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Microdosing Mindfulness: Understanding the Effects of Brief Mindfulness Meditation in Children with ADHD

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Abstract

Mindfulness Meditation (MM) is receiving increased empirical support as a method for addressing ADHD symptomology. Research shows that MM interventions lasting weeks or months promote key aspects of cognitive and psycho-emotional functioning in youth with ADHD. Using a pre-post within-subjects design, we sought to determine whether a *single* MM session supports neurocognitive and/or psycho-emotional functioning in youth with ADHD. Sixteen participants aged 10-14 completed measures of executive and psycho-emotional functioning before/after a 10-minute MM session and silent reading control. Functional neuroimaging assessed whether MM supported changes in prefrontal cortex (PFC) activation during cognitive tasks. We found that a single MM session supported inhibitory control and working memory. Improved inhibitory control also corresponded with a significant increase in PFC activity following MM. This study is the first to demonstrate improvements in key executive functions in youth with ADHD after a single MM session. Limitations, implications and future directions are discussed.

Keywords: Attention Deficit Hyperactivity Disorder, brief mindfulness meditation, children and youth, executive functioning, cognition, neuroimaging

Summary for Lay Audience

Attention Deficit Hyperactivity Disorder (ADHD) is the most common neurodevelopmental disorder in youth, and is associated with marked academic, social, and lifestyle deficits. Stimulant medications are usually the primary method of addressing the inattention and/or hyperactive symptoms brought on by ADHD. Although often beneficial, stimulants can elicit troubling side-effects, and do not address psychological difficulties young people with ADHD often face. Mindfulness Meditation (MM), an ancient practice that has recently proliferated in Western Culture, is now being researched as a possible treatment to supplement or replace existing ADHD interventions. Previous research has shown that children with ADHD benefit from long-term MM programs; however, there is little research that addresses how *brief* MM sessions impact young people. This study aimed to determine whether a single MM session affected thinking (cognition), feeling (psycho-emotion) and brain activity in young people with ADHD. Sixteen children aged 10-14 with ADHD completed tests to measure these factors. Participants were assessed before and after a 10-minute guided MM delivered through an evidence-based meditation app. They wore a neuroimaging device while completing cognitive measures so we could gauge whether their prefrontal cortex—a brain region that is often irregular in ADHD populations—was affected. We also had participants silently read for 10-minutes instead of meditating on another day, so we could attribute any potential results to the effects of MM. We found that inhibitory control and working memory—two of the main cognitive deficits associated with ADHD—were improved following the single MM session. We also found that increased activity in the prefrontal cortex co-occurred with improvements in inhibitory control, suggesting that the improvements following MM may be partially attributable to a change in prefrontal cortex activity. MM, where individuals must stay still and focused for

an extended time, is often challenging for individuals with ADHD. Our results are important because we showed that people can receive important benefits without partaking in prolonged practices. Brief MMs are also inexpensive and easy to access, and thus may be more feasible to engage with than expensive and longer interventions.

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Attention Deficit Hyperactivity Disorder (ADHD) is the most common neurodevelopmental disorder, affecting approximately 5% of Canadian school-aged children (Canadian Mental Health Association, 2014; Rapley, 2005). It is characterized by a repeated pattern of inattention and/or hyperactivity-impulsivity that interferes with typical daily functioning or development (American Psychiatric Association, 2017). Those with ADHD face academic impairments (they are more likely to drop out of high school and less likely to attend university), occupational impairments (they struggle with employment, and earn less) and social impairments (they are more socially withdrawn and have deficits in interpersonal relationships; Barkley et al., 1990). In short, there is an abundance of evidence showing ADHD is a common and impairing problem faced by young people; thus, there is a pointed interest in alleviating the deficits experienced by these youth. Several efficacious treatment methods exist to accomplish this, including pharmacological and behavioural management treatments, yet they all have shortcomings, such as exacerbating mood disturbances and/or being inaccessible to those of lower socioeconomic status (Cormier, 2008; Evans et al., 2014). Therefore, there is an ongoing search to find effective ADHD interventions that can supplement and/or replace existing ones (Chimiklis et al., 2018).

Mindfulness Meditation (MM) has begun to receive attention as a potential intervention for ADHD. Historically rooted in Buddhist practices, MM interventions are secular, standardized exercises in which nonjudgmental attention to experiences in the present moment is cultivated (Bodhi, 2011; Kabat-Zinn, 1992). MM emphasizes placing attentional awareness on the present moment while deliberately remaining open to feelings and emotions that arise (Kabat-Zinn, 1992; Michell et al., 2015). The majority of research in this area has focused on the impact of long-term MM interventions (i.e., weeks- or months-long). There has been a dearth of literature, however, devoted to understanding how a single MM bout impacts the neurocognitive and psycho-emotional functioning of children with ADHD. This thesis aims to address these gaps by 1) investigating the impact of a single MM bout on the cognitive functioning of children with ADHD; 2) using advanced neuroimaging to examine how a single MM bout impacts the attention-center of the brain (i.e., prefrontal cortex) and corresponding cognitive functions; and 3) examining how a single session of MM not only impacts neurocognitive functioning, but also aspects of psycho-emotional functioning such as self-efficacy, mood, motivation and affect. The following literature review will delve into the neurological basis of ADHD, the current interventions used to combat ADHD symptomology, the potential of MM as an intervention for ADHD, including its impact on neurocognitive and psycho-emotional functioning, and whether it is conducive to being administered in brief bouts.

Literature Review

Neurological Correlates of ADHD

The neurological basis of ADHD remained unclear until the early 20th century. A shift in understanding occurred when doctors noticed that patients with injuries to the frontal lobe displayed similar symptoms to those with ADHD (Anastopolous et al., 1994; Still, 1902). This led to the pervasive belief that children's inability to control their behaviour was the result of brain injury because both brain-injured patients and children with behavioural control issues struggled with deficits in executive functioning (Anastopolous et al., 1994; Strauss & Lehtinen, 1948). Executive functions are high-level cognitive abilities that directly and indirectly enable the regulation of thoughts and actions during goal-directed behaviours (Friedman & Miyake, 2017). They can serve as a proxy for global cognition (e.g. Gujral et al., 2014), and will be considered in further detail.

Executive Functions

Although it is now understood that ADHD is not the result of brain injuries, the disorder is nonetheless cognitively characterized by deficits in the brain's executive functioning (Diamond, 2013). There are key executive functions related to ADHD that repeatedly appear in the literature (Diamond, 2013). These are: 1) inhibitory control, the ability to intentionally restrain responses that are not useful; 2) sustained attention, the ability to focus on an activity or stimulus over a long period of time; 3) task switching (i.e. cognitive flexibility; the flexibility and capacity to switch focus in a fluid environment; and 4) working memory, the temporary storage and maintenance of limited amounts of information that can be accessed quickly (Barkley, 1997; Diamond, 2013; Miyake et al., 2000).

Deficits in executive functioning are linked to poor academic achievement, impaired school functioning, and lower intelligence scores (Biederman et al., 2006; Titz & Karbach, 2014). Lower socioeconomic status, poorer educational and occupational attainment, and maladaptive social behaviour are also associated with impairments in executive functions, which can be compounded by the additional presence of ADHD symptomology (Biederman et al., 2006). After noticing the consistency between patients with frontal lobe damage and ADHD, neuropsychological researchers speculated that ADHD and executive functioning deficits were rooted in frontal lobe abnormalities (Anastopolous et al., 1994; Miyake et al., 2000). Modern imaging research supports this contention; executive functioning deficits associated with ADHD indeed seem to be, in part, rooted in neurobiological dysfunction within the prefrontal cortex (PFC), which resides in the frontal lobe (Arnsten & Li, 2005).

Prefrontal Cortex

The PFC is a brain region involved in several cognitive functions such as analytical thinking, emotional control, memory forming abilities, and communication (Plakke & Romanski, 2014). The core symptoms of ADHD—impulsivity, inattention, and hyperactivity—have been posited to arise from weakened PFC regulation due to insufficient structural and functional circuitry, and reduced neural activity (Arnsten & Li, 2005; Yu-Feng et al., 2007). This assertion has been supported by studies showing that individuals with damage to the frontal lobes have difficulties performing executive tasks involving behavioural control and regulation (Friedman & Miyake, 2017; Miyake et al., 2000). Lesions in the PFC have also been shown to adversely impact executive functioning, resulting in forgetfulness, distractibility, impulsivity, and disorganization (Arnsten & Li, 2005). Imaging studies involving MRI, fMRI, and EEG have revealed that the right PFC—the region associated with inhibitory control—is often underdeveloped among those with ADHD (Casey et al., 1997; Overtoom et al., 2002; Sowell et al., 2003). A review by Seidman and colleagues (2005) found that at least one of the five PFC compartments had smaller volumes in children with ADHD compared to controls. Given the strong link between ADHD and the PFC, pharmacological and behavioural interventions aimed at treating ADHD symptomology often target PFC functioning.

Extant Interventions

ADHD interventions are aimed at alleviating the impairments associated with the disorder. They can be roughly divided into pharmacological and behavioural categories.

Pharmacological Interventions

In 2007, 59% of Canadian children with ADHD were treated with medication, and this number is now likely greater (Brault & Lacourse, 2012; Feldman et al., 2018). Although there are a variety of pharmacological interventions available (e.g. tricyclic antidepressants, monoamine oxidase inhibitors (MAOIs), atomoxetine), stimulants (methylphenidate and amphetamines) are the most prescribed and efficacious medicinal treatment for the majority of individuals with ADHD (Shier et al., 2013). As such, they are considered the first-line pharmacological agents for treating ADHD (Pliszka, 2007). Stimulants elicit the release of monoamines in the brain, resulting in increased levels of norepinephrine and dopamine, particularly in the PFC (Shier et al., 2013). Increases in these neurotransmitters seem to increase inhibitory control and decrease impulsivity (Advokat & Scheithauer, 2013). The data in support of stimulants are robust; teachers, parents, and children have all reported that they reliably reduce inattentive and hyperactive symptomology (Charach et al., 2004, Shier et al., 2013). Indeed, many parents contend their children could not reach his or her full potential without stimulants (Charach et al., 2014).

Despite the decrease in ADHD symptomology, it is unclear whether stimulants improve academic performance (achievement test scores, grades, and grade retention; Langberg & Becker, 2012). Moreover, the use of stimulants to treat ADHD is associated with undesirable side-effects, including stomach aches, loss of appetite, tics, insomnia, headaches, amplified irritability, increased heart rate and blood pressure, and greater emotionality (Pliszka, 2007). There are reports of sudden deaths resulting from stimulants when individuals have unknown underlying cardiac problems (Nissen, 2006; Shier et al., 2013) This is especially problematic considering that up to 30% of children do not respond to stimulants but can still experience their side effects (Ogrim et al., 2016). Stimulants also fail to treat the anxious or depressive symptoms often comorbid with ADHD (Cormier, 2008). Additionally, there is evidence that stimulants are over-prescribed, which can lead to abuse, particularly among youth who knowingly use them for non-clinical purposes (Connor, 2011; Kaye & Darke, 2012). With these various drawbacks considered, some parents are weary of medicinal treatments, preferring to rely on non-pharmacological methods when possible (Chacko et al. 2014). Given the need for alternatives, there is an ongoing search to find efficacious and complementary treatments for ADHD (Chacko et al. 2014).

Behavioural Interventions

Behavioural Management treatments are the most widely used and efficacious non-chemical treatment for ADHD (Pfiffner & Haack, 2014). In contrast to pharmacological interventions that work by reducing ADHD symptomology, Behavioural Management treatments focus on decreasing the functional impairments faced by individuals with the disorder (Pfiffner & Haack, 2014). Behavioural Management involves teaching caregivers to modify behavioural contingencies within the environments where children function (Evans et al., 2014). For example, parents may reward their daughter with outdoor play when she resists distraction, sublimates her fidgetiness, and sits down to complete her homework. They do not try and eliminate her hyperactivity and inattention entirely; rather, they redirect and postpone it. Behavioural Management can effectively address noncompliance, lack of dependence, homework problems, and aggression (Pfiffner & Haack, 2014). Some studies, however, suggest that changes in symptoms do not generalize to settings outside of where the behaviours were learned or to behaviours that were not targeted (Rajwan et al., 2012). Also, these treatments can be costly and require an extensive time commitment (Evans et al., 2014).

Due to the success of Behavioural Management, other behavioural therapies have become increasingly common to address ADHD, particularly Cognitive Behavioural Therapy (Evans et al., 2014). This “brain training” involves targeting the low self-esteem and negative thoughts that often co-occur with ADHD by changing the negative thinking patterns that individuals have related to themselves, their abilities, and their future (Sherman et al., 2019). Habitual pessimistic cognitive distortions, especially surrounding planning, disorganization, and poor time and task management are common for those with ADHD; cognitive behavioural therapy involves recognizing these automatic distortions and replacing them with realistic thinking (Sherman et al., 2019. Unfortunately, these treatments can also be demanding both financially and temporally, thus limiting their accessibility (Evans et al., 2014). Over the last several years, MM has received attention in both public and academic spheres as a promising alternative or adjunct treatment for ADHD with fewer limitations than existing behavioural interventions.

Mindfulness Meditation (MM)

MM helps combat several ailments and promote overall well-being in "healthy" individuals (Arias et al., 2006) as well as in clinical populations. For example, MM has clinical utility for those suffering from mood disorders (Farb et al., 2012), eating disorders (Hernando et al., 2019), substance use disorders (Black, 2014), and post-traumatic stress disorder (Kearney et al., 2013). MM also generally leads to substantial improvements in cognitive and psycho-emotional functioning (Mitchell et al., 2015; Lynch et al., 2018). We will now closely examine the benefits in these domains and consider potential mechanisms for their occurrence.

Cognitive Benefits of MM

An abundance of literature indicates that MM can ameliorate cognitive deficits associated with ADHD such as inattention and hyperactivity (Mitchell et al., 2015). This has been compellingly shown in clinical and non-clinical populations (Chimiklis et al., 2018; Valentine & Sweet, 1999). The reasons for these findings, however, are less clear. Hölzel and colleagues (2011) sought to better understand why MM supports cognitive functioning by reviewing decades of research, resulting in a foundational hypothesis. These researchers suggested MM produces benefits due to four distinct cognitive mechanisms mutually interacting to enhance self-regulation. These mechanisms are attention regulation, body awareness, emotion regulation, and change in self-perspective (Hölzel et al., 2011). The four components have disparate neurological underpinnings and contribute independently to the practice of MM. They are worth discussing in further detail.

Attention Regulation. Attention regulation is the ability to persistently focus attention on a chosen object, and the ability to return attention to the object when the mind wanders. It is vital to most types of MM (e.g., focused-attention meditation) and is considered a building block upon which other MM aspects are built (Lutz et al., 2008). The practice of regulating attention enables meditators to focus their attention for longer periods and avoid more distractions than non-meditators (Barinaga, 2003). Several studies have shown meditators have enhanced attentional performance and sustained attention (e.g. Slagter et al., 2007; Semple, 2010).

Neuroimaging research shows that the anterior cingulate cortex is the primary brain structure that facilitates attention regulation (van Veen & Carter, 2002). The anterior cingulate cortex activates during MM, enabling meditators to avoid distraction; then, through top-down regulation, other neurological systems are alerted to maintain focus, including the PFC (Tang et al., 2015; van Veen & Carter, 2002). Given that individuals with ADHD tend to have attentional focus deficits that directly lead to adverse outcomes—e.g., they are four times more likely to be in car accidents, which tend to be more severe (Bernfort et al. 2008)—the finding that MM seems to enhance attentional focus may partially explain the benefit of MM for those with ADHD (Keith et al., 2017; Slagter et al., 2007).

Body Awareness. Body awareness, the ability to notice subtle bodily sensations, is closely linked to proprioception—the sense of the position of limbs, fingers, and other parts of the body in space (Mehling et al., 2009; Sanz-Cervera et al., 2017). There is an indication that individuals with ADHD are deficient in these domains, perhaps due to a lack of insight into their bodily experiences (Sanz-Cervera et al., 2017). During many types of MM, attention is intentionally brought to somatic experiences like breathing, tingling, and muscle tension. Experienced meditators report more awareness and differentiation in bodily experiences than non-meditators (Hölzel et al., 2011). This has been experimentally demonstrated with the rubber hand illusion, a paradigm used to understand the mechanism of body awareness; those with MM practice report less agency over the rubber hand, indicating an increase in their sense of proprioception (Cebolla et al., 2016; Farb et al., 2015; Longo et al., 2008). Because those with ADHD tend to have less body awareness than their neurotypical counterparts, MM may be beneficial for these individuals because of its positive impact on body awareness (Cebolla et al., 2016; Sanz-Cervera et al., 2017). To this end, Sanz-Cervera and colleagues (2017) advise children with ADHD to learn relaxation and insight techniques to better feel and understand their body.

