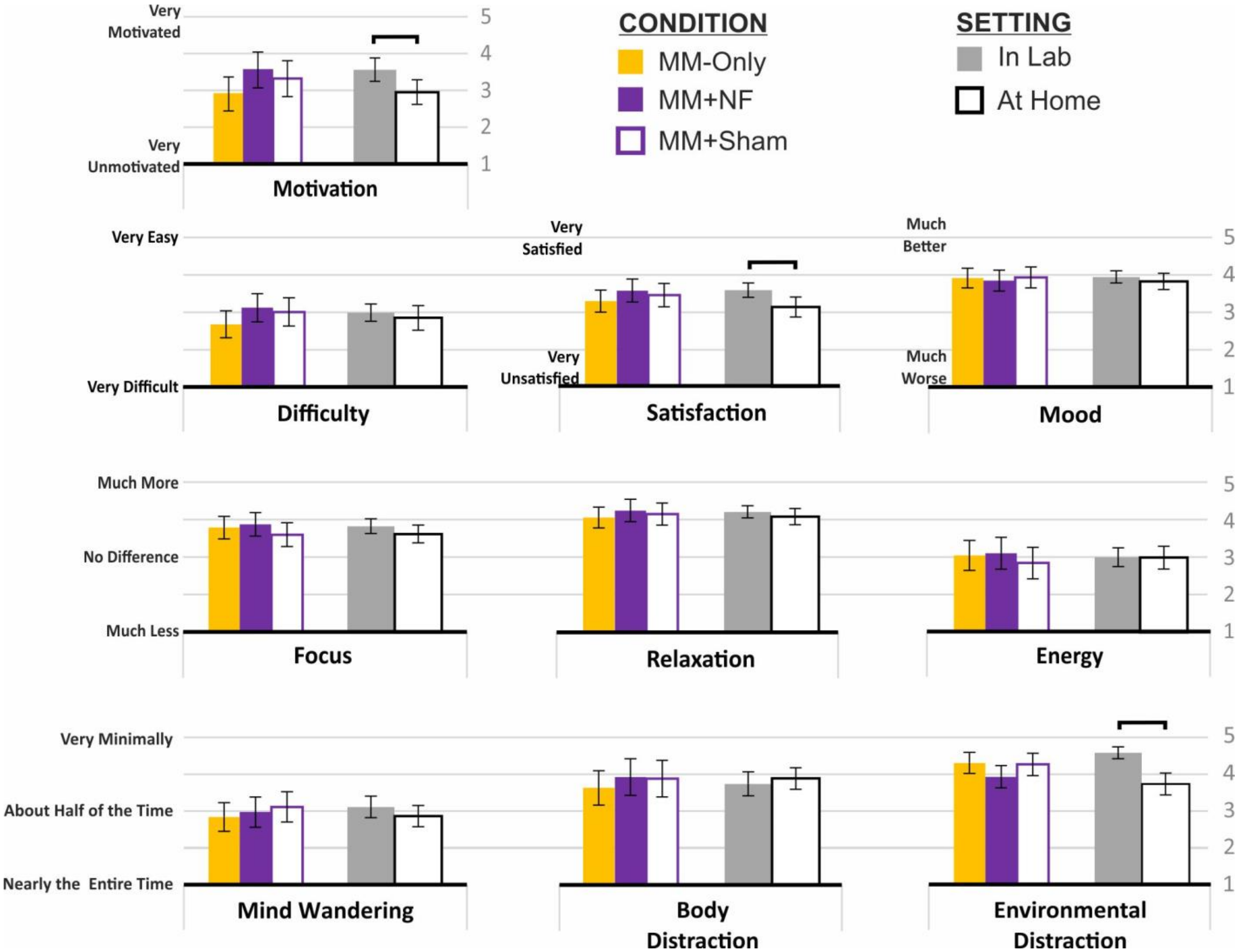
Figure 8 shows the overall daily meditation experience item ratings by group as well as by setting. This was investigated as there were both shared and individual differences between groups for in-lab training relative to at home training. In-lab training for all participants necessarily involved higher demand characteristics, contact with the team members, equipping technological monitoring (EEG), and enough cognitive, social, and behavioural buy-in to reach the lab for the sessions, which are important to contrast with how home meditation was experienced where these combined factors are absent. An overlay of this is also the more specific experimental contrast of seeing how true versus sham NF impacted meditation experiences relative to each other and *MM-Only* practices in-lab. The results of Group (*MM-Only*, *MM+NF*, *MM+Sham*)-by-Setting (In-Lab, At-Home) ANOVAs are reported below, with Group-by-Training Half (Sessions 1-4, Sessions 4-8) reported in the next chapter.

For ratings of motivation to complete daily MM practice, a main effect of setting was found ($F_{1,25}$ = 12.89, p = .001, η^2 = .34) to the effect that participants reported more motivation for in-lab meditation sessions compared to home practice, absent of any group-by-setting interaction ($F_{2,25}$ =.43, p = .654) or group main effect ($F_{2,25}$ = 2.09, p = .144). There was also a significant main effect of setting for satisfaction ($F_{1,25}$ = 9.40, p = .005, η^2 = .27) without interaction ($F_{2,25}$ = 0.26, p = .772) or group effects ($F_{2,25}$ =0.92, p = .412), with participants reporting more satisfaction after in-lab meditations.

There were no significant effects for ratings of difficulty (group-by-setting, $F_{2,25}$ =1.08, p = .355; group, $F_{2,25}$ =1.67, p = .208; setting, $F_{1,25}$ =.61, p = .443), mood (group-by-setting, $F_{2,25}$ =2.17, p = .135; setting, $F_{1,25}$ =1.19, p = .287; group, $F_{2,25}$ =.11, p = .899), focus (group-by-setting, $F_{2,25}$ =.73, p = .492; setting, $F_{1,25}$ =2.95, p = .098; group, $F_{2,25}$ =.85, p = .438), relaxation (group-by-setting, $F_{2,25}$ =1.26, p = .300; setting, $F_{1,25}$ =1.82, p = .190; group, $F_{2,25}$ =.46, p = .638), or energy (group-by-setting, $F_{2,25}$ =1.30, p = .289; setting, $F_{1,25}$ =.01, p = .939;, group $F_{2,25}$ =.44, p = .648).

For rating of amount of time reported as being distracted in session, there was a trending group-by-setting interaction for mind wandering ($F_{2,25}$ = 3.27, p = .055, η^2 = .21; setting, $F_{1,25}$ = 2.25, p = .146; group, $F_{2,25}$ = 0.50, p = .615). In exploring this, interestingly the *MM-Only* group indicated more mind wandering distraction in the lab, as can be viewed in Table 4. There were no significant effects for body-based levels of distraction (group-by-setting, $F_{2,25}$ = 0.12, p = .886; group, $F_{2,25}$ = 0.47, p = .633; setting, $F_{1,25}$ =1.40, p = .249). For in-session distraction associated with external environmental sources, only a significant main effect for setting was found ($F_{1,25}$ = 27.61, p < .001, η^2 = .52; group-by-setting, $F_{2,25}$ =1.42, p = .262; group, $F_{2,25}$ = 2.00, p = .156), with all groups finding at-home environments more distracting in meditation sessions, with the greatest difference found for the *MM+NF* group.

Figure 9. *Daily Post-Meditation Experience Ratings Between-Groups and Between-Settings*



Note. Means and 95% confidence intervals are shown. Horizontal brackets indicate significant effects $p < .05$ after Holm-Bonferroni correction for multiple comparisons ($\alpha = .05$).

Table 4. *Means and Standard Deviations of Daily Meditation Ratings for Groups by Setting*

		In-Lab		*At-Home*	
Rating	Group	*M*	*SD*	*M*	*SD*
Motivation	*MM-Only*	3.3	*1.1*	2.5	*1.0*
	MM+NF	3.8	*1.0*	3.4	*1.1*
	MM+Sham	3.7	*0.8*	3.0	*1.0*
	Total	**3.6**	***0.8***	**2.9**	**0.9**
Difficulty	*MM-Only*	2.5	*0.8*	2.7	*0.9*
	MM+NF	3.2	*0.7*	3.0	*1.2*
	MM+Sham	3.2	*0.6*	2.8	*0.9*
	Total	3.0	*0.6*	2.8	0.8
Satisfaction	*MM-Only*	3.5	*0.6*	3.1	*0.7*
	MM+NF	3.9	*0.7*	3.3	*1.1*
	MM+Sham	3.7	*0.8*	3.2	*0.8*
	Total	3.7	*0.5*	3.2	0.7
Mood	*MM-Only*	4.0	*0.5*	3.9	*0.6*
	MM+NF	4.1	*0.5*	3.6	*0.7*
	MM+Sham	3.9	*0.5*	4.0	*0.6*
	Total	4.0	*0.4*	3.8	0.6
Focus	*MM-Only*	3.9	*0.6*	3.7	*0.6*
	MM+NF	4.1	*0.8*	3.7	*0.8*
	MM+Sham	3.6	*0.5*	3.6	*0.7*
	Total	3.9	*.05*	3.6	0.6
Relaxation	*MM-Only*	4.1	*0.5*	4.1	*0.5*
	MM+NF	4.4	*0.5*	4.1	*0.7*
	MM+Sham	4.2	*0.6*	4.2	*0.7*
	Total	4.3	*0.4*	4.1	0.6
Energy	*MM-Only*	2.9	*0.8*	3.2	*0.7*
	MM+NF	3.2	*1.0*	3.1	*0.9*
	MM+Sham	3.0	*0.7*	2.8	*0.9*
	Total	3.0	*0.7*	3.0	0.8
Mind Wandering	*MM-Only*	2.7	*0.9*	3.0	*0.8*
	MM+NF	3.3	*0.9*	2.7	*1.0*
	MM+Sham	3.3	*0.7*	2.9	*0.7*
	Total	3.1	*0.8*	2.9	0.8
Body Distraction	*MM-Only*	3.6	*1.1*	3.7	*0.9*
	MM+NF	3.8	*0.8*	4.0	*1.0*
	MM+Sham	3.8	*0.9*	4.0	*0.5*
	Total	3.7	*0.9*	3.8	0.8
Environmental Distraction	*MM-Only*	4.7	*0.5*	3.9	*0.7*
	MM+NF	4.5	*0.4*	3.3	*1.1*
	MM+Sham	4.5	*0.6*	4.0	*0.9*
	Total	**4.6**	***0.4***	**3.7**	**0.8**

Note. Sample sizes were *MM-Only* (*n* = 10), *MM+NF* (*n* = 9), *MM+Sham* (*n* = 9). Ratings were made on a 5-pt Likert scale centered at a neutral point of three, with higher than 3 indicating a positive direction of effect and lower a negative direction of effect. Bold text indicates where a significant difference was found between settings, with p's < .001.

Qualitative Feedback

To gain further perspective on how the meditation training and overall research experience went for participants, qualitative feedback was gathered. This survey was optional but encouraged, sent out after study completion at FU and compensation, with one week to complete before expiration of the survey link. Participants indicated what group they were assigned to, but feedback was otherwise anonymous which participants were informed of. The questions were mainly open-ended with some ratings for how understandable the study and procedures were, and overall rating of experience working with the team. The response rate was only 39% but represented comparable distribution of participant completion between groups (*MM-only, n* = 3; *MM+NF, n* = 4; *MM+Sham, n* = 4) and evenly distributed across the months that data collection was completed. The questions and responses can be found in Appendix D.

Briefly, respondents rated their experience with the team as overwhelmingly positive ("*very positive*" 11/13, "*positive*" 2/13). Several respondents reported that the Brightspace (online LMS) platform and resources were helpful and easy to navigate, with no contrary reports. All respondents reported that they understood the procedures and methods involved in the study. Across groups, respondents commonly reported increased motivation to meditate and enjoyment of the peace/relaxation as favorite aspects of study participation. The time commitment of the study, including the commuting required, were reported by some participants as the least favorite part of the study. One participant in the *MM+NF* group indicated that meditating for 20 minutes was difficult, although it was not clear if this was in reference to home versus in-lab sessions. Appendix C contains one report made by a participant who found difficulty working with the neurofeedback integrated protocol; but their other reporting and outcomes suggested positive experiences and benefits none-the-less. Taken together, the results of the final feedback survey, though low in response rate and self-selected in nature, complement and provide further context for how the study was experienced and the real-world impacts it had on participants in daily life. Observationally, there did not appear to be an overall difference in the learning quality or positive versus negative experiences of participating between groups. This appears to fit well with the quantitative meditation experience ratings reported above.

Neurofeedback Conditions

Neurofeedback Meditation Experience Ratings

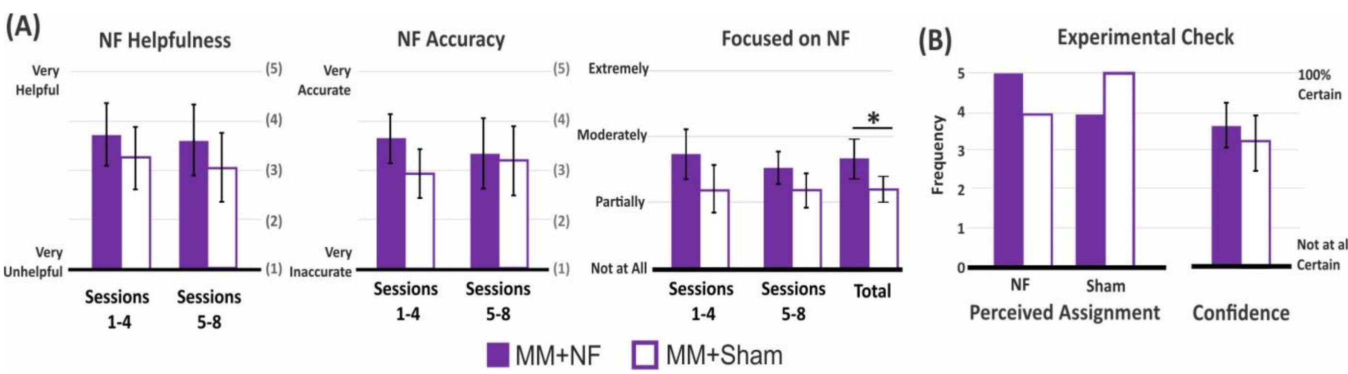
There were no significant interactions between the *MM+NF* and *MM+Sham* for how helpful or accurate the auditory feedback received was, nor how focused on the NF sounds participants were across sessions. Generally, participants reported the NF as benign to partially helpful in helpfulness and leaning towards “somewhat accurate”, with both measures averaging higher for *MM+NF*. However, the only statistically reliable finding was a between-group difference in the amount that the NF sounds were focused on, whereby *MM+NF* was more focused on the feedback than the *MM+Sham* group ($F_{1,16}$ = 3.62, p = .024), as shown in Figure 9A. There was no significant difference between *MM+NF* and *MM+Sham* regarding retrospective perceptions of group assignment after being unblinded to the sham-controlled design of the study at FU. Figure 9B shows that both groups were not statistically different ($X^2_{1,18}$ = .222, p = .637) and approximated chance, with the *MM+NF* group only slightly more confident on average ($F_{1,16}$ = 0.90, p = .343).

Table 5. *Percentage of Feedback Type Based on Lower-Alpha MM NF Protocol*

Group	Rolling Waves				Singing Bowl			
	M	*SD*	*Min*	*Max*	*M*	*SD*	*Min*	*Max*
MM+NF (*n* = 9)	35.5	8.4	15.4	42.3	3.9	3.6	0.0	12.3
MM+Sham (*n* = 9)	39.6	3.5	31.6	43.2	3.3	1.8	0.4	6.2
MM-Only (*n* = 10)	44.0	16.2	22.5	86.7	4.6	4.4	1.6	15.4

Note. MM+NF is in bold to emphasize this group as the only group receiving feedback, in the percentages reported. *MM-Only* and *MM+Sham* was calculated post-hoc on the EEG data acquired during session processed with the NF protocol threshold set to individual session baseline and do not represent feedback actually provided during sessions. Percentage of time of NF-interval FA blocks is reported on. No statistically significant differences were evident.

Figure 10. *Experiential Ratings Neurofeedback Integration in Meditation Sessions and Perception of Experimental Group Assignment*



Note. Panel (A) shows the average in lab ratings after the daily mindfulness meditations with veritable and sham neurofeedback conditions. Panel (B) shows results of the experimental check conducted at the end of each participants final session that had participants guess their group assignment as well as provide a confidence rating for their guess. Error bars indicate 95% confidence intervals of mean data.

Neurofeedback-Assisted Meditation Feedback Rates and EEG Results

Analysis was conducted to evaluate the per-session amount of each type of feedback participants received in the *MM+NF* training sessions, as well as if there were differences across training halves and overall, in alpha activity patterns between groups at the NF recording site (electrode Cz). As Figure 10A shows, substantially more of the feedback given in meditation sessions for the *MM+NF* group was of the 'Waves' (triggered by a drop below baseline in low alpha, cuing mental content check-in) compared to 'singing bowls' (triggered by sustaining low alpha above baseline, positive reinforcement cue). This was true overall for the *MM+NF* group, with no differences in the amount of each feedback examining first versus second half. An exploratory analysis was conducted offline and in retrospect to quantify and compare the session percentage of Wave and Singing Bowl feedback *MM-Only* and *MM+Sham* participants would receive based on their in-session generated EEG files. Interestingly, the *MM-Only* and *MM+Sham* participants resulted in putatively equivalent amounts of each feedback type (waves interaction bowls interaction) overall, in the 40% range of sessional feedback provided for Waves, and 4% for the Singing Bowl. Table 5 reports feedback proportions based on each groups' sessional EEG, bearing in mind only *MM+NF* received this feedback within-session.

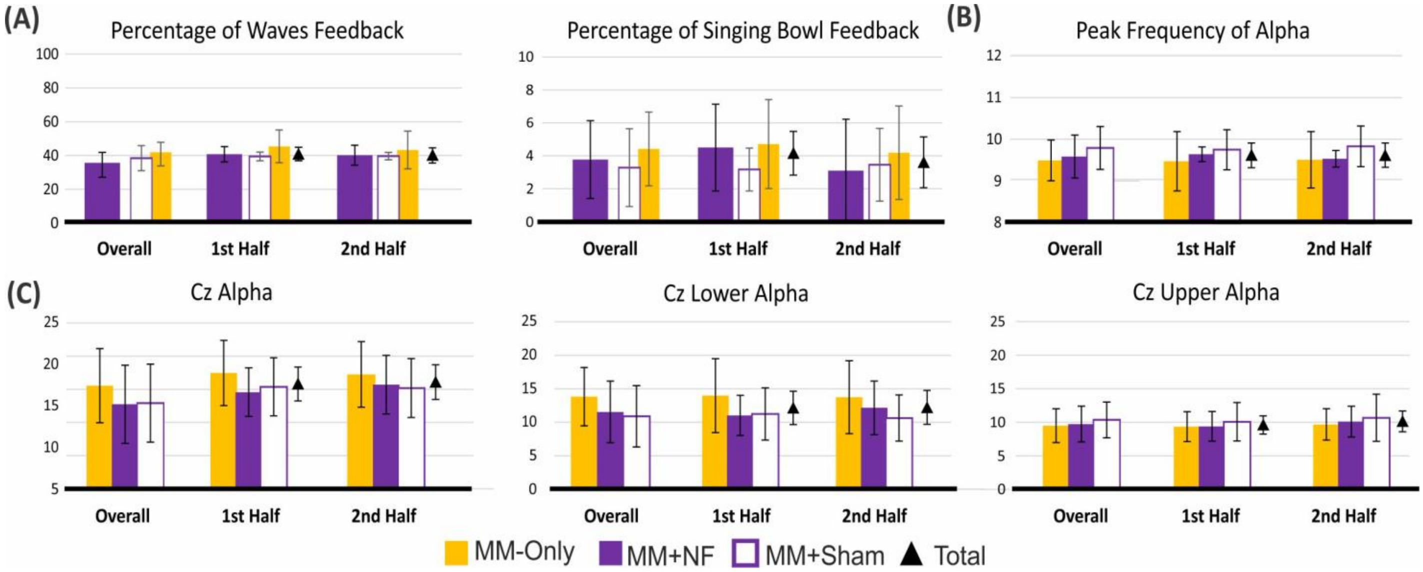
To evaluate whether these feedback proportions were consistent with alpha activity levels Cz (as the feedback was generated from this site), a follow-up analysis was conducted for alpha activity at Cz. These results are shown in Figure 10C. No overall between-group differences for broadband alpha ($F_{2,25}$ = 0.32, p = .728), lower alpha ($F_{2,25}$ = 0.51, p = .607), or upper alpha ($F_{2,25}$ = 0.12, p = .886) were found. Investigating training half (first two versus last two in-lab sessions) by group, no training half-by-group interactions were found for alpha ($F_{2,25}$ =1.81, p = .323), lower alpha ($F_{2,25}$ = 2.11, p = .142), or upper alpha ($F_{2,25}$ = 0.128, p = .880). No simple main effect of first versus second half of in-lab training emerged for any alpha measures (alpha, $F_{1,25}$ = 0.34, p = .564; lower alpha, $F_{1,25}$ = 0.09, p = .767; upper alpha, $F_{1,25} = 0.70$, $p = 0.412$). Descriptively, only *MM+NF* showed on average increases in low alpha amplitude between first and second training sessions ($M_{\pm SE} = 1.14 \pm 0.68$, $p = .130$), while *MM-Only* ($M_{\pm SE} = -0.23 \pm 0.73$, $p = .761$) and *MM+Sham* ($M_{\pm SE} = -0.59 \pm 0.35$, $p = .128$) showed negligible decreases.

Correlational analyses were conducted to test whether the alpha band amplitudes at Cz were coupled with the amount of wave and singing bowl feedback received by the *MM+NF* group in their in-lab meditation session. The correlational relationships were not significant. The correlation of Cz lower alpha amplitude with the percentage of wave feedback was $r = .18$, $p = .648$, and for singing bowls $r = -.060$, $p = .879$. These findings were not as expected and potentially reflective of data cleaning issues, which are outlined in more detail in the limitation section of this chapter. Broadband and upper alpha amplitudes at Cz were also not significantly correlated with the amount of either feedback, not were the other target bands when exploratory correlational analysis was conducted (*p's* > .10).

Exploratory analysis was conducted to investigate shifts in individual alpha peak frequencies[3]. The reasoning behind this analysis was that while average band amplitude changes might not be robust, a slowing of peak rhythmicity into lower range alpha frequencies could be another possible marker of neural/electrophysiological meditation-induced change; insofar as meditative states "downshifting" endogenous amplitude peaks into slower/lower alpha ranges might be indicative of entering a deeper, more relaxed, calm, and focused state. There was no interaction ($F_{2,25} = 0.99$, $p = 0.384$), or main effects between groups ($F_{2,25} = 0.363$, $p = 0.699$) or between training halves ($F_{1,25} = 0.00$, $p = 0.966$). The results of this analysis are shown in Figure 10B, reflecting the relative stability in peak frequency activity between groups and across training halves, in the 9-10 Hz range.

[3] Calculated as the frequency bin in which the highest amplitude of alpha activity emerged in each 1 second epoch of, averaged across cleaned and remaining data epochs used for other reported EEG analyses.

Figure 11. *In-Lab Measures of Neurofeedback and Meditation Training Sessions*



Note. (A) shows the percentage of the FA practice time of wave versus the sound of the singing bowl feedback. A gentle rolling wave sound was triggered after a 2-second or more drop in lower alpha below threshold, whereas a volume-tapered Tibetan singing bowl sound was triggered after low alpha was sustained for 3 seconds above threshold, continuous until tapering out off once lower alpha dropped back below the threshold. *MM+NF* group data are emphasized as this group was the only group actually receiving the feedback. *MM-Only* and *MM+Sham* bars indicate the amount of feedback percentages they would have received based on their meditation session lower alpha data. (B) Shows the results of an analysis of peak frequency shifts in alpha range activity. (C) Shows the overall and split half mean amplitudes of alpha activity in µV for each group. Error bars indicate 95% confidence intervals of mean data. No significant interaction or main effects were observed, α = .05.

Discussion

The goals of this chapter were broadly threefold. First, to evaluate whether the research study was overall designed and implemented in a way that was feasible in terms of tolerability and effective engagement given the demands and protocols involved in this study. This was investigated by examining overall participation retention and drop-out rates, subjective report data from daily meditation ratings, and from the optional feedback survey. This examination was extended to evaluate whether there were differences between-groups or between-practice setting (in-lab versus home) that occurred grossly out of trend of expected findings, such as no or poor experiential outcomes on measures such as motivation, mood, relaxation, or focus. Additional to this, specifically, the two NF conditions were examined to evaluate whether the sham-control blinding was effective and whether the NF protocol resulted in behavioural and EEG results during meditation consistent with expectations. On this background, the third goal was to outline the strengths and limitations of the study and protocols as they are directly relevant for interpretation of the data in Chapter 5, as well as for broader relevance and implications for replication or extension of research or clinical applications along the same lines of investigation as the current study.

Overall Implementation and Participant Experience

Retention, Adherence, and Adverse experiences. Given the length and commitment required for participants for this study, overall retention and completion rates were high. Only two participants dropped out once the study began, one due to a factor independent of the study (illness) while the other reported adverse effects resulting in early debrief and discontinuation of participation. Specifically, the adverse effect was related to sleep-cycle disruption associated with practicing meditation late at night against recommendations against this; and a follow-up with this participant several days after participation discontinuation revealed normalized sleep and occasional continued MM practice with the study recording in earlier times of day. At study end, participants were also able to report whether adverse experiences occurred at any point across the duration of the study. There were several participants who indicated "possible adverse or unpleasant effects" related to participation. Clarified in debriefing exit interviews, these instances had to do with experiencing mild physical and emotional discomfort or with inconveniences of participation (e.g., commuting). The discomforts reported were mild, non-enduring, and commonplace in meditation training, and often conceptualized as being a necessary aspect of MM training (e.g., physical tolerance of seated practice, physical and mental restlessness, experiencing normal range of positive and negative emotions in a mindful and accepting way; Compson, 2018; Lindahl et al. 2017).

Overall, feedback and ratings from participants, even those indicating the above challenges, were positive in terms of the methods involved in the study and their training (e.g., protocols, interactions with the research team, and participation experience, and supporting resources). Thus, it can be stated with confidence that the participants were able to effectively engage with the practical, applied, and technical aspects involved in this study despite additional daily and weekly demands involved in their participating in this study. The protocols and study design were implemented in a way that remained engaging or tolerated by participants, which, at the broadest level of evidence, is in support of the feasibility and effective implementation of study procedures and design.

Daily Meditation Training. Examination of group averaged daily meditation ratings offered a more nuanced picture of participation as it may or may not have differed between groups and/or according to setting (in-lab versus at home practices). Of particular interest was how motivated participants remained throughout the study, as motivational factors are key to study adherence and were as a factor hypothesized to be affected by the incorporation of NF into training. Motivation ratings were comparable across groups, averaging in the neutral-to-somewhat motivated range, with *MM+NF* averaging slightly more motivated than *MM+Sham*, and *MM+Sham* averaging slightly higher than *MM-Only*. This difference may have occurred because the NF conditions may have been associated with more in-lab novelty or higher demand characteristics with the addition of utilizing the NF. Support for this comes from the finding that in-lab meditations were reported to be both overall more motivating and satisfying for all participants on average, but with *MM+NF* demonstrating the highest average ratings for both measures. However, this interpretation must be tempered as the group-by-setting interactions did not reach statistical thresholds.

Another finding was overall, participants found the in-lab meditation sessions less environmentally distracting than their at-home practicing. Within this pattern, *MM+NF* participants were slightly, but not significantly more environmentally distracted than the other groups, which at first pass might have been associated with extra effort trying to figure out the NF contingencies. However, if this were the case, this might also be expected for *MM+Sham* (or even more so), but *MM+Sham* was nearly equivalent to *MM-Only* for environment distraction levels. Bodily-sensation distraction levels were low, comparable across setting and between groups, and mind wandering was the major source of distraction identified by participants irrespective of group or setting. Taken together, these findings argue against the notion that the EEG setup and NF protocols resulted in major distraction sources, and to the contrary, the quiet controlled lab setting likely helped to reduce environmental distractions for all groups, which might otherwise be present in-home practice settings. Conversely it suggests that the addition of NF, real or sham, was entirely tolerable in the experimental setting and did not significantly interfere with how participants experienced their training (at least as indicated by their daily meditation ratings).

There were no statistically significant differences in terms of ease versus difficulty between groups or by setting, and no groups found sessions very easy or very difficult. On average, the *MM-Only* group rated sessions as slightly more difficult. Despite not reaching statistical significance, this is an interesting finding, as it may suggest the provision of feedback may influence perceived difficulty reductively; even when the proportion of positive versus negative feedback cues favored the latter, as was the case in this experiment. On a broader level, that sessions were not perceived too easy or too difficult falls in line with what would be hoped for beginner meditators, completing 8 days straight of a 20-minute FA meditation. There were no significant differences between groups or across setting for mood, focus, relaxation, or distraction from mind wandering or bodily sensations, with ratings averaging to reveal beneficial effects after meditating for all groups, and irrespective of setting.