Emotion Regulation. Emotion regulation involves initiating, avoiding, inhibiting, maintaining, or modifying the, form, intensity, or duration of feelings, emotion-related physiological responses, attentional processes, and/or motivational states (Eisenberg & Spinrad, 2004). It is a central MM component and may explain why MM reduces stress and depressive symptoms, as research has shown that long term meditators show reductions in emotional interference, negative mood states, distracted and ruminative thoughts, as well as improved mood states (Garland et al., 2011; Jha et al., 2010; Shahar et al., 2010). This likely happens through MM facilitating reappraisal (stressful events being reconstrued as beneficial), and exposure (letting oneself be fully affected by an experience without internally reacting towards it; Hölzel et al., 2007; Hölzel et al., 2011).

MM decreases amygdala activation, which is the region of the brain responsible for emotional control (Harenski & Hamann, 2006; Hölzel et al., 2011). The PFC appears to exert inhibitory top-down control on the amygdala during MM, allowing for meditators to develop an objective view of their emotions (Hölzel et al., 2011). In other words, the neurological region responsible for logic overrides the region responsible for emotion. Meditators can control their emotions rather than being subservient to them. It is well-established that ADHD is marked by emotional dysregulation (Shaw et al., 2014); those with ADHD show increased emotional impulsiveness and emotional liability (i.e., irritability, hot temper, low frustration tolerance; Barkley & Fischer, 2010). Considering the beneficial effect MM appears to have on emotional regulation, this is yet another explanation for why MM is beneficial for those with ADHD.

Change in Self-Perspective. A less obvious, yet crucial goal of MM is to cultivate internal awareness (Hölzel et al., 2011). One gains meta-awareness and improved self-reference through MM; individuals can experience mental processes with more clarity and detachment from their typical identity (MacLean et al., 2010). This process is called “decentering” (Fresco et al., 2007). Although this notion is difficult to operationalize, there are self-reports, questionnaires, and cross-sectional studies indicating changes in self-concept are common, attainable, and sustainable with MM practice (Emavardhana & Tori, 1997; Haimerl & Valentine, 2001; Kerr et al., 2011).

Self-referential processes are believed to implicate the Default Mode Network (DMN; Hölzel et al., 2011). The DMN is a brain network that includes midline neurological structures like the medial PFC, posterior cingulate cortex, and inferior parietal lobule. The DMN is usually active during rest, and inactive during task performance (Bachmann et al., 2016). Meditators display more resting connectivity within the DMN than non-meditators, signifying they are experiencing increased control (Brewer et al., 2011; Jang et al., 2011). After an 8-week MM intervention, Farb et al. (2007) observed that participants showed a neurological shift in activation toward lateral prefrontal brain regions, providing evidence that MM relaxes the DMN. This also suggests a detachment from the concept of self and somatic events (Farb et al., 2007). Acquiring self-reference may be helpful for those with ADHD because, in addition to lacking external reference, they may also lack internal reference (Klein et al., 2011). This may be due to ADHD compromising their memory; i.e., they have difficulty recalling episodes that provide evidence of their internal qualities. This may be yet another causal pathway accounting for MM's benefits among those with ADHD, as there is a good indication that MM enhances self-reference.

Despite this abundance of research, elucidating the mechanisms underlying these changes remains challenging because there are likely several co-occurring conduits accounting for MM's impact on cognitive functioning (Tang et al., 2015). MM involves many aspects of cognition involving multiple interactive neural networks; thus, it has widespread effects on brain structure and corresponding cognitive function (e.g. Tang et al., 2015; Lazar et al., 2005).

The implication of the PFC, however, remains consistent throughout the literature. Individuals with experience in meditating have increased cortical thickness in the PFC (Lazar et al., 2005) and enhanced activation of the greater dorsolateral PFC and the ventrolateral PFC during emotional and executive processing (Allen et al., 2012; Tang et al., 2015). It is important to note that the reviewed research thus far has all used experienced meditators and/or graduates from meditational programs and interventions as participants. The cognitive and neurological effects of a single MM bout is understudied and requires attention.

Psycho-emotional Benefits of MM

MM has also led to psycho-emotional benefits in clinical and non-clinical populations (Lynch et al., 2018; Chimiklis et al., 2018). In their meta-analysis including 37 studies, Lynch et al. (2018) concluded that MM improves anxiety, stress, depression, burnout, anger, and psychological distress amongst healthy participants. These conclusions were tentative, however, as the studies reviewed were low quality insofar as they inadequately reported on adherence to meditation practice, rarely reported transparently on their methodology, underreported outcome measures, and generally lacked clarity (Lynch et al., 2018). Despite these studies' shortcomings, comparable results were found after an 8-week MM training intervention for youth with externalizing disorders. Researchers reported improvements on ratings of personal goal achievement, happiness, mindful awareness, attunement to others, and withdrawal (Bögels et al., 2008).

Congruently, psychological states such as affect, mood, and general self-efficacy have been shown to improve following MM (Charoensukmongkol, 2014; Economides et al., 2018; Lacaille et al., 2017). These conclusions, however, were drawn from work that lacked a control group (Economides et al., 2018), used a paradigm wherein MM was completed daily for 50 days (Lacaille et al., 2017), or from self-report research (Charoensukmongkol, 2014). Social outcomes also appear to be favourably impacted by MM; participants in a 3-month meditational retreat reported meaningful and lasting improvements on aspects of social functioning (e.g. empathy, extroversion, agreeableness, conscientiousness, and openness to experience; Sahdra et al., 2011). The vast majority of research examining the psycho-emotional impact of MM involves long-term

MM training paradigms; the scientific community has yet to definitively determine whether there are immediate benefits gained from a single bout of MM, and whether this is true for an ADHD population.

Similar to our understanding of the mechanisms underlying the benefit of MM on cognitive functioning, it also remains unclear exactly why MM supports psycho-emotional functioning. Some researchers hypothesize that MM stimulates psycho-emotional regulation by strengthening the mechanisms of prefrontal cognitive processes that downregulate activity in regions relevant to affective processing (e.g. the amygdala; Tang et al., 2015). This process is especially salient for novice meditators, as they need to consciously overcome habitual reactions to internal emotions, requiring increased PFC engagement (Allen et al., 2012; Tang et al., 2015). Effortful control over emotional states may result in further awareness that, in turn, increases sensitivity to affective cues, thereby promoting cognitive control and increasing attentiveness to surroundings (Teper et al., 2013). By promoting distance from one's emotions through encouraging focus on the present moment, MM allows for emotional regulation in the presence of emotionally suggestive stimuli (Teper et al., 2013). This means that MM does not reduce initial affective reactions— the initial pang! still occurs—but it helps mitigate negative consequences of their enduring effect by promoting executive functions that increase affective regulation (Teper et al., 2013). Individuals who meditate become more aware of their psychological states and are therefore more capable of distancing themselves from them in order to better to regulate their affect, reactions and mood. This finding is salient considering the aforementioned persistent challenges individuals with ADHD have with emotional regulation (Barkley & Fischer, 2010; Shaw et al., 2014).

Benefits of Mindfulness Meditation Interventions for ADHD

Given that children with ADHD often have deficits in executive functioning, and MM has been shown to support executive functioning, it is unsurprising that MM-based interventions appear to be efficacious treatments for those with ADHD (Chimiklis et al., 2018). Indeed, the findings in support of MM benefiting individuals with ADHD are robust. Many researchers attribute the benefits of MM in ADHD populations to its impact on their executive functioning (Chiesa et al., 2011). This was demonstrated by Zeidan and colleagues (2010) who used a randomized control methodology and found that four sessions of MM training improved executive functioning in undergraduates with ADHD who were novice meditators. They theorized this occurred because MM simultaneously promotes a vigilant and relaxed state of mind—a combination that enhances executive functioning by promoting attention (Moore & Malinowsky, 2009). In another study, after an 8-week meditation program for adults and adolescents with ADHD, participants reported decreases in ADHD symptoms, anxiety, and depression. They also improved on cognitive tests measuring attentional control, inhibition, and self-regulation (Zylowska et al., 2008). In a newer study, researchers observed ADHD symptomology reductions in adolescents following a similar 8-week MM program (Van de Weijer-Bergsma et al., 2012). Meta-cognitive problems were also decreased, and behavioural regulation was increased immediately and after an 8-week follow-up (Van de Weijer-Bergsma et al., 2012). In the most recent research into MM interventions for ADHD, Kiani and colleagues (2017) found that a group-based meditational program for children with elevated ADHD symptoms increased inhibition and planning.

Chimiklis et al. (2018) analyzed eight studies, wherein participants ranged from five to 17 years old, to determine the effect MM has on young people with ADHD. Indeed MM-based interventions decreased ADHD symptoms. Specifically, MM was associated with enhanced executive functioning and on-task behaviour, decreased parental stress, and improved parent-child relationships (Chimiklis et al., 2018). However, the authors caution that their conclusions be interpreted with caution, as the studies assessed had small sample sizes, lacked control groups, and used non-manualized treatments (i.e., treatments that are difficult to replicate as they do not follow a strict protocol). Chimiklis and colleagues (2018) highlighted the need for more robust studies with larger sample sizes that use manualized treatments and randomized control trials. All evidence reviewed thus far comes from research on experienced mediators versus non meditators, or experimental MM bouts that are either short term (4 days to one week) or long term (months to years). More work is needed assessing the impact of single MM sessions (Colzato et al., 2016).

Brief MM Bouts

It is often assumed that a significant time commitment is required to reap the benefits of meditation, but there is preliminary evidence indicating a single bout may be enough to support cognitive and psycho-emotional functioning (Howarth et al., 2019; Colzato et al., 2016; Johnson et al., 2015). Colzato et al. (2016) gave meditators a cognitive task wherein they had to quickly identify whether shapes were congruent or incongruent after a single MM bout. Cognitive control was significantly improved following the single 17-minute MM session (Colzato et al., 2016). Similarly, Luu and Hall (2017) found that after one 25-minute MM bout, executive functioning was enhanced (assessed by Stroop Task performance). Participant mood also improved following the brief MM session (Luu & Hall, 2017). Another recent study looking at single meditational bouts found consistent results: One 10-minute session of MM significantly increased the overall mood-state of college students compared to an active control group (Edwards et al., 2018). Johnson and colleagues (2015) also found one 25-minute MM bout to significantly improved Profile of Mood States scores compared to a sham meditation. Specifically, reduced tension, confusion and total distress were reported by meditators (Johnson et al., 2015). However, Johnson et al. (2015) also assessed the impact of the single bout on aspects of cognition (i.e. working memory, concentration, visual tracking, and word retrieval), and found that performance was unaffected. They speculated that one MM session was not enough to impact these processes (Johnson et al., 2015). Howarth and colleagues (2019) recently reviewed 85 “brief” mindfulness-based interventions—classified as 30 minutes or less on any one occasion, totaling no more than 100 min per week, and lasting up to 4 weeks—and found encouraging results: 93% of the studies reported positive results in psychological, emotional, and cognitive domains. However, almost all of the studies targeted healthy young adult populations, and still had some outcomes that were mixed significance and/or non-significant (Howarth et al., 2019).

Research on the effects of brief meditational bouts is clearly preliminary, and more is required to substantiate the effect of a single MM session on cognitive and psycho-emotional functioning (Colzato et al., 2016). Moreover, to our knowledge, there is no work examining how one MM bout affects children with ADHD. Our specific contributions to the literature will now be discussed.

Present Study

Contribution

We intend that our study’s contributions to the literature are threefold. First, we aim to identify whether a single, short bout of MM can improve the executive functioning of children with ADHD. Although it is often assumed that long durations of time are required to reap the benefits of meditation, there is evidence indicating an acute bout may be enough to positively impact cognitive processes (e.g. Colzato et al., 2016; Luu & Hall, 2017). If this is the case, we would be able to inform extant interventions, or create new ones, to optimize application to children with ADHD.

Second, we are using cutting-edge neuroimaging to improve the understanding of whether MM supports executive functioning through its effect on PFC functioning. Tang and colleagues (2015) call for more research investigating the underlying neurological mechanisms of MM, specifically those connecting neuroscientific findings with tangible behavioural data. Although there is considerable evidence that MM positively impacts executive functions, it is still unclear whether dynamic changes in PFC activity are the underlying neural process that drive those changes. This is relevant to ADHD populations, because it would lend support to MM as an alternative treatment that targets PFC activity and potentially improves executive functions beyond current treatments.

Third, we aim to determine whether a single MM bout impacts the psycho-emotional functioning of children with ADHD. This is crucial given the litany of psycho-emotional deficits experienced by children with ADHD (Barkley et al., 1990). There is research demonstrating that MM programs can improve psycho-emotional outcomes for children (e.g. improve mood, affect, self-efficacy, and motivation), but there is only minimal work showing whether a single session has a similar impact. Considering the potential benefits of a single MM paradigm (compared to an extensive program), and the importance of alleviating psycho-emotional stressors for children with ADHD, this study could help inform ways to improve the quality of life for children with ADHD.

Research Questions and Hypotheses

1) *How will a single MM bout impact the executive functions of children with ADHD?*

MM has been shown to promote higher order executive processes (Zeidan et al., 2010). Thus, we anticipate that a single MM bout will improve the executive functioning of children with ADHD, including their inhibitory control, working memory, sustained attention, and attention shifting.

2) How will a single MM bout impact the executive functions of children with ADHD?

In line with previous research, it is anticipated that improvements in executive functioning will be underpinned by increased PFC activation relative to other brain regions (Allen et al., 2012; Tang et al., 2015).

3) How will a single MM bout impact the psycho-emotional functioning of children with ADHD?

We expect that one MM bout will positively impact the psycho-emotional functioning of children with ADHD (i.e. their mood, affect, motivation, and self-efficacy). This prediction is consistent with research demonstrating the positive impact of MM on various disorders, psychological states, and social outcomes (e.g. Luu & Hall, 2017; Johnson et al., 2015).

Methodology

Participants

Our sample included 16 children diagnosed with ADHD. A sample size calculation was performed using G*Power with medium to large effect size Cohens *d*= 0.6-1, power of 0.95, alpha of 0.05, with primary outcome variable as change in executive functioning, indicating 16-20 participants were needed. Our goal was to recruit 20 participants, but we were only able to recruit 16. All participants were between 10 and 14 years old (M = 11.38; SD = 1.5). There were 12 males and 4 females in our sample, reflecting the common discrepancy in ADHD diagnosis with males diagnosed more often than females (Nøvik et al., 2006). Factors such as race, ethnicity, and religion were not relevant for inclusion; however, participants were excluded if they were not fully literate and/or did not speak English, if they had any neurological and/or developmental exceptionalities beyond ADHD, and if they were colour-blind (as it would interfere with their performance on the cognitive tasks). See Table 1 for a detailed breakdown of our sample's demographics.

Materials

Cognitive Assessments.

Stroop Task (Stroop, 1935). The Stroop Task is a non-invasive measure commonly used to assess the executive funning of children with ADHD (Yasumura et al., 2014). It reliably measures inhibitory control in this population (Yasumura et al., 2014). The first component of the task, the Congruent Stroop Task (Appendix A), requires participants to read as many words as they can on a list aloud for 30 seconds. The words are also colours, and they match; the word *red* is printed in red, for instance. They must simply say "red". The second part, the Incongruent Stroop Task (Appendix B), involves participants quickly reading aloud a list of colours that are mismatched to the colour in which they are printed. The participants are instructed to say the colour in which the word appears and inhibit their natural impulse to say the colour that is written. For example, if the word *red* is printed in blue, the participant should say "blue". Participants had 150 seconds to read as many words as possible. The number of errors made, and proportion of words read correctly were the outcome measures for both Stroop Tasks.

Trail Making Test (TMT; Reitan, 1955). The TMT also consists of two parts. The first part, TMT-A (Appendix C), measures sustained attention; the second part, TMT-B (Appendix D), measures task switching (i.e. cognitive flexibility; Reitan, 1955; Rosin & Levett, 1989). The measure has been used as a valid and reliable indicator of executive functioning in ADHD populations (Perugini et al., 2000). TMT-A requires participants draw one sequential line as quickly as possible to connect 25 encircled numbers that are distributed randomly on a piece of paper. TMT-B is similar, except participants alternate between connecting 25 numbers and letters (i.e., 1, A, 2, B, 3, C, etc.). The amount of time each participant took to complete the task, and the numbers of errors made were recorded.

Leiter-3 Reverse Memory Subscale (Roid & Koch, 2013). We used the reverse memory subscale of the Leiter-3 International Performance scale to assess working memory. The task is a complex mental activity that taps into the ability to mentally store and manipulate information (Roid & Koch, 2013). A popular tool in the assessment of children with disabilities in clinical and research settings, it is a reliable indicator of working memory capacity and has been validated with ADHD populations (Farmer, 2013; Roid & Koch, 2013). The task involves picture matrices of varying sizes (2x2; 2x6) being laid out in front of the participant (Appendix E). The experimenter then points to pictures in a pre-established sequence; the participant must point to the pictures in reverse order of what was presented. The number of pictures that need to be recalled in reverse order gradually increases from 2-9. After six errors, the final number of correctly recalled sequences is recorded.

Psycho-emotional Assessments

Mood. Mood was assessed using William et al.’s (2001) Adapted Version of the Profile of Mood States (Appendix F). Participants indicated the extent they were currently experiencing the presented mood on a 5-item Likert scale, ranging from 1 (“not at all”) to 5 (“extremely”). We assessed six positive moods (e.g., happy, energetic, friendly) that made up a “positive mood” construct, and five negative moods (e.g., sad, lonely, unhappy) that made up a “negative mood” construct. Participants’ mood states were evaluated at the beginning and end of the experimental protocol (see Appendix G for flow of protocol).

Affect. Affect was measured using Hardy & Rejeski's (1989) Feeling Scale (Appendix I). Participants indicated how they were feeling at the given moment on an 11-item Likert scale ranging from -5 ("very bad") to +5 ("very good") where 0 is neutral. This was used to assess how participants were feeling before and after every cognitive task (see Appendix G).

General Self-efficacy. We used Chen and colleagues' (2001) General Self-Efficacy scale (Appendix H) to assess participant's self-efficacy at the beginning and conclusion of the experimental protocol (identical to how mood was assessed). To do so, participants indicated the extent they agreed with 8 statements relating to general self-efficacy on a 5-item Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). For example, one statement was: *I will be able to successfully overcome many challenges.*

Motivation. The Effort and Importance subscale from the Intrinsic Motivation Inventory (Appendix J) was used to assess participants' motivation to complete and execute the cognitive battery at a high level (McAuley et al., 1989). Participants indicated how true 5 statements were for them on a 7-point Likert Scale, ranging from 1 ("not at all true") to 7 ("very true"). Items related to their effort level, their energy expenditure, and their appraisal of the importance of the tasks. For example, one item states: *I am going to try very hard on these brain games.* These data were collected prior to and following each cognitive battery (see Appendix G). For items presented after the cognitive battery, the original items were modified so they referred to the completed tasks, such as *I tried very hard on the brain games.*

Equipment

fNIRS Neuroimaging Device. A multichannel continuous wave fNIRS device (NIRScout; NIRx Medical Technologies, Brooklyn, NY) was used to measure hemodynamic cortical variations in key neurological regions. Specifically, data were obtained from the PFC (region of interest) and the motor cortex (control region). The motor cortex was used as a control region so that any apparent change in PFC hemoglobin levels could be attributed to the PFC in particular, not to overall hemoglobin deviations (e.g. Tang et al., 2016). The montage used was comprised of 16 dual-wavelength sources (760 and 850 nm) and 16 detectors that were each separated by 3 cm, an optimal distance for balancing depth sensitivity with signal to noise ratio (Strangman et al., 2013).

fNIRS measures changes in hemoglobin concentrations in the blood, a molecule that carries oxygen in the brain, which is an indirect measure of brain activity (Tupak et al., 2012). Oxygenated hemoglobin reflects the inflow of oxygen into neural tissue, whereas deoxygenated hemoglobin reflects the amount of oxygen that is absorbed by the tissue. In homeostasis, both the inflow of oxygenated hemoglobin and the formation of deoxygenated hemoglobin should be constant, as the amount of oxygen being consumed by the tissue is equal to the amount of oxygen being carried towards the tissue. During activation of the tissue (e.g., excitation of brain areas), oxygen is consumed within the tissue and hemodynamically the tissue responds by increasing the flow of blood toward that tissue (referred to as neurovascular coupling; Tupak et al., 2012). Representing both oxygenated and deoxygenated hemoglobin provides the most information about changes in blood volume in the tissue underneath the sensors (Herold et al., 2018).

During fNIRS data collection, infrared emitting optodes sit on the surface of the scalp and pass light through the skin and skull, which is then absorbed by the underlying neural tissue at varying concentrations (depending on the amount of blood within a region; Pinti et al., 2018. When the light reaches the detectors, the amount of light that was absorbed by the underlying neural tissue is used to calculate changes in oxygenated and deoxygenated hemoglobin concentration. Optical data was collected by the detectors at a sampling rate of 62.5 Hz and was converted into a measure of hemoglobin signal using the modified Beer-Lambert Law (Delpy et al., 1991).

The sources and detector optodes are embedded into a soft, snug cap that is placed on a participant's head (see Appendix K for equipment schematics). Because it is comfortable to wear, fNIRS is generally accepted by participants (Pinti et al., 2018). fNIRS is also less restrictive, expensive, and sensitive to motion artifacts compared to other imagine techniques (e.g., fMRI; Pinti et al., 2018; Tupak et al., 2012). Accordingly, fNIRS is considered a valuable and safe imaging technique with clinical populations, including those with ADHD (Schecklmann, et al., 2010).

fNIRS Data Preprocessing. The NIRx open-source nirsLAB software package (https://nirx.net/nirslab-1) was used to process the fNIRS data. The modified Beer-Lambert Law was used to convert optical density data into hemoglobin signals in millimole units (Delpy et al., 1991). Raw data were bandpass filtered with a consistent high cut-off frequency of 0.01 Hz, and a variable low cut-off frequency ranging between 0.00038 HZ - 0.0007 HZ depending on how long each participant took to complete the experimental session. The bandpass filter was used to remove baseline drift and some physiological noise (e.g., heart rate). Both oxygenated hemoglobin and deoxygenated hemoglobin were used in analyses.

fNIRS Channel Exclusion. A total of 55 channels comprised the PFC and motor montage. Channels 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 35, 43, and 54 corresponded to the PFC region; channels 29, 30, 31, 32, 33, 34, 36, 37, 38, 39, 40, 41, 42, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, and 55 corresponded to the motor region. Each channel was evaluated for signal quality using the coefficient of variation

(CV) method. The CV value was set to 15, which is commonly used in other fNIRS studies (e.g. Kenville et al., 2017; Piper et al., 2014), and any channel that exceeded that value was removed from further fNIRS processing. All data were then exported into an excel macro that was designed to selectively average the oxygenated and deoxygenated hemoglobin concentration during the different cognitive tasks.

Smiling Mind Mobile Application. Smiling Mind (Smiling Mind Pty Ltd, 2015) is a free, CBT-based MM mobile application. It has been empirically established as an efficacious tool (Bakker et al., 2016). There is evidence that it can improve—and maintain improvements—in anxiety and depressive symptoms, resilience, and overall mental health for youth (Flett et al., 2018; Bakker et al., 2016). The specific MM used was called "A Longer Bubble Journey" (Appendix L). It was selected because it was a focused-attention, age-appropriate MM for our sample. It is 10-minutes long and a male voice guides the listener in a body scan while maintaining a focus on their breath. Listeners are instructed to attend to specific aspects of their present experience and bodily functioning by following a bubble's journey throughout their body.

Design

We used a counter-balanced within-subjects design wherein each participant participated in each experimental condition. It consisted of 3 sessions separated by 1 week. Day 1 was a familiarization session; day 2 was an experimental (MM) or control session (silent reading of a self-selected age-appropriate magazine); day 3 was also an experimental or control session, whichever condition was not previously administered. Day 2 and day 3 were counterbalanced across participants.

Procedure

Children with an ADHD diagnosis between 10-14 years of age were recruited from the Child and Youth Developmental Clinic at Western University and Western's Mary J. Wright Research and Education Centre at Merrymount through paper (Appendix M) and e-mail advertisements (Appendix N), as well as throughout the community of London, Ontario via recruitment flyers. All participants were asked to refrain from taking medication for 24 hours prior to coming to the lab. This was done to mitigate potential confounding factors that occur when some participants are medicated, and others are not. Prior work has followed a similar procedure (see Willcutt et al., 2007).

Day 1: Familiarization and Questionnaires

Participants and their guardians visited the lab for approximately 45 minutes. They were told about the study's protocol and what to expect on each day of their visit. Guardians were provided with a Letter of Information/Consent form; children were provided with a Letter of Information/Assent.

Parent Protocol. Following obtaining informed consent, one researcher helped guardians complete two assessments to verify their child's ADHD status (the results of these assessments are displayed in Tables 2 and 3). This was necessary as those within the experimental condition needed to have an ADHD diagnosis in order for our claims to be valid for the relevant population. In consultation with a Clinical Child Psychologist, we used the Vanderbilt Parent Rating Scale (VADPRS) and the Behaviour Rating Inventory of Executive (BRIEF) as ADHD assessments. The VADPRS includes all 18 of the DSM-V criteria for ADHD. The assessment asks parents to rate the severity of several behaviours on a 4-point Likert scale, ranging from "never" to "very often". An ADHD diagnosis is considered present if scores indicate that a behaviour occurs "often" or "very often" for the requisite number of criteria. Using parental ratings, The BRIEF is designed to provide an understanding of the child's executive functions in routine situations. The BRIEF is another indicator of the presence of ADHD, as those with ADHD typically score in the clinical range due to executive functioning deficits (Shimoni et al., 2012). This 86-item questionnaire measures eight different aspects of executive functioning, including inhibition, shifting, emotional control, initiation, working memory, planning and organization, order and organization, and monitoring. Finally, guardians completed the aforementioned Demographic Questionnaire (results in Table 1), as well as a Medication Questionnaire (results in Table 4). Note that the VADPRS and BRIEF were used to get a sense of our participants holistically and the precise challenges they experienced; however, these data were not used in analyses or interpretations during the current project. Future work will look to examine whether differences in ADHD categorization and symptomology led to variance in outcomes.

Child Protocol. Meanwhile, another researcher familiarized the participant with the study. This first involved measuring the circumference of the participant's head to determine the size of fNIRS cap to be used in subsequent days. Next, practice trials with the cognitive battery were completed until the participant understood the tasks. Participants were then acquainted with the fNIRS neuroimaging equipment to ensure comfort; they tried on the cap, touched the infrared optodes and previewed what their neural activity looked like. Finally, participants were familiarized with MM as a concept; common myths were discussed and dispelled (Ramsay, 2015), questions were answered, and participants sampled the MM audio for one-minute.

Day 2/3: MM Session

Participants returned to the lab the following week to complete the experimental condition. Once the experiment began, psycho-emotional measures (i.e. mood, self-efficacy, motivation, and affect) were obtained. Then, one round of the cognitive battery (i.e. Stroop Task, TMT, and Leiter-3) was administered while PFC and motor cortical activity were recorded using fNIRS. Next, participants were led in the guided MM via the Smiling Mind application while sitting or lying on a meditation pillow. This was delivered through noise-cancelling headphones. Participants were instructed to close their eyes (if they felt comfortable doing so) and listen to the instructions from the voice as it guided an imaginary bubble through their body. They were told not to worry if their mind wandered, but just to gently bring their attention back to the voice. The experimenters were present in the room during the meditation to ensure adherence to the protocol (e.g., the participant remained still); however, the lights were dimmed, the experimenters were silent, and participants were left in a corner of the room (the “meditation station”) to approximate privacy. Afterwards, the cognitive battery was completed again while fNIRS data was collected. Participants were then given a children’s magazine of their choice to silently read for 10-minutes. Two time points were used to assess the immediate impact of the intervention, and the impact after a 10-minute delay. Following this, participants completed the cognitive battery while wearing the fNIRS cap one last time.

Day 2/3: Control Session

The same protocol was followed for Day 2, except participants were asked to read magazines for a 10-minute bout instead of engaging in MM. This control activity satisfies Davidson and Kaszniak’s (2015) conditions for a control group in MM experiments; i.e., the interventions were similar in length, they required the same amount of practice, and, participants were blinded as much as possible to what the intervention of interest was. Once the last measure was completed, parents and children were debriefed and compensated.

Table 1

Sample Demographics

	N	% of Sample
Participant Age		
10	7	43.75
11	2	12.5
12	3	18.75
13	2	12.5
14	2	12.5
Participant Gender		
Male	12	75
Female	4	25
Parent’s Education Level		
Some high school, no diploma	1	6.25
High school graduate, diploma or the equivalent	0	0
Some college credit, no degree	2	12.5
Trade/technical/vocational training	2	12.5
Associate degree	1	6.25
Bachelor’s degree	5	31.25
Master’s degree	4	25
Professional degree	1	6.25
Parent’s Employment		
Employed for wages	15	93.75
Self-employed	0	0

Out of work	0	0
Homemaker	1	6.25
Household Income		
Prefer not to say	2	12.5
< $30 000	0	0
$30 000 - $40 000	1	6.25
$40 000 - $50 000	2	12.5
$50 000 - $60 000	1	6.25
$60 000 - $70 000	2	12.5
$70 000 - $80 000	3	18.75
$80 000 - $90 000	2	12.5
$90 000 - $100 000	0	0
> $100 000	3	18.75

Table 2

NICHQ Vanderbilt Assessment Scale

	N	% of Sample
Inattentive		
Clinically significant	13	81.25
Not clinically significant	3	18.75
Hyperactive/impulsive		
Clinically significant	8	50
Not clinically significant	8	50
Oppositional-defiant disorder		
Clinically significant	8	50
Not clinically significant	8	50
Conduct disorder		
Clinically significant	1	6.25
Not clinically significant	15	93.75
Anxiety		
Clinically significant	1	6.25
Not clinically significant	15	93.75
Performance		
Clinically significant	13	81.25
Not clinically significant	3	18.75

Table 3

Behavior Rating Inventory of Executive Function (BRIEF)

	N	% of Sample
Inhibition		
Clinically significant	7	43.75
Not clinically significant	9	56.25
Self-Monitor		
Clinically significant	10	62.5
Not clinically significant	6	37.5
Behaviour regulation index		
Clinically significant	10	62.5
Not clinically significant	6	37.5
Shift		
Clinically significant	13	81.25
Not clinically significant	3	18.75
Emotional Control		
Clinically significant	9	56.25
Not clinically significant	7	43.75
Emotion regulation index		
Clinically significant	10	62.5
Not clinically significant	6	37.5
Initiate		
Clinically significant	8	50
Not clinically significant	8	50

Working Memory		
Clinically significant	10	62.5
Not clinically significant	6	37.5
Planning		
Clinically significant	8	50
Not clinically significant	8	50
Task Monitoring		
Clinically significant	11	68.75
Not clinically significant	5	31.25
Organization		
Clinically significant	8	50
Not clinically significant	8	50
Cognitive regulation index		
Clinically significant	13	81.25
Not clinically significant	3	18.75

Table 4

Medication Questionnaire

	N	% of Sample
ADHD diagnosis present		
Yes	15	93.75
No	1	6.25
Age ADHD was diagnosis		
Unsure	1	6.25
4	1	6.25
5	0	0
6	2	12.5
7	4	25
8	3	18.75
9	4	25
10	0	0
11	1	6.25
ADHD subtype		
Predominantly inattentive	3	18.75
Predominantly hyperactive	1	6.25
Combined subtype	3	18.75
Unsure/no diagnosis given	9	56.25
Currently taking medication		
No response	1	6.25
Yes	9	56.25

No	6	37.5
Other diagnosis present		
Yes	6	37.5
No	10	62.5
Medicated for another diagnosis		
Yes	2	12.5
No	14	87.5

Results

Research Question 1: How will a single MM bout impact the executive functioning in children with ADHD?