Overall, these and the previously discussed daily meditation ratings fell in line with positive MM state-induced effects (e.g., improved mood, relaxation, and focus) reported by other investigators (e.g., Cahn & Polich, 2006; Chambers et al, 2008; Sedlmeier et al., 2012). Importantly, these effects were comparable between groups, irrespective of practice setting; and suggest that healthy young adults meditating in the context of the conditions and protocols involved in this study provides state-induced psychological benefits that were expected and in-line with other empirical studies and theory. Crucially, involving the NF manipulations did not appear to negatively impact the benefits of the MM practice.

Neurofeedback Conditions

The retrospectively assessed perceptions of condition assignment for *MM+Sham* and *MM+NF* were comparable between groups, and approximated chance level. This can be regarded as a successful blind, insofar as neither group seemed sure of assignment. It was also a blinding result comparable to other sham-controlled NF studies (Arnold et al., 2013; Lansbergen, et al, 2011). In a sham-controlled NF study conducted by Logemann et al. (2010), they reported that 71% of true NF and 83% of sham NF participants in their study believed they were assigned to sham condition. While a satisfactory finding for the experimental validity of the current study, there are some interpretive cautions. The participants were asked for their perception of what condition they were assigned to right after the full disclosure of the study purpose and sham condition during the follow-up session that occurred more than 10 days after their last in-lab session. Participants were also unblinded just prior to providing the experimenter their perception and confidence ratings of group assignment. Together, the introduction of novel information, demand characteristics, and retrospective interval may have resulted in responses different than if participants were asked immediately after the last session; however, unblinding before the 10-day follow-up questionnaire session would have also been a significant confound for this data subset.

With these data alone, it could reasonably be argued that neither the *MM+NF* nor *MM+Sham* conditions were believable. However, the ratings of how helpful and accurate the auditory feedback was between groups was statistically comparable and tended to favor perceptions of higher accuracy and helpfulness for the *MM+NF* group, though only slightly. There were also slight, but not significant differences in Cz (NF site) alpha increasing in the second half of training, while *MM+Sham* showed slight decreases. The *MM+NF* did statistically differ from *MM+Sham* in how much they were focusing on the NF across sessions. This finding, though not strong, could be reasonably interpreted as them recognizing and receiving utility in the cues provided, supporting that the veritable NF was being integrated by participants as the completed their (FA)MM training sessions.

Split-half changes or between-group differences in the amount of feedback types for *MM+NF* were anticipated but were not evident. There are a two interpretations of this, one of which is that the low-alpha NF was not ideal and robustly responsive to the *MM+NF* training parameters; or, related to this, that low-alpha was robustly related to meditative states as was suggested by others (Rodriguez-Larios & Alaerts, 2020), acknowledging they were able to use more rigorous, and thus potentially more sensitive measures than were available in the current study (e.g., more recording sites and signal resolution). Interestingly, that the ‘wave feedback’ was 40% for all groups, parallels the mean meditation experience report for groups on average reporting mind wandering about half the time. Bearing in mind the sample was comprised of beginners, in a relatively underpowered sample, undergoing a brief training program, this amount of mind wandering and mind wandering audio feedback (i.e., waves) is actually within the realm of what might reasonably be expected. It was also easier to illicit the wave feedback compared to the singing bowl audio feedback, with the former requiring only 2 seconds of low alpha below baseline and the latter requiring 3 seconds above the pre-meditation low alpha baseline levels. The difficulty of receiving this feedback, and thus the infrequency of hearing the singing bowl, may have ultimately resulted in the presentation of this feedback as a distraction, despite efforts to program this feedback to be soft and tapered to reduce this potential effect.

EEG. The analysis of Cz EEG data for the *MM+NF* in-lab sessions raised significant concerns about the reliability of the EEG data, which may be at least partially independent of how the NF protocols unfolded in-lab. Briefly, the finding of the cleaned and analyzed data included the following:

i) A correlational analysis did not indicate that in-session alpha activity (lower, upper, or broadband) was coupled with the amount of feedback in session.

ii) ANOVA of alpha-related activity at site Cz (the recording electrode for NF) also did not reveal significant changes separating *MM+NF* group from either other group in terms of average amplitudes or peak frequency shifts favoring lower alpha rhythmicity.

iii) A split half repeated-measures ANOVA showed no significant changes in Cz between the first and second half of the in-lab training sessions for any of the three groups, when at least trending evidence of increased alpha activity might reasonably be expected in and across several days of meditation training (Tang et al., 2017; Cahn & Polich, 2006).

Although it is possible, that the NF-protocol was entirely ineffective in influencing trainings (as the EEG results might otherwise suggest), taken into context other pieces of information this does seem entirely likely. Other information includes trends of subjective reports and session ratings as reviewed here that show some distinguishing NF effects, as well other non-EEG findings that will be reported in the next chapter. The protocol itself was pre-piloted first using the composite signal generator function in the software to verify low-alpha threshold sensitivity and responsiveness and subsequently on a convenience sample of novice and intermediate meditators including the author, to establish human data translation of the protocol (which showed moderately reliable effects in the that pre-pilot testing).

Other studies employing NF have also failed to report EEG effects (e.g., Logemann et al, 2010). A major challenge that arose in working with the BioExplorer software and Neurobit amplifier was that the export settings were of 1-second pre-processed epochs to a text file output. Dashboard visualization of continuous raw data in spectrographic or numerical display is an option and was useful in pre-piloting and validation of frequency generated training data and pre-piloting meditation data from volunteers prior to the study launch. However, ultimately there was no option for accessing the raw data once any recording session was finished, and so working with the data in finer resolutions than the exported 1-second epochs was not possible. This significantly limited the cleaning options and pipelines that the author was typically used in (e.g., using MATLAB EEGlab toolboxes), and the potential to explore automated and ICA-based methods for EEG data cleaning. Due to time and resource constraints, a heavy-handed manual cleaning of each file was conducted (described in Chapter 3 and Appendix E), that may have resulted in a significant data loss and non-optimized data cleaning and retention. Importantly it is also possible that people can improve in their feelings of calm and focus without large changes in their alpha activity. This has been suggested by others, as continuous EEG is more correlative than causative in predicting cognitive, behavioural, and physiological states (Thibault & Raz, 2018). In this data set as well, participants across groups reported increased feelings of relaxation and focus after meditations both in and out of lab.

Interpretations of the effectiveness of the NF protocol are further complicated by an appreciable variability in how NF protocols are experienced between individuals, which has been brought up as a practical and theoretical challenge in NF studies and applications writ large (Weber, Ethofer, Ehlis, 2020; Schönenberg, Weingärtner, Weimer & Scheeff, 2021). Of particular challenge is a purportedly high base rate of “BCI non-learners”. Recent literature suggests that about 30% of individuals do not show the ability to learn neuromodulation using technologies and protocols like the ones deployed in the current study (Davelaar et al., 2018; Weber et al., 2020). Given the lower than anticipated sample size, this issue is amplified. There have been suggestions that training in MM can improve BCI control (Tan et al., 2014). However, the limited amount of pilot data presented in this chapter did not trend in that direction, and it is not clear given the aforementioned challenges with the EEG data how to effectively identify or sort potential learners from non-learners. Future studies might consider screening for NF learnability prior to testing integrated MM NF protocols.

Increasing sample size and replicating this study is one potential way to address this, and much of the participant data and feedback suggests that this study is feasible for replication, should the associated resources and interest exist. Another method is to run a study with a lower sample size but that boosts the “dose” by increasing the duration of meditation sessions or the total course (i.e., number of days) of training. However, based on the feedback received from participants, longer training and associated demands might not be as well tolerated as they were in this study.

The other approach would be to increase “potency” or effectiveness of the NF integrated component. The novel (FA) MM+NF protocol designed and implemented in this study was a first attempt to achieve this pilot study aims. There is room for future optimization based on the results, experiences, and feedback of the participants and research team. For example, the decision to focus on lower alpha range only for meditation feedback may have been an overly constraining first approach. Having the neurofeedback cues based on broadband alpha may have made the access to positive neurofeedback cues (singing bowl) more easily achieved, more frequent, and ultimately more useful for helping shape the desired outcome of increasing alpha in session; insofar as it being a marker of a relaxed and focused state conducive to FA MM proficiency. More research is needed to understand if lower alpha band range practically constitutes the most effective NF target for enhancing MM training experiences or outcomes. If so, it might still be prudent in future research and development endeavours to take a graded approach; beginning with broadband alpha neurofeedback to start with, and reducing the target window over training, in a manner that is consistent with shaping behaviourism principles (Sherlin et al., 2011).

There are also nearly limitless parameter modifications that might also improve the experience of NF-assisted MM training, including optimizing amplitude and duration thresholds for feedback cues and the stimuli used. This is currently an area of academic discussion in applied and basic fields of NF science (Pérez-Elvira et al, 2021; Pigott, Cannon, & Trullinger, 2021). In the initial conception of the NF protocol, having the singing bowl feedback continuously in the background, with a more sophisticated volume tapering relative to baseline was desired. This was not achievable with the NF program used in this study but is likely a better approach in terms of having more continuous access (and therefore awareness building potential) of increased alpha activity in meditation. In the current form based on pilot and pre-pilot participant feedback, the stimuli choices for feedback cues generally appeared to be acceptable and understood by participants. It is conceivable that having some self-selected options of soundscape cues may have improved the effectiveness of these cues (reward, salience), or even self-selection of parameter constraints (duration or thresholds to elicit a NF cue) but this would have been a complicating factor from the point of view of a tightly controlled research study.

Summary

As an initial pilot of a sophisticated and technical research design and protocol series, at the broadest level, many aspects of the study were successful. This includes the interleaved home and lab practices for 8 days of meditation supported by the platforms and resources developed and used to support the research project and participant experience. Participants across groups showed positive state-dependent changes congruent with what has come to be expected on average from MM training practices and programs, with no significant adverse or negative effects; with the caveat of one participant who, as previously discussed, had their problem resolved once the project lead was alerted. Generally, it can be stated that the MM training in-lab and at home were implemented sufficiently and feasible for replication, or as a starting place for modification or expansion in future research endeavors and serve as a valid foundation for interpreting the results presented in the next chapter. However, the small sample size and the possibility of “overcleaned” EEG data limit strong conclusions about the robust effectiveness of the *MM+NF* protocol at present, limitations that also extend into the data and interpretations of the next chapter.

CHAPTER FIVE

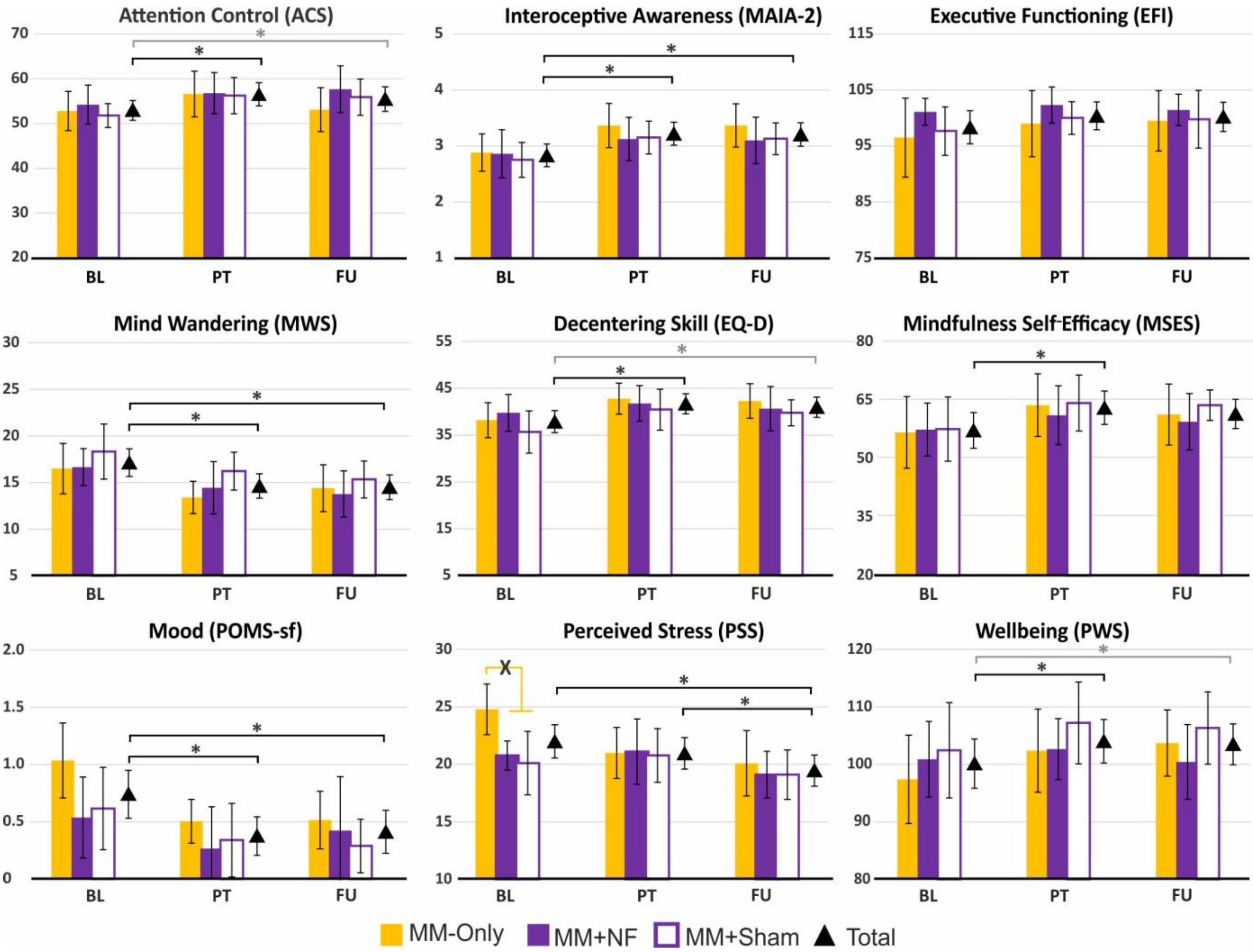
Experimental Results and Hypothesis Testing

This chapter examines the changes in psychological variables, cognitive-behavioural task performance, and electrophysiological before and after eight days of focused attention (FA) mindfulness meditation (MM) training, according to three in-lab experimentally manipulated conditions: i) Mindfulness meditation only (*MM-Only*), ii) Mindfulness mediation with veritable low-alpha neurofeedback (*MM+NF*), and iii) Mindfulness meditation with sham neurofeedback (*MM+Sham*). Efficacy measures included psychological self-report scales administered at baseline (BL), post-meditation training (PT), and at a 10-day follow-up (FU). Cognitive-behavioural outcome measures, as well as resting state and alpha control task EEG were acquired at BL and PT time points. Additionally, EEG and daily meditation experience ratings were acquired over the course of participants meditation training. The aim of these analyses was to evaluate whether and to what extent the addition of NF integrated into a brief (FA) MM training regimen would significantly change the course and outcomes of training when compared against the same training without NF, and against an equivalent training with a sham NF condition. This chapter is organized by first reporting on the self-report report measures, where the broadest markers of outcome efficacy are contained, followed by the cognitive-behavioural task results, then finally the neural/EEG tasks and measurements which are most relevant from a neural-mechanistic standpoint. The final section of this chapter summarizes the key results and revisits them against the hypotheses outlined in Chapter Two.

Self-Report Questionnaire Measurements at Baseline, Post-training, and Follow-Up

Figure 12 shows the findings of repeated measures testing for the questionnaires administered at BL, PT, and FU. The statistical test values of main scale indices are contained in Table 6 along with the means and standard errors. Only descriptive summaries are provided below, with the exception for subscale results which were not summarized in table form.

Figure 12. *Results of Psychological Self-Report Questionnaires Across Experimental Intervals*



Note. Black lines with asterisks denote significant main effects across measurement sessions that survived statistical correction for multiple comparisons, whereas the gray line and asterisk denotes a comparison that did not survive after correction. The X marks an interaction effect and the significant difference found between the MM-Only group at BL with post-hoc tests. Means and 95% confidence intervals are shown. Significance was computed with α = .05, corrected with the Holm-Bonferroni method. BL is Baseline Session, PT is Post-Training Session, FU is Follow-Up Session ten days after training ended.

Attention Control. For the Attentional Control Scale (ACS) no significant group-by-session of main between-group effects occurred. However, there was a significant effect for session with significant increases in total ACS scores increasing between BL and PT. These increases were maintained on trend at FU compared to BL. Subscale follow-up analyses indicated that these effects were driven by the Focus ($F_{1.8,46.5,50}$ = 8.46, *p* = .001) subscale of the ACS as opposed to the Shifting subscale ($F_{2,50}$ = 1.35, *p* = .269, η^2 = .06).

Mind wandering. For the Mind Wandering Scale (MWS), no statistically significant session-by-group interaction or main between-group main effects were found. A significant between session effect with total mind wandering was found, characterized by self-reported weekly time spent in mind wandering decreasing significantly from BL to PT, raining significantly lower at FU compared to BL.

De-Centering Skill. For the Experiences Questionnaire – Decentering (EQ-D), no significant interaction group-by-session interaction or between-group main effects were found. A significant between session effect was found characterized by self-reported decentering abilities increasing from BL to PT. These increases were reliably maintained at FU compared to BL.

Mindfulness Self-Efficacy. Two measures were administered to assess for changes in mindfulness-related self-efficacy. The Mindfulness Self-Efficacy Scale – Revised (MSES-R) measures comparable mindfulness self-efficacy but as deployed in daily living outside of formal meditation, whereas the Self-Efficacy for Mindfulness Meditation Practice Scale (SEMMP) assesses the self-efficacy of deploying mindfulness related attitudinal traits and skills within meditation practice.

For the MSES-R, no significant group-by-session interaction or between-group main effects were found. A significant between-session main effect was characterized by self-efficacy of mindfulness increasing from BL to PT. Compared to BL, these increases were not reliably maintained at FU. Subscale analyses indicated these effects were driven by higher scores on the Interpersonal

Effectiveness ($F_{2,50} = 7.18$, $p = .002$, $\eta^2 = .23$), Emotional Regulation ($F_{1.7, 39.9} = 6.24$, $p = .007$, $\eta^2 = .21$), and Distress Tolerance ($F_{2,50} = 4.90$, $p = .012$, $\eta^2 = .27$) but not the Equanimity, Social Skills, and Taking Responsibility subscales (all *p*'s > .10).

For the SEMMP, a significant group-by-session interaction whereby all groups increased in within-practice deployment of mindfulness skills, but with *MM-only* demonstrating the most improvement. However, they were also relatively initially lower in ratings, as can be seen in Figure 13A.

Interoceptive Awareness. On the Multidimensional Assessment of Interoceptive Awareness – Version 2 (MAIA-2), no significant group-by-session interaction or between-group main effects were found. A significant between-test sessions effect was found, characterized by total interoceptive awareness scores increasing from BL to PT that remained significantly high at FU compared to BL. Subscale analyses across indicated this effect was driven by increases on the Self-Regulation ($F_{1.6, 37.9} = 16.56$, $p < .001$, $\eta^2 = .41$), Body Listening ($F_{2,50} = 7.29$, $p = .002$, $\eta^2 = .23$), Noticing ($F_{2,50} = 6.54$, $p = .003$, $\eta^2 = .21$), Attention Regulation ($F_{1.6, 37.4} = 7.16$, $p = .004$, $\eta^2 = .23$), Not Worrying ($F_{2,50} = 5.69$, $p = .006$, $\eta^2 = .19$), Trusting ($F_{1.5, 36.9} = 6.16$, $p = .009$, $\eta^2 = .20$), and Emotional Awareness ($F_{2,50} = 5.24$, $p = .009$, $\eta^2 = .18$) subscales, but not the Non-Distraction subscale ($F_{1.7, 40.1} = 1.99$, $p = .156$, $\eta^2 = .07$),

Executive Function. For the Executive Function Index (EFI), there was no statistically significant interaction or main between-group or between-test session effects.

Perceived Stress. On the Perceived Stress Scale (PSS), a significant group-by-session interaction emerged. Pairwise comparisons did not reveal any between-group differences of means collapsed across all time points (*p*'s > .1), but a one-way ANOVA of just BL PSS scores was significant ($F_{2,27} = 5.42$, $p = .011$), which indicated *MM-Only* was higher in PSS scores at BL compared to the other groups. The overall pattern was characterized by past week perceived stress ratings decreasing from BL to FU, but primarily for the *MM-Only* group who had higher perceived stress scores at BL. The PSS scores for the other groups were relatively stable across intervals.

Psychological Wellbeing. On the Psychological Wellbeing Scale (PWS), no significant group-by-session interaction or main between group effects were found. A significant between session main effect was found, characterized by total psychological well-being scores increasing from BL to PT, that were maintained at FU from BL. This effect was primarily driven by Mastery ($BL_{M\pm SE}$ = 14.2 ±.62, $PT_{M\pm SE}$ = 15.6 ±.58, $p = .002$) and Self-Acceptance ($BL_{M\pm SE}$ = 17.3 ± .59, $PT_{M\pm SE}$ = 18.4 ±.53; $p = .006$), as opposed to Relations, Growth, Purpose, and Autonomy subscales (p's > 0.1, but all descriptively increased on average).

Mood. On the Profile of Mood Survey – Short Form (POMS-SF) no significant group-by-session interaction or between-group main effects were evident. A significant between session main effect was found, characterized by total negative mood adjustment endorsement decreasing from BL to PT, and remaining significantly lower at FU compared to BL. This effect was driven by decreases in Fatigue ($BL_{M\pm SE}$ 1.83 ± .185, PT = 1.16 ±.14, $p < .001$; FU =1.28 ±.17; $p = .001$ from BL), Tension ($BL_{M\pm SE}$ = 1.82 ±.185, PT = 1.34 ±.17, $p = .003$; FU = 1.29 ±.17, $p < .001$ from BL), Depression ($BL_{M\pm SE}$ = 0.89 ± .120, PT = 0.51 ± .089, $p = .001$; FU = 0.50 ± .12, $p = .01$ from BL), Anger ($BL_{M\pm SE}$ = 0.94 ± .12, PT = 0.59 ±.11, $p = .008$; FU = 0.59 ±.08, $p = .003$ from BL), but not Vigor or Confusion (p's $> .1$).

Table 6. *Means and Statistics for Self-Report Questionnaires*

Scale	Group	Session	M	SEM	Statistical Test Results					
Attention (ACS)	*MM-Only*	BL	52.8	2.2	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	56.6	2.6	Group X Session	4	50	.98	.429	.07
		FU	53.1	2.5	Group	2	25	.29	.751	.02
	MM+NF	BL	54.2	2.2	**Session**	**2**	**50**	**5.82**	**.005**	**.19**
		PT	56.8	2.3						
		FU	57.7	2.7						
	MM+Sham	BL	51.8	1.4						
		PT	56.2	2.1						
		FU	55.9	2.1	*Pairwise Session Tests*		M_{Dif}	$M_{Dif}SE$	*p*	
	Total	**BL**	**52.9**	**1.1**	**PT -**	**BL**	**3.6**	**1.2**	**.004**	
		PT	**56.5**	**1.3**	**FU -**	**BL**	**2.6**	**1.3**	**.048**	
		FU	**55.5**	**1.4**	FU -	PT	-1.0	0.8	.240	
Mind Wandering (MWS)	*MM-Only*	BL	16.5	1.4	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	13.4	0.9	Group X Session	4	50	.41	.801	.03
		FU	14.4	1.3	Group	2	25	.99	.384	.07
	MM+NF	BL	16.7	1.0	**Session**	**2**	**50**	**9.83**	**.000**	**.28**
		PT	14.4	1.4						
		FU	13.8	1.3						
	MM+Sham	BL	18.3	1.5						
		PT	16.2	1.0						
		FU	15.3	1.0	*Pairwise Session Tests*		M_{Dif}	$M_{Dif}SE$	*p*	
	Total	**BL**	**17.1**	**0.8**	**PT -**	**BL**	**-2.5**	.678	.001	
		PT	**14.6**	**0.7**	**FU -**	**BL**	**2.5**	.700	.001	
		FU	**14.5**	**0.7**	FU -	PT	-0.1	.632	.772	
Decentering (EQ-D)	*MM-Only*	BL	38.2	1.9	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	42.8	1.7	Group X Session	3.5	43.7	.56	.672	.04
		FU	42.3	1.9	Group	2	25	.63	.539	.05
	MM+NF	BL	39.8	2.0	**Session**	**1.7**	**43.7**	**6.90**	**.004**	**.22**
		PT	41.8	1.9						
		FU	40.7	2.4						
	MM+Sham	BL	35.7	2.3						
		PT	40.4	2.2						
		FU	39.8	1.4	*Pairwise Session Tests*		M_{Dif}	$M_{Dif}SE$	*p*	
	Total	**BL**	**37.9**	**1.2**	**PT -**	**BL**	**3.8**	**1.1**	**0.002**	
		PT	**41.7**	**1.1**	**FU -**	**BL**	**-3.8**	**1.3**	**.028**	
		FU	**41.0**	**1.1**	FU -	PT	-0.8	0.8	.332	
Mindfulness Self-Efficacy - Daily (MSES-R)	*MM-Only*	BL	56.7	4.7	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	63.7	4.1	Group X Session	3.1	38.5	.32	.814	.03
		FU	61.3	4.0	Group	2	25	.12	.883	.01
	MM+NF	BL	57.4	3.5	**Session**	**1.5**	**38.5**	**6.20**	**.008**	**.20**
		PT	61.1	3.8						
		FU	59.4	3.7						
	MM+Sham	BL	57.6	4.2						

		PT	64.2	3.7						
		FU	63.7	2.0	<u>*Pairwise Session Tests*</u>		M_{Dif}	M_{Dif} *SE*	*p*	
	Total	**BL**	**57.2**	**2.3**	**PT -**	**BL**	**5.8**	**1.6**	**.002**	
		PT	**63.0**	**2.2**	FU -	BL	-5.8	2.2	.061	
		FU	61.5	1.9	FU -	PT	-1.6	1.1	.192	
Interoceptive Awareness (MAIA-2)	*MM-Only*	BL	2.9	0.2	<u>*RM-ANOVA Effects*</u>	*df1*	*df2*	*F*	*p*	η^2
		PT	3.4	0.2	Group X Session	3.7	46.6	.52	.713	.04
		FU	3.4	0.2	Group	2	25	.42	.664	.03
	MM+NF	BL	2.9	0.2	**Session**	**1.9**	**46.6**	**15.39**	**.000**	**.38**
		PT	3.1	0.2						
		FU	3.1	0.2						
	MM+Sham	BL	2.8	0.2						
		PT	3.2	0.1						
		FU	3.1	0.1	<u>*Pairwise Session Tests*</u>		M_{Dif}	M_{Dif} *SE*	*p*	
	Total	**BL**	**2.8**	**0.1**	**PT -**	**BL**	**0.4**	**.088**	**.000**	
		PT	**3.2**	**0.1**	**FU -**	**BL**	**-0.4**	**.086**	**.000**	
		FU	**3.2**	**0.1**	FU -	PT	0.0	.057	.804	
Executive Functioning (EFI)	*MM-Only*	BL	96.5	3.6	<u>*RM-ANOVA Effects*</u>	*df1*	*df2*	*F*	*p*	η^2
		PT	99.0	3.0	Group X Session	3.6	44.7	.27	.879	.02
		FU	99.5	2.7	Group	2	25	.62	.544	.05
	MM+NF	BL	101.1	1.2	Session	1.8	44.7	2.10	.139	.08
		PT	102.3	1.6						
		FU	101.4	1.4						
	MM+Sham	BL	97.7	2.2						
		PT	100.0	1.5						
		FU	99.8	2.6						
	Total	BL	98.4	1.5						
		PT	100.4	1.3						
		FU	100.2	1.3						
Perceived Stress (PSS)	***MM-Only***	**BL**	**24.8**	**1.1**	<u>*RM-ANOVA Effects*</u>	*df1*	*df2*	*F*	*p*	η^2
		PT	21.0	1.1	**Group X Session**	**4**	**50**	**2.82**	**.035**	**.18**
		FU	20.1	1.4	Group	2	25	1.12	.341	.08
	MM+NF	BL	20.8	0.6	**Session**	**2**	**50**	**7.24**	**.002**	**.22**
		PT	21.1	1.4	<u>*Pairwise Group Tests*</u>		M_{Dif}	M_{Dif} *SE*	*p*	
		FU	19.1	1.0	*MM+NF* -	*MM-Only*	-1.6	1.4	.259	
	MM+Sham	BL	20.1	1.4	*MM+Sham* -	*MM-Only*	-2.0	1.4	.177	
		PT	20.8	1.2	*MM+Sham* -	*MM+NF*	-0.3	1.5	.820	
		FU	19.1	1.1	<u>*Pairwise Session Tests*</u>		M_{Dif}	M_{Dif} *SE*	*p*	
	Total	**BL**	**22.0**	**0.7**	PT -	BL	-1.0	.687	.186	
		PT	**21.0**	**0.7**	**FU -**	**BL**	**1.0**	**.679**	**.001**	
		FU	**19.5**	**0.7**	**FU -**	**PT**	**-1.5**	**.582**	**.015**	
Wellbeing (PWS)	*MM-Only*	BL	97.4	3.9	<u>*RM-ANOVA Effects*</u>	*df1*	*df2*	*F*	*p*	η^2
		PT	102.4	3.7	Group X Session	4	50	1.44	.235	.10
		FU	103.7	2.9	Group	2	25	.51	.606	.04
	MM+NF	BL	100.9	3.4	**Session**	**2**	**50**	**6.11**	**.004**	**.20**
		PT	102.7	2.7						
		FU	100.4	3.3						

	MM+Sham	BL	102.4	4.2						
		PT	107.2	3.6						
		FU	106.3	3.2	*Pairwise Session Tests*		M_{Dif}	M_{dif} *SE*	*p*	
	Total	**BL**	100.1	**2.2**	**PT -**	**BL**	**3.9**	**1.1**	**.002**	
		PT	104.0	**1.9**	**FU -**	**BL**	**-3.9**	**1.4**	**.029**	
		FU	103.5	**1.8**	FU -	PT	-0.5	1.0	.547	
Mood (POMS-sf)	*MM-Only*	BL	1.04	0.17	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	0.50	0.10	Group X Session	4	50	1.3	.301	.09
		FU	0.52	0.13	Group	2	25	1.2	.306	.09
	MM+NF	BL	0.54	0.18	**Session**	**2**	**50**	**11.5**	**.000**	**.32**
		PT	0.27	0.19						
		FU	0.42	0.24						
	MM+Sham	BL	0.62	0.18						
		PT	0.34	0.16						
		FU	0.29	0.12	*Pairwise Session Tests*		M_{Dif}	M_{dif} *SE*	*p*	
	Total	**BL**	**0.74**	**0.11**	**PT -**	**BL**	**-0.37**	**0.09**	**.000**	
		PT	**0.38**	**0.09**	**FU -**	**BL**	**0.37**	**0.08**	**.001**	
		FU	**0.41**	**0.10**	FU -	PT	0.04	0.08	.628	
Mindfulness Practice Self-Efficacy (SEMMP)	*MM-Only*	BL	53.7	2.5	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	64.6	2.3	**Group X Session**	**2**	**25**	**4.7**	**.018**	**.28**
	MM+NF	BL	61.3	2.6	Group	2	25	.48	.627	.04
		PT	63.7	3.2	**Session**	**1**	**25**	**19.13**	**.000**	**.43**
	MM+Sham	BL	59.6	3.4	*Pairwise Group Tests*			*All p's* > .09		
		PT	62.9	2.3	*Pairwise Session Tests*		M_{Dif}	M_{dif} *SE*	*p*	
	Total	**BL**	**58.0**	**1.7**	**PT -**	**BL**	**5.7**	**1.3**	**.000**	
		PT	**63.8**	**1.4**						
Interest in Practicing Meditation	*MM-Only*	BL	4.5	0.2	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	4.4	0.2	Group X Session	2	25	2.82	.079	.18
	MM+NF	BL	4.3	0.2	Group	2	25	1.62	.219	.11
		PT	3.6	0.3	Session	1	25	4.14	.053	.14
	MM+Sham	BL	4.1	0.2						
		PT	4.1	0.3						
	TOTAL	BL	4.3	0.1						
		PT	4.0	0.2						
Perceived Meditation Skill	*MM-Only*	BL	52.5	4.0	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	54.9	4.1	Group X Session	2	25	.22	.806	.02
	MM+NF	BL	49.1	8.4	Group	2	25	.12	.885	.01
		PT	55.2	8.5	Session	1	25	3.14	.089	.11
	MM+Sham	BL	52.8	4.5						
		PT	59.0	3.8						
	TOTAL	BL	51.5	3.3						
		PT	56.3	3.2						

Note. Bolded fonts indicate where significant effects were found that survived correction for multiple comparison, $\alpha = .05$. Interest in practicing meditation was a single item Likert rating (1 "No Interest", 5 "High Interest"). Perceived meditation skill was also single item ratings based on the percentile class relative to a hypothetical group of 100 peers.

Across Training Meditation Experience Ratings

Self-report measures to help distinguish the psychological similarities or differences between the training conditions were also recorded through daily meditation experience ratings, completed immediately after daily practices in-lab and at home. This data was analyzed according to first half (sessions 1-4) versus second half (sessions 5-8) of training average. The results of this analysis set are shown in Figure 13.

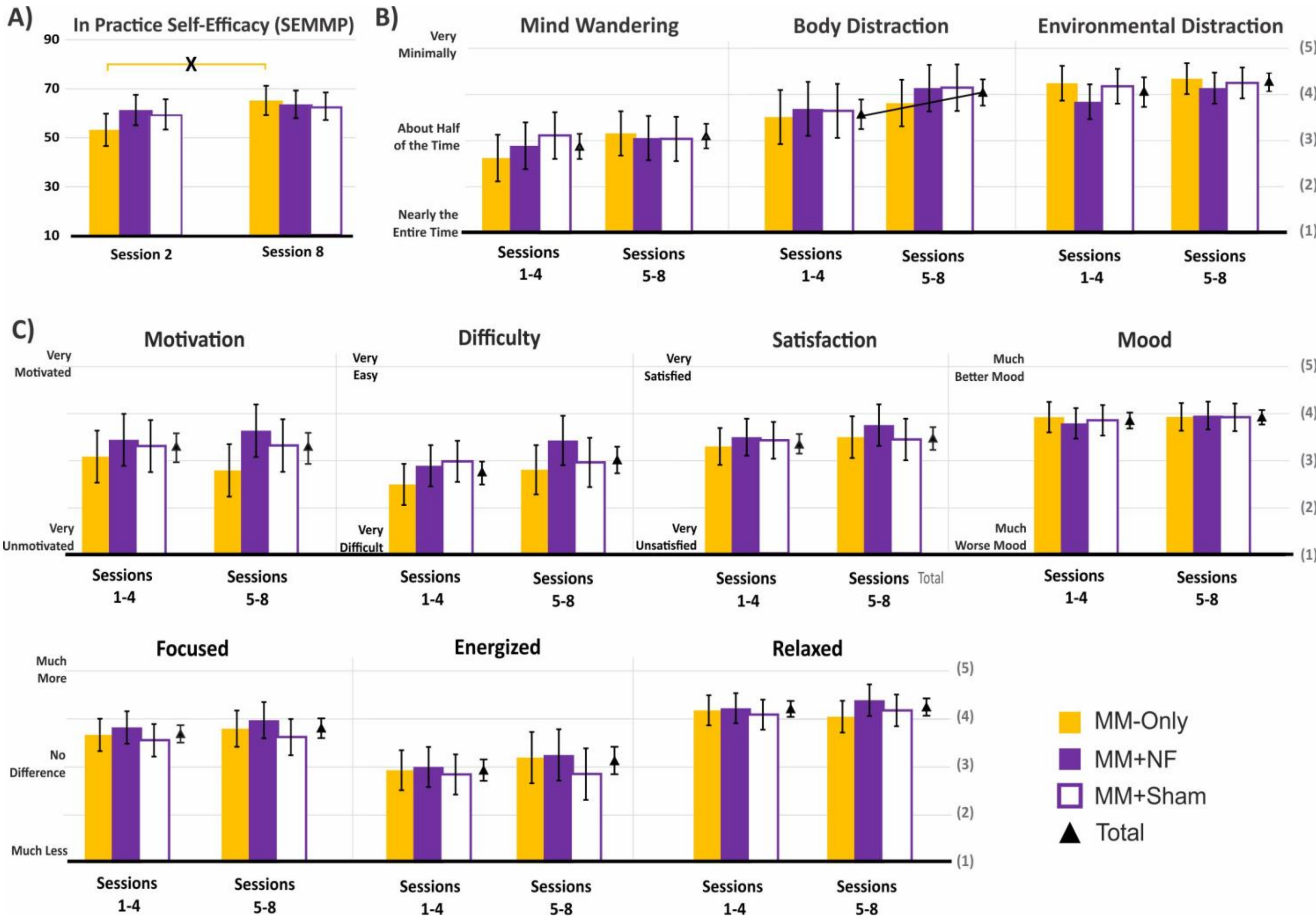
Meditation Session Ratings. Figure 13C shows the average differences between training halves and groups for the remaining daily meditation session rating items including motivation, difficulty, satisfaction, mood, focus energy, and relaxation. There were no between-group, between-training half, or interaction effects across ratings. The only rating that approached statistical significance was for difficulty, with an overall trend of participants rating meditation less difficult in the second half of training compared to the first ($F_{1,24} = 3.62$, $p = .069$, $\eta^2 = .13$).

Meditation Distraction Ratings. Figure 13B shows the training half averaged ratings of time spent distracted by mind wandering (thoughts), environment (external stimuli), and the body (internal stimuli). There were no between-group and training half interactions, or between-group main effects for any of the distraction categories. A significant main effect between training halves was observed for time spent distracted by body ($F_{1,24} = 16.79$, $p < .001$, $\eta^2 = .41$), with a trending effect for amount of sessions mind wandering ($F_{1,24} = 3.43$, $p < .076$, $\eta^2 = .125$) but not reliable or trending for environmental distraction ($F_{1,24} = 1.36$, $p = .213$, $\eta^2 = .64$), with the amount of session time in the direction of less distraction from each source in the second half of training.

Interest in Learning and Practicing Meditation. Single-item ratings at BL and FU were also collected, asking participants to give a rating in their interest to engage in routine meditation practice (Likert scale: 0 “No interest,” 5 “High interest”). There was a trending interaction ($p = .079$) and across-study effect (p = .053) for interest in continued meditation practice, characterized by a minor drop overall in interest, most pronounced for *MM+NF*. However, all groups were still overall on the side of moderate to high sustained interest in continuing to learn and practice meditation at the end of the study.

Perceived meditation skill. A single-item rating at BL and FU was administered, asking participants to indicate with a percentile rating on a normal distribution curve (see Appendix B) how well they believed they would be able to engage in meditation practices relative to 100 peers. Overall, a small trending increase in percentile rating emerged over study participation, with no interaction or between-group effects.

Figure 13. *Results of the Daily Meditation Experience Ratings between Training Halves*



Note. Panel (A) shows mindfulness self-efficacy measured by the SEMMP scale at training sessions two and eight. RM-ANOVA testing was significant for an interaction, with X denoting post-hoc significant change within the *MM-Only* condition underlying the effect. Panel (B) shows ratings of the amount of session time distracted by different information sources. Panel (C) shows ratings completed after each daily meditation. Within-subject effects and pair-wise time contrasts that survived multiple test correction are denoted by a black line connecting Total group means. Means and 95% confidence intervals are shown. Significance was computed with $\alpha = .05$ corrected with the Holm-Bonferroni approach for multiple comparisons.

Cognitive-Behavioural Tasks

Go/No-Go

Task performance for each group before and after meditation training was evaluated for accuracy (hits and no hits), speed (median reaction time), and reaction time consistency (IIV). There were no significant interactions or main effects for any Go/No-Go performance measures (p's > .25). Table 7 contains the performance details for each group by test session. There were 192 hit trials per task session, with many participants achieving maximal accuracy pre- and post-training. In summary, performance on the Go/No-Go task was not significantly changed by (FA) MM training in any condition. Participants across groups performed equivalently very well, at ceiling, at baseline, and after training.

Table 7. *Response Accuracy and Reaction Times for the Go/No-Go Task*

			MM-Only		*MM+NF*		*MM+Sham*	
Measure	Group	Trial	Hits	No Hit	Hits	No Hit	Hit	No Hit
Accuracy	BL	Go	191.7 (.2)	0.3 (.2)	191.2 (.4)	0.8 (.4)	190.8 (0.5)	1.2 (.5)
		No-Go	6.7 (1.3)	41.3 (1.3)	6 .1 (.9)	41.9 (.9)	7.4 (.9)	40.6 (.9)
	PT	Go	191.2 (.4)	0.5 (.3)	191.4 (.4)	0.6 (.4)	191.0 (.5)	1.0 (.5)
		No-Go	6.1 (1.2)	41.9 (1.2)	6.7 (.8)	41.3 (.8)	5.9 (.9)	42.1 (.9)
Median Reaction time	BL	Go	.351 (.010)		.353 (.009)		.346 (.011)	
	PT	Go	.346 (.011)		.354 (.008)		.339 (.006)	
IIV Reaction Time	BL	Go	44.4 (0.4)		43.7 (0.3)		44.0 (0.5)	
	PT	Go	43.7 (0.4)		44.1 (0.4)		43.5 (0.4)	

Note: Sample sizes were *MM-Only* (n = 10), *MM+NF* (n = 9), *MM+Sham* (n = 9). No statistically significant differences were observed within or between-groups before and after meditation training. Means are shown with standard errors in brackets. IIV was calculated as coefficient of variability.

Multi-Source Interference Task (MSIT)

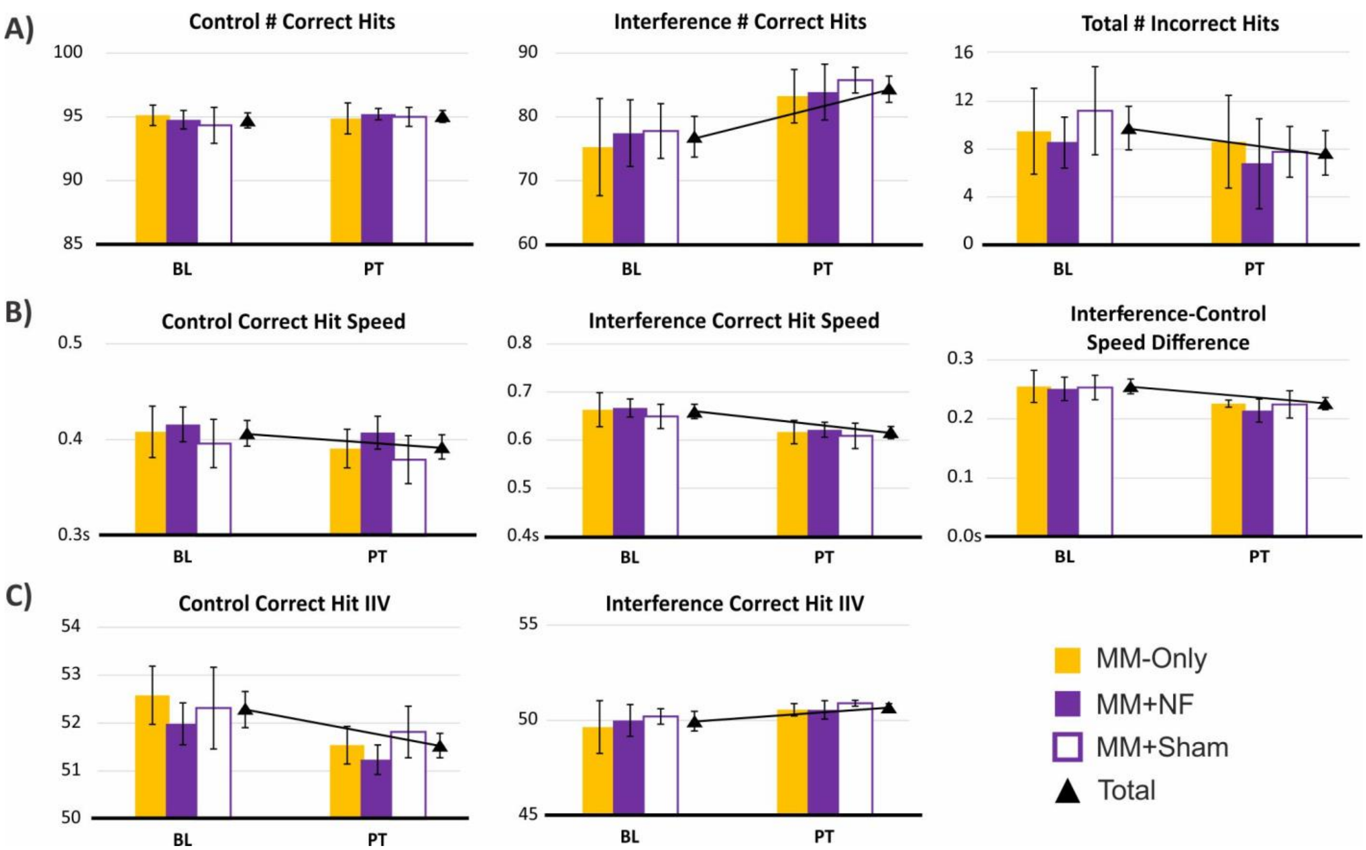
Task performance was evaluated for each group before and after training by MSIT condition (control and interference) for accuracy (correct hits), speed (median reaction time), and reaction time consistency (IIV). One *MM-Only* participant's data was removed as an outlier (>35% missed responses). The results are shown in Figure 14.

Control Condition. For accuracy, no significant effects were found (group-by-session interaction, $F_{2,24} = 0.31$, $p = .736$; group, $F_{2,24} = 0.31$, $p = 0.734$; session, $F_{1,24} = 1.11$, $p = 0.303$). There was a significant effect between sessions for speed ($F_{1,24} = 8.95$, $p = .006$, $\eta^2 = 0.27$) such that reaction times decreased from BL to PT, in absence of a significant interaction ($F_{2,24} = 0.37$, $p = .698$) or between-group effect ($F_{2,24} = 1.47$, $p = 0.249$). Additionally, IIV also showed a between-session main effect ($F_{1,24} = 16.16$, $p = .001$, $\eta^2 = .40$), whereby IIV decreased significantly from BL ($M_{IIV} = .523$) to PT ($M_{IIV} = .515$), in the absence of a group ($F_{2,24} = 1.36$, $p = .247$) or interaction effect ($F_{2,23} = .631$, $p = .540$).

Interference Condition. For accuracy, there was no significant interaction ($F_{2,24} = 0.25$, $p = .784$) or between-group main effect ($F_{2,24} = 0.23$, $p = 0.800$). There was a significant between-session effect ($F_{1,24} = 29.14$, $p < .001$, $\eta^2 = 0.55$), with the number of correct hits increasing significantly from BL to PT. For speed in the interference condition, there was no interaction effect ($F_{2,24} = 0.32$, $p = 0.729$) or between-group effect ($F_{2,24} = 0.55$, $p = 0.587$). There was a significant between session effect ($F_{2,24} = 70.22$, $p < 0.001$, $\eta^2 = 0.75$), with a significant decrease in correct hit interference reaction times BL ($M_{\pm SE} = .661 \pm .007$) to PT ($.616 \pm .006$). This pattern remained when analyzing the within subject calculated differences between interference and control reaction times. There was no interaction ($F_{2,24} = 0.37$, $p = .697$) or between-group main effect ($F_{2,24} = 0.67$, $p = 0.523$) but there was a significant between-session effect ($F_{1,24} = 44.73$, $p < .001$, $\eta^2 = .66$) with the difference in reaction time decreasing significantly from BL ($M_{\pm SE} = .253 \pm .012$) to PT ($.221 \pm .010$). In terms of consistency of reaction time

(IIV) there was no interaction ($F_{2,24}$ = 0.18, *p* = .834) or between-group main effects ($F_{2, 24}$ = 0.18, *p* = .834). There was a significant main effect between-sessions ($F_{1,24}$ = 9.09, *p* = .006, η^2 = 0.28). This was in the opposite direction of control trial findings, with interference condition speed for accurate hits decreasing from BL ($M_{\pm SE}$ = 50.0±.6) to PT (50.7±.1).

Figure 14. *Accuracy and Speed Performance on the MSIT*



Note. (A) shows the number of correct hits made in the control and interference trials and the number of total control and interference trial errors. The maximum number of correct hits for each block type was 96. (B) shows the reaction time of correct hits for control and interference trials, and the average intraindividual difference in reaction time between the interference and control conditions. Data shows average median reaction time in seconds. (C) shows the consistency in speed for accurate hits made in the control and interference trials. Data shows the average coefficient of variation for IIV. RM-ANOVA testing was not significant for interactions or between-group effects. Significant within-subject effects and pairwise contrasts that survived multiple test correction are denoted by a black line connecting combined group means. Means and 95% confidence intervals are shown. Significance was computed with *α* = .05, corrected for multiple comparison using the Holm-Bonferroni method. BL refers to the baseline session, PT refers to the post-training session.

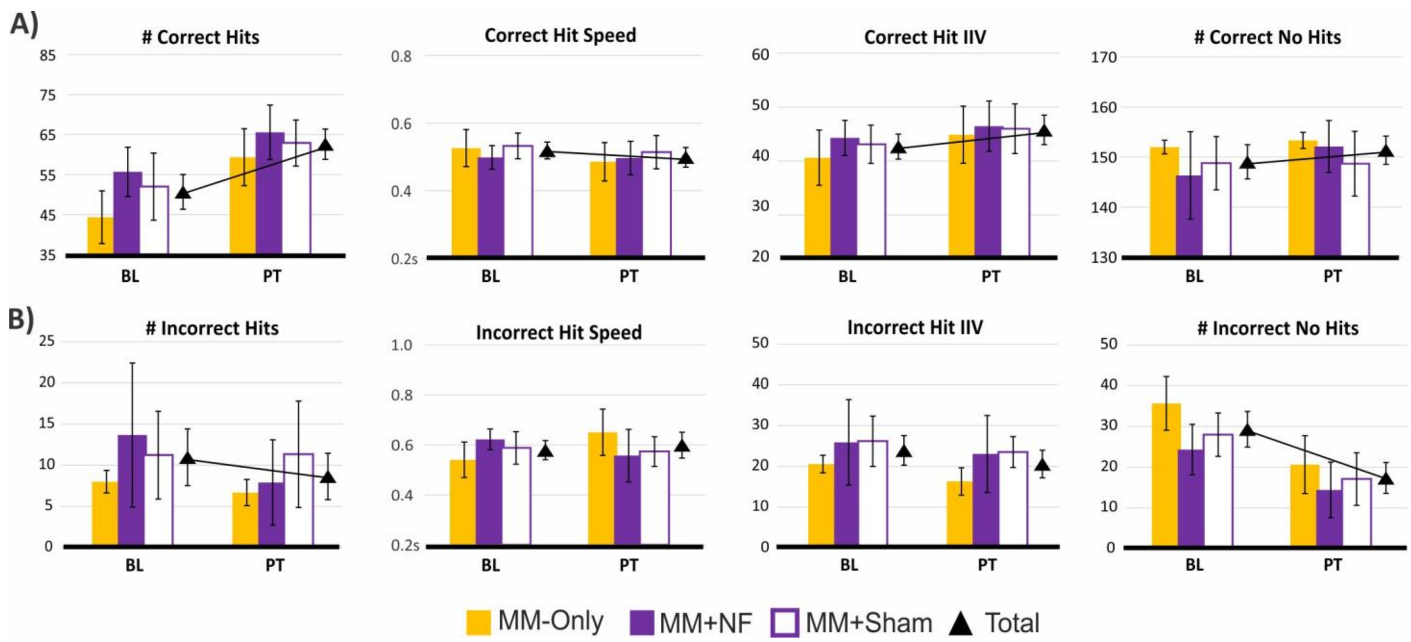
Distractor n-Back Task.

Task performance was evaluated for each group before and after training for overall accuracy (correct hits), speed (median reaction time), and reaction time consistency (IIV), with follow-up analysis conducted by n-back distractor condition (none, neutral, positive, negative).

Overall Performance. Overall performance results are shown in Figure 15. For accuracy, no significant group-by-session interaction ($F_{2,25} = 1.14$, $p = .336$) or main effect for group occurred ($F_{2,25} = 1.95$, $p = .154$). A significant between-session main effect ($F_{1,24} = 66.32$, $p < .001$, $\eta^2 = .73$) was found, with significant increases in correct hit numbers from BL ($M_{\pm SE} = 50.7 \pm 2.2$) to PT ($62.6 \pm 1.9$). This same effect pattern was obtained for correct hit speed, with no significant interaction ($F_{2,25} = 0.148$, $p = .249$) or group effect ($F_{2,25} = 0.34$, $p = .716$), but a significant between-session main effect ($F_{1,24} = 48.05$, $p = .037$) characterized by significant decrease in reaction time from BL ($M_{\pm SE} = .519 \pm .012$) to PT ($.499 \pm .015$). For correct hit IIV, no interaction ($F_{2,25} = 1.86$, $p = .177$, $\eta^2 = .13$) or group effect ($F_{2,25} = 2.10$, $p = .145$, $\eta^2 = .15$) occurred, but a significant between-session main effect ($F_{1,24} = 48.05$, $p < .001$, $\eta^2 = .67$) did, with reaction time consistency decreasing from BL ($M_{\pm SE} = 42.0 \pm 0.7$) PT ($45.4 \pm .05$).

Overall, for incorrect hits results, no significant interaction ($F_{2,25} = 2.96$, $p = .071$) or between-group main effect ($F_{2,25} = .70$, $p = .502$) were found, but a between-session main effect was ($F_{1,24} = 5.13$, $p = .033$, $\eta^2 = .18$), with incorrect hit numbers decreasing from BL to PT. The median reaction time of incorrect hits did not reveal any significant effects (Interaction. $F_{2,15} = 3.52$, p = .056, $\eta^2 = .32$; Group, $F_{2,15} = 0.07$, $p = .936$; Session, $F_{1,15} = .128$, $p = .725$). For incorrect hit IIV, no significant effects were found (Interaction, $F_{2,15} = .07$, $p = .929$; Group, $F_{2,15} = 2.37$, $p = .128$; Session, $F_{1,15} = 2.82$, $p = .114$).

Figure 15. *Overall Accuracy and Speed Performance on the n-Back Task*



Note. (A) Shows results for the correct responses, comprised of total correct hits and correct no-hit response counts, and reaction time speed and consistency for correct hits. (B) shows results for the incorrect responses, indicated with incorrect hits and incorrect miss response counts, as well as reaction time speed and consistency for correct hits. Speed was calculated with group averaged individual median reaction time. IIV was calculated by group averaged individual coefficients of variation. RM-ANOVA testing was not significant for interactions. Significant within-subject effects and pair-wise comparisons that survived multiple test correction are denoted by a black line connecting lines. Means and 95% confidence intervals are shown. Significance was computed with α = .05, corrected with the Holm-Bonferroni method. RT is Reaction Time, IIV is Intraindividual Variability, BL is Baseline Session, PT is Post-Training Session.

***n*-Back performances by distractor condition.** A follow-up of performance according to distractor block type was conducted with the results displayed graphically in Figure 16. Table 8 contains the mean information for each performance domain, with bolding highlighting significant differences. The statistical threshold values and effect sizes are contained in the text summary for block types.

No Distractor. For the number of correct hits in the no distractor *n*-back block, a significant interaction was found ($F_{2,25} = 15.04$, $p < .001$, $\eta^2 = 0.56$; Group, $F_{2,25} = 0.57$, $p = .571$, $\eta^2 = .05$; Session, $F_{1,24} = 47.07$, $p < .001$, $\eta^2 = .66$). Underlying this was a significant increase for *MM-Only* accuracy ($p < .001$), whereas *MM+Sham* showed less but still significant improvements ($p = .007$), and *MM+NF* accuracy did not significantly change ($p = .499$). Notably, *MM-Only* BL correct hits were relatively lower to begin with. No significant differences emerged for correct hit reaction times (interaction, $F_{2,25}$ = 3.11, p = .063; group ($F_{2,25}$ = 0.24, p = .791; session, $F_{1,24}$ = 2.29, p = .144). For IIV, a significant interaction was found ($F_{2,25}$ = 12.67, p < .001, η^2 = .51; group, $F_{2,25}$ = 1.08, p = .354; sessions, $F_{1,24}$ = 32.75, p < .001, η^2 = .58). Underlying this was a significant increase for *MM-Only* (p = .002), a lesser increase for *MM+Sham* (p = .012), and no significant change for *MM+NF* (p = .794).