To answer this question, we conducted several repeated measures ANOVAs with a two-level factor of condition (MM vs. Control), and a three-level factor of time (pre-intervention, immediately post-intervention, and 10-minutes post-intervention; hereon referred to as Pre, Post-1, and Post-2, respectively). For inhibitory control, repeated measures ANOVAs were conducted for congruent and incongruent trials of the Stroop Task; outcome variables were comprised of number of errors and proportion correct. For sustained attention/task switching, repeated measures ANOVAs were conducted for Trail Making A and B Tests separately; outcome variables were time to completion (seconds) and number of errors. For working memory, a repeated measures ANOVA was conducted with the outcome variable comprised of the number of maximum items held in working memory (assessed by the reverse memory subscale of the Leiter-3 task). Age and sex were included as covariates in analyses if they were significant predictors of outcomes. There were no extreme outliers consistent across outcome variables and conditions. See Table 5 for the descriptive statistics results of the cognitive tasks. There were also no differences in performance regardless of whether participants first participated in the MM condition or the control condition (all ps$>$.05).

Table 5

Descriptive Statistics for Cognitive Tasks

	MM *M (SD)*	Control *M (SD)*	N
Congruent Stroop # Errors - Pre	0.00 (0.00)	0.63 (1.41)	16
Congruent Stroop # Errors - Post-1	0.06 (0.25)	0.25 (0.58)	16
Congruent Stroop # Errors - Post-2	0.25 (0.58)	0.69 (1.14)	16
Congruent Stroop Proportion Correct - Pre	1.00 (0.00)	0.99 (.02)	16
Congruent Stroop Proportion Correct - Post-1	1.00 (0.00)	1.00 (.01)	16
Congruent Stroop Proportion Correct - Post-2	1.00 (0.01)	0.98 (.04)	16
Incongruent Stroop # Errors - Pre	4.88 (3.40)	4.37 (3.18)	16
Incongruent Stroop # Errors - Post-1	2.75 (2.09)	5.31 (3.20)	16
Incongruent Stroop # Errors - Post-2	3.25 (3.09)	4.06 (3.34)	16
Incongruent Stroop Proportion Correct - Pre	0.95 (.03)	0.96 (.04)	16
Incongruent Stroop Proportion Correct - Post-1	0.97 (.02)	0.95 (.04)	16
Incongruent Stroop Proportion Correct - Post-2	0.97 (.03)	0.96 (.04)	16
Trail Making A Time to Completion - Pre	66.80 (26.34)	63.27 (28.06)	16
Trail Making A Time to Completion - Post-1	53.57 (22.59)	53.63 (23.76)	16
Trail Making A Time to Completion - Post-2	48.64 (23.48)	66.43 (29.12)	16
Trail Making A Number of Errors - Pre	0.06 (0.25)	0.19 (0.54)	16
Trail Making A Number of Errors - Post-1	0.00 (0.00)	0.06 (0.25)	16
Trail Making A Number of Errors - Post-2	0.00 (0.00)	0.06 (0.25)	16
Trail Making B Time to Completion - Pre	103.06 (22.83)	101.35 (33.66)	16
Trail Making B Time to Completion - Post-1	87.84 (31.40)	97.21 (31.05)	16
Trail Making B Time to Completion - Post-2	89.16 (27.89)	166.37 (263.33)	16

Trail Making B Number of Errors - Pre	1.56 (2.68)	0.63 (0.89)	16
Trail Making B Number of Errors - Post-1	0.44 (0.63)	0.69 (1.08)	16
Trail Making B Number of Errors - Post-2	0.56 (1.21)	0.75 (1.44)	16
Leiter-3 Number Complete - Pre	15.13 (2.47)	15.69 (1.78)	16
Leiter-3 Number Complete - Post-1	16.44 (2.28)	15.25 (2.27)	16
Leiter-3 Number Complete - Post-2	16.89 (1.96)	16.00 (2.37)	16

Inhibitory Control

For congruent Stroop Task performance, with *number of errors* as the outcome variable, there was a marginal main effect of condition $F(1, 15) = 4.412$, $p = .053$, $\eta p^2 = 0.227$, with the MM condition leading to fewer errors ($M = 0.10$, $SD = 0.276$) than the Control condition ($M = 0.52$, $SD = 1.041$); there was no main effect of time $F(2, 30) = 1.319$, $p = .282$, $\eta p^2 = 0.081$, and no interaction $F(2, 30) = 0.972$, $p = .390$, $\eta p^2 = 0.061$. Mauchly's Test of Sphericity indicated that the assumptions of sphericity had not been violated, $\chi^2(2) > 2.028$, *p*s > .243. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 0.034, all *p*s > .857). There were no baseline differences in congruent Stroop errors between MM and Control $t(15) = -1.775$, $p = .096$.

For congruent Stroop Task performance with *proportion correct* as the outcome variable, there was a significant main effect of condition $F(1, 15) = 5.381$, $p = .035$, $\eta p^2 = 0.264$, with the MM condition leading to a greater proportion correct ($M = 1.00$, $SD = 0.017$) than the Control condition ($M = 0.99$, $SD = 0.121$); there was no main effect of time $F(1.351, 20.270) = 2.062$, $p = .163$, $\eta p^2 = 0.121$, and no interaction $F(1.371, 20.556) = 0.879$, $p = .393$, $\eta p^2 = 0.055$. Mauchly's Test of Sphericity indicated that the assumptions of sphericity had been violated for both the main effect of time and the interaction, $\chi^2(2) > 8.594$, *p*s < .014; consequently, Greenhouse-Geisser was reported to adjust for lack of sphericity. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 1.046, all *p*s > .325). There was no baseline difference in congruent Stroop *proportion correct* between MM and Control $t(15) = 1.809$, $p = .091$.

For incongruent Stroop Task performance, with *number of errors* as the outcome variable, there was a significant main effect of condition $F(1, 15) = 5.336$, $p = .036$, $\eta p^2 = 0.262$, with fewer errors occurring following the MM intervention (*M* = 3.63, *SD* = 2.858) compared to the Control intervention (*M* = 4.58, *SD* = 3.238); there was no main effect of time $F(2, 30) = 1.510$, $p = .237$, $\eta p^2 = 0.091$, but there was a significant interaction, $F(2, 30) = 3.901$, $p = .031$, $\eta p^2 = 0.206$ (see Figure 1 for a representation of this interaction). Mauchly's Test of Sphericity indicated that the assumptions of sphericity had not been violated, $\chi^2(2) > 0.902$, *p*s > .156. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 0.164, all *p*s > .692). There was no baseline difference in incongruent Stroop Task *number of errors* between MM and Control $t(15) = 0.605$, $p = .554$.

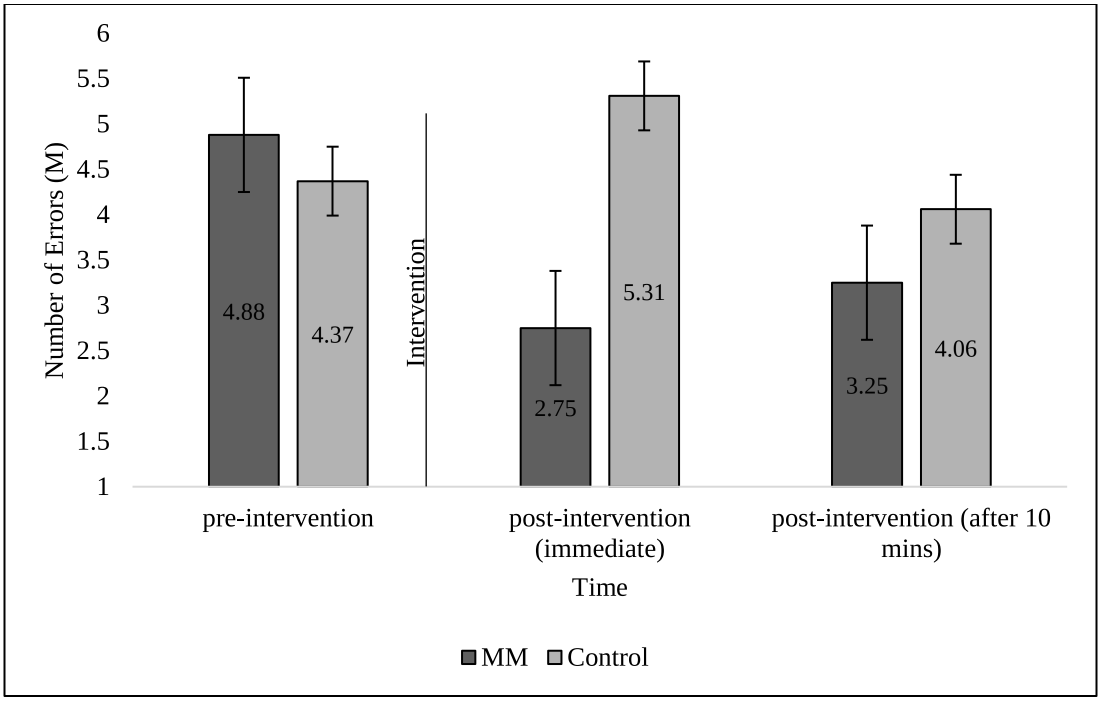

Figure 1. Participants in the MM condition exhibited a significant decrease in the number of errors they made on the Incongruent Stroop Task from pre-intervention to post-intervention. The same decrease in numbers of errors was not observed in the Control condition. Error bars represent standard error.

For Incongruent Stroop Task performance, with *proportion correct* as the outcome variable, there was a marginal main effect of condition F(1, 15) = 4.337, $p = .055$, $\eta p^2 = 0.224$, (MM; $M = 0.97$, $SD = 0.027$; Control; $M = 0.95$, $SD = 0.035$), and no main effect of time F(2, 30) = 1.161, $p = .327$, $\eta p^2 = 0.072$. The interaction was significant F(1.483, 22.245) = 4.332, $p = .036$, $\eta p^2 = 0.224$. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated for the interaction, $\chi^2(2) > 6.002$, $p = 0.050$ (but had not been violated for time, $\chi^2(2) = 2.845$, $p = 0.241$). Greenhouse-Geisser was reported to adjust for lack of sphericity. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 0.149, all *p*s > .706). There was no baseline difference in Incongruent Stroop *proportion correct* between MM and Control $t(15) = -0.467$, $p = .647$.

Sustained Attention/Task switching

For Trail Making A, with *time to completion* as the outcome variable, there was no main effect of condition F(1, 14) = 0.542, $p = .474$, $\eta p^2 = 0.037$, (MM; $M = 56.34$, $SD = 15.357$; Control; $M = 61.11$, $SD = 80.945$), no main effect of time F(1.439, 20.148) = 0.312, $p = .664$, $\eta p^2 = 0.022$, and no interaction F(2, 28) = 0.601, $p = .555$, $\eta p^2 = 0.041$. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated for time, $\chi^2(2) = 6.42$, $p = .040$ (but had not been violated for the interaction, $\chi^2(2) = 0.38$, $p = .827$). Greenhouse-Geisser was reported to adjust for lack of sphericity. Age was a significant predictor of outcomes F(1, 13) = 6.817, $p = .022$, $\eta p^2 = 0.344$, so it was included as a covariate in the analysis. Sex was not included as a covariate, as it was not a predictor of outcomes F(1, 13) = 0.102, $p = .754$, $\eta p^2 = 0.008$. There was no baseline difference in time to completion between MM and Control $t(15) = 0.572$, $p = .576$.

For Trail Making A, with *number of errors* as the outcome variable, there was no main effect of condition F(1, 14) = 0.318, p = .582, ηp^2 = 0.022, (MM; M = 0.02, SD = 0.08; Control; M = 0.10, SD = 0.348), time F(1.375, 19.250) = 0.152, p = .779, ηp^2 = 0.011, or interaction F(2, 28) = 0.538, p = .590, ηp^2 = 0.037. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated for the main effect of time, $\chi^2(2)$ = 7.879, p = .019 (but had not been violated for the interaction, $\chi^2(2)$ = 3.587, p = .166). Greenhouse-Geisser was reported to adjust for lack of sphericity. Sex was a significant predictor of outcomes F(1, 13) = 5.695, p = .033, ηp^2 = 0.305, so it was included as a covariate in the analysis. Age was not included as a covariate, as it was not a predictor of the outcome F(1, 13) = 1.725, p = .212, ηp^2 = 0.117. There was no baseline difference in number of errors between MM and Control $t(15)$ = -1.464, p = .164.

For Trail Making B, with *time to completion* as the outcome variable, there was no main effect of condition F(1, 14) = 0.005, p = .942, ηp^2 = 0.000, (MM; M = 93.35, SD = 27.375; Control; M = 100.811, SD = 34.456), time F(1.378, 19.298) = 0.633, p = .485, ηp^2 = 0.042, or the interaction F(2, 38) = 0.671, p = .519, ηp^2 = 0.046. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated for the main effect of time only, $\chi^2(2)$ = 7.793, p = .020. Greenhouse-Geisser was reported to adjust for lack of sphericity. Age was a significant predictor of outcomes, F(1, 13) = 6.039, p = .029, ηp^2 = 0.317, so it was included as a covariate in the analysis. Sex was not included as a covariate, as it was not a predictor of the outcome, F(1, 13) = 0.094, p = .764, ηp^2 = 0.007. There were no baseline differences in time to completion between MM and Control $t(15)$ = 0.225, p = .825.

For Trail Making B, with *number of errors* as the outcome variable, there was no main effect of condition F(1, 15) = 0.625, p = .442, ηp^2 = 0.040, (MM; M = 0.85, SD = 1.534; Control; M = 0.69, SD = 1.134), no main effect of time F(2, 30) = 1.407, p = .261, ηp^2 = 0.086, and no interaction effect between condition and time F(2, 30) = 1.572, p = .224, $\eta p^2 = 0.095$. Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(2) > 2.028$, ps >.086. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 1.233, all ps > .287). There were no baseline differences in number of errors between MM and Control $t(15) = 1.614$, p = .127.

Working Memory

For Leiter-3, with *working memory span* as the outcome variable, there was a significant main effect of condition F(1, 14) = 5.037, p = .042, $\eta p^2 = 0.265$, with a greater gain in WM span occurring in the MM condition (M = 16.22, SD = 2.238) compared to the Control condition (M = 15.65, SD = 2.137). There was no main effect of time F(2, 28) = 2.058, p = .147, $\eta p^2 = 0.128$, but there was a significant interaction found F(2, 28) = 6.136, p = .006, $\eta p^2 = 0.305$ (see Figure 2). Mauchly's Test of Sphericity indicated that the assumptions of sphericity had not been violated, $\chi^2(2) > 0.622$, ps > .369. Age was a significant predictor of outcomes, F(1, 13) = 13.821, p = .003, $\eta p^2 = 0.515$, so it was included as a covariate in the analysis. Sex was not included as a covariate, as it was not a predictor of the outcome, F(1, 13) = 0.920, p = .335, $\eta p^2 = 0.066$. There were no baseline differences in Leiter-3 working memory span between MM and Control $t(15) = -0.839$, p = .415.

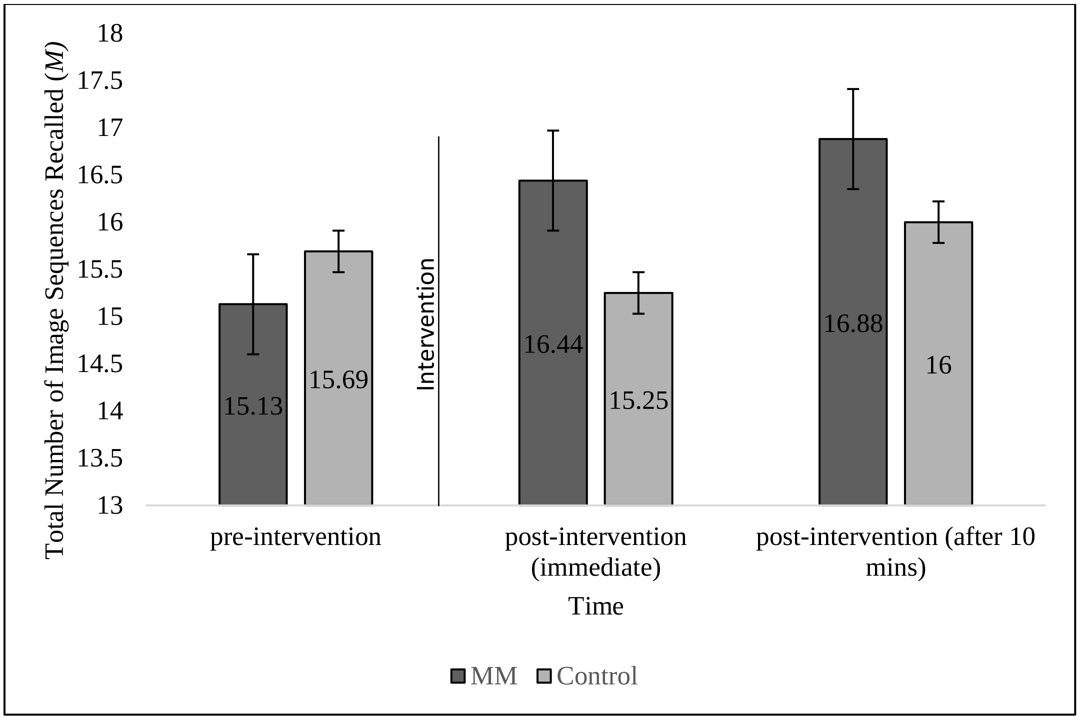

Figure 2. Participants in the MM condition exhibited a significant increase in working memory scores on the reverse memory task from pre-intervention to post-intervention. Participants in the Control condition did not show the same increase in working memory scores from Pre to Post-intervention. Error bars represent standard error.