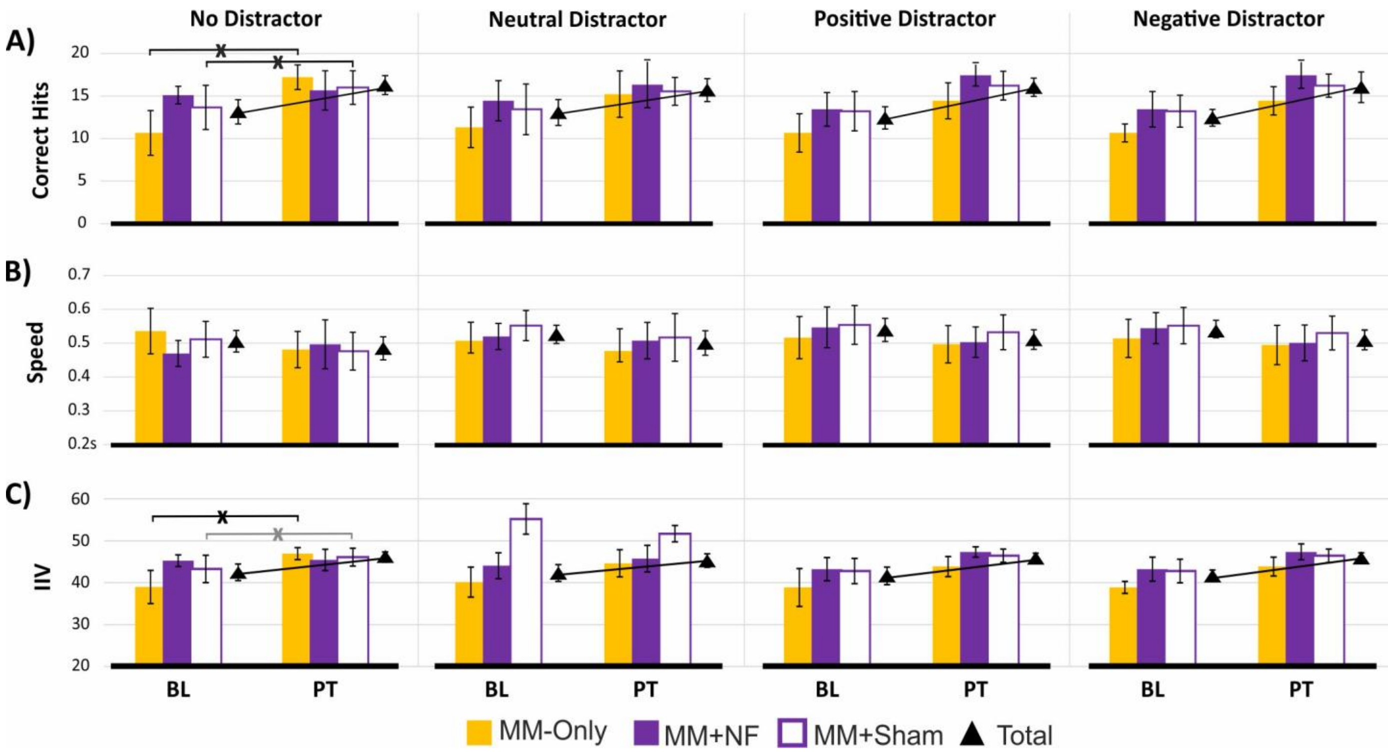
Neutral Distractor. Only a between-session main effect was found for correct hit count ($F_{1,24}$ = 14.71, p = .001, η^2 = 0.38; interaction, $F_{2,25}$ = 0.85, p = .439; between-group, $F_{2,25}$ = 0.93, p = .410). For the median reaction time of correct hits, no significant differences occurred (interaction, $F_{2,25}$ = 0.18, p = .840; group, $F_{2,25}$ = 0.79, p = .464; session, $F_{1,24}$ = 2.40, p = .135). For IIV, only a main effect between test sessions was found ($F_{1,24}$ = 12.45, p = .002, η^2 = .34; interaction, $F_{2,25}$ = 0.93, p = .410; group, $F_{2,25}$ = 0.85, p = .442) with IIV increasing after meditation training.

Positive Distractor. No significant interaction was found for the number of correct hits ($F_{2,25}$ = 0.21, p = .813). Between test session ($F_{1,24}$ = 29.29, p < .001, η^2 = .55) and between-group ($F_{2,25}$ = 3.55, p = .045, η^2 = 0.23) main effects were found, but the latter did not survive after correction for multiple comparisons. For the reaction time of correct hits, no significant differences occurred (Interaction, $F_{2,25}$ = 0.30, p = .741; Group, $F_{2,25}$ = 0.54, p = .591; Session, $F_{1,24}$ = 4.07, p = .055). No interaction emerged for IIV for correct hits ($F_{2,25}$ = 0.15, p = .859). A main between-session effect was found ($F_{1,24}$ = 18.17, p < .001, η^2 = .43), with an overall increase in IIV. The between-group main effect did not survive after correction for multiple comparisons ($F_{2,25}$ = 3.66, p = .041, η^2 = .23).

Negative Distractor. For the number of correct hits, no significant interaction ($F_{2,25}$ = 2.94, p = .07) or group main effect was found ($F_{2,25}$ = 2.95, p = .070). A significant between-test session effect was, however ($F_{1,24}$ = 24.32, p < .001, η^2 = .50). For the median reaction time of correct hits in the negative distractor block, no significant differences were found ($F_{2,25}$ = 1.22, p = 0.314; between-group,

$F_{2,25}$ = 0.67, *p* = .521; between session, $F_{1,24}$ = 0.61, *p* = .444). For correct hit IIV, only one main effect between-test session was found ($F_{1,24}$ = 14.97, *p* = .001, η^2 =.38; interaction, $F_{2,25}$ = 1.74, *p* = 0.197; group, $F_{2,25}$ = 2.25, *p* = .127), with overall IIV increasing.

Figure 16. *Accuracy and Speed Performance Results According to n-Back Distractor Block Type*



Note. Panel (A) shows the average number of accurate responses (correct hits) for each condition, by group, across measurement sessions. Panel (B) shows results for speed of correct hits. Speed was calculated with group averaged individual median reaction times. Panel (C) shows speed consistency of correct hits indicated by IIV. IIV was calculated by group averaged individual coefficients of variation. Significant within-subject effects and pairwise contrasts that survived multiple test correction are denoted by a black line connecting combined group (Total) means. X's denote significant interaction effects post-hoc pairwise tests with *p* <.05 that survived correction for multiple comparisons. Those comparisons that did not survive correction for multiple comparison are shown in gray. Means and 95% confidence intervals are shown. Significance was computed with α = .05, corrected with the Holm-Bonferroni method. RT is Reaction Time, IIV is Intraindividual Variability, BL refers to the baseline test session and PT the post-training test session.

Table 8. *Distractor n-Back Task Accuracy, Speed, and Speed Consistency*

			Correct Hits		Median RT		IIV	
n-Back Block	Group	Time	Mean	*SE*	Mean	*SE*	Mean	*SE*
No Distractor	***MM-Only***	**BL**	**10.7**	***1.3***	0.536	*0.034*	**39.0**	***2.0***
		PT	**17.2**	***0.7***	0.481	*0.027*	**46.9**	***0.7***
	MM+NF	BL	15.1	*0.5*	0.469	*0.019*	45.2	*0.7*
		PT	15.7	*1.2*	0.496	*0.036*	45.4	*1.3*
	MM+Sham	**BL**	**13.7**	***1.3***	0.511	*0.026*	**43.3**	***1.6***
		PT	**16.0**	***1.0***	0.476	*0.028*	**46.1**	***1.1***
	Total	BL	13.1	*0.7*	0.505	*0.016*	42.5	*1.0*
		PT	16.3	*0.6*	0.484	*0.017*	46.1	*0.6*
Neutral	*MM-Only*	BL	11.3	*1.2*	0.507	*0.028*	40.1	*1.8*
		PT	15.2	*1.4*	0.477	*0.033*	44.6	*1.6*
	MM+NF	BL	14.4	*1.2*	0.520	*0.019*	44.0	*1.5*
		PT	16.3	*1.4*	0.507	*0.027*	45.8	*1.6*
	MM+Sham	BL	13.4	*1.5*	0.552	*0.022*	42.7	*1.8*
		PT	15.6	*0.8*	0.517	*0.035*	45.4	*1.0*
	Total	BL	**13.1**	***0.8***	0.526	*0.013*	**42.3**	***1.0***
		PT	**15.7**	***0.7***	0.500	*0.018*	**45.3**	***0.8***
Positive	*MM-Only*	BL	10.7	*1.1*	0.516	*0.031*	38.9	*2.3*
		PT	14.4	*1.1*	0.497	*0.028*	43.8	*1.2*
	MM+NF	BL	13.4	*1.0*	0.547	*0.030*	43.2	*1.4*
		PT	17.4	*0.6*	0.503	*0.022*	47.3	*0.6*
	MM+Sham	BL	13.2	*1.2*	0.554	*0.029*	42.8	*1.5*
		PT	16.2	*0.8*	0.532	*0.026*	46.4	*0.8*
	Total	**BL**	**12.4**	***0.7***	0.539	*0.017*	**41.6**	***1.0***
		PT	**16.0**	***0.5***	0.511	*0.014*	**45.9**	***0.6***
Negative	*MM-Only*	BL	11.7	*0.5*	0.542	*0.028*	40.9	*0.7*
		PT	12.4	*0.8*	0.523	*0.029*	41.8	*1.1*
	MM+NF	BL	12.7	*1.0*	0.491	*0.023*	42.2	*1.4*
		PT	16.1	*0.8*	0.503	*0.026*	45.9	*0.9*
	MM+Sham	BL	11.7	*0.9*	0.487	*0.027*	41.0	*1.4*
		PT	15.1	*0.7*	0.533	*0.025*	44.8	*0.8*
	Total	**BL**	**12.0**	***0.5***	0.507	*0.015*	**41.4**	***0.7***
		PT	**14.6**	***0.9***	0.520	*0.015*	**44.2**	***0.6***

Note. Bolded numbers indicate measures where significant effect occurred, $p < .05$. Sample size was $n = 9$ for each group. BL = baseline session, PT = post-training session.

Electroencephalographic Tasks

Electroencephalographic recordings were acquired pre- and post-training (i.e., BL & PT) during resting state and a visual alpha-NF control task**.** The former was included as an evaluative marker of functional neural changes as they may have emerged over meditation training according to their assigned protocols. The alpha-NF task was included to evaluate the transfer of NF control skills resulting from the different training conditions. The resting state and alpha-NF results are shown in Figure 17. EEG recordings were also acquired for all in-lab meditations sessions to evaluate functional neural network differences across training within meditation practices. Alpha activity (7-13 Hz) was a primary focus, with additional analyses of upper (7-10 Hz) and lower (10-13Hz) alpha sub-band amplitude, and alpha range peak frequency. Theta (3-7 Hz), beta (14-30 Hz), and gamma (30-45 Hz) band activity was also investigated for markers of state and trait changes in neural network functioning.

Resting State EEG

There were no significant effects for broadband alpha (Interaction, $F_{2,22} = 0.54$, $p = 0.591$; Group, $F_{2,22} = 0.30$, $p = 0.742$; Session, $F_{1,22} = 0.05$, $p = 0.826$). This was also true for lower alpha (Interaction, $F_{2,22} = 1.32$, $p = 0.287$; Group, $F_{2,22} = 0.33$, $p = 0.726$; Session, $F_{1,22} = 0.45$, $p = 0.508$) and upper alpha (Interaction, $F_{2,22} = 0.08$, $p = 0.923$; Group, $F_{2,22} = 0.59$, $p = 0.563$; Session, $F_{1,22} = 0.04$, $p = 0.851$). No significant differences were found for peak frequency shifts in the alpha band range (Interaction, $F_{2,22} = 0.37$, $p = 0.692$; Group, $F_{2,22} = 1.94$, $p = 0.168$; Session, $F_{1,22} = 1.49$, $p = 0.236$).

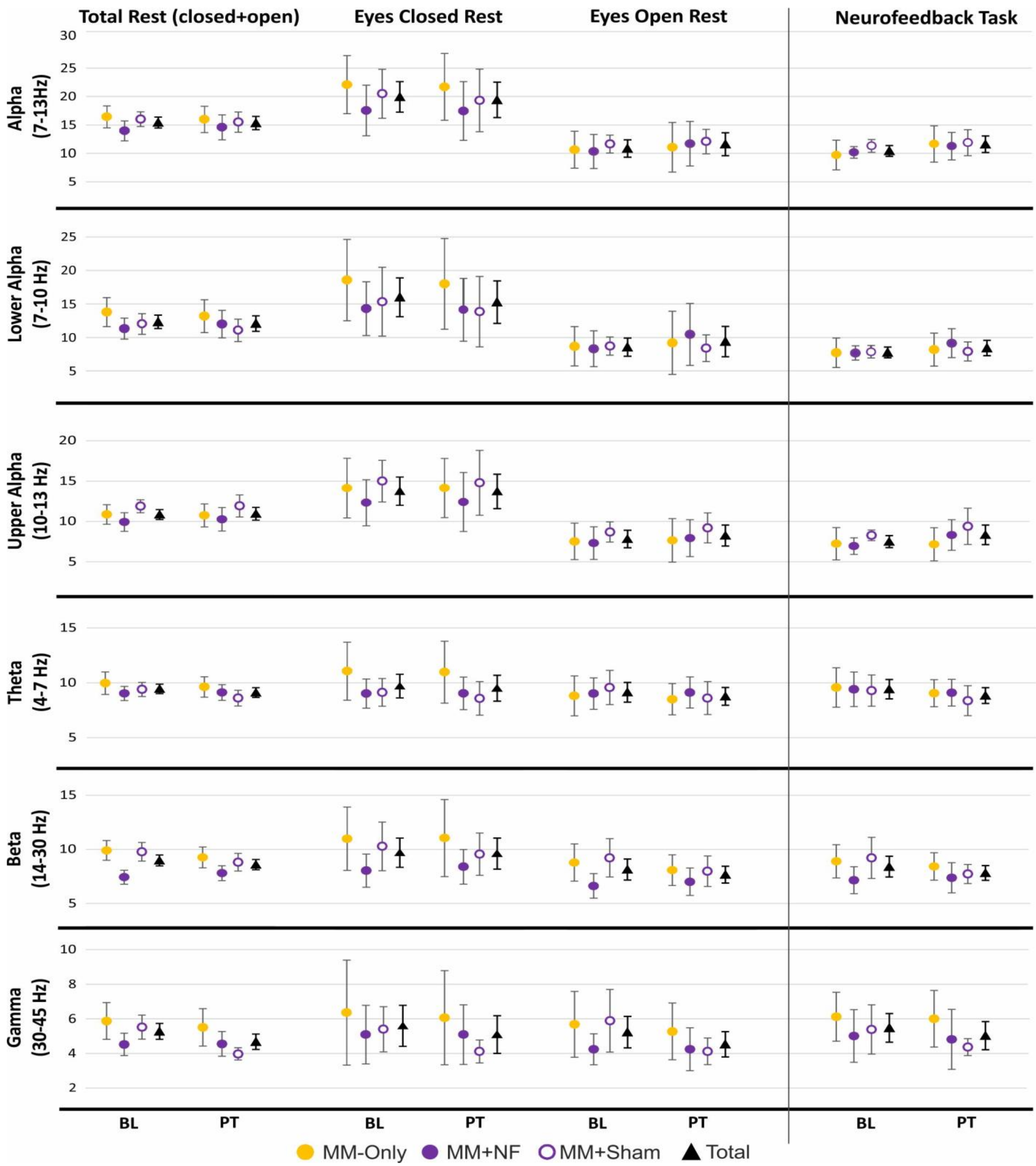
For theta, no effects were found (Interaction, $F_{2,22} = 1.80$, $p = 0.189$; Group, $F_{2,22} = 0.32$, $p = .728$; Session, $F_{1,22} = 3.44$, $p = .077$). For beta, there was a significant interaction, but it did not survive correction for multiple comparison, and main effects of group and session were also not statistically significant ($F_{2,22} = 4.27$, $p = 0.027$, $\eta^2 = 0.28$; Group, $F_{2,22} = 1.85$, $p = 0.180$, $\eta^2 = 0.14$; Session, $F_{1,22} = 4.34$, $p = 0.049$, $\eta^2 = 0.16$). This was also true of gamma (Interaction, $F_{2,22} = 3.57$, $p = .045$, $\eta^2 = 0.25$; Group, $F_{2,22} = 0.65$, $p = 0.533$, $\eta^2 = 0.06$; Session, $F_{1,22} = 6.35$, $p = .020$, $\eta^2 = 0.22$). Separate analysis of eyes-open and eyes-closed resting state data across these activity bands did not reveal any significant interaction or main effects (*p*'s > .10). These data are displayed in Figure 16.

Alpha Neurofeedback Control Task

Participants had the goal of 'catching birds' to increase a bird count score. This was done by upregulating and sustaining alpha range activity above a baseline calibrated threshold of alpha (eyes open mental arithmetic), while also keeping muscle and blink artifacts to a minimum. The threshold parameters and potential strategies to succeed were never introduced to participants. Instead, they had to rely on visual feedback of changing bar graph displays and a score counter as well as the auditory feedback of birds chirping. There was notable large variability between participants in the bird scores achieved at BL and PT (trial scores ranged from 0 to 200+). To reduce the order of magnitude of these differences and facilitate analysis, a ratio of PT/BL score was calculated, then natural log rhythm transformed. The results are shown in Figure 18B. Descriptively, *MM+NF* performed best, with all groups averaging toward improved PT performances. However, a one-way ANOVA did not indicate significant group differences ($F_{2,23} = .44$, $p = .649$).

Figure 17 and Table 9 display the EEG activity measures of interest recorded from participants as they completed the alpha-NF task. Briefly, alpha activity trended towards higher levels at PT relative to BL but did not survive correction for multiple correction. Amplitudes in Theta, Beta, and Gamma ranges tended to decrease, but these effects, too, were either not statistically reliable before or after corrections for multiple comparisons were applied. Peak alpha frequency analysis did not reveal significant interaction ($F_{2,22} = 0.39$, $p = 0.683$) or between-group ($F_{2,22} = 1.94$, $p = 0.168$) or between session main effects ($F_{1,22} = 1.18$, $p = 0.289$).

Figure 17. *Pre- and Post-Training EEG from Resting State and Alpha-Neurofeedback Tasks*



Note. Means and 95% confidence intervals are shown. Units are averaged amplitudes across Fz, Cz, and Pz sites in µV. No significant group-by-session interaction effects were found with $\alpha = .05$ and Holm-Bonferroni corrections applied.

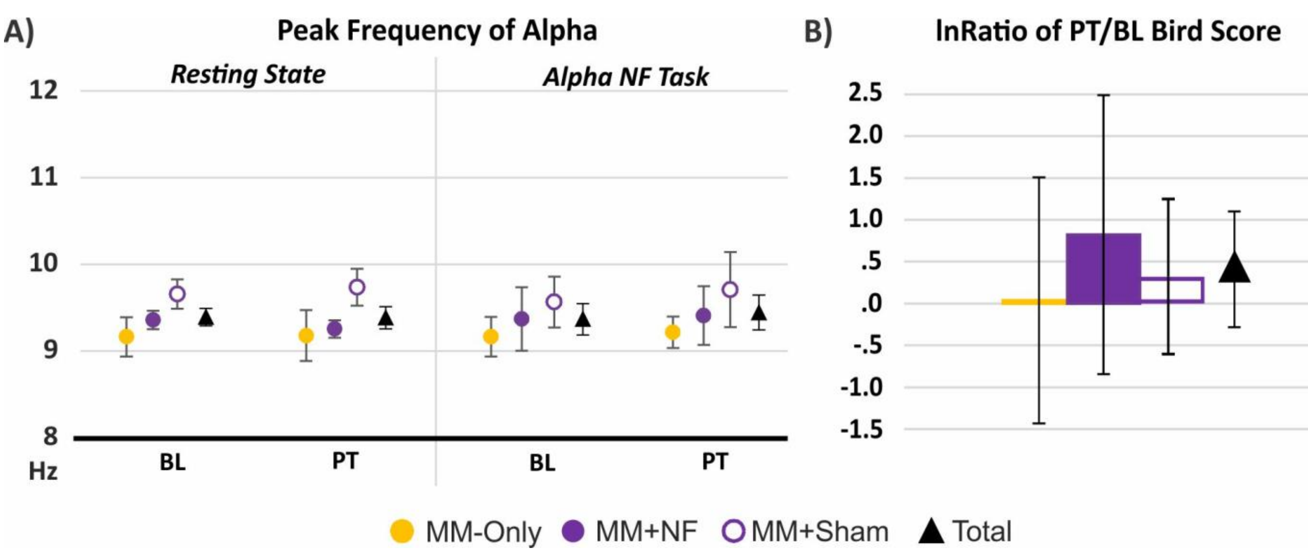
Table 9. *Mean EEG Amplitudes on the Alpha Neurofeedback Control Task*

Measure	Group	Session	M	SEM	Statistical Test Results					
Alpha (7-13 Hz)	*MM-Only*	BL	9.7	1.3	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	11.6	1.6	Group X Session	2	22	.51	.609	.04
	MM+NF	BL	10.1	0.5	Group	2	22	.30	.742	.03
		PT	11.2	1.2	Session	1	22	5.82	.044	.17
	MM+Sham	BL	11.3	0.6						
		PT	11.8	1.1						
	Total	BL[1]	10.4	0.5						
		PT	11.6	0.7						
Lower Alpha (7-10 Hz)	*MM-Only*	BL	7.7	1.1	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	8.2	1.2	Group X Session	2	22	1.73	.200	.13
	MM+NF	BL	7.7	0.5	Group	2	22	.33	.726	.03
		PT	9.1	1.1	Session	1	22	4.12	.054	.15
	MM+Sham	BL	7.8	0.5						
		PT	7.9	0.7						
	Total	BL[1]	7.7	0.4						
		PT	8.4	0.6						
Upper Alpha (10-13 Hz)	*MM-Only*	BL	7.2	1.0	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	7.2	1.0	Group X Session	2	22	.96	.398	.08
	MM+NF	BL	7.0	0.5	Group	2	22	.59	.563	.05
		PT	8.3	0.9	Session	1	22	3.33	.081	.13
	MM+Sham	BL	8.3	0.2						
		PT	9.4	1.1						
	Total	BL[1]	7.5	0.4						
		PT	8.3	0.6						
Theta (4-7 Hz)	*MM-Only*	BL	9.0	0.9	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	9.1	0.6	Group X Session	2	22	.61	.398	.05
	MM+NF	BL	9.5	0.8	Group	2	22	.32	.728	.03
		PT	9.1	0.6	Session	1	22	6.29	.020	.21
	MM+Sham	BL	9.3	0.7						
		PT	8.4	0.7						
	Total	BL	9.5	0.4						
		PT	8.9	0.4						
Beta (14-30 Hz)	*MM-Only*	BL	9.0	0.8	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	8.6	0.6	Group X Session	2	22	1.91	.171	.14
	MM+NF	BL	7.3	0.6	Group	2	22	1.85	.180	.14
		PT	7.5	0.7	Session	1	22	2.54	.125	.10

	MM+Sham	BL	9.3	0.9						
		PT	7.9	0.4						
	Total	BL	8.5	0.5						
		PT	8.0	0.3						
Gamma (30-45 Hz)	*MM-Only*	BL	6.0	0.7	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
		PT	5.9	0.8	Group X Session	2	22	.90	.422	.07
	MM+NF	BL	4.9	0.8	Group	2	22	.65	.533	.06
		PT	4.7	0.9	Session	1	22	2.09	.161	.08
	MM+Sham	BL	5.3	0.7						
		PT	4.2	0.3						
	Total	BL	5.4	0.4						
		PT	4.9	0.4						

Note. Sample sizes were MM-Only (n = 8), MM+NF (n = 9) and MM+Sham (n = 9). Mean amplitudes of Fz, Cz, Pz activity in μV are reported. No tests survived Holm-Bonferroni correction for multiple comparisons. [1] Did not pass Levene's Test for equality of variance between-groups (p < .05).

Figure 18. *Peak Frequency of Alpha Activity and Alpha Neurofeedback Task Performance*

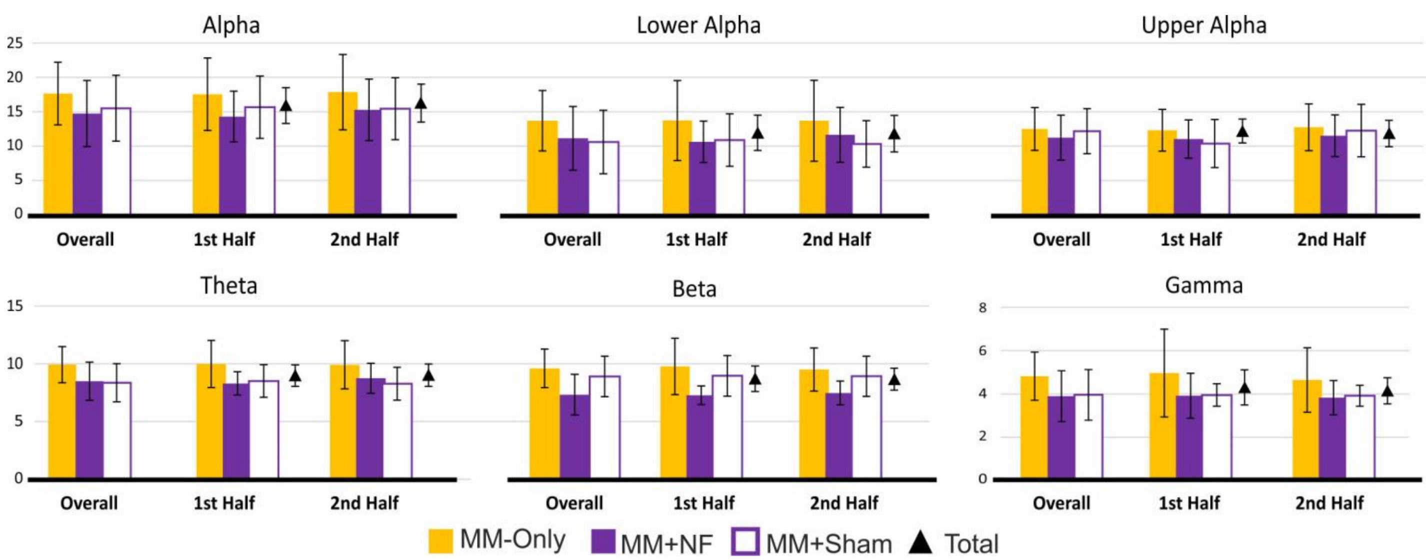


Note: Panel (A) shows the peak (highest amplitude) frequency bin within alpha band range (7-13 Hz) pre- and post-meditation training for each group for the combined resting state (eyes closed and eyes open) and alpha neurofeedback control test for midline electrodes averaged (Fz, Cz, Pz). Panel (B) shows the natural log transformed PT/BL ‘bird score’ from the alpha control task. BL refers to baseline session, PT post-training session. Means and 95% confidence intervals are shown. No interaction or main effects occurred that survived statistical correction for multiple comparisons in shown data.

Meditation Training EEG Recordings

EEG was recorded for each in-lab meditation session for all participants at midline electrode sites (Fz, Cz, Pz). Despite no resting state changes in EEG activity bands of interest the in-lab recordings offered insight into functional network changes as they might emerge across the brief training meditation program at the center of this study. Of particular interest was the NF-assisted training condition, as participants in this group specifically had NF guidance directly tied to their EEG to help them modulate their EEG signal (and related neural network activity) for their in-lab meditations. This data set was analyzed by averaging the half of meditation sessions in-lab (sessions 1 and 3) with the last half (sessions 5 and 7) for each group. The results of this analysis are presented graphically in Figure 19 and are described below with statistical values reported. EEG measures of interest were also directly compared between eyes-closed resting state at BL and the FA recordings made across training. The results of this analysis are summarized in Table 10.

Figure 19. *Results of EEG Measures during In-Lab Meditation Sessions*



Note. Means and 95% confidence intervals are shown. Units are µV as averaged across midline electrodes sites (Fz, Cz, Pz) for each frequency range. No interaction or main between-group or between testing session effects occurred with α = .05.

Table 10. *EEG Measures Pre-Training Eyes-Closed Rest versus Focused Attention Meditation*

Measure	Group	BL Rest	Total FA	*M* Dif.	Statistical Test Results					
Alpha (7-13Hz)	*MM-Only*	20.95	18.55	-2.40	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	17.51	14.77	-2.74	Interaction	2	24	.30	.744	.02
	MM+Sham	19.05	15.56	-3.49	Group	2	24	.63	.543	.05
	Total	**19.17**	**16.29**	**-2.88**	**State**	**1**	**24**	**24.13**	**.000**	**.50**
Lower Alpha (7-10Hz)	*MM-Only*	17.10	14.54	-2.55	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	14.27	11.17	-3.10	Interaction	2	24	.24	.791	.02
	MM+Sham	14.14	10.61	-3.53	Group	2	24	.63	0.539	.05
	Total	**15.17**	**12.11**	**-3.06**	**State**	**1**	**24**	**27.92**	**.000**	**.54**
Upper Alpha (10-13Hz)	*MM-Only*	13.85	13.01	-0.84	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	12.42	11.24	-1.17	Interaction	2	24	.26	.774	.02
	MM+Sham	14.13	12.22	-1.92	Group	2	24	.33	.720	.03
	Total	**13.47**	**12.16**	**-1.31**	**State**	**1**	**24**	**4.38**	**.047**	**.15**
Alpha Peak Frequency	*MM-Only*	14.07	9.48	-4.59	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	11.93	9.58	-2.35	Interaction	2	24	.48	.627	.04
	MM+Sham	12.44	9.80	-2.64	Group	2	24	.36	.704	.03
	Total	**12.81**	**9.62**	**-3.20**	**State**	**1**	**24**	**9.82**	**.005**	**.29**
Theta (3-7Hz)	*MM-Only*	10.41	9.97	-0.44	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	9.06	8.51	-0.55	Interaction	2	24	.04	.963	.00
	MM+Sham	8.89	8.37	-0.52	Group	2	24	.95	.400	.07
	Total	**9.45**	**8.95**	**-0.50**	**State**	**1**	**24**	**8.38**	**.008**	**.26**
Beta (14-30Hz)	*MM-Only*	11.09	10.12	-0.97	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	8.06	7.36	-0.69	Interaction	2	24	.14	.874	.01
	MM+Sham	10.02	8.95	-1.06	Group	2	24	2.69	.088	.18
	Total	**9.72**	**8.81**	**-0.91**	**State**	**1**	**24**	**9.07**	**.006**	**.27**
Gamma[1] (30-45Hz)	*MM-Only*	6.60	5.06	-1.54	*RM-ANOVA Effects*	*df1*	*df2*	*F*	*p*	η^2
	MM+NF	4.98	3.88	-1.10	Interaction	2	24	.14	.866	.01
	MM+Sham	5.50	3.94	-1.56	Group	2	24	.96	.396	.07
	Total	**5.69**	**4.29**	**-1.40**	**State**	**1**	**24**	**12.51**	**.002**	**.34**

Note. Sample sizes were MM-Only (n = 8), MM+NF (n = 9) and MM+Sham (n = 9). Mean amplitudes of midline (Fz, Cz, Pz) activity in μV are reported, except for Alpha Peak Frequency which reports mean frequency bin of highest μV activity within 7-13 Hz range at site Cz. Significant effects (p < .05) that survived Holm-Bonferroni correction for multiple comparisons are shown in bold. [1] Did not pass Levene's Test for Equality of Variances.