Research Question 2: How will a single MM bout impact the PFC and what is the corresponding impact on executive functioning?

fNIRS outcome variables consisted of change scores in oxygenated and deoxygenated hemoglobin from Post-1 to Pre, and from Post-2 to Pre. Only fNIRS data that corresponded to significant executive functioning outcomes were analyzed (i.e., Incongruent Stroop and Leiter-3). See Table 6 for the fNIRS data descriptive statistics results. We conducted several repeated measures ANOVAs with a two-level factor of condition (MM vs. Control) and a two-level factor of time (change scores from Post-1 to Pre; change scores from Post-2 to Pre). This was done for the PFC and motor regions separately. Age and sex were included as covariates in analyses if they were significant predictors of outcomes. There were no extreme outliers consistent across outcome variables and conditions. There were also no differences in PFC hemoglobin concentration regardless of whether participants first participated in the MM condition or the control condition (all $ps>.05$).

Table 6

Descriptive Statistics for fNIRS data

	MM *M (SD)*	Control *M (SD)*	*N*
PFC Oxygenated Hemoglobin Change Between Post 1-Pre *(Incongruent Stroop)*	0.00001 (0.60)	0.10 (0.44)	15
PFC Oxygenated Hemoglobin Change Between Post 2-Pre *(Incongruent Stroop)*	0.002 (0.64)	-0.001 (0.37)	15
PFC Deoxygenated Hemoglobin Change Between Post 1-Pre *(Incongruent Stroop)*	0.20 (0.43)	-0.10 (0.26)	15
PFC Deoxygenated Hemoglobin Change Between Post 2-Pre *(Incongruent Stroop)*	0.30 (0.35)	0.001 (0.41)	15
Motor Oxygenated Hemoglobin Change Between Post 1-Pre *(Incongruent Stroop)*	-0.30 (1.38)	0.004 (0.65)	15
Motor Oxygenated Hemoglobin Change Between Post 2-Pre *(Incongruent Stroop)*	0.20 (2.32)	0.50 (1.14)	15
Motor Deoxygenated Hemoglobin Change Between Post 1-Pre *(Incongruent Stroop)*	0.40 (0.87)	-0.10 (0.35)	15
Motor Deoxygenated Hemoglobin Change Between Post 2-Pre *(Incongruent Stroop)*	0.30 (0.54)	0.20 (0.75)	15
PFC Oxygenated Hemoglobin Change Between Post 1-Pre *(Leiter-3)*	-0.60 (1.96)	-0.10 (0.65)	15
PFC Oxygenated Hemoglobin Change Between Post 2-Pre *(Leiter-3)*	-0.50 (2.13)	0.10 (1.13)	15
PFC Deoxygenated Hemoglobin Change Between Post 1-Pre *(Leiter-3)*	-0.30 (0.10)	-0.10 (0.18)	15
PFC Deoxygenated Hemoglobin Change Between Post 2-Pre *(Leiter-3)*	-0.003 (1.03)	-0.001 (0.51)	15
Motor Oxygenated Hemoglobin Change Between Post 1-Pre *(Leiter-3)*	-0.10 (1.62)	-0.30 (1.27)	15
Motor Oxygenated Hemoglobin Change Between Post 2-Pre *(Leiter-3)*	-1.10 (2.31)	-0.20 (1.31)	15

Motor Deoxygenated Hemoglobin Change Between Post 1-Pre *(Leiter-3)*	0.20 (1.23)	-0.10 (0.91)	15
Motor Deoxygenated Hemoglobin Change Between Post 2-Pre *(Leiter-3)*	-0.10 (1.07)	0.20 (0.97)	15

Incongruent Stroop

For the PFC, with oxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 14) = 0.005, p = .947, $\eta p^2 < 0.001$ (MM; M = 0.03 SD = 0.62; Control; M = 0.05, SD = 0.405), no main effect of time F(1, 14) = 0.420, p = .528, $\eta p^2 = 0.29$, and no interaction F(1, 14) = 0.922, p = .353, ηp^2 = 0.062. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 0.178, all *p*s > .680). For the PFC, with deoxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was a significant main effect of condition F(1, 14) = 6.410, p = .024, $\eta p^2 = 0.314$ (MM; M = 0.25, SD = 0.39; Control; M = -0.05, SD = 0.34), no main effect of time F(1, 14) = 1.840, p = .196, $\eta p^2 = 0.116$, and no interaction F(1, 14) = 0.263, p = .616, $\eta p^2 = 0.018$. A paired-samples t-test confirmed that the MM and Control conditions did not differ in pre-deoxygenated hemoglobin t(14) = -1.976, p = .068. A Bonferroni correction was used to correct for potentially increased type-1 error rates. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 0.232, all *p*s > .639).

For the motor region, with oxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 14) = 0.421, p = .527, $\eta p^2 = 0.29$ (MM; M = -0.05, SD = 1.85; Control; M = 0.25, SD = 1.03), time F(1, 14) = 1.972, p = .182, $\eta p^2 = 0.123$, or interaction F(1, 14) = 0.05, p = .943, $\eta p^2 = 0.000$. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 1.385, all *p*s > .262). For the motor region, with deoxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 14) = 2.321, p = .150, $\eta p^2 = 0.142$ (MM; M = 0.35, SD = 0.705; Control; M = 0.05, SD =

0.55), time F(1, 14) = 0.444, p = .516, ηp^2 = 0.031, or interaction F(1, 14) = 2.593, p = .130, ηp^2 = 0.156. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 3.338, all *p*s > .093).

Leiter-3

For the PFC, with oxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 14) = 0.806, p = .385, ηp^2 = 0.054 (MM; *M* = -0.55, *SD* = 2.045; Control; *M* = 0.01, *SD* = 0.890), no main effect of time F(1, 14) = 1.275, p = .278, ηp^2 = 0.803, and no interaction F(1, 14) = 0.003, p = .954, ηp^2 = 0.000. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 3.338, all *p*s > .220). For the PFC, with deoxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 14) = 0.172, p = .685, ηp^2 = 0.012 (MM; *M* = -0.15, *SD* = 1.015; Control; *M* = -0.05, *SD* = 0.345), a significant main effect of time F(1, 14) = 5.592, p = .033, ηp^2 = 0.285, and no interaction F(1, 14) = 1.168, p = .298, ηp^2 = 0.077. A paired-samples t-test, using a Bonferroni correction, confirmed that the MM and Control conditions did not differ in pre-deoxygenated hemoglobin concentrations $t(14)$ = -0.757, p = .461. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 3.074, all *p*s > .105).

For the motor region, with oxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 13) = 0.196, p = .665, ηp^2 = 0.15 (MM; *M* = -0.06, *SD* = 1.965; Control; *M* = -0.25, *SD* = 1.29), no main effect of time F(1, 13) = 3.554, p = .082, ηp^2 = 0.215, and no interaction F(1, 13) = 1.687, p = .217, ηp^2 = 0.115. Sex was a significant predictor of outcome, so it was included as a covariate F(1, 12) = 10.246, p = .008. Age was not included as a covariate, as it was not a predictor of outcome F(1, 12) = 1.203, p = .294. For the motor region, with deoxygenated hemoglobin change scores from post-intervention to pre-intervention as the outcome variable, there was no main effect of condition F(1, 14) = 0.000, p = .985, ηp^2 = 0.000 (MM; M = 0.05, SD = 1.15; Control; M = 0.05, SD = 0.94), no main effect of time F(1, 14) = 0.000, p = .985, ηp^2 = 0.000, and no interaction F(1, 14) = 2.623, p = .128, ηp^2 = 0.158. Age and sex were not included as covariates, as they were not predictors of outcome (all Fs < 3.444, all ps > .088).

Bivariate correlations were also conducted between significant fNIRS outcomes and the corresponding executive functions. This was done to address the research question aimed at understanding whether significant changes in neural activity were correlated with significant changes in executive functioning. No correlations were found between PFC deoxygenation and Incongruent Stroop errors made and proportion correct (all rs < 0.46; all ps > .071).

Research Question 3: How will a single MM bout impact the psycho-emotional functioning of children with ADHD?

To answer this research question for mood and general self-efficacy, we conducted several repeated measures ANOVAs with a two-level factor of condition (MM vs. Control), and a two-level factor of time (pre-intervention, post-intervention). For motivation and affect, we also conducted several repeated measures ANOVAs with a two-level factor of condition (MM vs. Control), but we had a three-level factor of time (pre/post first cognitive battery, pre/post second cognitive battery, and pre/post third cognitive battery). Refer to Table 7 to see the descriptive statistics results for mood and general self-efficacy, and Table 8 to see the results for motivation and affect. There were no extreme outliers consistent across outcome variables and conditions. There were also no differences in psycho-emotional outcomes regardless of whether participants first participated in the MM condition or the Control condition (all ps>.05).

Table 7

Descriptive Statistics for Mood and General Self-Efficacy

	MM *M (SD)*	Control *M (SD)*	*N*
Ratings of Positive Mood - Pre	3.51 (1.06)	3.63 (0.99)	16
Ratings of Positive Mood - Post 2	3.54 (1.14)	3.74 (0.84)	16
Ratings of Negative Mood - Pre	1.65 (0.51)	1.55 (0.48)	16
Ratings of Negative Mood - Post 2	1.59 (0.45)	1.54 (0.45)	16
Ratings of General Self-Efficacy - Pre	3.72 (0.76)	3.82 (0.81)	16
Ratings of General Self-Efficacy - Post 2	3.87 (0.73)	3.91 (0.87)	16

Table 8

Descriptive Statistics for Motivation and Affect

	MM *M (SD)*	Control *M (SD)*	*N*
Ratings of Affect Before Cognitive Tasks - Pre	3.63 (1.71)	3.81 (1.37)	16
Ratings of Affect Before Cognitive Tasks - Post-1	3.38 (1.71)	3.50 (1.67)	16
Ratings of Affect Before Cognitive Tasks - Post-2	3.88 (1.23)	4.31 (1.01)	16
Ratings of Affect After Cognitive Tasks - Pre	3.56 (1.71)	3.81 (1.33)	16
Ratings of Affect After Cognitive Tasks - Post-1	3.63 (1.54)	4.06 (0.93)	16
Ratings of Affect After Cognitive Tasks - Post-2	3.88 (1.26)	4.31 (1.01)	16
Ratings of Motivation Before Cognitive Tasks - Pre	5.74 (1.04)	5.73 (1.13)	16
Ratings of Motivation Before Cognitive Tasks - Post-1	5.66 (1.30)	5.74 (1.13)	16
Ratings of Motivation Before Cognitive Tasks - Post-2	5.59 (1.37)	5.93 (0.95)	16
Ratings of Motivation After Cognitive Tasks - Pre	5.40 (1.28)	5.75 (1.04)	16
Ratings of Motivation After Cognitive Tasks - Post-1	5.35 (1.22)	5.90 (1.13)	16
Ratings of Motivation After Cognitive Tasks - Post-2	6.09 (1.13)	6.09 (1.13)	16

For mood, with *positive mood* as the outcome variable, there was no main effect of condition F(1, 15) = 0.644, p = .435, ηp^2 = 0.041 (MM; M = 3.53, SD = 1.101; Control; M = 3.69, SD = 0.914), no main effect of time F(1, 15) = 0.440, p = .517, ηp^2 = 0.028, and no interaction effect F(1, 15) = 0.326, p = .576, ηp^2 = 0.021. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 2.083, all *p*s > .173). There was no baseline difference in positive mood between MM and Control t(15) = -0.241, p = .813.

With *negative mood* as the outcome variable, there was no main effect of condition F(1, 14) = 0.098, p = .758, ηp^2 = 0.007 (MM; M = 1.62, SD = 0.484; Control; M = 1.55, SD = 0.465), no main effect of time F(1, 14) = 0.061, p = .808, ηp^2 = 0.004, and no interaction F(1, 14) = 2.589, p = .130, ηp^2 = 0.156. Age was a significant predictor of outcome, F(1, 13) = 6.403, p = .025, ηp^2 = 0.330, so it was included as a covariate in the analysis. Sex was not included as a covariate, as it was not a predictor of the outcome F(1, 13) = 0.082, p = .780, ηp^2 = 0.006. Moreover, there was no baseline difference in negative mood between MM and Control t(15) = -0.968, p = .348.

With *general self-efficacy* as the outcome variable, there was no main effect of condition F(1, 15) = 0.764, p = .396, ηp^2 = 0.049 (MM; M = 3.80, SD = 0.748; Control; M = 3.87, SD = 0.842), time F(1, 15) = 2.239, p = .155, ηp^2 = 0.130, or interaction F(1, 15) = 0.241, p = .631, ηp^2 = 0.016. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 0.904, all *p*s > .359). There was no baseline difference in general self-efficacy between MM and Control, t(15) = -1.103, p = .288.

With *change in affect (prior to the cognitive tasks) across the experiment* as the outcome variable, there was no main effect of condition F(1, 15) = 1.015, p = .330, ηp^2 = 0.063 (MM; M = 3.63, SD = 1.558; Control; M = 3.87, SD = 1.355), no main effect of time F(2, 30) = 2.783, p =

.078, $\eta p^2 = 0.156$, and no interaction effect $F(2, 30) = 0.300$, $p = .743$, $\eta p^2 = 0.020$. Mauchly's Test of Sphericity indicated that the assumptions of sphericity had not been violated for the time or the interaction effect, $\chi^2(2) > 0.2435$, *p*s > .625. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 0.057, all *p*s > .814). There was no baseline difference in affect between MM and Control, $t(15) = -0.545$, $p = .594$.

With *change in affect (following the cognitive tasks) across the experiment* as the outcome variable, there was no main effect of condition $F(1, 15) = 1.226$, $p = .286$, $\eta p^2 = 0.076$ (MM; *M* = 3.69, *SD* = 1.504; Control; *M* = 4.06, *SD* = 1.090), a marginal main effect of time $F(2, 30) = 3.274$, $p = .052$, $\eta p^2 = 0.179$ with affect generally increasing across the experiment in both conditions; and no interaction effect $F(1.324, 19.854) = 0.155$, $p = .767$, $\eta p^2 = 0.010$. Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated for time, $\chi^2(2) = 5.422$, *p*s > .066; it was, however, violated for the interaction, $\chi^2(2) = 10.017$, $p = .007$, so Greenhouse-Geisser was reported to adjust for lack of sphericity. Age and sex were not included as covariates as they were not predictors of outcomes (all Fs < 0.437, all *p*s > .520). There was no baseline difference in affect (post-cognitive tasks) between MM and Control, $t(15) = -1.073$, $p = .300$.

With *pre-cognitive task motivation* as the outcome variable, there was no main effect of condition $F(1, 15) = 0.445$, $p = .515$, $\eta p^2 = 0.029$ (MM; *M* = 5.78, *SD* = 1.236; Control; *M* = 5.80, *SD* = 1.106), time $F(1.245, 18.675) = 0.328$, $p = .622$, $\eta p^2 = 0.021$, or interaction $F(2, 30) = 1.337$, $p = .278$, $\eta p^2 = 0.082$. Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated for the interaction effect, $\chi^2(2) > 5.489$, *p*s > .064; it was, however, violated for the main effect of time, $\chi^2(2) = 13.055$, $p = .001$, so Greenhouse-Geisser was reported to adjust for lack of sphericity. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 0.047, all *p*s > .832). There were no baseline differences found in pre-cognitive task motivation between MM and Control, $t(15) = 0.068$, $p = .947$.