For midline alpha amplitude, there were no significant effects (Interaction, $F_{2,25} = 0.65$, $p = 0.532$; Group, $F_{2,25} = 0.43$, $p = 0.659$; Training Half, $F_{1,25} = 0.69$, $p = 0.413$). This was also the case for lower alpha (Interaction, $F_{2,25} = 1.76$, $p = 0.192$; Group, $F_{2,25} = 0.550$, $p = 0.584$; Training Half, $F_{1,25} = 0.17$, $p = 0.685$), upper alpha (Interaction, $F_{2,25} = 0.10$, $p = 0.905$; Group, $F_{2,25} = 0.163$, $p = 0.850$; Training Half,

$F_{1,25}$ = 1.03, p = 0.319), and Cz site alpha peak frequency (Interaction, $F_{2,25}$ = 0.99, p = 0.384; Group, $F_{2,25}$ = 0.363, p = 0.699; Training Half, $F_{1,25}$ = 0.00, p = 0.966). Regarding other measured EEG bands, no effects were found for theta (Interaction, $F_{2,25}$ = 1.95, p = 0.163; Group, $F_{2,25}$ = 1.19, p = 0.322; Training Half, $F_{1,25}$ = 0.10, p = 0.750), beta (Interaction, $F_{2,25}$ = 0.56, p = 0.577; Group, $F_{2,25}$ = 1.84, p = 0.180; Training Half, $F_{1,25}$ = 0.04, p = 0.850), or gamma (Interaction, $F_{2,25}$ = 0.11, p = 0.892; Group, $F_{2,25}$ = 0.83, p = 0.449; Training Half, $F_{1,25}$ = 0.32, p = 0.575). Amplitudes in all bands analyzed were significantly lower during FA meditation than compared to participants eyes closed BL resting state, as can be viewed in Table 10. A significant decrease in individual alpha peak frequency was found whereby peak frequency was downshifted from upper alpha range into lower alpha range during the FA meditation compared to eyes closed rest at BL. In summary, no reliable changes were detected within- or between-groups for alpha, theta, beta, or gamma activity ranges across first and second training halves or between groups when looking at FA recorded EEG. Compared to BL eyes closed rest, amplitudes were globally lower during FA, although an alpha peak frequency shift into lower alpha range was observed.

Discussion

The intention of this chapter was to evaluate the efficacy of a novel NF-MM integrated brief meditation training program compared to (FA) MM training without NF assistance, in a non-clinical sample of young/emerging adult beginner meditators. Second, it was to delineate the mechanistic interactivity of integrated NF into MM training, to generate a deeper of understanding of the potential impacts on experiences and outcomes of NF-assisted meditation training protocols. Chief among the hypotheses, was that the possibility *MM+NF* would demonstrate neural, cognitive-behavioural, or psychosocial mechanistic distinctions compared to the other training conditions. A summary of findings according to the psychological (i.e., self-report questionnaires/ratings), neurocognitive (i.e., cognitive-behavioural computer test), and neural (EEG) findings are provided followed by discussion of the overall pattern of results in terms of which hypotheses are supported. Strengths, limitations, and recommendations follow. In brief, the set of competing hypotheses were:

Hypothesis 1. *NF enhances MM training through neurocognitive mechanisms of change.* This hypothesis would be supported if *MM+NF* demonstrates significant post-training improvements on objective neural (EEG) and neurocognitive (cognitive-behavioural tasks) above the other groups, alongside self-reported improvements in functioning and wellbeing. These results would provide support that MM+NF acts specifically and efficaciously to enhance MM training.

Hypothesis 2. *NF enhances MM training through non-specific psychosocial mechanisms of change.* This hypothesis would be supported if *MM+NF* and *MM+Sham* conditions outperform *MM-Only* on subject report measures, in the absence of significant neural (EEG) or cognitive-behavioral task differences. These results would support the notion that NF's predominant influence is through expectancy or other psychosocial effects, as opposed to target neural or cognitive training effects.

Hypothesis 3. *NF interferes with MM training*. This hypothesis is supported if the *MM+NF* training results in worse post-testing gains on cognitive and behavioural measures than the *MM-Only* condition or show reduced benefits of training on self-report measures.

Hypothesis 4. *No Major NF Influence.* This hypothesis is supported if the addition of NF does not result in meaningful differences across mechanistic or outcome variables relative to *MM-Only*.

Self-Report Measures

Primary Psychological Outcomes Efficacy Measures

Essentially, all key psychological outcomes were achieved by all groups, equivalently. These included improved psychological well-being, improved mood, reduced stress, and decreased stress and tension over time. These effects were acquired over eight days of training and persisted when measured at follow-up ten days later, without participants continuing to meditate during this time period (by self-report). Many more immediate changes in improved calmness, relaxation, focus, and mood were also noted after each daily practice by participants. These results fall in line with the outcomes reported in other MM-based training programs supporting the notion that the training program, even with NF condition variations, was generally efficacious for enhancing the mental wellness of study participants. Although there was no no-training control group, stable test-retest reliabilities of these measures (Chapter 3) and common positive direction off all variables suggests against these improvements resulting from the passage of time alone. These benefits were also shown alongside side reported increased MM specific skills and traits. This included overall increased de-centering skill, improved sense of mastery and self-acceptance across training (as facets of wellbeing), as well as increases in self-reported mindfulness skills and attitudes outside of formal meditation sits.

Practically speaking, this is an appreciable foundation in terms of meaningful benefits gained across a relatively short period of training by procedures and protocols used in this study. They are also important in the context of an efficacy trial, insofar as meeting the condition of the ‘standard’ training or intervention (i.e., *MM-Only*) demonstrate ‘standard’ results (i.e., comparable to other research and theory predictions) to compare and interpret the other experimental conditions against. In this case, interestingly, at the broadest level of psychological outcomes, all groups appeared to report and perform equivalently well across outcome measures, suggesting equivalent efficacy and no clear mechanistic distinctions. However, this and many of the remaining findings must be tempered against the underpowered sample size of this study and questions of MM and NF ‘dose.’ These critical limitations are elaborated on later, but also extend across the other measurements and outcomes below.

Cognitive-Behavioural Self-Report Outcomes

Beyond the primary psychological outcomes, several cognitive-behavioural self-report measures related to MM training cognitive outcomes were included (e.g., constructs related to cognitive and emotional self-regulation; Chiesa, Calati, Serretti, 2011; Ospina et al., 2007). The pattern of these results included reductions in time spent mind wandering, improved attentional control (in focusing but shifting), and several facets of interoceptive awareness (self-regulation, body listening, noticing, attention regulation, not worrying, trusting, and emotional awareness). These areas showed significant improvement across training, absent of between-group differences or interactions. In particular, the finding of improved focus and reduced mind wandering is in line with expected outcomes training on a breath focused (FA) MM technique. Notably, executive functions were not endorsed as significantly changed after training. It may be the case that time spent in practice and training of open-monitoring (OM) techniques may be more associated with improved executive functioning skills than FA training *per se* (Whitfield et al., 2022; Dahl, Lutz & Davidson, 2015). Overall, results self-report measures are supportive of measurable changes in cognitive and emotional control skills associated with completion of the meditation training protocols (Farb et al, 2015; Moore & Malinowski, 2009). Another key finding is that integrating the real and sham NF protocols into training did not yield significantly better or worse outcomes on self-reported measures of cognitive and emotional regulation abilities, compared to training without these NF conditions.

Cognitive-Behavioural Test Results

Paralleling the self-report results, all groups were comparable in pre-to-post training differences across tasks on measures of accuracy, reaction time, and intraindividual variability of reaction times. There were no performance differences on the Go/No-Go task that was included as a measure of focused attention/vigilance and reaction inhibition. Participants in all groups performed at ceiling levels before and after training, suggesting the task may have been too easy as delivered, particularly for a healthy young adult demographic. Performance improvements after training were observed on the MSIT, a more difficult task that also taps into vigilance, concentration, and inhibition, as well as on the n-back distractor task, which additionally assesses working memory and distraction resiliency. For the MSIT and the n-Back distractor tasks, the overall pattern was for higher speed and accuracy after training, coupled with increased intraindividual variability in correct hit reaction speed. A reasonable interpretation of this is that participants improved their self-and/or task-monitoring as a result from training to the extent the increased ability to ‘catch errors’ before they were made for a small subset of trials resulting in slower reaction time to obtain an accurate response; thus, increasing overall IIV with overall speed and accuracy still increasing after training.

An alternative hypothesis is that these changes may have primarily been driven by task familiarity and practice effects. Some researchers have failed to find reliable changes in attention and executive function domains with neuropsychological testing after multi-week MM training programs with (Lao, Kissane, & Meadows, 2016). Certainly, task familiarity and practice effects cannot be ruled out given the absence of a no-training experimental condition. Practice effects are particularly unknown for the novel version of the distractor n-back task used here, which could be improved with psychometric and neuroimaging validation studies. However, working memory improvements have been on 2-back task accuracy found after engaging in even a single FA mediation practice (Ka, Deng, & Hommel, 2021) as well as after 8-week MM training programs (Basso et al., 2019) in non-experienced meditators compared with matched non-meditation control groups. Thus, the improvements in these tasks may reflect veritable meditation training induced enhancements in the prefrontal and parietal networks of attention and working memory, similar with Ziegler et al.’s (2019) findings of app-based meditation training in a young adult app-based meditators.

Electroencephalographic Findings

EEG recordings were made before, after, and throughout meditation training sessions to directly assess for neural network changes resulting from (FA) MM training. Overall, the results were surprisingly null across all bands of interest for the pre- and post-training resting state measurements as well as for the in-lab meditation session recording. The non-appearance of changed alpha activity was particularly unanticipated, given: i) that the NF protocol introduced specifically targeting alpha range activity (in line with the working hypotheses alpha activity was mechanistically relevant), ii) a substantial body of research has reliably reported increased alpha amplitude as a reliable marker of meditation proficiency (at rest and within practice; Cahn & Polich, 2006; Fell et al., 2010) and entering a state of relaxed focus in general (Olbrich et al., 2011). Thus, these null findings did not fit with expectations based on theory and empirical findings of increased alpha activity in MM or NF literature.

One explanation for the absence of notable EEG change is that the training truly did not lead to any substantially increased alpha activity at all; perhaps suggesting something unusual about the (FA) MM practice used in this study. Relative to eyes-closed baseline rest, broadband amplitudes were significantly lower on average during FA MM possibly suggesting more effort and less focus and calm. However, much of the self-report (e.g., increased ratings of calm and focus after meditation) and neurocognitive data (favoring attentional improvement) are in line with the premise that the (FA) MM training was designed and delivered as expected with respect to principles and practices and other outcomes associated with of MM training.

Another explanation is that the ‘dose’ of (FA) MM overall, and/or of the NF-integrated protocol for the *MM+NF* group, was insufficient to produce robust or reliable outcomes (Logemann et al., 2010). Numerous studies have shown increases in amplitudes even within single sessions concentrative meditation sessions in young adult new trainees comparable the present study’s participant sample (Chow, Javan, Ros, & Frewen, 2016; DeLosAngeles et al., 2016). That individual alpha peak frequencies shifted lower when participants were engaged in meditation when compared against non-meditative rest is in line with what has been observed in other studies with more advanced meditator samples during FA practices (Saggar et al. 2012), but here again, the MM+NF group was no different from the others. There was weak but favorable evidence in that the NF protocol showed some limited transfer of skill; with *MM+NF* outperforming the other groups in the alpha control neurofeedback task administered as well as showing increased lower-alpha amplitudes occurring during the post-training test relative to the other groups. These effects did not reach statistical significance but provide some support for the notion that the MM and NF protocols were not ineffectual as some of the EEG results might otherwise convey. These findings echo concerns discussed in Chapter Four, of EEG data challenges and quality, in part elated to inability to access raw recording data. Subsequently, an aggressive manual cleaning procedure was implemented, as opposed to a more fine-tuned approach.

Hypothesis Testing

Within the context of the present study's procedures, protocols, and sample, *Hypothesis Four* (no significant NF influence) was most strongly supported. Both NF-integrated training conditions (real and sham) appeared relatively benign on training experiences and outcomes compared to (FA) MM training without including NF experimental procedures. Training in all conditions yielded a highly similar pattern of positive training experience and beneficial outcomes. Thus, *Hypothesis Three* (NF interferes with MM training) was not strongly supported. *Hypothesis One* (NF enhances MM training through specific neurocognitive mechanisms of change) and *Hypothesis Two* (NF enhances MM training through non-specific psychosocial mechanisms of change) were also not strongly supported, insofar as the relative equivalency to the *MM-Only* group on primary psychological efficacy outcomes measures did not signify any major enhancement associated with NF integration by either putative NF mechanism. However, there is still slightly more that can be said about the data fit for each hypothesis.

With regards to *Hypothesis One*, EEG measures were largely null across training for all groups, and the cognitive-behavioural computerized test results and self-report changes across training were equivalent to *MM-Only* (and Sham). These findings do not offer much insight into any specific or general neural changes or mechanisms across the different training conditions as hoped for.

With regards to *Hypothesis Two*, participant ratings of daily meditation motivation, difficulty, and perceived skill could be appreciated as important psychosocial determinants of training behaviours and predict different outcomes over a longer training course. Looking across these data for subtler patterns of non-specific or psychosocial influences also did not turn over much support for this hypothesis. Daily motivation to meditate was comparable between groups, as well as across first and second training halves within groups. Thus, being informed that NF-assistance was available for in-lab meditation training, and use of the NF-integrated meditation protocol, did not appear to make a significant impact on motivational levels to maintain daily practice. Interest levels in meditating and satisfaction with meditation sessions also did not markedly change before or after training for groups. For session difficulty, groups averaged statistically more similar in the first half of training compared to the second; although not reaching statistical significance, the groups did begin to diverge, with *MM+NF* reporting sessions getting moderately easier, *MM-Only* mildly easier, and *MM+Sham* reporting slightly more difficulty in the second half. Falling short of statistical significance, caution is warranted in interpreting this pattern, though optimistically these findings suggest that the inclusion of the NF and related feedback (which was not high in the proportion of positive reinforcement cueing) was not a dissuading factor compared to the MM group who received no feedback at all. Self-efficacy of MM related skills and attitudes as deployed within meditation practicing, was higher for *MM+NF* and *MM+Sham* compared with *MM-Only* at session two, but by session eight all groups were equivalent (i.e., *MM-Only* "caught up" after a few days, though this may have been a regression to the mean). The overall direction of these differences (or lack thereof in many cases), suggest against major influence of psychosocial factors on training experiences and outcomes of the NF-integrated training groups. Of course, these interpretations are limited as indirect evidence. Future studies might seek to include direct measurements of expectancy of outcomes prior to different training conditions, and/or directly manipulate training expectations for conditions for stronger evaluations of *Hypothesis Two*.

Conclusion

Eight days of (FA)MM daily meditation training that came interleaved with a low range alpha (FA)MM-NF protocol resulted in comparable mental wellness and mechanistic outcome patterns to an equivalent sham-NF EEG training condition and (FA)MM training alone. At face-value, these results fit with speculations raised regarding the efficacy NF-based protocols and interventions as not reliably superior in outcomes compared to other established cognitive and mental health training systems that do not involve the same level of resource costs in many cases (Thibault, Lifshitz, Raz, 2016). There also did not appear to be robust or reliable markers of neural, neurocognitive, or psychosocial mechanisms differentiating the different training conditions based on the current sample, experimental design, or protocols developed and deployed in this study. The strengths and limitations are discussed in the final chapter, alongside recommendations gleaned from the running of this feasibility and efficacy trial.

CHAPTER SIX

Final Discussion

The primary aims of this dissertation were to evaluate the feasibility and efficacy of a brief course of focused attention (FA) mindfulness meditation (MM) with a low alpha neurofeedback (NF) protocol integrated to assist with training, in a non-clinical sample of young/emerging adult beginner meditators. Additionally, the purpose of the dissertation, therefrom, was to delineate the mechanistic interactivity of integrated NF into MM training, to generate a deeper understanding of the potential impacts on experiences and outcomes of NF-assisted meditation training protocols. This is an important topic to critically investigate from basic, applied, as well as translational science perspectives. There are already clinical and commercial applications leveraging the potential compatibility to enhance meditation training and outcomes. However, there is limited strong theoretical and empirical literature pointing to the robustness of NF-assisted meditation training, or the underlying additive or interactive neural, cognitive, or behavioural mechanisms that might incrementally lead to training benefits.

At the most applied level, understanding the extent to which NF-assisted training could be beneficial could be understood as a matter of informed consumerism, given the added costs (both from a resource and accessibility standpoint) associated with NF equipment, applications, and software. From a basic science perspective, using an interactivity lens and experimental approach may help inform which neural, cognitive, or behavioural mechanisms and pathways are fundamental for providing optimal mental health and wellness training outcomes in a way that provides insight into both MM and NF practices independently as well as in operation together. If core mechanisms could be clearly delineated, the potential for significant steps forward for optimizing mental training and wellness protocols and systems, heightening the accessibility or effectiveness of associated health and wellness outcomes.

Conceivably, within the steps following a basic proof-of-concept demonstration such as was achieved here, is the possibility for translating research aims and protocols towards targeted clinical populations who might seek to benefit the most from effective individually tailored interventions capable of tapping into neural, cognitive, and behavioural pathways of therapeutic change.

A major component of this dissertation was the development and feasibility testing of MM NF integrated training with the use of a novel FA (MM) EEG-NF protocol. The protocols developed and the measures chosen were based on a review of theoretical and empirical findings. Specifically, increased alpha power, and in some cases lower alpha frequency in particular, have been linked with deeper meditation states in both novices and expert meditators. Alpha band activity has also been associated with attentional processes more generally. These relationships were extensively reviewed in the introductory chapters, with enough empirical and theoretical evidence gathered to suggest that alpha (and low alpha) may serve a mechanistic role in bridging state and trait neural and cognitive changes; and thus, would constitute an effective phenomenon to target and attempt to upregulate during meditation practices. Thus, the feasibility element of the study was extended beyond training procedure tolerance, acceptability, and MM fidelity, and set up to also more closely attempt to examine mechanistic interactivity in order to improve our understanding of how outcomes might differ (for better or worse) with the incorporation of NF. Potential cognitive, behavioural, or socioemotional factors that might differ according to the different NF conditions over the course of (FA) MM training were accounted for by the study design and chosen measures.

A conditional set of competing theoretical outcomes and hypotheses were set *a priori* based on interpretive frameworks, to help understand the consequences and implications of training with NF assistance in regular meditation versus conventional (i.e., no NF) practice. Feasibility and program evaluation analyses indicated that at the broadest level, the overall training protocols and study design were well-tolerated by participants and were generally successful in leading towards expected changes in line with increased state and trait MM abilities. As discussed in the previous chapter, with the current sample, all groups were highly comparable, with several mental health and cognitive performance indicators improving across training irrespective of condition, which suggested that, within the context of this study, the incorporation of NF into regular (FA) MM had a relatively benign effect on training and outcomes. It was not clearly offering significant incremental benefits, but nor was it apparently deleterious, in veritable or sham form. Unfortunately, given the comparability of results, including the overarching null EEG results, mechanistic understandings were not made clear as was desired in this dissertation's conception.

Though this study was large and comprehensive in some respects, it is but a small part in larger efforts required to uncover the MM-based mechanisms or outcomes that are most amendable to enhancement with NF-assistance incorporated into regular meditation practice.

However, taken together, the results support the feasibility of the study design, success of the manipulation, and acceptability of the training procedures, which are all useful findings for basic and applied scientific efforts with shared goals. Although it fell short in of one of its primary aims; clear mechanistic understanding of interactivity, it was successful as a proof-of-concept study, as a smaller-scale pilot and feasibility study that none-the-less contributes novel insight and knowledge into the interesting cross-section of MM and NF science. Methodological strengths and key contributions are summarily discussed, along with limitations, and recommendations learned from the development and execution of this study.

Study Strengths and Contributions

Study Design

To the author's knowledge, there are no research studies that have examined the interactivity of MM with NF in a brief longitudinal randomized controlled study such as this. Like all research designs, there were strength and limitations and trade-offs that had to be made, and the design choice to alternate MM+NF/Sham with MM home practice was no different. This study integrated many of the recommendations made by other prominent researchers in the NF and MM fields, including the use of multiple control groups, thorough description of the NF and MM resources procedures, and multimethod multi-measurement approach (Davidson & Kaszniak, 2015; Ros et al., 2020). The inclusion of a sham-condition was in line with collective calls for improving the quality of NF research efforts by including a non-mechanistically specific but matched control group for efficacy evaluation (Ros et al., 2020). A pure between-independent group comparison design is an established gold standard approach for evaluating efficacy (Kazdin, 2021). However, these designs are not always optimal at capturing the mechanistic interactivity that might be driving differential group outcomes underlying efficacy outcome differences, particularly for interventions that have multiple active components.

Designing the study with ABAB (x2) methodology within NF conditions was a way to enhance the delineation of mechanistic interactions and outcome trajectories, from both within-person and between-condition factorial approaches within the context of the broader efficacy evaluation (Kazdin, 2021). In this sense, though underpowered, it was a powerful design. It was also the best way to efficiently deploy limited study resources to achieve study aims while still considering the theoretical amounts of training required to begin showing neural, cognitive, and behavioural changes. Practically speaking, that there was only one NF device in the lab to run the real and sham training sessions with, and at least several days of training believed to induce measurable functional changes, this design was also the most feasible approach to use given these circumstances. Additionally, this design offered an ecological edge that a pure NF versus MM training design would not be able to offer. It is likely that people will not seek to meditate solely or exclusively with NF-assistance, be it by intention or by virtue of not having the equipment on hand every desired practice time. Novices are likely to have some blending of NF-assisted meditation with alone (or group) practice. Although controlled in its alternation of home practice and in-lab NF-assisted practice, the present study offers insight into how experiences and outcomes may differ (or not) when NF-assistance is brought into training as an intermittent, not entirely as a dependent MM training aid.

Training Dose for Meaningful Outcomes

Across eight days of alternated no-NF and NF-assisted training, relative to conventional guided (FA) MM practicing, no significant differences were found in key experiential areas (e.g., difficulty, motivation, focus, relaxation, etc.) or in primary outcome measures (e.g., mind wandering, focus, mood, wellbeing) with all significant effects in these areas in the direction of benefits and enhancements. Thus, although mechanistically unclear (with regards to the role of NF), there is a core contribution to be made here in terms of the 'dosage' required to obtain measurable and meaningful outcomes from MM practices. Specifically, for regular (FA) MM practice, as this constitutes the bulk of training practice in this sample, with and without the incorporation of NF. It cannot be said that the incorporation of the NF protocol (and sham) had no effect on training outcomes that might have been otherwise detected with a larger sample size or larger 'doses' of training, but the pattern of results seems to indicate that the MM training factors seemed to drive the effects for all groups, given the high similarity in outcomes and comparability to other studies training young adult novice meditators (e.g., Chow et al., 2016; Tang, Askari & Choi, 2020). This suggests that the training dose of (FA) MM with or without true and sham NF additions (total time in meditation was approximately 2 hours and 40 minutes), was sufficient enough to induce neural plasticity in cognitive-affective self-regulation networks as others predict MM-based training to accomplish even in earliest stages of routine practice (Allen et al., 2012; Cahn & Polich, 2006).

Enduring Outcome Effects

An additional and related strength was the inclusion of follow-up testing. Lasting mood improvements, reduced mind wandering, and increased interoceptive awareness were among the psychological effects that endured after a period of tens days without practice after participants completed their training (albeit the abstinence of meditation in this period as requested was evaluated solely by self-report). Attentional control, de-centering skill, and psychological wellbeing effects were also statistically trending (insofar as not surviving correction for multiple comparisons) and may have emerged with more robustness or greater reliability in a larger sample. Taken together, these data contribute to overarching questions of ‘dosage’ (i.e., how much training is required to reliably show immediate and enduring neural, cognitive, behavioural, or wellness changes), a topic that is of a major scientific in the field of contemplative neuroscience (Levi et al., 2021; Bowles, Davies, & VanDam, 2022). These results reinforce the postulation that even brief regular training can result in positive cognitive and behavioural outcomes, particularly in self-reports, and perhaps also in functional or structural neural effects that were not detected in this study but underlie the self-reported areas of enhancement.

Mindfully Integrated NF

The (FA)MM+NF protocol that was developed and implemented in this study took care to not sacrifice MM instructions to achieve a highly integrated MM+NF training experience truly centered in MM practice. It was important to the author to have participants approach the incorporation of the NF in a way that still involved the application and mindset of overarching principles and attitudes of mindfulness that are brought into all MM techniques (e.g., non-judgment, patience, curiosity, trust, non-striving, acceptance, letting go). This was achieved using specific instructions and reminders of how to attend to the neurofeedback in a mindful way, more generally supported by the MM instructions and practices resources all participants were regularly in contact with throughout training. This is an important feature distinguishing this study from other NF-based meditation protocols and applications, as it is not always clear to what degree NF-regulation is being trained and practiced versus core MM practice in other deployments of NF-MM protocols (e.g., Antle et al., 2018; Bhayee et al., 2016).

It appears that neither the real or sham protocol interfered with or disrupted the acquisition of key MM training experiences, skills, or outcomes, which comes as a useful finding. First, it provides support for the feasibility and utility of including sham-NF based controls as recommended by others (Ros et al., 2020; Thibault & Raz, 2017; but *c.f.*, Pigott, Cannon, & Trullinger, 2021). With regards to NF specifically, this seems to suggest against NF significantly undermining any core aspects of MM skills, traits, or self-efficacy in these domains, at least across a brief course of training. The MM training shared by participants also may have served as a protective factor in motivation and self-efficacy (e.g., non-judgmental, accepting, compassionate attitudinal stances), given that the positive feedback cues were relatively sparse for many *MM+NF* (and equally *MM+Sham*) participants across training. These interpretations are, of course, closely coupled with the specific sample and protocols used here, and require replication with broader sample sizes, protocols, or experimental designs for improved confidence and generalization.

Practice Setting

The strongest factor predicting experiential differences was linked to setting and not assigned experimental training condition. Having to go into the lab for meditation sessions affected self-reported motivation more than the inclusion of NF setup and protocols. The in-lab setting was also associated with less external environmental distractibility, despite EEG equipment hooked up to participants heads each time. There may be distinctly separate reasons shared across training groups underlying these effects. Underlying this might be higher motivational ratings occurring out of cognitive dissonance coping (e.g., investing the time and effort to get to the lab, affecting motivational ratings), higher demand characteristics (social expectations), or general enjoyment of the in-lab components or settings. The lab space was also a well controlled, quiet, and (protocols aside) distraction free environment. Home practice spaces for individuals may not offer this level of protected, quiet dedicated space and time for practicing. Thus, having a quiet a place to go to, outside of home, and with some level of social reinforcement seem to have had a stronger influence on training experiences, much more so than any positive (e.g., helpful feedback, expectancy effects) or negative (e.g., hassle, extra task/information) factors that might be associated with the integration of EEG/NF technology into training. This is another interesting finding yielded by the experimental design of interleaved measurements of home versus in-lab experiences.

Multimethod Measurement Approach

Another strength of this study lies in the use of a comprehensive multimodal measurement approach. Such an approach is necessary to effectively uncover training effects most effectively on different levels of mechanisms and outcomes, as neural and psychological processes are entwined. The pathways, time courses, and directional interplay between different levels of brain-behavioural systems and psychological constructs hold the key to a deeper scientific understanding and more effective scientific developments and applications. Future studies with these aims should also consider this approach, particularly as the gap between the neural and phenomenological experiences are of interest in the field of contemplative science. The incorporation of phenomenological interviewing within a multimodal measurement approach may be essential for understanding how different NF-protocols influence different meditation techniques at individual and group levels. This information may accelerate the understanding and development of highly effective or specialized MM+NF protocols.