With *post-cognitive task motivation* as the outcome variable, there was no main effect of condition $F(1, 15) = 4.199$, $p = .058$, $\eta_p^2 = 0.219$ (MM; M = 5.62, SD = 1.209; Control; M = 5.91, SD = 1.098), time $F(1.350, 20.252) = 3.670$, $p = .059$, $\eta_p^2 = 0.021$, or interaction effect $F(2, 30) = 3.074$, $p = .061$, $\eta_p^2 = 0.170$. Mauchly's Test of Sphericity indicated that the assumptions of sphericity had not been violated for condition or the interaction, $\chi^2(2) = 4.889$, *p*s > .087; it was, however, violated for time, $\chi^2(2) = 9.192$, $p = .010$, so Greenhouse-Geisser was reported to adjust for lack of sphericity. Age and sex were not included as covariates as they were not predictors of outcome (all Fs < 0.030, all *p*s > .865). There was no baseline difference in pre-cognitive task motivation between MM and Control, $t(15) = -0.316$, $p = .756$.

Discussion

This study aimed to understand the effects of a single MM session on neurocognitive and psycho-emotional outcomes in young people with ADHD. Prior research shows that extensive MM interventions (weeks or months long) help alleviate ADHD symptomology for youth with ADHD (e.g. Kiana et al., 2016; Zylowska et al., 2008). Our research, however, was the first to examine whether a *single* session of MM impacted crucial aspects of functioning in children with ADHD.

We found that one MM session effectively increased performance on cognitive measures of inhibitory control and working memory in our sample of children with ADHD. These are two key aspects of executive functioning that are often dysfunctional in those with the disorder (Lipszyc & Schachar, 2010; Diamond, 2005; Diamond, 2013). There was also a corresponding change in PFC deoxygenated hemoglobin during the inhibitory control task following engagement in MM. Given that the same change in PFC deoxygenation was not present in the Control condition, this suggests an increase in neurological activity in the PFC following MM. The same change in PFC deoxygenation was not observed during the working memory task. Additionally, there was no apparent effect of one MM bout on other aspects of executive functioning (i.e., sustained attention, task switching) or psycho-emotional outcomes (i.e., mood, affect, self-efficacy, motivation).

Research Question 1: How will a single MM bout impact the executive functions of children with ADHD?

Inhibitory Control

Our results lend preliminary support to the notion that a single MM session can improve inhibitory control in children with ADHD. These results are in line with previous work showing that MM interventions can support inhibitory control (Friese et al., 2012; Kiani et al., 2017; Zylowska et al., 2008). This may be because MM practice supports response de-automatization; i.e., MM supports individuals in their ability to respond to situations in a flexible way consistent with what a situation demands instead of relying on their habitual automatic responses (Deikman, 1963; Kang et al., 2013; Wenk-Sormaz, 2005). Although a few studies have shown that a short bout of MM promotes inhibitory control in typically developing adults and undergraduates (Luu & Hall, 2017, Wenk-Sormaz, 2005, Friese et al., 2012), our study is among the first to demonstrate similar findings following a short MM bout for ADHD populations.

Several mediating processes (acting independently or interactively) may underlie this result. One mechanism may be relaxation (Friese et al., 2012). MM can lead to feelings of deep relaxation (Lazar et al., 2000), which in turn may increase self and inhibitory control (Tyler & Burns, 2008). Physiological relaxation is also induced by MM, characterized by reductions in heart rate variability and respiratory rate (Melville et al., 2012). Additionally, MM can facilitate awareness of one's internal experience (Brown et al., 2007). Increased awareness is related to improved self-control (Alberts et al., 2011; Friese et al., 2012). Whether inhibitory control improvements occur because MM facilitates relaxation, increased awareness, a third variable, or a combination of these processes is unclear; further research is needed to clarify these mediating processes. What is apparent, however, is that improvements in tasks assessing inhibitory control were found in our sample of children with ADHD following a single MM bout.

In addition to these mediating processes, multiple neurological explanations have also been proposed to explain MM's evident impact on inhibitory control. The majority of these neurological explanations implicate changes in amygdala activity. MM is associated with decreased amygdala activation (Tang et al., 2015; Hölzel et al., 2011), which is theorized to be the result of the PFC exerting top-down control over the structure (Hölzel et al., 2011; Harenski & Hamann, 2006). Simply put, MM seems to enable the "logical" PFC to overtake the influence of the "emotional" amygdala, thereby enabling meditators to better inhibit expression of automatic emotional responses (Hölzel et al., 2011). This also provides an explanation for why inhibitory control appears to be improved by MM in ADHD populations (Kiani et al., 2017). Because ADHD is partly characterized by dysfunction of the PFC (Arnsten & Li, 2005), and deficits in PFC functioning are related to decreased inhibitory control (Mesulam, 1998), MM increasing PFC function may help compensate for these deficits, thus improving inhibitory control (Tang et al., 2015; Lazar et al., 2005).

Working Memory

Our results also provide initial evidence that working memory in youth with ADHD may be enhanced by a single MM bout. This finding is consistent with studies that have found working memory improvements following extensive MM training (i.e., weeks or months) with healthy populations (Jha et al., 2010; Mrazek et al., 2016; Zeidan et al., 2010), as well as with ADHD populations (Bachmann et al., 2018; Janssen et al., 2019). The present results are pioneering in that they showed working memory may be improved following one MM bout in a sample of ADHD children and youth.

Neuroimaging research provides some possible insights into why working memory was enhanced. Bachmann and colleagues' (2018) fMRI work examining individuals with ADHD found that working memory improvements following MM were associated with increased activation in brain circuits related to working memory, such as the right posterior insula. The insula, which is associated with regulating cognitive processes (Mrazek et al., 2016), is thicker in experienced meditators (Tang et al., 2015). This increased thickness suggests improved awareness of the present moment (Tang et al., 2015), a phenomenon that often results from MM (Hölzel et al., 2011). Therefore, working memory improvements may be the result of a reciprocal relationship between insula functioning and improved awareness; as the insula thickens, momentary awareness correspondingly improves, with MM commencing this process. Working memory improvement could be a by-product of this relationship. This explanation, however, fails to account for why we found that one session resulted in improved working memory, given that Tang et al. (2015) only found thicker insulas in experienced meditators.

The current study's findings of enhanced working memory capacity may be better explained by the aforementioned Default Mode Network (DMN). ADHD is often conceptualized as a result of DMN disruption (Bachmann et al., 2018; Fair et al., 2010; Sonuga-Barke & Castellanos, 2007). Those with the disorder display atypical connectivity within the DMN, as well as between the DMN and other cortical structures (Sonuga-Barke & Castellanos, 2007). The

DMN can remain active in individuals with ADHD when it should be inactive, resulting in constant disruption of other neural networks (Sonuga-Barke & Castellanos, 2007). Bachmann and colleagues (2018) found that activation in parts of the DMN (specifically the bilateral inferior parietal lobule and precuneus) corresponded to improved working memory following MM. This may occur because meditators can exert greater control over DMN activity than non-meditators (Brewer et al., 2011; Tang et al., 2015), and the DMN appears to relax following MM (Farb et al., 2007). In light of these observations, our finding of improvements on the working memory task following MM may be rooted in amplified activation in the precuneus and parietal lobule, thereby facilitating greater control over the DMN. This may result in improved present-moment awareness and enhanced functioning of brain circuits related to working memory.

Attention and Task Switching

Our results suggest that attention and tasking switching were not impacted by one MM bout. This stands in contrast to previous work that found mindfulness interventions enhance these executive functions (Luu & Hall, 2017; Semple, 2010). However, in these studies, the MM interventions took place over longer periods of time (eight weeks, and four weeks, respectively). Thus, it is possible MM supports gains in attentional and cognitive control only after long-term engagement, and a single session was not long enough to elicit the changes observed in longer paradigms. Johnson and colleagues (2015) reported similar findings to our study; they also did not find an impact of one MM session on measures of cognitive functioning. These researchers speculated this occurred because MM takes more time to impact attention-related brain structures than other structures (Johnson et al., 2015).

There is prior research examining the effect of brief MM on attention that found results consistent with ours. A single 10-minute mindfulness exercise did not impact attentional processes in undergraduate students (Watier & Dubois, 2012). Colzato et al. (2016) also found that attentional focus was unaffected by a single MM bout. In both these studies—and in our research—a focused attention meditation (body scan) was used. In these meditations, attention is usually improved, but only to one focal point, rather than globally. (Colzato et al., 2016). There is an indication that our measure of attention, the TMT, may have been a better measure of global than focal attention (Ranchet et al., 2011), and thus may have failed to reflect potential improvements in focal attention that MM may have induced. If we used a different attention task that assessed focal attention (e.g. the *n*-back test; Kane et al., 2007), we may have observed different results.

Research Question 2: How will a single MM bout impact the PFC and what is the corresponding impact on executive functioning?

Inhibitory Control

We found a significant change in deoxygenated hemoglobin in the PFC from pre to post MM bout during the Incongruent Stroop Task. These results converge with previous research demonstrating that the PFC is associated with inhibitory control (Overtoom et al., 2002; Sowell et al., 2003). We did not observe a change in hemoglobin concentration in the control condition, or in the motor region (i.e., control region) during the same task, suggesting that the increased activity in the PFC while inhibitory control was being exerted could potentially be attributed to the MM session.

There is an ongoing debate as to whether the measure of oxygenated or deoxygenated hemoglobin is the best proxy of neural activation (Herold et al., 2018). Nevertheless, observing significant changes in deoxygenated hemoglobin alone is considered sufficient to draw meaningful conclusions because it is more spatially focused and blocks out more physiological noise compared to oxygenated hemoglobin (Dravida et al., 2017; Herold et al., 2018). Changes in deoxygenated hemoglobin are independently related to—and a greater predictor of—increases in the blood oxygen level dependent contrast obtained in fMRI than oxygenated hemoglobin, indicating that the measure of deoxygenated hemoglobin has vascular sensitivity (Huppert et al., 2006). Therefore, even though we did not also find oxygenated hemoglobin changes following MM, our results still provide evidence for an increase in PFC activity underlying the improvement in inhibitory control. Furthermore, our results replicate Deepeshwar and colleagues' (2015) fNIRS research that sought to determine how MM impacts performance on the Stroop Task. They similarly found that meditation induced changes in deoxygenated hemoglobin concentration during Stroop performance (Deepeshwar et al., 2015). Participants in their study also improved on the Stroop Task following MM, providing converging evidence that MM influences the PFC, as it inhibits habitual responses that are no longer appropriate (Deepeshwar et al., 2015; Mesulam, 1998).

Working Memory

There was no significant change in oxygenated or deoxygenated hemoglobin levels in the PFC or motor regions during the working memory task despite positive gains in working memory following the MM bout. There is evidence that time and training impact the underlying neurological response of mindfulness; the brief duration of the MM may not have been impactful enough to lead to discernible neural changes underlying working memory engagement (Chiesa et al., 2011). A single MM session may thus have been inadequate to induce measurable changes in neural activity corresponding to working memory (especially among nonmeditators; Chiesa et al., 2011; van Lutterveld et al., 2017).

However, this justification fails to explain why inhibitory control was supported by changes in PFC activation whereas working memory was not. This may be elucidated by considering brain regions impacted in working memory processes, like the basal ganglia and cingulate cortex (Bachmann et al., 2018; Debarnot et al., 2014). Indeed, meditative practices have been found to activate these regions (Brewer et al., 2011; Ritskes et al., 2003). Thus, any changes in activation may have been accounted for by regions not measured in this study, with a negligible effect on the PFC. This is especially relevant given that our sample had ADHD, in which the neural correlates of working memory are known to be abnormal (Bachmann et al., 201; Salavert et al., 2018).

Research Question 3: How will a single MM bout impact the psycho-emotional functioning of children with ADHD?

A brief MM bout did not impact mood (positive or negative), self-efficacy, affect, or motivation in our sample. This contrasts with several studies that found these psycho-emotional measures improved by brief MM (e.g. Economides et al., 2018; Edwards et al., 2018; Johnson et al., 2015; Luu & Hall, 2017). However, these findings were obtained from research with neurotypical adult participants, and thus may not reflect functioning of children or individuals with ADHD.

Another reason our findings may have been inconsistent with previous work is because there is evidence that many young people, especially those with ADHD, report that they struggle with MM (Murrell et al., 2015; Keller et al., 2015). Keller et al. (2015) demonstrated that numerous school-aged children have a negative attitude toward MM. This may be exacerbated among children with ADHD, who often struggle with remaining still for an extended period of time (Forness & Kavale, 2001). In fact, Murrell and colleagues (2015) suggested that MM practices could, by their very nature, increase psychological distress and ADHD symptoms, as they bring attention to one's inattention. This notion was supported by data: 71% of high school students with ADHD report being uncomfortable sitting for a long period of time during meditation (Murrell et al., 2015). Distress related to sitting has been reported by participants in other MM studies (Craven, 1989; Lomas et al., 2015; Shapiro, 1992). Although this was not formally assessed in our study, experimenters reported observing that participants seemed resistant to the prospect of MM. This apparent negativity could explain why the increase in psycho-emotional functioning observed in previous research was not present.

Implications

The novel finding that key executive functions may be improved by a single MM bout in children with ADHD has important implications. In particular, finding that inhibitory control can be improved after a short intervention is important because it is the most pervasive among the executive functioning deficits in ADHD (Lipszyc & Schachar, 2010). Indeed, stimulant medications, the first-line treatment for ADHD, work primarily by facilitating the release of neurotransmitters that target inhibitory control (Advokat & Scheithauer, 2013; Pliszka, 2007). Thus, MM could be particularly helpful as a tool for individuals with impulse control deficits (i.e., the 4% of people with ADHD in the hyperactive-impulsive and the 60% in the combined subtype; Ford et al., 2003). MM breaks can serve as an additional tool to potentially help target and eliminate disruptive behavior in these youth. Our research suggests that MM does not need to be a weekly (or even daily) practice to be effective, but rather a single session could help remediate inhibitory difficulties and working memory challenges among children with ADHD. This is important for classrooms because teachers report lack of time as a main reason for being unable to regularly enact informal learning activities (Lohman, 2006).

As previously discussed, MM can be difficult for those with ADHD to partake in due to the extensive sitting they often require (Forness & Kavale, 2001; Murrell et al., 2015). Even typically developing populations can find extensive MM undesirable; between 38% to 75 % of long-term meditators report adverse effects of the MM (e.g., relaxation-induced anxiety and panic, increases in tension, boredom, pain, confusion and disorientation, feeling “spaced out”), and the longer the meditation, the more adverse effects are experienced (Craven, 1989; Shapiro, 1992). Thus, it is figures that children may find the intervention more tolerable if they are not committed to extensive programs. And, given our results showing that one session can be beneficial, there may no need for extensive programs. More importantly, taking this initial step may serve as an important “foot in the door”; experiencing short-term benefits encourages individuals to start forming helpful long-term habits (Mantzios & Giannou, 2018). The ubiquity of digital MM resources further eases access to—and familiarization with—MM, thereby increasing the likelihood that MM practice could become a more habitual, regular practice. Research on MM habit formation suggests that even brief engagement in mindfulness leads to incremental escalation of the automatic tendency to be mindful in daily life (Mantzios & Giannou, 2018), which leads to an abundance of positive outcomes (e.g. Kang et al., 2017). Therefore, engaging in brief MM bouts represents a useful and novel approach to incorporating mindfulness into one’s lifestyle.

The reduced financial burden of a single MM session is another important implication of our findings. There is no literature comparing the cost-effectiveness of mindfulness to medications for children with ADHD (Meppelink et al., 2016). However, there is preliminary evidence (Janssen et al., 2019) that, for adults with ADHD, adding a mindfulness component to existing interventions improves the overall cost-effectiveness of the intervention. Janssen et al.