Component Focus

Another challenge of studying MM programs in non-clinical and clinical contexts is that many are multi-week and multi-component in technique training and practicing (e.g., IMBT, Tang et al., 2007; MBSR, Kabat Zinn, 1990; MBCT, Segal, Williams, & Teasdale, 2012; Chiesa & Serretti, 2009). From an efficacy perspective, the entourage effect of all componential techniques and information may be first and foremost of interest. However, these programs can be hard to study mechanistically, as it is difficult to effectively disentangle which components are primary drivers of change and with respect to which outcomes (e.g., specific versus general cognitive regulation, different facets of well-being, etc.). This study focused on one of the foundational techniques learned earliest in many standardized MM training programs, breath-focused awareness. An interesting finding on this background were the reports of improved sustained attention abilities with little to no effect on shifting or executive functions; with these results coinciding with improved mood, wellbeing, and emotional regulation reports across training. Notably, set-shifting was not directly assessed with objective testing, nor were more many other areas of executive functions. Despite this, the self-report pattern tends to be in line with what other researchers have suggested in terms of different skills training resulting in distinct ability development, insofar as some of the higher order/more complex cognitive and emotional regulation traits may be developed by more advanced training with open-monitoring or loving-kindness and compassion-based techniques (Fredrickson et al., 2017). The results also show that measurable levels of emotional regulation benefits can be acquired with the focused attention technique, which is promising, should individuals believe that they must otherwise commit or complete multi-week training to begin to see or feel positive effects.

Limitations and Further Recommendations

A main finding was that several mental health and cognitive performance indicators improved across training irrespective of condition. There are two major overarching limitations in interpreting these findings. Namely, the challenge of an underpowered final sample size relative to the study design, and the absence of a non-active (i.e., no training) control group. Although broadly commensurate with other published neuroimaging work and in considering this a pilot trial, the sample size of the current study is small, which affected the statistical power for detecting interactive effects. This is compounded by the interleaved nature of training, whereby the dose of FA-NF was not as large as that of the overall MM training dose. Hence, the vast majority of significant findings were for across-time main effects, that leveraged the total sample size (n = 28 in most cases); ultimately capturing the total MM effects common between groups but lacking the statistical power to detect medium to small interactive effect sizes that might otherwise reveal important mechanistic processes or outcome trajectories between conditions over the training period.

The initial power calculations conducted prior to the start of the study suggested group samples sizes in the 20-30 range across most key outcome variables and across testing modalities for detecting medium-to-small range effects sizes for interactions. Replication with planned sample sizes of this magnitude or using designs that involve higher doses or longer training courses may yield different patterns of mechanistic and outcome that the current sample size was not sensitive enough to detect. However, based on the feedback received from the participants, longer training in terms of session length or length of training in days, may result in demands that are not so well tolerated as they were in this study. Increasing the ratio of NF within the session or having optimized the feedback parameters and protocols of the NF may be the best way forward.

The other limitation for interpreting the across training findings, is the absence of an equal time interval no-training control group. Within the context of this study, there is no direct way to account for the contribution of practice effects or time/maturity effects in the levels of cognitive, behavioural, and psychological benefits reported by participants across the study timeframe. However, though this limitation stands, the outcomes reported here were highly comparable in size and direction to the cognitive, behavioural, and mental health outcomes reported in other research studies in comparable samples of young adult novice meditators with other active and non-active control groups to compare to across time (Chow et al., 2016; Tang, Ma, Wang, & Posner, 2007; Sedlmeier et al., 2012). This provides a reasonable degree of support that data reflect bonified MM-specific improvements in attentional control and self-regulation; as does the finding enhancements in of trait and skill specifically tied to MM principles and practices (e.g., de-centering, interoceptive awareness, self-efficacy of mindfulness abilities).

Sample Characteristics and Generalizability

Another limitation of the current study pertains to characteristics of the sample. It is not possible to strongly draw conclusions that the experiences and outcomes reported here would be the same if ran on sample of individuals with different social, demographic, clinical, or neural characteristics not represented in the current sample. This study included only young adults, in the broadest age range set of what has been referred to as 'emerging adulthood'. This is considered a neurodevelopmental stage characterized by the final phases of major structural and functional maturation of frontal lobe networks (Reifman & Niehuis, 2023; Taber-Thomas & Pérez-Edgar, 2014). This population was chosen balancing high recruitment availability in the research setting, and well as the theoretical and practical neuroscientifically-based consideration that they may constitute a group particularly responsive to brief attentional/frontal self-regulation. Although some demographic diversity was present, including a mix of student and community recruited participants, and some racial-ethnic diversity, most of the sample were white, well-educated, and many currently in post-secondary study and all spoke English as a first language. Whether similar results might be reasonably expected for individuals or groups with substantially different sociodemographic or neurodevelopmental characteristics, such as to children, teens, or older adults, or from different socioeconomical or cultural or linguistic backgrounds, remains to be confirmed or disconfirmed with studies with larger representative samples.

This study was also not a clinical trial. Although it may potentially serve as proof-of-concept translatable to clinically trials, it is beyond the scope of the current study to make draw conclusions about how individuals with clinical diagnoses or characteristics might experience or benefit from the procedures and protocols involved in this study. It was the hope that a larger degree of mechanistic understanding might have been gleaned from this study, as this information is highly informative for mapping intervention components to symptomologies in clinical trials. Conceivably, as more understanding develops into whether or not, and which, neural, cognitive or behavioural facets are most affected by NF-integrated MM training, clinical applications can be further explored. Clinical populations of interest as this work continues may include disorders with increasingly well-characterized structural and functional network differences linked to cognitive and/or emotional self-regulation difficulties (e.g., ADHD, PTSD; Albert et al., 2017; Kluetsch et al., 2014).

Limitations are also related to the pre-existing levels of familiarity and training in meditation. All participants were familiar with the general concept of meditation as a form of mental training but were otherwise new to MM training and had no substantial training in secular or traditional forms of meditation. Thus, they may not have been completely naïve to the concept of meditation, and probably all came in with some preconceptions and expectations of the process and outcomes. However, in terms of proficiency and skill, all can be considered beginner novices with respect to MM and meditation training in general. Ecologically speaking, a core target audience for commercial technology-assisted meditation training programs and apps are people in the early explorative phase seeking mental wellness or optimization methods (i.e., novices/beginners willing to spend money to achieve the best experience or outcome in their efforts); so in this sense the sample captures that important characteristic and associated experiences. This sample also had some limitations related self-selection bias. Those who responded to study recruitment came in with moderate to very high interest in receiving meditation training, and thus, they were much likely more intrinsically motivated to start and maintain practicing than a randomly drawn community sample. These were favorable ecological characteristics for the purposes of this study, but generalization cannot be made with regards to individuals or groups greatly differing from the sample in these aspects.

Neurocognitively speaking, it was also important to have participants who had not yet begun to acquire neural and cognitive functional changes associated with long-term meditation practice in MM-based training, or similarly, other forms of contemplative training. Thus, baseline levels of understanding and meditation practice effects would be equivalently low between groups, and also potentially maximize the measurable changes in early learning curve of skill and benefit acquisition (Bowles, Davies, Van Dam, 2022). Whether individuals with different levels of contemplative training or training backgrounds (e.g., traditional background) would show the same pattern of results, is not clear. It is likely there would be significant differences in both outcome responsiveness and subject experiential levels. Future studies recruiting more experienced meditator samples (e.g., intermediate or expert samples) would potentially yield uniquely valuable information, particularly in terms of the feedback and suggestions they might offer in terms of how NF might be contextualized, harnessed, and integrated into various training approaches or techniques and with respect to different phases of long-term training (Eberth & Sedlmeier, 2012; Bowles, Davies, Van Dam, 2022).

Methodological

Finally, there are some limitations and caveats pertaining to EEG methodological challenges and analyses specific to this study. As alluded to in earlier chapters, an unexpected problem arose pertaining to EEG data and its downstream quality of use. In brief, the software and technology were new to the lab and much different from the standard equipment and software used across the author's training in several other EEG labs (in programming, data management, hardware-software interactivity). During the pre-piloting phase of development and analysis, the export settings were set to 1-second epochs, deemed sufficient for pre-piloting analysis (and likely the eventual epoch size to segment and analyze in the full study). An export text was automatically made after each recording according to this and other smoothing parameters for pre-elected measures of interest, as well as a software specific playback file (.bxs). Re-importing the .bxs file results in the ability to flexibly visualize the data using various spectral visualization tools including down to the native raw acquisition parameters (e.g., 125 samples per second). This led to an erroneous assumption that the raw EEG data file would be accessible in the same forms that fed the high-resolution visualization and analyses tools. However, this was not the case, and the 1-second mean computed data for each site (Fz, Cz, Pz, LO1) and variable of interest in text (.txt) format were the only data available for subsequent analysis and cleaning[4]. All EEG files were manually screened and cleaned as outlined in Chapter 3 and Appendix E, in a blinded fashion. However, relative to other automated and semi-automated methods the author has used in previous EEG-involved research for cleaning and analysis (e.g., Fang et al., 2016; Sergeeva et al., 2017; Tarrant, Viczko, & Cope, 2018; Viczko et al., 2018; Viczko, Tarrant, & Jackson, 2021), the data quality in the current appeared reduced by this limitation and approach. Overcleaning and resultant data loss appeared to fit as one potential explanation for the weak or absent EEG findings. Thus, although the data that remained was valid, it was likely not in maximal quality of form to help address the efficacy and mechanistic questions as best as otherwise possible, and particularly so given additional limitations discussed (e.g., already low power due to small sample size; then data loss on top). The recommendation attached to this might simply be a

[4] *Note:* The author has reached out to the software developer support team for data recovery options. There are some highly sophisticated and time-consuming approaches that are being explored, but full data recovery and re-analyses were not made achievable in a reasonable timeline with respect to completion of the authors doctoral degree, and the data quality was minimally sufficient for the intents and purposes of this dissertation.

matter of being more aware to double-check assumptions and to run a pre-piloting of all cleaning and analyses prior to launching; a good recommendation for all researchers conducting all types of research, generally. However, there are a few more specific recommendations that emerged from other limitations in this study.

A novel FA (MM)+NF protocol was designed and piloted for this project. As is the case for most first attempts, the strengths, challenges, and limitations inherent in its realization may offer guidance for others who might plan to replicate or expand on this body of work or similar research endeavours. Some final considerations and suggestions are provided below.

EEG Setup. The sparse montage used in this study for the in-lab meditation sessions was well tolerated by participants and the research team alike, as these sessions were intended to be as fast and minimalist at possible. Ideally, more artifact detection channels would have been helpful for online artifact flagging during the NF protocols as well as offline for assisting with data cleaning. An increased montage is certainly recommended for pre/post training measurements, as it allows for more sensitive and sophisticated cleaning and analysis procedures. However, specifically for making repeated in-lab meditation recording with and without NF, longer (and messier, e.g., headcap) set-ups would have significantly increased participation burden in ways that might increase dropout rates or create other psychosocial confounds (e.g., motivation, distraction). One option to help address these challenges might be to employ one of the (research-validated) wearable EEG-NF device already commercially or clinically widely in use. This dually might serve to increase the ecological validity and generalizability of results, as many individuals are not likely to train with conventional laboratory equipment. However, the caution would be to find one that has the programming and data accessibility requirements needed to achieve some of the considerations and recommendations above. User-friendliness and proprietary software can also be barriers for experimental customization, as well as data transparency and ownership.

EEG Tasks. As noted, a denser montage might be particularly recommended for the pre/post EEG outcomes involved in a study rather than as repeatedly deployed across the course of even a brief course of meditation training. It also opens us the opportunity to bootstrap EEG-event-related potential (ERP) methods into existing neurocognitive test batteries, which often are indirectly attempting to reveal changes in the neural networks via behavioural level effects. Thus, even if behavioural performance differences are not detected over the course of brief training periods, network neural markers of changes preceding more overt eventual cognitive and behavioural changes may reveal themselves. Such data is very valuable in deciphering the neurocognitive mechanisms and timelines of change associated with MM training with and without NF protocols involved, and an added benefit is that ERP science is a large and well-developed field for helping design and interpret findings against in meditator and non-meditator populations on tasks like the Stroop, MSIT, and n-back variations.

NF Protocol Parameters. The decision to focus on lower alpha range activity (7-10 Hz) as opposed to broadband alpha (7-13 Hz) was based on the notable findings from Rodriguez-Larios and Alaerts (2020) study. Notably, they used a 22-electrode EEG montage which allowed more sophisticated analyses and an experience sampling paradigm during a single test session of guided meditation using an experience sampling paradigm to characterize low alpha (and upper theta) relationships across FA MM, mind wandering, and mental arithmetic activities. However, focusing exclusively on this subset of alpha for the NF-MM protocol may have been too constraining practically speaking. Although the sub-banding of alpha in upper and lower distinctions may reflect meaningfully distinct neurocognitive processes as some have suggested (Klimesch, 2012; Klimesh et al., 2007), the exact cutoffs are somewhat arbitrary and are not likely to pay respect functional and structural individualities affecting alpha activity characteristics (including frequency and power distributions across the scalp). From the authors perspective, in hindsight, having the NF window operating on full spectrum alpha range amplitude (7-13 Hz) would have been a better approach to optimized the availability and utility of NF cues for participants, perhaps leading to stronger enhancements in user experiences and outcomes that were descriptively or trending in emergence in the current study. Lower alpha, however robust or specific it may be in marking different meditation related states and processes, would still be captured and operational in a full alpha range upregulating NF protocol. It would also avoid the downside of limiting useful meditation feedback signals beyond an arbitrary alpha cutoff that may not be individually calibrated. In this sense, a shaping approach built into protocols may be useful, whereby the NF is slowly restricted from full alpha range towards a smaller target range (e.g., lower alpha) over time, based on individual EEG characteristics and relatedly, levels of performance feedback being achieved within and across sessions (Frederick, 2016; Sherlin et al., 2011). As it currently stands, more research is needed to better understand lower alpha’s association with various forms mental activity, including in meditation training, as well as its amenability for targeted change with NF protocols.

Concluding Remarks

How introduction of technology like NF into meditation training ultimately affects the brain-behaviour relationship leading to improved cognitive and emotional self-regulation abilities and outcomes characteristic of MM training much further investigation. The comprehensive collection of results, strengths, limitations, and recommendations that were born out of this dissertation project bode well for future research efforts aimed at generating a deeper understanding of neurofeedback and meditation compatibility for improved mental health and wellness outcomes. Other more covert areas of influence also remain largely unexplored, such as how the integration of NF and related technologies interplay with their own and embedded cultural factors, including Western and Eastern tenets, philosophies, and understandings woven into the fabric of each mental training approach. The explosion of accessible technology that allows everyday person to monitor and act on previously hidden mental-physiological phenomena holds exciting promises for helping improve the lives of health of many people. However, as we continue to build our understanding and invent new application for these tools, amid all the fervor and fast-paced marketing, development, and research, a final recommendation is that we collectively undertake this great endeavour in a scientific and mindful way.

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Appendix A: Meditation Training Scripts and Information

This appendix contains the following:

1. Meditation recording transcript.
2. Instructions for MM+NF and MM+Sham participants before each in-lab meditation
3. Background mindfulness meditation educational information.[1]
4. Troubleshooting information and recommendations for meditation practice.[1]

[1]These appendix sections contain the information as presented to participants on the Brightspace platform designed to orient participants to the study, access home MM recordings and daily post-meditation experience links, and access support resources for training and participation.

Appendix A.1 - Meditation Recording Transcript

The recorded meditation instructions were the same for all participants. The only difference in delivery is that the *MM+NF* and *MM+Sham* groups were provided additional instructions immediately prior to their in-lab meditation (A.2). Meditation transcript:

> *[00:00] Please begin by finding a comfortable position, seated in a chair or a cushion on the floor. Keep your head and back upright but not strained, hands resting wherever they are comfortable, face up or down on your lap.*
>
> *Notice the temperature and pressure of your body where it is contacting surfaces, making adjustments to support a comfortable and supported meditation posture.*
>
> *As we begin, please gently close your eyes. Let your facial muscles around your forehead eyes and jaw relax and soften, lips slightly parted, tongue lightly on the roof of your mouth or wherever it's comfortable.*
>
> *Begin to scan your attention from the very top of your head down to neck, shoulders, your arms and hands, down your chest, back, legs, knees, right down to your feet and toes. Noticing and feeling if there are any places that feel tense or tight.*
>
> *Take a deep slow breath into your nose, and exhale through the mouth giving permission to allow these areas to soften and let go is we do so. Let's do this for four more breaths as we settle into our bodies. Inhale letting ourselves notice where the tension may be and what it is like. Feeling it at the top of the breath for just a moment and then on the exhale letting go, softening and relaxing.*
>
> *As we do this, make sure you are still keeping an upright posture without slouching or straining, but relaxing everything else that we do not really need in our body in mind right now. Just letting things soften and fall away as we breathe.*
>
> [03:15] *I invite you now to fall into natural breathing rhythm, just observing without attempting to control it. Begin to focus your attention on the sensations of breathing at one point on the nose. This could be the very tip or the edge of the nostrils, another place where you are able to feel and track subtle changes in the temperature and flow of your breath.*
>
> *For the next little while, we will try to connect with how each breath feels in this specific area. The texture, changes in temperature, resistance and speed of the air, refining and concentrating our attention to each passing moment sensation. Our awareness and attention narrowing, like light beams through a magnifying glass.* [04:05]
>
> [FA Block 1 Recording / NF: 90 seconds]
>
> [05:35] *As you do this, you may become aware that your mind has wandered and it is no longer present on the breath, or perhaps has become distracted by other internal or external sensations unrelated to tracking your breath. This is natural, and in many ways the purpose. To learn to be observant of how your mind works, how it might try to push pull or wander in content and process. A second part of this process is to learn to kindly patiently and non-judgmentally guide back; like you would guide a puppy first learning to walk with a leash. Not yanking, gently guiding and re-guiding back.* [06:10]

[FA Block 2 Recording / NF: 115 seconds]

[08:05] *Try to stay as close to your breath moment-by-moment as you can, but in a relaxed and non-striving way. Being open, curious, connected, and present with it.* [08:20]

[FA Block 3 Recording / NF: 115 seconds]

[10:15] *If you catch yourself distracted, simply make a short mental note of it with a label like sound or thinking and return to focusing on the sensations of your breathing at your nose. Each breath a new breath a new moment to start again from.* [10:40]

[FA Block 4 Recording / NF: 80 seconds]

[14:40] *When you catch yourself lost in thought or feeling restless with how difficult trying to stay focused and present can be, see if you can be kind to yourself in this process. Acknowledge of this is okay. Giving yourself space, compassion, and encouragement as you might do for a loved one. It may also help to take a pause and do one or two breaths like we started with. Noticing your whole body seated here on the in breath and permitting or inviting yourself to relax deeper. Softening and falling through mental and physical barriers, tension… letting it all ride out on the exhale before gently returning with renewed intention to track sensations of your breath at the nose.* [12:50]

[FA Block 5 Recording / NF: 110 seconds]

[14:40] *Keep observing your breaths, allow it is natural air and flow. Over the next several breaths, begin to progressively include more awareness of the area's it touches and influences. Observing how everything influences our whole body in mind, beginning to user attention and awareness like a floodlight rather than a spotlight. From the nose tip to begin to trace how it feels, entering and exiting into the nose edges, into the nose… then down throat airway, into the lungs… following the cycling and sensations deeper, until you can feel your breath expanding and contracting in the lower belly.* [15:15]

[FA Block 6 Recording / NF: 60 seconds]

[16:15] *Now we are going to use our imagination to picture our incoming breath like it's nourishing light. Glowing extending and expanding from lower belly out with each inhale and exhale. Progressively expanding our attention and awareness of its reach, farther with each breath, ballooning to incorporate the pelvis, torso, chest, knees and elbows; and right down to our toes and fingertips all the way to the very top of our head. Feeling our breath influence and occupy our whole space.* [17:00]

[17:40] *For the last couple minutes, let go of any technique or goal or focus… and just be here. Open to each moment with each new rise and fall of sensation or perception in our internal or external environment. Taking it all in without fixing or anything, letting things arrive and pass they do, simply quietly being.* [18:10]

[18:35] *As this meditation comes to a close, I invite you notice your physiological or physical state. Don't seek out anything just notice in a holistic sense. Notice your state of mind in the same way.*

When you are ready, gently open your eyes and other senses to the world, not sorting or labeling or focusing on anything in particular. Just letting all things be in your awareness, perfectly fine as they are, and just you are. Perfect and whole: in just being.

Take a final moment to recognize and congratulate yourself for taking the time to prioritize being with yourself as a practice. May it help you find a better sense of ease and well-being today, and help you to become more present, mindful, and engaged in all aspects of your daily life. [19:49]

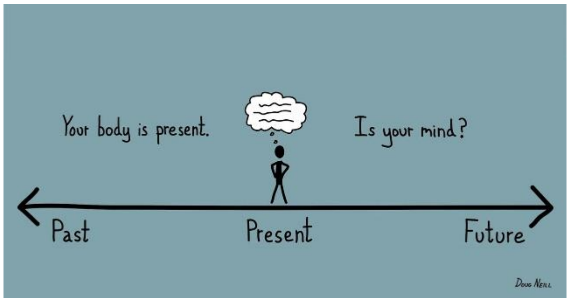
Appendix A.2 - Instructions for *MM+NF* and *MM+Sham* participants before each in-lab meditation

During some stretches in the middle sections of the meditation, you will have the addition of EEG neurofeedback come on in the background to help support you. As you continue to meditate according to the meditation instructions, I invite you to be peripherally aware of its guiding sounds when they turn on. The sound of rolling waves suggesting you may have fallen out of a relaxed and focused mindset, perhaps reflecting mind wandering or mental or physiological tension. Gently note and see if there are mental or physical things to let go of, while returning to be with the breath if you find you are getting lots of this feedback. In contrast, there will also be the sound of a singing bowl, with the volume of it tied to when your mind has continuously held a calm, gentle, or deeper-focused state.

Appendix A.3 - Background mindfulness meditation educational information

The following information was provided to participants in a “Getting Started” tab. All participants had to complete a one question quiz at the end to indicate having read over the material prior to the first in-lab meditation. All participants acquiesced to this, verified by Brightspace timestamps. Font sizes adjusted smaller here.

What is mindfulness and how is it practiced?



The awareness that arises through paying attention, on purpose, in the present moment, non-judgmentally in the service of self-understanding and wisdom.”

This is Jon Kabat-Zinn's (1990) definition. He developed Mindfulness-Based Stress Reduction (MBSR), one of the most popular and effective mindfulness meditation programs in the world. Practicing mindfulness not only heightens awareness of every activity, but it also gives you insight into how your mind works. This can help us break thinking or behavioural patterns that add to stress or block us from connecting with ourselves and others.

You may notice that this definition doesn't mention meditation. This is because mindfulness is a specific type of mindset that can be folded into any activity, like going for a walk, doing chores, listening to others, listening to music, looking at art – anything! Some people are naturally mindful while other people are not as much. However, everyone can learn to be more mindful. With practice it can become less effortful, natural, more habitual, - much the same as doing soccer drills is likely to improve your playing during game time! Being able to be mindful can create a richer experience, which can be helped by intentionally set time aside to train and cultivating this ability.

Mindfulness meditations are specific techniques that are designed to increase mindfulness in a “concentrated” and structured way, so that our “mindfulness muscles” develop effectively and are generalizable to our daily life outside of meditation practice. There are many types of mindfulness meditations that are practiced over many weeks in longer programs (like in MBSR). For this research project we are focusing exclusively on the first foundational techniques usually taught: learning to sustain attention mindfully - using our breath as the focus and anchor of our practice.

Mindfulness training has been scientifically shown to improve self-regulation and wellbeing in clinical and non-clinical studies. It is worth pointing out that research studies typically look at group averages; that is, on average most people reliably show measurable improvements in self-regulation and wellbeing after practicing meditation, as compared to groups of individuals not meditating. Thus, positive results are statistically very likely but not guaranteed. The chances of acquiring noticeable benefits are increased by sticking to practice (i.e., not giving up) and seeking direction if you are struggling.

The study lead, Jeremy Viczko, and his PhD supervisor, Dr. Colette Smart, are both experienced in teaching and practicing mindfulness meditation. You may ask a member of the research team during you in-lab sessions or email us if you have comments, questions, or concerns that arise across your participation.

Below are the 7 Principles of Mindfulness

These are the attitudes that you should aim to adopt to support effective meditation sessions to cultivate higher levels of mindfulness in and out of practice.

1. Beginner's Mind: See everything, even the familiar, as if it were completely new. The essence of the "Beginners Mind" is curiosity and openness.

2. Non-Judging: Thoughts, emotions, and sensations will arise. You may instinctively have verbal thoughts or non-verbal impressions that label experiences or events as "good" or "bad". Try to see the "raw" information, taking it all in without applying conceptual labels. Try to be a neutral observer instead of a judge and jury of all of your experiences.

3. Patience: Let things unfold in their own time. Be patient with yourself as you learn this new skill. As you learn patience with yourself you may find it easier to be patient with others.

4. Trust: Trust in yourself and your feelings. Your thoughts and feeling are happening in the moment for a reason. It's important to be open to them, even when you don't immediately understand them. Give yourself permission to express what the mind and body want, without the habit of questioning or needing to explain or understand things right in the moment.

5. Non-striving: Enter meditation with no goals or expectations. When you find yourself seeking or becoming attached to some result, you are likely to be "getting in your way". A paradox of meditation is the harder you strive the more things slip away. It is okay to slip up and find yourself trying hard to meditate. Note when you catch yourself doing this and try to relax your mind and body back to the present.

6. Letting Go: A major skill to practice in mindfulness meditation is the art of letting go. Mistakes, difficulties, thoughts, emotions – they can be really "sticky" and hook into our minds and body's. No one is perfect, and all things pass. We can help pass through some of the difficulties we create ourselves by letting go.

7. Acceptance: Means seeing things as they actually are and working with whatever that is, the good, the bad, the ugly the beautiful. This makes "letting go" a lot easier. Acceptance in mindfulness is not the same as passive resignation. Acceptance in mindfulness is tied into compassion and equanimity (holding equal space for all events). In mindfulness we take a stance of being actively and compassionately accepting of all things that arise in passing moments. To deny "negative" or "positive" experiences means we are blocking out information that can help us grow and change, or act in ways that most align with our values.

Note that the short form of these will be posted in each of the home practice sessions, if you forget what each means head on back here to have another read - the application of these is the difference between meditating versus idly listening to the sound of your breath for 20min 😉

It is also ***strongly recommended*** that you look over the Meditation FAQ in the **Additional Resources** tab, as inevitably you may have a question about one of the topics reviewed (best time to meditate, troubleshooting and optimizing your own practice, handling challenges etc.). Most beginners hit snags related to the points covered in the FAQ. Try using this resource first, then if you still have unanswered questions or issues email the study lead, PhD Candidate Jeremy Viczko ([email provided]) for extra support and guidance."

Appendix A.4 - Troubleshooting information and recommendations for meditation practice.

The following was provided in a "Support and Additional Resources" tab on the BrightSpace page that hosted the meditation recordings and other links for participants to access throughout the study:

FAQ and Tips for Beginners

When is the best time to meditate?

Timing is important! Simply not getting distracted may seem overly straightforward on paper, but the difficulty of meditation becomes evident when put into practice. Select one or two times a day that will be the best block of time for practicing.

It is easier to maintain practice when a **predictable consistent time** can be allotted. Carve out 20-30 minutes as your **"just you" time**. Pick a time where you are less likely to be distracted by work, family, friends.

It is often not ideal to save meditation until just before bed (or your usual nap time if you're a napper). If you find yourself **falling asleep during the meditation, move your practice to a time when you have higher energy** so you can keep the proper amount of vigilance (you will not be working towards the benefits of meditation if you are sleeping during practice time!). **Meditation takes mental energy, but for some people it can also create mental and physical energy**. If you find the meditation energizes you, perhaps right before bed is also not ideal (if it delays sleep).

I'm struggling with the best way to sit!

Although sitting instructions are frequently given (including in this study) don't over think it too much – this is a brain workout, not a body workout. Aim balancing comfort with and upright but not a strained posture; no slouching or lying down (which can interfere with breathing). ***A chair adjusted so your feet can be completely flat on the ground, not straining upper legs or knees, is probably the best place to start out.***
The idea behind the traditional crossed-legged seating (which you don't need to do if it's not your preference) is to take-up a position where you're able to relax, but simultaneously pay close attention to your meditation objective without drifting off to sleep. If you want to experiment with this take a little time to try sitting for a few minutes prior to starting find what feels comfortable, not strained or tense.

A common instruction some find useful is to imagine yourself being pulled up by the top of your head by a single golden thread.

Finally - **YES you are free to move and make small and large adjustments during your meditation**. This isn't statue training or boot camp. But it is mindfulness training, so there is a catch: if/when you do want to make an adjustment: don't immediately- reactively - make your adjustment.

Pause for just a moment FIRST to really sense in detail what is driving the urge to move - AND THEN make the movement.

In this way you are really **practicing and flexing those mindfulness muscles**: learning to use awareness to act out of a place of **intention rather than reaction**.

Is mindfulness going to be very calming or relaxing?

It can be! Being mindful can certainly enhance our experience of feeling positivity or calmness. A side effect of “listening to the body” is that when it is heard - as opposed to being braced against - the mind and body “settle in” together, which can lead to relaxed and peaceful experiences.

But the point is not to seek out only the positive. ***In fact, doing so is likely to undermine achieving these things, possibly even leading to frustration (a paradox to be aware of)***

Mindfulness opens our hearts and minds to the world unfolding right before us, to the pleasant and unpleasant things. Mindfulness is intended to be practiced on **whatever arises in the present moment**: any-and-all pleasant, neutral, or unpleasant sensations, experiences, thoughts and emotions. Mindfulness teaches us to listen to our inner and outer world – to be curious, personal and equally embracing of all the information and experiences, “good” and “bad”. When we can adopt a stance of patience, acceptance, and compassion towards the difficult, annoying, or bad things in life, we give ourselves new mental space and perspective to act wisely and intentionally from as opposed to acting reactively with avoidance or lashing out.

Sometimes our brain or body don’t want to be settled and would rather be heard. In mindfulness meditation we want to be able to be open and curious as to why, while at the same time being non-judgmental and accepting of our thoughts and feelings. Instead of judging or “forcing” anything, be kind and patient and very patient and presently listen (like you would with a dear friend or family member). Sitting with your own unpleasant feelings face-to-face is still a major accomplishment, also leading to growth, clarity, and resilience.

Is it expected to be easy or hard to meditate for 8 sessions?

Sometimes it’s easy, sometimes it’s not. Training in mindfulness meditation is analogous to training on a new workout routine. Both starting and sticking to gym workout routine can feel difficult at times (particularly if you have never been to a gym or haven't been in a long time). Even sticking with a (relatively) short 20-minute daily meditation routine for 8 days, **you may feel interest/motivation wax and wane**.

"The motivation hump" is a normal part of training. To be able to *really feel the psychological resistance*, yet still meet it face-to-face with acceptance, kindness, but a stick-to-it attitude is a **golden opportunity** to practice "real-world" mindfulness skills you have been honing with sitting practices. Consider it the first Boss Battle of your training ;) - you will definitely "level-up" by overcoming it, and unlock the skill do this in other areas of life too.

Commitment is required to achieve the benefits. It's a cumulative process much the same way physically working out regularly strengthens and hones muscle. Sticking to a daily mindfulness meditation practice will strengthen your "mindfulness muscles" in your brain networks, also making them stronger and easier to use in daily life. This is why it's important to keep up the practice even when your commitment starts wavering and the initial novelty wanes.

Inevitably all meditators feel shifts in their desire to maintain practice, so remind yourself of this and congratulate yourself for stepping up and going to "the mental gym" especially on days when it's not as easy to get going!

There seems to be no consistency with how "good", "bad" - or even completely neutral - in how I feel like I am doing...

First – the very fact so set aside time to meditate is ALWAYS a good thing in the long run - *even if you didn't end up feeling like you got deep into it or came out more relaxed in a session.*
Have patience. The experience of meditation is highly subjective, so no two sessions will ever feel the same. As a result, it's hard to draw valid comparisons between a great meditation and a "bad" or highly distracted one. **All meditators (even "experts") experience both, and ups and downs!**
How meditations vary in experience is more representative of how our lives change rather than a fault within us training. Attempting a breath meditation, then unintentionally ruminating over what groceries you need to buy for dinner later can (and will) happen, **but it's how you handle it when you catch yourself doing this that strengthens your mindfulness and other mental abilities.**

The **7 Principles of Mindfulness** (outlined in the Getting Started page) **exist to help us cope, tolerate, or fall through difficulties** we experience within (and in between) meditation sessions. Don't get hung up on expectations, or negative self-reflections, and still give yourself major mental cookies for being able to stick through a difficult session or two. It might not feel like it, but it's still getting important self-work done.

If it really feels like you aren't getting the hang of it revisit the principles/attitudes before you go again tomorrow. Check-in and see if you are *really* practicing with these attitudes being embraced and folded in. It may also help to take a few extra minutes before starting, to do a body scan and controlled breathing exercise to get ground before starting.

The team is cheering for you and here to help. Feel free to ask us when you are in about any of these points, and we can try to troubleshoot with you.

Feeling dizzy or disoriented - eyes closed versus open...

For some individuals, having their eyes closed while they focus inward or on their breath can result in some dizziness or disorientation within a meditation. The strategy to help with this is to open your eyes, halfway or less, and look at a point downward and directly in front of you while you continue with the meditation. Once steadied and grounded by having a little bit of visual anchoring, you can try to go back to having your eyes closed, as per the instructions in this meditation. For the in-lab sessions, eyes-closed is much preferred as eyes-open meditation gives off different EEG patterns that are hard to compare or give feedback on. If you are continuously having issues with disorientation in the lab or home sessions, let the team know so we can figure out and document in our research notes the best strategies for you.

Is mindfulness meditation religious or spiritual? Will it conflict with my other belief system?

Mindfulness is a state of mind that is available and achievable by everyone regardless of backgrounds or beliefs. Mindfulness meditations are the techniques that are designed to help people learn to be fully connected and engaged in present moment experiences to help people be more flexible, resilient, or free from becoming distracted, overwhelmed, or spending too much time in "mental time travel" (i.e., thinking about the past or future more often than being in the present where they can be most effective). Mindfulness meditation practices are considered secular. That is to say, practicing mindfulness is not practicing a religious or spiritual technique. Mindfulness is not connected to any mythical, religious, or spiritual belief system. **It is accepted as being non-conflictual with other belief systems.** If you are unsure, feel free to have a discussion with your religious or spiritual leader. We can also provide you with more information on public positions, research, history and theory on what mindfulness is versus is not.

Mindfulness meditation will treat psychological problems.

Not necessarily – *and that is also not the purpose or tailoring of this research study*. When your mind becomes quiet and calm, repressed or charged thoughts and emotional issues can come up—issues you may have been keeping at arm's length or that you didn't even realize existed. This can be a good thing if you have the support and ability to handle them but can be a bad thing if you are not prepared with internal and external resources needed to work through things. For this study you and other participants have been screened for factors that suggest mindfulness meditation should be a safe and positive experience.

Some temporary discomfort should be expected throughout practice at some point in training. Discomfort is inevitable in daily life. Often facing an uncomfortable thought or sensation mindfully "seeing it clearly", increases it. However, **continuing with the mindfulness practice typically reduces the negative impact**, and with enough practice, can lead people to develop positive relationships with "negative" aspects of themselves, others, or the world. A goal of practicing mindfulness is to have you be become non-judgmentally, curious, and well-acquainted with the passing discomforts (and comforts) that occur in your life in and outside of practice.

To re-iterate, it is common (and a good training sign) to experience some frustration or discomfort at some point during meditation training. This is the "heavy ammunition" for practicing your mindfulness meditation on. To be able to fold in and move passed unpleasant physical or mental events without reacting impulsively or avoiding them is a (some might argue *the*) major beneficial skill of being proficient in mindfulness.

However, significant lasting distress is uncommon and a sign that continuing practice may not be wise at this time. If you have symptoms of panic, or thoughts and emotions that are persistently distressing in ways that consistently intrude or overtake your practice over multiple sessions, please inform the research team to find the correct supports for you.

Contact Information

For general concerns related to scheduling, participation, or troubleshooting please contact us at [email provided] using the email subject heading "Meditation Study" or leave a phone message [phone number provided]

If you are having concerns about the meditation practice and its effects or related issues or questions, please contact Jeremy Viczko directly at [email provided].

Appendix B. Self-report Forms and Questionnaires

This appendix contains the following forms and questionnaires:

1. Demographic Questionnaire[1]
2. Five-Factor Mindfulness Questionnaire–15 [1]
   (FFMQ-15; Baer et al, 2008; Gu et al. 2016)
3. Attitude and Affinity for Technology Scale [1]
   (Edison & Geissler, 2003)
4. Mindfulness-based Self-Efficacy Scale – Revised Short Form [2]
   (MSES-R; Cayoun et al., 2011)
5. Experiences Questionnaire – Decentering Subscale [2]
   (EQ-D; Fresco et al., 2007)
6. Attention Control Scale [2]
   (ACS; Derryberry & Reed, 2002)
7. Executive Function Index [2]
   (EFI; Spinella, 2005)
8. Multidimensional Assessment of Interoceptive Awareness - Version 2 [2]
   (MAIA-2; Mehling et al., 2018)
9. Mind Wandering Scale [2]
   (MWS; Mrazek et al., 2013)
10. Psychological Wellbeing Scale
    (PWS; Ryff, 1995) [2]
11. Perceived Stress Scale [2]
    (PSS Cohen et al., 1983)
12. Profile of Mood Scale – Short Form [2]
    (POMS-SF; Shacham, 1983)
13. Meditation Experiences Diary [3]
14. Self-efficacy for Mindfulness Meditation Practice scale [2*]
    (SEMMP; Birdee et al., 2020)
15. Follow-up and Debriefing Questions [4]

Note: Questionnaires that are associated with published, peer-reviewed articles are indicated by their primary source citation listed below.

[1] Administered once, pre-training.

[2] Administered repeatedly, pre-training, post-training, and follow-up/debrief.

[2*] Administered twice, after 1st and 5th at-home meditation practice sessions.

[3] Administered after every meditation session, in-lab and at-home.

[4] Administered once, at follow-up/debrief.

Appendix B.1 - Demographic Questionnaire

This box is for Research Team to fill out:
Study: ________ Date: _____________ Participant Study ID: _________________

Demographic Questionnaire

Please circle your responses, unless a space is provided for your answer. All responses will be kept confidential.

In this study, we are interested in understanding the psychological health related effects of training in mindfulness meditation. We know from prior research that certain demographic variables can influence learning and response to meditation training, such as lifestyle, life experiences, handedness and also sex and gender. In the following questionnaire, we will be asking you about some of these personal questions, so that we can better understand who benefits from the training we are going to be providing.

Please provide respond to as many questions as possible. If you are uncomfortable providing some details, please indicate by writing "Prefer Not to Answer" or "PNA" beside that questionnaire item.

Age: ________

Dominant Handedness:

Right Left Ambidextrous

What was your assigned sex at birth:

Male Female Intersex Other:_________________

Gender Identification (circle all that apply):

Male Female Non-binary Gender Queer/Non-Conforming

Identification not listed here:_________________

Ethnicity (circle all that apply):

White	First Nation, Inuit, or Metis	
Asian	African	Indian
Middle-Eastern	Hispanic	Other: ________________

Are you currently a student?:

Yes No

If yes, list school program of study and current year of study:

Please put a checkmark beside the highest level of education you have received:

___ High school Diploma

___ Some College/Trades School/University (degree or certification not obtained)

___ Completed a Bachelor Degree or Professional Degree

___ Currently in an Advanced Degree (Master or PhD)

___ Completed an Advanced Degree (Master or PhD)

Total Years of Post-Secondary Education: _________

Employment status outside of school, if any:

Unemployed Part-time Full-time Other:________________

If employed, type of work: ____

Yearly Income:

<$25,000 $25-49,999 $50,000–99,999 $100,000 or more

Do you have any religious or spiritual practice?

Yes No

If yes, please briefly identify or describe: __________________________________

Does your spiritual practice involve meditation or other contemplation rituals or practices?

Yes No

If yes, please describe and provide how much time per week on average spent on spiritual practice:

____

____

How interested and motivated are you in learning and practicing meditation?
Mark an 'X' beside the statement that most accurately captures your feeling:

___ Would prefer not to (no interest and motivation)

___ Not very interested (low interest and motivation)

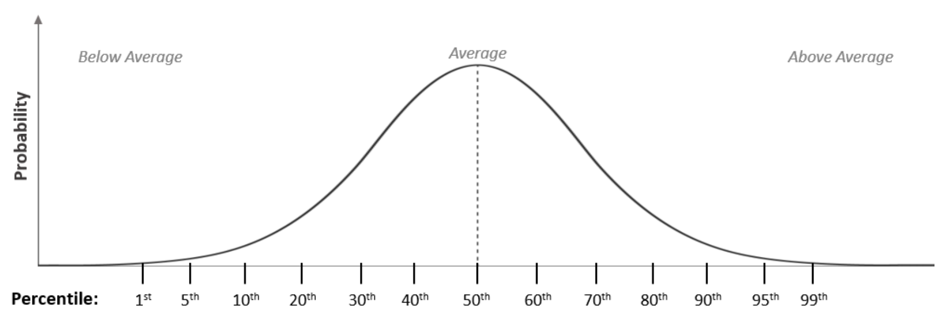
___ Indifferent/Neutral

___ Somewhat interested (moderate interest and motivation)

___ Very Interested (high interest and motivation)

Below shows a line graph of a normal population distribution with "percentile rankings," a graphic tool which is used to understand many different human skills and characteristics. A percentile rank is different from a percent grade like you would receive in school. Instead, what a percentile indicates is where you compare *in rank order compared to 100 other same age peers.*

For example, if someone's height is at the 25th percentile this means in a randomly created group of 100 peers they would be taller than 24 peers and shorter than 74 peers.



How skilled do you believe you will be at meditation, currently and relative to 100 other peers?

Please rate yourself with a percentile rank value between 1-100: ________

Appendix B.2 - FFMQ-15

Please use the 1 (never or very rarely true) to 5 (very often or always true) scale provided to indicate how true the below statements are of you. Circle the number in the box to the right of each statement which represents your own opinion of what is generally true for you. For example, if you think that a statement is often true of you, circle '4' and if you think a statement is sometimes true of you, circle '3'.

	Never or very rarely true	Rarely true	Some -times true	Often true	Very often or always true
1. When I take a shower or a bath, I stay alert to the sensations of water on my body.	1	2	3	4	5
2. I'm good at finding words to describe my feelings.	1	2	3	4	5
3. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.	1	2	3	4	5
4. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.	1	2	3	4	5
5. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.	1	2	3	4	5
6. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.	1	2	3	4	5
7. I have trouble thinking of the right words to express how I feel about things.	1	2	3	4	5
8. I do jobs or tasks automatically without being aware of what I'm doing.	1	2	3	4	5
9. I think some of my emotions are bad or inappropriate and I shouldn't feel them.	1	2	3	4	5
10. When I have distressing thoughts or images I am able just to notice them without reacting.	1	2	3	4	5
11. I pay attention to sensations, such as the wind in my hair or sun on my face.	1	2	3	4	5
12. Even when I'm feeling terribly upset I can find a way to put it into words.	1	2	3	4	5
13. I find myself doing things without paying attention.	1	2	3	4	5
14. I tell myself I shouldn't be feeling the way I'm feeling.	1	2	3	4	5
15. When I have distressing thoughts or images I just notice them and let them go.	1	2	3	4	5

Appendix B.3 - Attitude and Affinity for Technology Scale

Please circle the answer that best describes how you feel about each statement

		Strongly Disagree	Moderately Disagree	Neither agree nor disagree	Moderately Agree	Strongly Agree
1.	Technology is my friend…	1	2	3	4	5
2.	I enjoy learning new computer programs and hearing about new technologies.	1	2	3	4	5
3.	People expect me to know about technology and I don't want to let them down.	1	2	3	4	5
4.	If I am given an assignment that requires that I learn to use a new program or how to use a machine, I usually succeed.	1	2	3	4	5
5.	I relate well to technology and machines.	1	2	3	4	5
6.	I am comfortable learning new technology.	1	2	3	4	5
7.	I know how to deal with technological malfunctions or problems.	1	2	3	4	5
8.	Solving a technological problem seems like a fun challenge.	1	2	3	4	5
9	I find most technology easy to learn.	1	2	3	4	5
10.	I feel as up-to-date on technology as my peers.	1	2	3	4	5

Global attitudes towards technology

Technophobia = negative affect towards technology
If 'technophobia' is defined as feeling discomfort about computers or any new technology, which of the following best describes you: [please check only one box below]

[ ] Highly Technophobic

[ ] Moderately Technophobic

[ ] Mildly Technophobic

[ ] Not Technophobic

Appendix B.4 - MSES-R

MSES-R

Fill in the circle that that best describes how you view yourself, based on the scale below. Select the appropriate response based on how much you agree with each statement right at this moment.

Try not to spend too much time on any one item. There are no right or wrong answers.

		Not at all	A little	Moderately	A lot	Completely
1.	I get easily overwhelmed by my emotions	0	1	2	3	4
2.	I find it difficult to make new friends	0	1	2	3	4
3.	I try to avoid uncomfortable situations even when they are really important	0	1	2	3	4
4.	When I feel emotional it takes a long time for it to pass	0	1	2	3	4
5.	I feel comfortable saying sorry when I am in the wrong	0	1	2	3	4
6.	It is often too late when I realise I overreacted in a stressful situtation	0	1	2	3	4
7.	I get so caught up in my thoughts I end up feeling sad or anxious	0	1	2	3	4
8.	When I have unpleasant feelings in my body I prefer to push them away	0	1	2	3	4
9	I can resolve problems easy with my partner (or best friend if single)	0	1	2	3	4
10	I can face my thoughts even if they are unpleasant	0	1	2	3	4
11.	My actions are often controlled by other people or circustances	0	1	2	3	4
12.	I get caught up in unpleasant memories or anxious thoughts about the future	0	1	2	3	4
13.	I can deal with physical discomfort	0	1	2	3	4
14.	I feel I cannot love anyone	0	1	2	3	4
15.	I am often in conflict with one (or more) family member	0	1	2	3	4
16.	I avoid feeling my body when there is pain or discomfort	0	1	2	3	4
17.	I do things that make me feel good straight away if if I will feel bad later	0	1	2	3	4
18.	When I have a problem, I tend to believe it will ruin my whole life	0	1	2	3	4
19.	When I feel physical discomfort, I relax because I know it will pass	0	1	2	3	4
20.	I can feel comfortable around people	0	1	2	3	4
21.	Seeing or hearing someone with strong emotions is unbearable to me	0	1	2	3	4
22.	If I get anxious or angry it is generally because of others	0	1	2	3	4

Appendix B.5 - Experiences Questionnaire – Decentering Subscale (EQ-D)

EQ-D

Please rate your agreement with each of the following statements in terms of the frequency they are true for you:

		Never				All the Time
1.	I am better able to accept myself as I am	1	2	3	4	5
2.	I can slow my thinking at times of stress	1	2	3	4	5
3.	I notice that I don't take difficulties so personally	1	2	3	4	5
4.	I can separate myself from my thoughts and feelings	1	2	3	4	5
5.	I can take time to respond to difficulties	1	2	3	4	5
6.	I can treat myself kindly	1	2	3	4	5
7.	I can observe unpleasant feelings without being drawn into them	1	2	3	4	5
8.	I have the sense that I am fully aware of what is going on around me and inside me	1	2	3	4	5
9	I can actually see that I am not my thoughts	1	2	3	4	5
10	I am consciously aware of a sense of my body as a whole	1	2	3	4	5
11.	I view things from a wider perspective	1	2	3	4	5

Appendix B.6 - Attention Control Scale (ACS)

Circle that that best describes your recent experiences in day-to-day life over the past week

		Almost never	Sometimes	Often	Always
1.	It's very hard for me to concentrate on a difficult task when there are noises around	1	2	3	4
2.	When I need to concentrate and solve a problem, I have trouble focusing my attention	1	2	3	4
3.	When I am working hard on something, I still get distracted by events around me	1	2	3	4
4.	My concentration is good even if there is music in the room around me.	1	2	3	4
5.	When concentrating, I can focus my attention so that I become unaware of what's going on in around me	1	2	3	4
6.	When I am reading or studying, I am easily distracted if there are people talking in the same room	1	2	3	4
7.	When trying to focus my attention on something, I have difficulty blocking out distracting thoughts	1	2	3	4
8.	I have a hard time concentrating when I'm excited about something.	1	2	3	4
9.	When concentrating I ignore feelings of hunger or thirst.	1	2	3	4
10.	I can quickly switch from one task to another	1	2	3	4
11.	It takes me a while to get really involved in a new task	1	2	3	4
12.	It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures	1	2	3	4
13.	I can become interested in a new topic very quickly when I need to	1	2	3	4
14.	It is easy for me to read or write while I'm also talking on the phone	1	2	3	4
15.	I have trouble carrying on two conversations at once	1	2	3	4
16.	I have a hard time coming up with new ideas quickly	1	2	3	4
17.	After being interrupted or distracted, I can easily shift my attention back to what I was doing before.	1	2	3	4
18.	When a distracting thought comes to mind, it is easy for me to shift my attention away from it	1	2	3	4
19.	It is easy for me to alternate between two different tasks	1	2	3	4
20.	It is hard for me to break from one way of thinking about something and look at it from another point of view	1	2	3	4

Appendix B.7 - Executive Function Index (EFI)

	Rate how well each of the following statements describes you.	Not at all		Somewhat		Very much
1	I have a lot of enthusiasm to do things.	1	2	3	4	5
2	When doing several things in a row, I mix up the sequence	1	2	3	4	5
3	I try to plan for the future	1	2	3	4	5
4	I can sit and do nothing for hours.	1	2	3	4	5
5	I take risks, sometimes for fun.	1	2	3	4	5
6	I have trouble when doing two things at once, multi-tasking	1	2	3	4	5
7	I'm interested in doing new things.	1	2	3	4	5
8	I have a lot of concern for the well-being of other people.	1	2	3	4	5
9	I'm an organized person.	1	2	3	4	5
10	I save money on a regular basis.	1	2	3	4	5
11	I do or say things that others find embarrassing.	1	2	3	4	5
12	People who are foolish enough to be taken advantage of deserve it.	1	2	3	4	5
13	I only have to make a mistake once in order to learn from it.	1	2	3	4	5
14	I tend to be an energetic person.	1	2	3	4	5
15	I make inappropriate sexual advances or flirtatious comments.	1	2	3	4	5
16	When someone is in trouble, I feel the need to help them.	1	2	3	4	5
17	I sometimes I lose track of what I'm doing.	1	2	3	4	5
18	I feel protective towards a friend who is being treated badly.	1	2	3	4	5
19	I think about the consequences of an action before I do it.	1	2	3	4	5
20	I lose my temper when I get upset.	1	2	3	4	5
21	I take other people's feelings into account when I do something.	1	2	3	4	5
22	I have trouble summing up information in order to make a decision with it.	1	2	3	4	5
23	I start things, but then lose interest and do something else.	1	2	3	4	5
24	I swear/use obscenities.	1	2	3	4	5
25	I don’t like it if my actions or words hurt someone else	1	2	3	4	5
26	I use strategies to remember things.	1	2	3	4	5
27	I monitor myself so that I can catch any mistakes.	1	2	3	4	5

Appendix B.8 - Multidimensional Assessment of Interoceptive Awareness - 2 (MAIA-2)

Below you will find a list of statements. Please indicate how often each statement applies to you generally in daily life.

.	**Circle one number on each line**					
	Never					**Always**
1. When I am tense I notice where the tension is located in my body.	0	1	2	3	4	5
2. I notice when I am uncomfortable in my body.	0	1	2	3	4	5
3. I notice where in my body I am comfortable.	0	1	2	3	4	5
4. I notice changes in my breathing, such as whether it slows down or speeds up.	0	1	2	3	4	5
5. I ignore physical tension or discomfort until they become more severe.	0	1	2	3	4	5
6. I distract myself from sensations of discomfort.	0	1	2	3	4	5
7. When I feel pain or discomfort, I try to power through it.	0	1	2	3	4	5
8. I try to ignore pain	0	1	2	3	4	5
9. I push feelings of discomfort away by focusing on something	0	1	2	3	4	5
10. When I feel unpleasant body sensations, I occupy myself with something else so I don't have to feel them.	0	1	2	3	4	5
11. When I feel physical pain, I become upset.	0	1	2	3	4	5
12. I start to worry that something is wrong if I feel any discomfort.	0	1	2	3	4	5
13. I can notice an unpleasant body sensation without worrying about it.	0	1	2	3	4	5
14. I can stay calm and not worry when I have feelings of discomfort or pain.	0	1	2	3	4	5
15. When I am in discomfort or pain I can't get it out of my mind	0	1	2	3	4	5
16. I can pay attention to my breath without being distracted by things happening around me.	0	1	2	3	4	5
17. I can maintain awareness of my inner bodily sensations even when there is a lot going on around me.	0	1	2	3	4	5
18. When I am in conversation with someone, I can pay attention to my posture.	0	1	2	3	4	5

How often does each statement apply to you generally in daily life? Circle one number on each line

	Never					Always
19. I can return awareness to my body if I am distracted.	0	1	2	3	4	5
20. I can refocus my attention from thinking to sensing my body.	0	1	2	3	4	5
21. I can maintain awareness of my whole body even when a part of me is in pain or discomfort.	0	1	2	3	4	5
22. I am able to consciously focus on my body as a whole.	0	1	2	3	4	5
23. I notice how my body changes when I am angry.	0	1	2	3	4	5
24. When something is wrong in my life I can feel it in my body.	0	1	2	3	4	5
25. I notice that my body feels different after a peaceful experience.	0	1	2	3	4	5
26. I notice that my breathing beccmes free and easy when I feel comfortable.	0	1	2	3	4	5
27. I notice how my body changes when I feel happy / joyful.	0	1	2	3	4	5
28. When I feel overwhelmed I can find a calm place inside.	0	1	2	3	4	5
29. When I bring awareness to my body I feel a sense of calm.	0	1	2	3	4	5
30. I can use my breath to reduce tension.	0	1	2	3	4	5
31. When I am caught up in thoughts, I can calm my mind by focusing on my body/breathing.	0	1	2	3	4	5
32. I listen for information from my body about my emotional state.	0	1	2	3	4	5
33. When I am upset, I take time to explore how my body feels.	0	1	2	3	4	5
34. I listen to my body to inform me about what to do.	0	1	2	3	4	5
35. I am at home in my body.	0	1	2	3	4	5
36. I feel my body is a safe place.	0	1	2	3	4	5
37. I trust my body sensations.	0	1	2	3	4	5

Appendix B.9 - Mind Wandering Scale (MWS)

MWS

Instructions:
Below is a collection of statements about your Day-to-Day Experiences.
Using the scale below, please indicate how frequently or infrequently you currently have each experience over the last several days.
Please answer according to what really reflects your experience rather than what you think your experience should be.
Please treat each item separately from every other item.

In my day-to-day life...		Almost Never	Very infrequently	Somewhat infrequently	Somewhat frequently	Very Frequently	Almost Always
1.	I have difficulty maintaining focus on simple or repetitive work	1	2	3	4	5	6
2.	While reading, I find I haven't been thinking about the text and must therefore read it again	1	2	3	4	5	6
3.	I do things without paying full attention	1	2	3	4	5	6
4.	I find myself listening with one ear, thinking about something else at the same time	1	2	3	4	5	6
5.	I mind-wander during lectures of presentations	1	2	3	4	5	6

Appendix B.10 – Psychological Wellbeing Scale (PWS)

INSTRUCTIONS: Circle *one response* below each statement to indicate *how much you agree or disagree*.

1. **"I like most parts of my personality."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

2. **"When I look at the story of my life, I am pleased with how things have turned out so far."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

3. **"Some people wander aimlessly through life, but I am not one of them."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

4. **"The demands of everyday life often get me down."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

5. **"In many ways I feel disappointed about my achievements in life."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

6. **"Maintaining close relationships has been difficult and frustrating for me."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

7. **"I live life one day at a time and don't really think about the future."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

8. **"In general, I feel I am in charge of the situation in which I live."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

9. **"I am good at managing the responsibilities of daily life."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

10. **"I sometimes feel as if I've done all there is to do in life."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

11. **"For me, life has been a continuous process of learning, changing, and growth."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

12. **"I think it is important to have new experiences that challenge how I think about myself and the world."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

13. **"People would describe me as a giving person, willing to share my time with others."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

14. **"I gave up trying to make big improvements or changes in my life a long time ago."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

15. **"I tend to be influenced by people with strong opinions."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

16. **"I have not experienced many warm and trusting relationships with others."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

17. **"I have confidence in my own opinions, even if they are different from the way most. other people think."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

18. **"I judge myself by what I think is important, not by the values of what others think is important."**

Strongly agree	Somewhat agree	A little agree	Neither agree nor disagree	A little disagree	Somewhat disagree	Strongly disagree

Appendix B.11 - Perceived Stress Scale (PSS)

The questions in this scale ask you about your feelings and thoughts ***during the last 10 days***.

In each case, you will be asked to indicate by circling how often you felt or thought a certain way.

0 = Never **1 = Almost Never** **2 = Sometimes** **3 = Fairly Often** **4 = Very Often**

Appendix B.12 - Profile of Mood Scale – Short Form (POMS-SF)

Below is a list of words that describe words that describe feelings that people have.

Please read each word carefully, then circle the number that describes how you have been feeling during the:

PAST WEEK, INCLUDING TODAY

	Not at all	A little	Moderately	Quite a bit	Extremely

Appendix B.13 - Meditation Experiences Diary

After completing your daily meditation, please answer the following questions as accurately and honestly as possible.