(2019) supplemented treatment as usual (i.e., pharmacotherapy and/or psycho-emotional treatments such as psychoeducation and skills training) with an 8-week mindfulness-based intervention and found that the combined intervention was more cost-effective than treatment as usual when participants adhered to the intervention. Hence, it figures that one MM session could be even more cost-effective. Furthermore, the cost-effectiveness discrepancy would be even more pronounced in today's digital landscape that has seen the proliferation of free, efficacious MM services for children and adults (Flett et al., 2018; Bakker et al., 2016).

Limitations

This study has highlighted important aspects of the impact of a short bout of MM in children with ADHD but is not without limitations. First, we fell a few participants short of our target sample size (target of 20, current sample of 16). This may have contributed to some of the lack of significant findings. We did not have an age-matched, neurotypical control group, which limited our ability to compare and contrast the implications of MM on neurocognitive and psycho-emotional functioning in typical versus atypical development. Also, we only recruited children with a formal ADHD diagnoses, but there is lots of variability in terms of how ADHD is diagnosed (Bruchmüller et al., 2012). As is the case with research with all clinical populations, it is possible that our sample had meaningful differences in terms of their ADHD diagnoses, which would ultimately affect our claims. Ideally, an independent diagnostic interview would be conducted to verify ADHD status, but we did not have the resources during this project.

Furthermore, the repetitive nature of a within-subjects methodology can be taxing for participants (Charness et al., 2012). In our study, the cognitive battery was completed six times (see Appendix G). Accordingly, performance on the battery may have improved because of familiarization with the tasks or deteriorated as a result of boredom or fatigue (White et al., 2018). We tried to mitigate some of these effects by having a familiarization day precede the experiment wherein participants were exposed to the cognitive battery before data were collected. There is evidence that familiarization phases help reduce practice effects (White et al., 2018; Duff et al., 2001). Moreover, alternate forms of the same tasks were used, which is another technique shown to reduce practice and boredom effects (Duff et al., 2001). Further, if there were notable practice effects, all participants would have likely performed better across tasks regardless of condition, which was not the case; no ceiling effects were found. In other words, participants never mastered the cognitive tasks and scored perfect. It should be noted that there are several advantages associated with within-subject designs that outweigh the disadvantages; for instance, their internal validity does not rely on random assignment, they offer a boost in statistical power, and they align better with most theoretical mindsets (Charness et al., 2012).

Demand characteristics may have also influenced our results. This is always a challenge in meditational research where true double-blinded procedures are impossible because participants will always know if they are assigned to a MM condition (Davidson & Kaszniak, 2015). This means that our participants could have anticipated our hypotheses (i.e., we expected them to perform better on the cognitive tasks following the MM) and exerted more effort to conform to this expectation (McCambridge et al., 2012). They may have tried to be a desirable (or undesirable) participant. This is especially relevant for young people, who tend to seek approval from authority figures, and correspondingly behave to achieve this end (McDavid, 1965). Experimenter bias is also worth considering; through conscious or unconscious processes, the experimenters' strongly held beliefs about the benefits of meditation may have caused participants to try harder post-intervention to conform to the researchers' expectations of improved performance (McCambridge et al., 2012). Indeed, the role of bias has been observed in previous meditational research wherein bias occurs in several forms including the presence of confounding variables, departures from intended interventions, measurement of interventions, missing data, outcome measurement, and selection of reported results (Evans et al., 2018). In accordance with Davidson and Kaszniak's (2015) recommendations, we used an active control group (reading) to help mitigate these factors, and we attempted to blind them to which activity was our experimental condition. However, there is still the possibility these actions were insufficient (McCambridge et al., 2012).

Future Directions and Conclusions

As mentioned, there is very little work comparing the cost-effectiveness of MM interventions with current treatments for individuals with ADHD (Meppelink et al., 2016). In fact, Meppelink and colleagues (2016) proposed a study to do this, but it never came to fruition. This information is vital when it comes to the practical uptake of MM. Economics literature repeatedly demonstrates that if there is no financial incentive to switch from what is familiar, people seldom consider alternatives (Campbell et al., 2011). As such, for MM to be considered a viable alternative to treatment as usual, evidence of its effectiveness alone is insufficient, there has to be evidence of its cost-effectiveness too.

More comparative work should also be done examining how the effect size of brief MM bouts compare to that of extensive MM interventions. It is important to determine whether there are meaningful differences in terms of how much extensive interventions and short interventions impact various outcomes of functioning (including cognitive, psycho-emotional, and neurological aspects). It is entirely possible that, while both are effective, longer bouts are *more* effective. This work must be done before definitive commentary can be made on the ability to replace (rather than supplement) brief MM for longer interventions.

Finally, there is remarkably little literature assessing attitudes toward MM, and seemingly no literature examining how children with ADHD think or feel about MM. Research shows that if students feel positively towards a task—even if the task has a traditionally negative connotation (e.g. homework)—they are more likely to engage with it, and spend longer doing so (Buijs & Admiraal, 2013). Therefore, beliefs and comfort in engaging in MM practices could ultimately influence the effectiveness of MM as an intervention. Participatory and/or qualitative research is needed to assess how children with ADHD think and feel about MM so that interventions can be tailored and optimized to suit those individuals. This is especially important because people are more likely to adhere to practices when they are personalized to their needs and preferences (Hyland et al., 2016). This information would also inform campaigns that dispel the various myths associated with MM (see Ramsay, 2015), and inform students of its potential benefits.

Our study is the first to show that a single session of MM can support inhibitory control and working memory in young people with ADHD. Moreover, to our knowledge, we were the first to institute advanced functional imaging to demonstrate that improved inhibitory control corresponded with a significant change in PFC functioning in youth with ADHD. Thus, our study provides critical initial evidence that MM has a direct impact on neural functioning within the PFC to support inhibitory control in youth with ADHD. Considering the free cost and easy access associated with many short MM sessions and given that short MM sessions may be more attainable for individuals who struggle sitting still for long periods of time, brief MM bouts may increase the overall accessibility, and thus ultimate uptake of MM for young people with ADHD. Taken all together, the findings of this provide initial evidence that a single MM bout may be used to improve key cognitive deficits that individuals with ADHD experience.

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Appendices

Appendix A

Congruent Stroop Task

BLACK	**BLACK**
GREEN	**ORANGE**
BLUE	**RED**
RED	**GRAY**
YELLOW	**GRAY**
ORANGE	**GREEN**
RED	**ORANGE**
BLUE	**BLACK**
ORANGE	**BLUE**
GREEN	**RED**
GRAY	**BLUE**
BLACK	**YELLOW**
YELLOW	**RED**

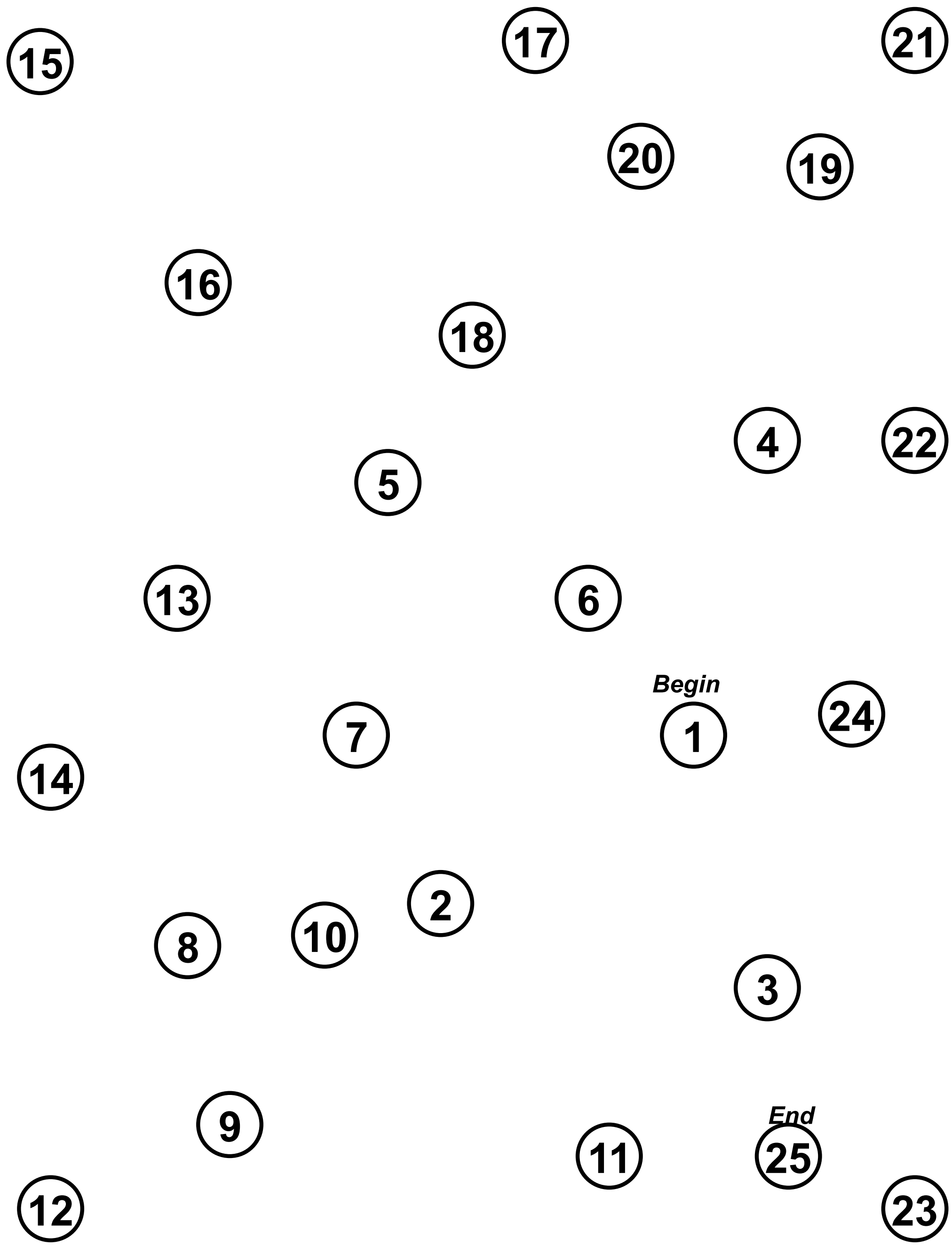
Appendix B

Incongruent Stroop Task

BLACK	**BLACK**
GREEN	**ORANGE**
BLUE	**RED**
RED	**GRAY**
YELLOW	**GRAY**
ORANGE	**GREEN**
RED	**ORANGE**
BLUE	**BLACK**
ORANGE	**BLUE**
GREEN	**RED**
GRAY	**BLUE**
BLACK	**YELLOW**
YELLOW	**RED**

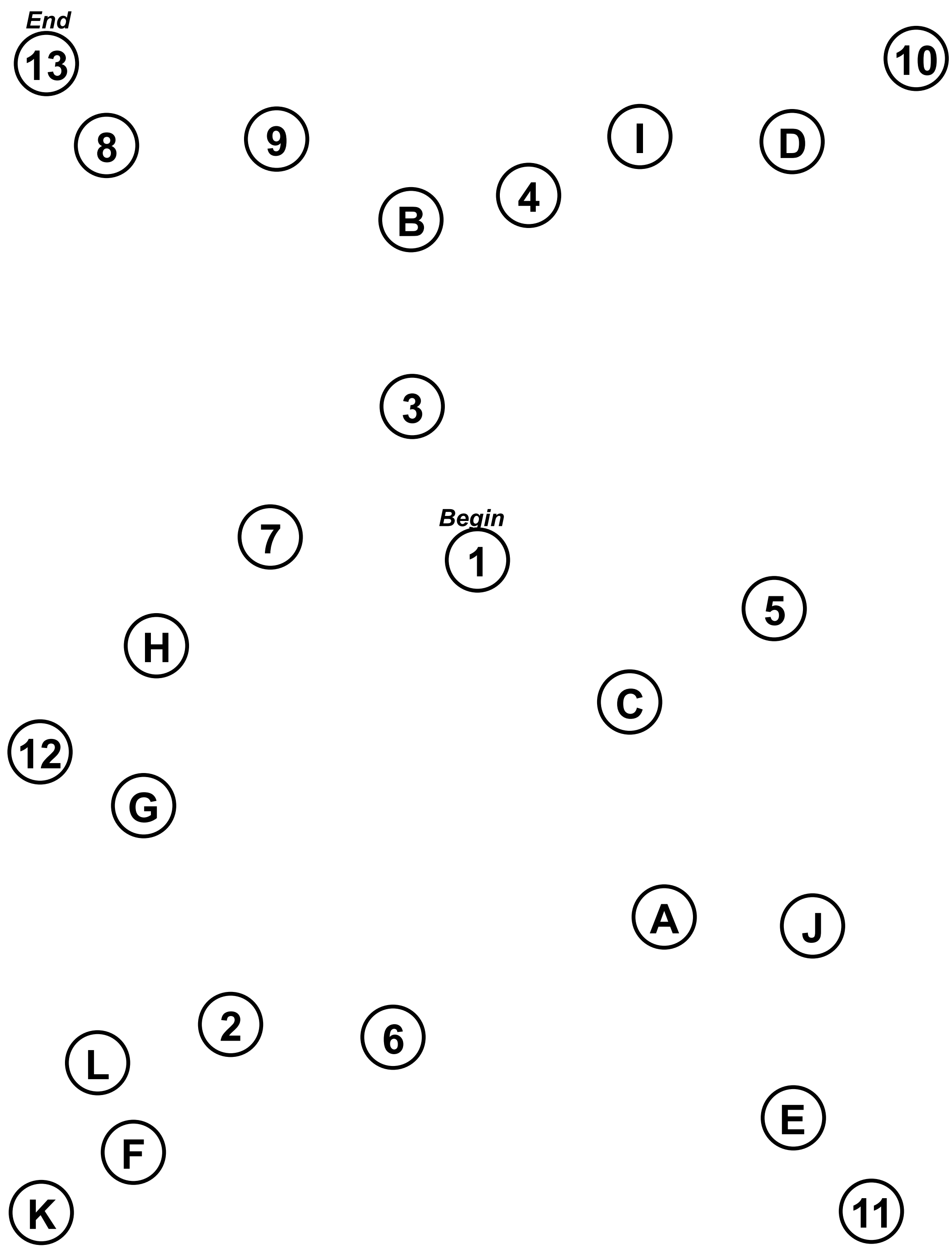
Appendix C

Trail Making Test A



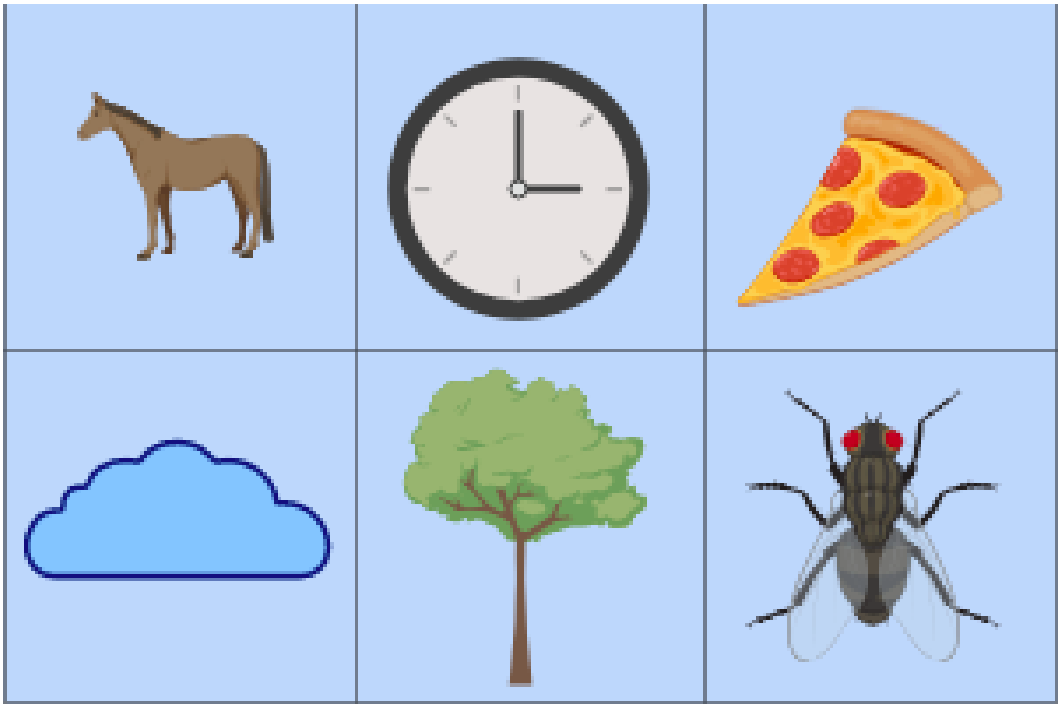
Appendix D

Trail Making Test B



Appendix E

Example of Working Memory Task



Appendix F

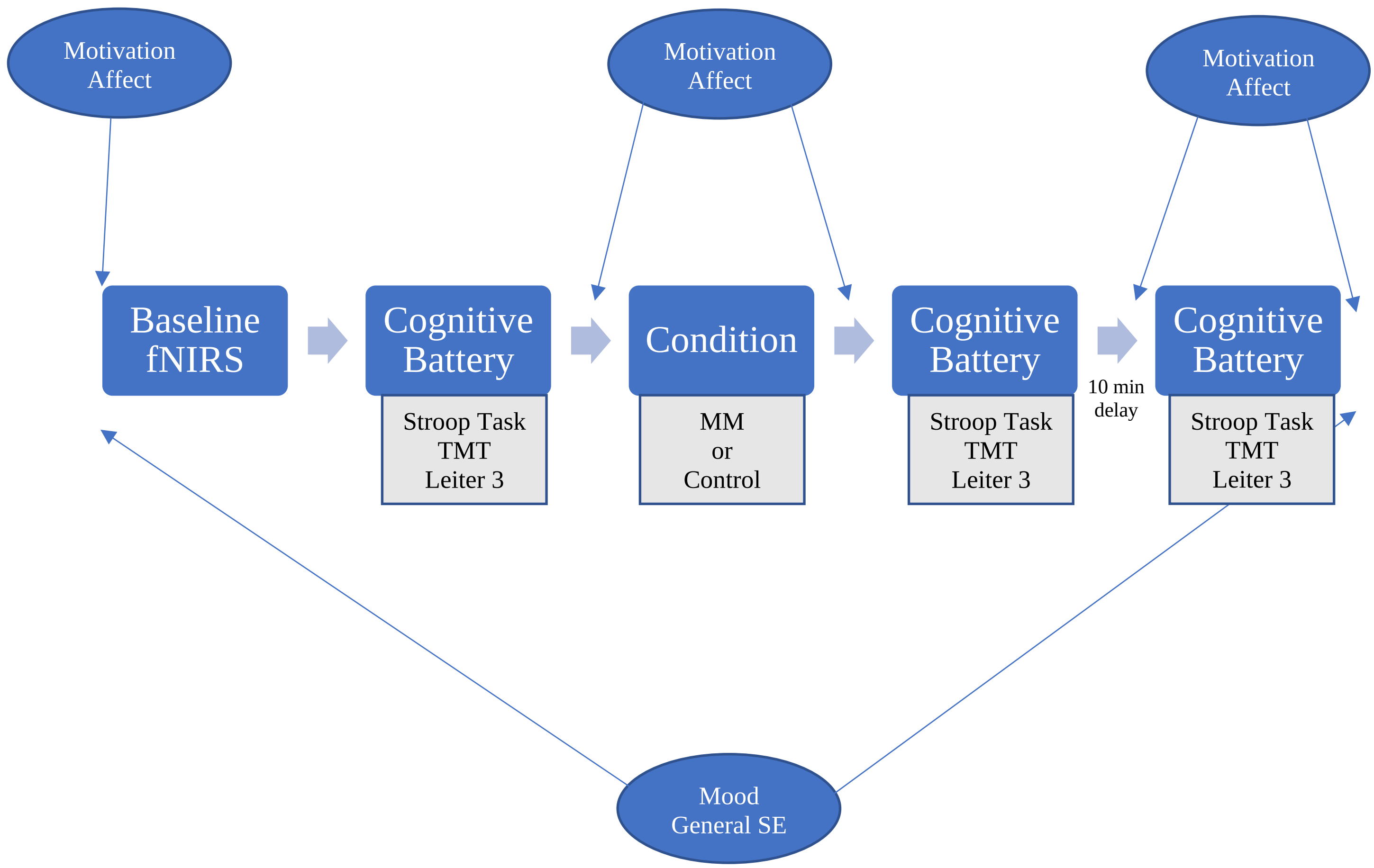
Adapted Profile of Mood States Measure (Williamson et al., 2001)

Active	1	2	3	4	5
Awake	1	2	3	4	5
Bored	1	2	3	4	5
Energetic	1	2	3	4	5
Excited	1	2	3	4	5
Friendly	1	2	3	4	5
Happy	1	2	3	4	5
Lonely	1	2	3	4	5
Sad	1	2	3	4	5
Tired	1	2	3	4	5
Unhappy	1	2	3	4	5

Note. Positive mood states were captured by items: Active, Awake, Energetic, Excited, Friendly, and Happy. Negative mood states were captured by items: Bored, Lonely, Sad, Tired and Unhappy.

Appendix G

Experimental Protocol



Appendix H

General Self-Efficacy Measure (Chen et al., 2001)

General self-efficacy - relates to "one's estimate of one's overall ability to perform successfully in a wide variety of achievement situations, or to how *confident* one is that she or he can perform effectively across different tasks and situations".

	Strongly Disagree				**Strongly Agree**
I will be able to achieve most of the goals I have set for myself	☐	☐	☐	☐	☐
When facing difficult tasks, I am certain that I will accomplish them	☐	☐	☐	☐	☐
In general, I think that I can obtain outcomes that are important to me	☐	☐	☐	☐	☐
I believe I can succeed at most any endeavor to which I set my mind	☐	☐	☐	☐	☐
I will be able to successfully overcome many challenges	☐	☐	☐	☐	☐
I am confident that I can perform effectively on many different tasks	☐	☐	☐	☐	☐
Compared to other people, I can do most tasks very well	☐	☐	☐	☐	☐
Even when things are tough, I can perform quite well	☐	☐	☐	☐	☐

Appendix I

Affect Measure (Hardy & Rejeski, 1989)

Feeling Scale (FS)
(Hardy & Rejeski, 1989)

While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed this scale to measure such responses.

+5 Very good

+4

+3 Good

+2

+1 Fairly good

0 Neutral

-1 Fairly bad

-2

-3 Bad

-4

-5 Very bad

Appendix J

Motivation Measure (McAuley et al., 1989)

For each of the following statements, please indicate how true it is for you, using the following scale:

1	2	3	4	5	6	7
Not at all true		**Somewhat true**			**Very true**	

For the brain games I'm about to do:

1. I am going to put a lot of effort into these brain games. ______
2. I am going to try very hard to do well at these brain games. ______
3. I am going to try very hard on these brain games. ______
4. It is important to me to do well at these brain games. ______
5. I am going to put a lot of energy into these brain games. ______

For each of the following statements, please indicate how true it is for you, using the following scale:

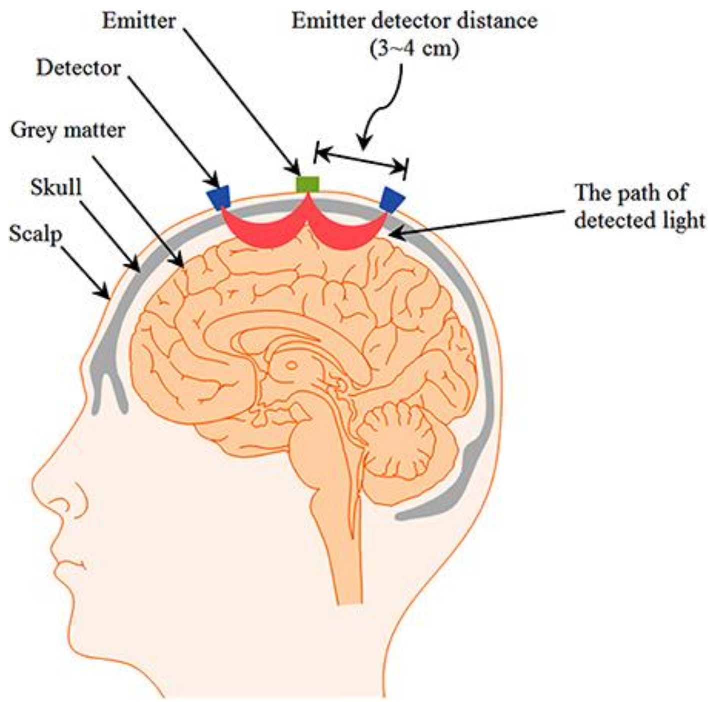
1	2	3	4	5	6	7
Not at all true		**Somewhat true**			**Very true**	

For the brain games you just completed:

1. I put a lot of effort into the brain games. ______
2. I tried very hard to do well on the brain games. ______
3. I tried very hard on the brain games. ______
4. It was important to me to do well on the brain games. ______
5. I put a lot of energy into the brain games. ______

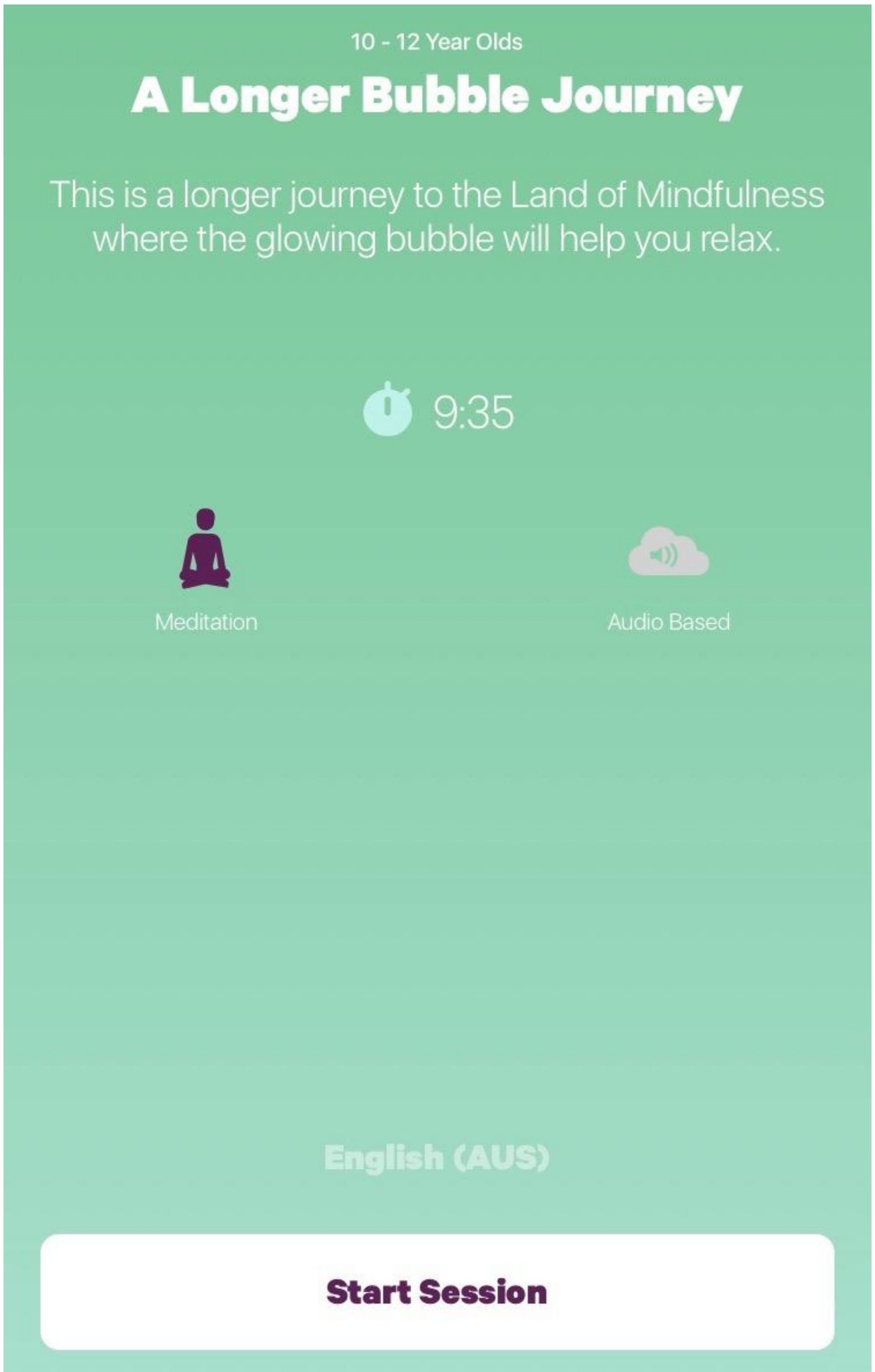
Appendix K

fNIRS Schematics (Naseer & Hong, 2015; Sonkaya, 2018)



Appendix L

Smiling Mind 'A Longer Bubble Journey' (Smiling Mind Pty Ltd, 2015)



Appendix M

Paper Recruitment Fliers

Western

PARTICIPANTS NEEDED FOR RESEARCH TO UNDERSTAND THE BENEFITS OF PHYSICAL ACTIVITY AND MINDFULNESS ON CHILDREN WITH ADHD

We are looking for volunteers to take part in a study looking at how long physical activity and mindfulness impacts brain function in children between 10 and 14 years old, who have an ADHD diagnosis.

If you are interested and agree to participate you would be asked to: undergo short sessions of physical activity and mindfulness. We would also record your brain activity using a cap while you play some brain games.

Your participation would involve 4 sessions on different days, each session will be just over 1 hour long.

Participants will be compensated for their time.
For more information about this study, or to volunteer for this study, please contact:

Active Minds Group
Faculty of Education, Western University

Appendix N

Email Recruitment Flier

Research Investigating Physical Activity and Mindfulness as a Potential Treatment for Children with ADHD

Needed: Participants with ADHD diagnosis between 10 and 14

What: A study to better understand the effects of meditation and physical activity on attention in children with ADHD

Where: Western Interdisciplinary Research Building (WIRB) on Perth Dr. (beside Visual Arts center)

Duration: The study will involve 4 sessions (separated by 1-week). Each session will last approximately 1-1.5hrs.

Appendix O

Ethics Approval Form

Western Research

Date: 3 May 2019

To: Dr Barbara Fenesi

Project ID: 113304

Study Title: Understanding the effects of acute exercise and mindfulness on cognitive functioning in children with ADHD using advanced functional imaging techniques

Application Type: HSREB Amendment Form

Review Type: Delegated

Full Board Reporting Date: May 21, 2019

Date Approval Issued: 03/May/2019

REB Approval Expiry Date: 15/Mar/2020

Dear Dr Barbara Fenesi ,

The Western University Health Sciences Research Ethics Board (HSREB) has reviewed and approved the WREM application form for the amendment, as of the date noted above.

Documents Approved:

Document Name	Document Type	Document Date
Appendix 16 technology Questionnaire	Paper Survey	Received April 23, 2019
Appendix 17 Paired Associations Task	Paper Survey	Received April 23, 2019
Appendix 17 Paired Associations Task 2	Paper Survey	Received April 23, 2019
Appendix-15-Leiter-3	Paper Survey	Received April 23, 2019
LOI-C (Control) April 7	Consent Form	Received April 23, 2019
LOI-C(ADHD) April 7	Consent Form	Received April 23, 2019
Study protocol	Protocol	Received April 23, 2019

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Karen Gopaul, Ethics Officer on behalf of Dr. Joseph Gilbert, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Curriculum Vitae

Name:	**Marcus Dylan Gottlieb**
Post-secondary Education and Degrees:	Western University London, Ontario, Canada MA Counselling Psychology 2018 - 2020
	Western University London, Ontario, Canada BA (Hons.) Psychology 2013 - 2018
	The University of Leeds Leeds, United Kingdom Junior Year Abroad, Sociology 2016
Honours and Awards:	Social Sciences and Humanities Research Council (SSHRC) Scholarship 2019 - 2020
	Global and Intercultural Engagement Honour 2017
Related Work Experience	**Graduate Student Clinician** Child and Youth Development Clinic 2019-2020
	Strengthening Families Program Group Leader Muslim Resource Center 2019-2020
	Instructor Therapist Magnificent Minds 2018
	Camp Director Happi Organization for Newcomers to Canada 2017
	Therapist Ellen Yack and Associates Paediatric Clinic 2017
	Child Literacy Worker Learning Disabilities Association, London Region 2013-2015