1. **Before starting the meditation, how motivated did you feel to do your daily meditation?**
   1 = Very unmotivated (did not want to)
   2 = Not very motivated
   3 = Indifferent/neutral
   4 = Somewhat motivated
   5 = Very Motivated (I was looking forward to it)
2. **Did you find it difficult or easy to meditate today? ___**
   1 = Very difficult
   2 = Somewhat difficult
   3 = Not particularly difficult or easy
   4 = Somewhat easy
   5 = Very easy
3. **How satisfied are you with your ability to meditate this session? ___**
   1 = Very unsatisfied
   2 = Somewhat unsatisfied
   3 = Neither satisfied nor dissatisfied
   4 = Somewhat satisfied
   5 = Very Satisfied
4. **Compared to before this meditation, how do you feel? ___**
   1 = My mood is much worse
   2 = My mood is somewhat worse
   3 = No difference
   4 = My mood is somewhat better
   5 = My mood is much better
5. **Compared to before this meditation, how do you feel? ___**
   1 = Much less focused
   2 = Somewhat less focused
   3 = No difference
   4 = Somewhat more focused
   5 = Much more focused
6. **Compared to before this meditation, how do you feel? ___**
   1 = Much less relaxed
   2 = Somewhat less relaxed
   3 = No difference
   4 = Somewhat more relaxed
   5 = Much more relaxed
7. **Compared to before this meditation, how do you feel? ___**
   1 = Much less energized
   2 = Somewhat less energized
   3 = No difference
   4 = Somewhat more energized
   5 = Much more energized

8. **How much of your session did you find yourself distracted by mind wandering? ____**
   1 = Nearly the entire time
   2 = More than half the time
   3 = About half the time
   4 = Less than half the time
   5 = Very minimally
9. **How much of your session did you find yourself distracted by body events (sensations related to posture, muscles, skin contact, temperature, digestion or other organs etc.)? ____**
   1 = Nearly the entire time
   2 = More than half the time
   3 = About half the time
   4 = Less than half the time
   5 = Very minimally
10. **How much of your session did you find yourself distracted by environmental events (sights, sounds, smells, touch etc.)? ____**
   1 = Nearly the entire time
   2 = More than half the time
   3 = About half the time
   4 = Less than half the time
   5 = Very minimally

Additional Questions for MM+NF and MM+Sham groups after in-lab meditations:

11. **Do you find the neurofeedback to be helpful this session?**
   1 = Not at all helpful
   2 = Not very helpful
   3 = Neither helpful nor unhelpful
   4 = Somewhat helpful
   5 = Very helpful

12. **Did you feel the neurofeedback was accurate this session?**
   1 = Not at all accurate
   2 = Not very accurate
   3 = I could not tell
   4 = Somewhat accurate
   5 = Very accurate

13. **Overall, how focused on the neurofeedback were you?**
   1 = Completely focused
   2 = Partially focused
   3 = Not at all focused

Appendix B.14 - Self-efficacy for Mindfulness Meditation Practice Scale (SEMMP)

During my practice of mindfulness meditation…

		1 = Never		3 = Rarely		5 = Sometimes		7 = Usually		9 = Often
1.	I am able to notice thoughts as they arise	1	2	3	4	5	6	7	8	9
2.	When I set the intention, I am able to be in open awareness of my thoughts	1	2	3	4	5	6	7	8	9
3.	I am able to notice when my mind wanders	1	2	3	4	5	6	7	8	9
4.	I am able to be compassionate with myself when my mind wanders	1	2	3	4	5	6	7	8	9
5.	I am able to be aware of my thoughts without judgment	1	2	3	4	5	6	7	8	9
6.	I am able to notice emotions as they arise	1	2	3	4	5	6	7	8	9
7.	I am able to observe my emotions without responding immediately	1	2	3	4	5	6	7	8	9
8.	I am able to relate physical sensations in my body to my emotions	1	2	3	4	5	6	7	8	9
9	I am able to maintain compassion toward myself	1	2	3	4	5	6	7	8	9

Appendix B.15 - Follow-up Questionnaire

Follow-up and Debrief

You have completed your participation in this study which examines the benefits and effects of meditation training. The research team would like to thank you for the dedication and contribution you have made to make this study work, and to the scientific literature on this subject.

We will now conduct a debrief to give you more details on the study, and answer any follow-up questions you may have. Before we give an overview of the research project, we have a few follow-up questions we would like to ask you. Please answer as honestly as possible, there are no right, wrong, or expected answers from you.

14. **Did your interest in meditation increase or decrease as a result of this study?**
    1 = Decreased significantly
    2 = Decreased somewhat
    3 = It did not significantly change
    4 = Increased somewhat
    5 = Increased significantly

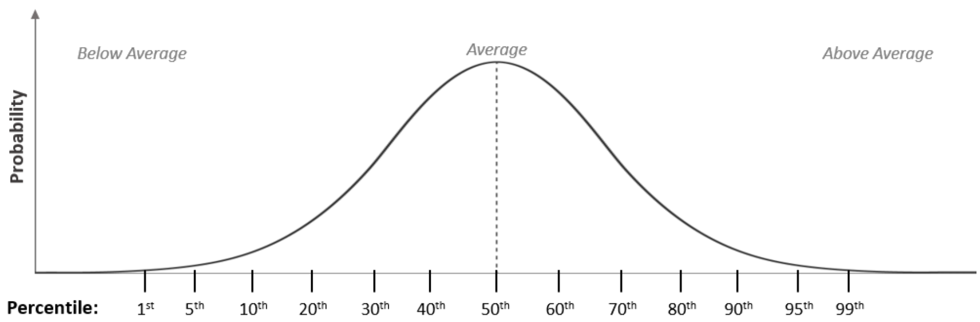
15. **Have you continued to use this practice since the training ended?**
    1 = No
    2 = Yes

16. **Have you tried other meditation practices since completing this study's training?**
    1 = No
    2 = Yes

17. **Which practices, and how many minutes total over the last 2 weeks?**
    Body focused (e.g., Body Scan)? Y/N ___ minutes
    Breath focused? Y/N ___ minutes
    Open-monitoring? Y/N ___ minutes
    Loving-Kindness/Compassion? Y/N ___ minutes
    Movement (e.g. Yoga, Qigong, Taichi) ___ minutes
    Other ___________ ___ minutes

18. **Below shows a line graph of a normal population distribution with "percentile rankings," a graphic tool which is used to understand many different human skills and characteristics. A percentile rank is different from a percent grade like you would receive in school.** ***Instead, what a percentile indicates is where you compare in rank order compared to 100 other same age peers*****. For example, if someone's height is in the 25^{th} percentile this means**

that in a randomly selected group of 100 peers, they would be taller than 24 peers but shorter than 74 peers overall.



19. How skilled do you believe you are at meditation, currently and relative to 100 other peers?

Please rate yourself with a percentile rank value between 1-100: ________

20. Did have any particularly unpleasant or adverse experiences that you think might have been related to the meditation training you completed in this study?

1 = Yes, certainly
2 = Yes, potentially
3 = I don't know
4 = No

If 1, 2, or 3 were provided in the previous answer, please ask them to elaborate. Ask for specific symptoms or concerns, the timing, frequency, duration and intensity.
Record participant response in the space provided:

Appendix C: Final Feedback Survey Responses

Links were sent out the day after last participation session for voluntarily completing a feedback survey. 13/28 participants completed the survey. Highlighted response for x1 MM+NF participant suggests that more optimized individual calibration in future protocol designs.

Group	My favorite part participating in this study was...	My least favorite part of participating in this study was...	Positive, negative, and/or interesting experiences of my meditation training included...	What if any changes did you experience in terms of in attitude or behaviours towards yourself and your daily life experiences?	What if any changes did you experience in terms of changes in attitude or behaviours towards others and the world?
MM-Only	Finishing the meditation	Nothing	Getting the 50$	I think I'm a little less hard on myself	Not much
MM-Only	Getting to experience the EEG and learn about the study after!	The time commitment	Was overall a positive experience	I find i am more conscious of my breathing/feelings of anxiety, and how to calm them down	I think i have a relatively similar view of others/the world
MM-Only	Getting some insight to how labs operate as well as giving me a reason to start practicing meditation.	Nothing in particular for me, but my schedule was particularly open for the duration of the study. I can see the strict schedule of the study being problematic if circumstances had been different, or if I wasn't very motivated to practice.	I felt better overall during the practice period; more attentive, alert and energetic. After the practice period ended and I had to stop during the period before the debrief, I was noticable more fatigued(not feeling as well rested, despite getting the same amount or more sleep), though this might be due to external factors, as I had coursework being after the practice session ended.	Nothing drastic, but perhaps a bit more alert of physical sensations in the body.	Again, nothing drastic, but a little more relaxed and less worry and anxiety associated with outside factors that I have no control over.
MM+NF	How peaceful it was. I also enjoyed getting the SONA credits for two of my courses. The $50 was definitely a bonus too but I was actually already sold on participating when I heard "meditation" and "SONA participation credit.	Listening to the neurofeedback and trying to concentrate while listening to the neurofeedback noises.	Interesting: the neurofeedback told me to visualize and focused on feeling the air flowing in when I inhaled. Whenever I did that, that's when the neurofeedback went crazy telling me I fell out of focus.	I found I have been able to focus better now that I've continued meditating even after participation of the study.	I have been feeling more peaceful and calmer towards others and the world.
MM+NF	Intentionally making time to meditate	difficulty meditating for 20 minutes			
MM+NF	Having the EEG machine hooked up since it was a new experience for me	Becoming distracted or wondering how long I had left. i kept my eyes closed but my mind would wander to how much time was left	Positive: I got to learn something new and become more conscious of my breathing in certain situations Negative: The feelings of dizziness that occured when I was mediating	I don't think I've seen too much of a change in my attitude or behaviors in my daily life besides being more mindful of how my body reacts when faced with an emotional or stressful situation.	Same as previous answer
MM+NF	The 20 minutes of absolute peace in my hell of a day.	that it only lasted for 8 days.	the fact that I started to feel that I was getting better after just the first 2 sessions was pretty crazy.	Most noticeable changes felt were that I was more self aware of my body, my mood at a particular moment and what I want and dont want in general and how I felt about something. Another thing was, whenever now I feel overwhelmed I just focus in on my breath and it does wonders!!	I feel like a person treats other people or things in the world with the same eyes they view themselves with. I felt like since this study I have been more patient and understanding towards myself and others around me too.
MM+Sham		The gel in the hair haha .. also a bit hard to remember to do my at home mediations, but that's on me.	I felt calmer for sure during the 8 days which was interesting. It positively influenced me to try mediation in my day to day life.	I felt more able to chill out during the day, even though those 8 days coincided with a stressful period of time.	I felt less reactive and more at ease/ able to not judge things/people/ situations so quickly.
MM+Sham	Going to the in-lab sessions to have a relaxing part of my day.	The long commitment, but it was worth it!	I found the at-home sessions more difficult.	I found myself to be more relaxed towards myself.	I found it easier for myself to be more patient, and appreciative of the little things.
MM+Sham	The in-lab mind exercises	Having to travel to the lab			
MM+Sham	Being motivated to actively and regularly practice mindfulness meditation	Commuting to UVic several times	Interesting- it was a lot easier to mediate in the lab (despite the EEG) and made me feel more concentrated and relaxed compared to at home.	It made me feel better that I was actively spending time for myself every day.	It helped me to slow down a bit before immediately reacting to outside influences.

(Same paticipant rows continued from previous page)			
Group	**Were you able to understand the procedures and methods? (1) Yes (2) No**	**Were the resources and materials: (1) easy or hard to use, (2) helpful or unhelpful? If so, which resources and materials in particular?**	**My experience with the Research Team was: (1) Very Postive (2) Positive (3) Neutral (4) Not Positive**
MM-Only	Yes	All easy clear and helpful :)	Very Positive
MM-Only		I found the resource and materials helpful One thing I would recommend is potentially using a few different meditation recordings, I found that by the 6th-8th meditation session I knew around what time points I was at because it was quite repetitive	Positive
MM-Only	Yes	I found the resources to be adequate. The Brightspace page was simple enough to navigate and I appreciated the quick reminders attached to each at home practice session. The guided meditations were a bit hit or miss for me, as I found the guidance to be somewhat more distracting than helpful. However, this is possibly because I had already done extensive reading about meditation though I had not practiced, so I already knew most of the ideas and methodologies intended for beginners.	Very Positive
MM+NF	Yes		Very Positive
MM+NF	Yes	Brightspace is not always the best user experience, however the resources were easy to use and helpful.	Very Positive
MM+NF	Yes	They were easy and helpful to use, I found the FAQ portion especially helpful since some of the questions came up for me when I was doing the meditation	Very Positive
MM+NF	Yes	easy to use and very helpful. The 7 principles of mindfulness were very interesting.	Very Positive
MM+Sham	Yes	Easy, helpful. The bright space page was really easy to navigate.	Very Positive
MM+Sham	Yes	I found the resources easy to use, and the EEG was more comfortable than I thought it would be.	Very Positive
MM+Sham	Yes	1) Easy 2) Somewhat helpful	Positive
MM+Sham	Yes	1. Easy- well written and clear 2. Helpful- the FAQ in particular was great for tips and reminders throughout	Very Positive

Appendix D: Emotional Distractor *n*Back by Block Type

Participant Sample Size, *N* = 30
Max Correct Hits = 20 / 60 Trials per Block, 2-Back condition

Measure		*M*	SE	Pairwise Comparisons		Mean Difference	Difference SE	*p*
Correct Hits	No	13.2	0.6	No	Neutral	.05	.50	.917
$F_{3,81}$ = 2.08, *p* = .110	Neutral	13.1	0.7		Positive	.55	.61	.372
	Positive	12.6	0.6		Negative	1.25	.62	.051
	Negative	11.9	0.5	Neutral	Positive	.50	.53	.355
					Negative	1.20	.65	.074
				Positive	Negative	.70	.50	.175
Incorrect Hits	No	2.5	0.5	No	Neutral	.26	.45	.569
$F_{3,81}$ = 2.28, *p* = .085	Neutral	2.3	0.4		Positive	.06	.34	.852
	Positive	2.5	0.4		Negative	-.70	.37	.069
	Negative	3.2	0.5	Neutral	Positive	-.19	.39	.619
					Negative	-.961*	.46	.046
				Positive	Negative	-.766*	.34	.031
Median Reaction Time	**No**	**.501**	**.016**	**No***	Neutral	-.02	.01	.142
(Correct Hits)	Neutral	.521	.013		**Positive***	**-.04**	**.01**	**.003**
$F_{3,81}$ = 3.28, *p* = .025	**Positive**	**.541**	**.017**		Negative	-.01	.01	.701
	Negative	**.506**	**.016**	Neutral	Positive	-.02	.02	.213
					Negative	.01	.02	.381
				Positive*	**Negative***	**.04**	**.01**	**.010**
IIV	No	.43	.01	No	Neutral	.00	.01	.789
of Mean Reaction time	Neutral	.42	.01		Positive	.01	.01	.425
(Correct hits)	Positive	.42	.01		Negative	.01	.01	.135
$F_{3,81}$ = 1.08, *p* = .326	Negative	.41	.01	Neutral	Positive	.01	.01	.464
					Negative	.01	.01	.209
				Positive	Negative	.01	.01	.449
Matthew's Correlation	No	.64	.03	**No***	Neutral	-.01	.03	.754
Coefficient	Neutral	.65	.03		Positive	.02	.03	.496
$F_{3,81}$ = 3.32, *p* = .024	Positive	.62	.03		**Negative***	**.075***	**.03**	**.028**
	Negative	.57	.02	**Neutral***	Positive	.03	.03	.271
					Negative*	**.084***	**.03**	**.016**
				Positive*	**Negative***	**.055***	**.03**	**.042**

Appendix E: Manual EEG Cleaning

EEG data recorded from the baseline and post-training EEG tasks (resting state and alpha neurofeedback control task) as well as the in-lab meditation training sessions (pre-meditation artifact calibration baseline and subsequent meditation recordings) were all cleaned according to the same procedures, mixing semi-automated and manual epoch flagging and removal. The author blinded himself to the participant ID and group assignment after collating all the raw text output files from BL, TR, and PT into a single excel document for each participant prior to cleaning procedures.

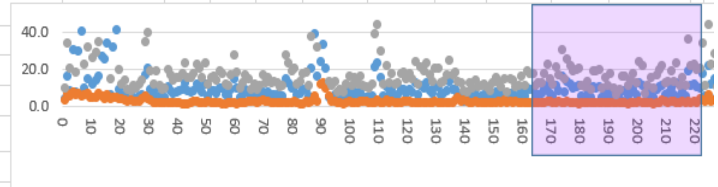
This approach was taken as the raw data became unavailable once each recording session stopped and the data was exported in 1-second intervals in a .txt output file; limiting the use of more fine-grained cleaning pipelines and procedures. The following images are included to further illustrate the procedures using a TR file from the same participant:

E.1 An example of a straightforward of the semiautomated threshold artifact removal. The amplitude data across all channels and target bands was automatically removed based on Eye movement amplitude increases above a threshold. Fz Beta was 1.5-2 SD above other EEG recording sessions for this training session, for reasons unknown (whereas all other channels and bandwidths were comparable), and thus the Fz channel for Beta filtered data was removed. This type of peculiarity and cleaning approach occurred in 7 recordings (affecting beta and gamma ranges predominantly) but never occur in the same or channel and site combination for any participant in subsequent TR recordings. Data was analyzed averaged as first two versus last two training sessions to avoid complete data loss due to channel contamination.

E.2 Example of the second step of manual data removal based on clustered flagged data. Epochs were flagged (yellow) when EOG+2*EMG amplitude from the LO1 channel crossed threshold. Data were inspected in the context of the initial epoch of semiautomated data removal (red) and whether amplitudes across channels (Fz in particular) demonstrated increased amplitudes above preceding and subsequent stretches of epochs. A conservative approach was taken, and the highlighted section (green outline grey fill) illustrates the epochs across all channels removed in this case. Notable the removed data extends to include an epoch on either side of the flagged data as it was observed that amplitude in theta and alpha ranges was usually still higher than preceding and subsequent amplitude on the fringes of the automated data.

E.1

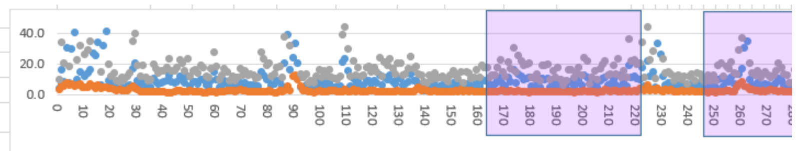
Pre1 MM Threshold	Eye	EMG	MG*2 %	M	SD	SEM	Time	MFile	EOG	EMG	2xEOG	# epoch	filtere	% filte	# left
Calibration	6.3	2.7	13.9	37.4	26.5	3.9	5-50	tal FA				566	90	16	476
Closed	9.1	3.1	21.2	16.0	8.5	1.25	55-100	al OM				63	7	11	56
Mental Rehhearsal	5.6	2.1	54.2	31.5	19.9	2.97	115-160	TOTAL	14.0	3.4	27.4	629	97	15	469
Total	5.0	2.0	54.2	69.3	35.3	11.15	5-160	creen	5.0	2.7	19.0	PreMM%ile 0.9			
Screen	5.0	2.7	19.0					Cutoff:	14.0	3.3	25.0	MM%ile 0.9			



Seconds	Trac k NF	Eye Move	EMG 45-	2xEMG + EOG	Noise Pass	Nois ePa	Cz Theta	Cz Alph	Cz Beta	Cz Gam	Cz Lo Alpha	Cz Hi Alpha	Cz Peak	Cz Peak AlphaF	Cz Peak	Cz Peak	Fz Thet	Fz Alpha	Fz Beta	Fz Gam	Fz Lo Alph	Fz Hi Alph	Pz Theta	Pz Alpha	Pz Beta	Pz Gamm	Pz Lo Alpha	Pz Hi Alpha	C C r r
					97.5th%ile		15.2	21.8	12.1	6.4	14.5	18.4	14.2	11.2	9.7	6.3	14.0	19.0	11.3	7.9	13.6	15.7	11.6	27.1	10.8	5.7	15.3	27.1	
525	7.2	8.7	2.1	17.3	18.2	0.0	7.0	7.1	7.7	2.2	6.2	3.7	3.4	8.3	3.5	6.1	4.1	5.7	5.6	3.0	5.3	3.9	3.4	7.8	5.7	2.3	6.3	7.8	
526	5.9	7.7	2.1	15.6	18.2	0.0	8.2	6.0	7.2	3.2	5.1	3.7	3.9	7.8	4.1	4.6	6.4	4.2	6.3	3.3	4.3	1.4	5.3	5.9	4.6	2.7	5.6	5.9	
527	6.9	7.5	2.4	15.3	18.1	0.0	6.3	6.7	6.9	3.0	6.2	2.8	3.7	7.6	4.2	4.5	8.9	5.8	7.1	3.1	4.6	2.0	4.6	4.1	4.6	2.6	3.8	4.1	
528	5.2	21.6	3.0	40.6																									
529	6.1	47.5	4.4	88.0																									
530	8.5	31.2	6.0	60.6																									
531	6.4	5.5	3.2	12.8	18.6	1.0	8.6	6.3	7.9	3.8	6.7	3.7	3.5	8.1	5.5	4.5	8.7	8.6	8.7	7.2	9.3	3.6	7.1	9.2	7.4	3.1	7.2	9.2	
532	10.0	6.9	1.8	13.8	18.7	0.2	5.9	10.0	8.3	3.5	7.3	5.7	3.9	9.0	5.2	4.8	7.8	8.4	7.4	5.1	6.0	2.9	5.4	11.9	7.9	2.3	6.2	11.9	
533	9.3	3.6	1.5	7.9	18.7	0.0	6.5	9.3	8.1	4.0	9.6	2.8	6.1	7.3	3.9	5.2	6.8	9.9	7.4	5.1	10.0	3.0	4.1	8.0	4.9	2.7	7.4	8.0	
534	5.9	6.3	1.9	12.5	18.6	0.0	8.4	6.0	8.3	3.0	4.8	4.1	6.3	7.3	3.6	6.4	6.7	6.2	6.5	3.9	5.2	4.1	7.2	6.6	5.8	2.4	6.3	6.6	
535	14.0	12.3	2.0	23.8	18.6	0.5	6.1	14.2	12.5	3.3	7.5	9.5	4.5	10.8	4.4	4.8	7.5	14.6	11.2	3.4	7.5	9.0	6.1	9.9	11.2	3.1	5.0	9.9	
536	16.6	5.9	2.1	12.5	18.7	0.5	8.3	16.7	8.9	2.9	12.6	12.0	8.6	11.2	3.7	4.9	9.6	15.8	8.1	3.3	12.8	11.7	6.0	11.9	6.8	2.4	7.7	11.9	
537	9.3	7.3	2.1	14.9	18.7	0.0	10.3	9.4	5.4	3.0	9.9	5.8	7.7	10.5	4.9	6.2	7.0	9.2	4.7	2.8	9.7	4.9	8.0	7.7	5.5	2.8	3.8	7.7	

E.2

Pre1 MM Threshold	Eye	EMG	MG*2 %	M	SD	SEM	Time	MFile	EOG	EMG	2xEOG	# epoch	filtere	% filte	# left
Calibration	6.3	2.7	13.9	37.4	26.5	3.9	5-50	tal FA				566	100	18	466
Closed	9.1	3.1	21.2	16.0	8.5	1.25	55-100	al OM				63	7	11	56
Mental Rehhearsal	5.6	2.1	54.2	31.5	19.9	2.97	115-160	TOTAL	14.0	3.4	27.4	629	107	17	459
Total	5.0	2.0	54.2	69.3	35.3	11.15	5-160	creen	5.0	2.7	19.0	PreMM%ile 0.9			
Screen	5.0	2.7	19.0					Cutoff:	14.0	3.3	25.0	MM%ile 0.9			



Seconds	Trac k NF	Eye Move	EMG 45-	2xEMG + EOG	Noise Pass	Nois ePa	Cz Theta	Cz Alph	Cz Beta	Cz Gam	Cz Lo Alpha	Cz Hi Alpha	Cz Peak	Cz Peak AlphaF	Cz Peak	Cz Peak	Fz Thet	Fz Alpha	Fz Beta	Fz Gam	Fz Lo Alph	Fz Hi Alph	Pz Theta	Pz Alpha	Pz Beta	Pz Gamm	Pz Lo Alpha	Pz Hi Alpha	CCCCCCCC11((9 rrrrhhhhnnl u 0
					97.5th%ile		15.2	21.8	12.1	6.4	14.5	18.4	14.2	11.2	9.7	6.3	14.0	19.0	11.3	7.9	13.6	15.7	11.6	27.1	10.8	5.7	15.3	27.1	
812	9.2	8.7	2.6	17.8	17.7	0.8	8.8	9.5	6.2	3.9	7.3	6.6	6.5	8.5	6.3	4.4	6.4	7.9	5.7	4.0	6.4	5.3	8.8	10.9	5.7	3.2	8.2	10.9	
813	8.1	6.0	2.1	12.5	17.7	0.0	8.6	7.6	6.3	4.3	8.7	3.2	5.1	7.8	5.2	3.6	7.0	8.7	7.4	5.2	9.7	3.1	8.6	6.1	4.9	3.1	6.8	6.1	
814	8.0	6.6	3.5	15.0																									
815	7.8	9.3	2.8	19.2	17.6	0.0	12.5	7.9	7.2	4.2	4.9	6.7	4.3	7.6	5.5	5.3	10.1	8.4	6.6	5.0	5.5	4.4	9.1	7.4	5.2	3.0	5.2	7.4	
816	5.7	15.1	2.8	29.2																									
817	6.5	8.6	3.8	18.9																									
818	8.3	10.1	2.9	20.6	17.8	0.7	21.2	8.1	11.2	4.7	7.1	4.8	3.9	7.8	12.6	4.4	14.0	7.3	9.8	3.6	6.3	4.2	9.6	8.9	6.3	3.8	5.9	8.9	
819	8.3	12.8	2.4	25.0	17.9	1.0	9.1	8.5	10.6	6.3	6.2	3.7	4.6	9.2	14.2	4.4	6.3	8.0	7.6	5.3	5.5	5.7	6.0	6.5	7.6	4.0	4.3	6.5	
820	6.2	9.8	3.6	20.7																									
821	5.2	11.3	3.2	23.0	18.1	0.8	9.1	5.3	4.6	4.2	4.2	4.6	3.8	11.2	5.3	4.2	6.7	5.0	5.9	3.6	3.7	2.9	11.3	6.2	3.2	3.7	5.5	6.2	
822	9.0	12.1	2.7	23.9	18.1	0.3	14.3	9.2	6.8	4.3	6.9	3.7	2.9	10.3	6.6	4.4	8.5	7.6	6.4	4.1	6.3	4.1	8.3	6.6	5.5	4.3	6.0	6.6	
823	5.8	4.8	2.6	11.0	18.2	0.5	15.1	5.2	9.2	5.4	4.5	2.8	3.4	8.1	10.4	3.9	11.3	6.1	8.6	5.5	5.3	2.5	6.4	14.3	6.7	3.9	4.0	14.3	
824	12.8	5.7	2.8	12.7	18.1	0.0	14.2	12.6	7.0	4.2	10.5	6.5	4.4	8.3	9.3	3.6	13.9	10.5	6.6	3.8	7.7	5.9	6.1	14.3	6.6	3.1	12.1	14.3	
825	10.5	6.0	2.8	13.3	18.1	0.0	12.0	10.6	8.6	5.5	8.4	8.1	5.5	8.9	7.4	3.9	9.3	10.5	5.5	5.3	7.7	8.5	10.2	14.0	8.5	3.7	10.6	14.0	
826	11.2	5.1	3.0	12.0	18.1	0.0	7.5	11.1	7.4	5.3	9.2	6.4	6.0	9.4	6.8	4.9	6.8	9.8	6.1	4.7	9.5	5.8	6.9	16.4	6.0	3.5	12.5	16.4	
827	7.4	6.0	2.3	12.7	18.1	0.0	5.7	7.4	8.2	4.1	5.8	3.7	5.6	9.7	5.2	6.0	6.3	7.0	7.6	4.3	6.0	2.7	3.8	8.8	6.6	3.7	7.7	8.8	
828	7.0	5.5	3.4	13.2																									
829	6.8	3.8	3.0	9.6	18.0	0.0	10.7	7.0	7.0	4.3	5.0	3.8	4.1	10.7	3.5	3.8	5.5	8.0	6.5	3.8	4.9	5.0	5.2	8.6	8.1	3.0	6.7	8.6	
830	5.8	5.0	2.8	11.5	18.0	0.0	8.3	5.5	8.9	5.0	3.6	4.7	3.3	9.1	4.8	6.3	10.0	7.2	7.3	4.5	5.3	5.5	6.7	7.7	7.2	2.5	4.8	7.7	
831	9.6	5.5	2.4	12.1	18.0	0.0	7.2	9.3	6.6	4.1	7.4	5.3	3.5	8.1	5.4	5.9	9.2	10.1	6.3	4.5	9.2	5.4	4.0	6.8	5.3	3.4	5.1	6.8	