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The Psychotherapeutic Effects of Consumer-Grade EEG Neurofeedback on Mental Health and Well-being

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Abstract

The current study assessed whether pairing mindfulness meditation with consumer-grade neurofeedback (using Muse) would be a feasible and satisfying (i.e., fulfillment and pleasure) intervention for mental health and well-being. This was assessed via a four-day mindfulness program where participants (N=34) were assigned to mindfulness with neurofeedback (*n*=17) or guided meditation (control; *n*=17) group. On each day of the program, participants engaged in two mindful sessions (five minutes each) in the morning and afternoon. Participants were administered a series of affective measures before and after the program, as well as throughout. Upon completion, participants were asked to rate their satisfaction with their program. A series of factorial repeated measures ANOVAs were performed to assess for differences between groups. Results confirmed the feasibility of this format of intervention. There was no significant difference in satisfaction reports between groups. Further, no significant differences were found between groups in pre- and post-measures of depressive, anxious, and trauma symptoms, as well as mindful traits. There were significant differences in scores of positive and negative moods found between neurofeedback and control groups, suggesting an added benefit to pairing neurofeedback with mindfulness practice. Overall, this initial feasibility study demonstrated that mindfulness with neurofeedback may have some enhanced psychological benefits compared to meditation alone. However, this intervention needs to be carried out on a much larger and more diverse scale, with consideration for electrophysiological changes, to strengthen its efficacy as an intervention for mental health and wellbeing.

Key Words

mindfulness, meditation, neurofeedback, consumer-grade EEG, mental health, wellbeing, intervention.

Summary for a Lay Audience

Separately, mindfulness and neurofeedback practice has demonstrated to be beneficial to physical and mental health. More specifically, mindfulness meditation has risen in popularity in recent years as a tool to help users improve their psychological well-being and enhance attention. However, many may struggle to achieve a restful and mindful state in today's fast-paced world. This has resulted in the creation of different variations of mindfulness activities to help individuals achieve a calm and restful brain state (i.e., colouring books and smartphone apps). One of these manifestations has been in consumer-grade EEG headsets like Muse by InteraXon which pairs mindfulness with neurofeedback. However, it is important to assess the feasibility and effectiveness of pairing mindfulness with neurofeedback. The current study assessed whether pairing mindfulness meditation with consumer-grade neurofeedback (using Muse by InteraXon) would be a feasible and satisfying intervention for mental health and well-being. Participants engaged in a four-day mindfulness program where one group practiced traditional guided meditation and the other practiced mindfulness meditation with neurofeedback. Participant mood was assessed throughout the program, and upon completion, participants were asked how satisfying they found the program. Researchers hypothesized that this format of intervention would be feasible and that participants in the meditation with neurofeedback group would find the intervention more satisfying than in non-neurofeedback groups. Results confirmed that pairing mindfulness with neurofeedback in an at-home intervention format was feasible. Similar satisfaction ratings were provided for both neurofeedback and non-neurofeedback groups. In the mindfulness with neurofeedback group, significantly higher scores of positive mood and lower scores of negative mood were reported compared to the non-neurofeedback group. This information suggests that the addition of neurofeedback to mindfulness may hold some benefit to emotion. Further exploration of this format of intervention should consider carrying out studies on a larger and more diverse scale, incorporating suggestions of fake feedback conditions and changes in the brain.

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Chapter 1: Introduction

1.1 Mindfulness as a Practice

Mindfulness meditation has recently gained popularity with its proposed benefits for individual well-being and overall mental and physical health, which has led to the introduction of mindfulness practice in various formats (i.e., apps, wearable devices, colouring books). As more mindfulness-based technologies and activities emerge for public use, there are now several ways that someone can practice mindfulness and experience the potential benefits. One of the mindfulness-based technologies now commercially available is EEG neurofeedback. The purpose of the current study was to assess the feasibility, satisfaction (i.e., fulfillment and pleasure), and effectiveness of an at-home mindfulness program using neurofeedback. In addition, a measure assessing the subjective experience of learning in neurofeedback was piloted. Please note that some of the background literature presented in this introduction are of a correlational nature, meaning that causality cannot be implied.

While mindfulness has been incorporated into various modern activities (i.e., colouring books, smart-phone apps, virtual reality), the practice of mindfulness meditation has been around for thousands of years with roots in many cultural, contemplative, and philosophical traditions such as Buddhism (Buddhagosa, 1976). In the philosophical foundations of Buddhism, mindfulness can be defined as an individual's complete awareness and mastery of the mind (Kabat-Zinn, 2015). In contemporary psychological and neuroscience literature, mindfulness as a practice can be described as giving one's complete attention to the current moment in time without any judgment of inner thoughts or outer experiences (Kabat-Zinn, 1990; Kabat-Zinn, 2015). Mindfulness can be intentional in that we can take deliberate action to achieve a mindful state. It can also be unintentional and effortless when one achieves a mindful state on their own, which is often seen with increased and persistent practice (Kabat-Zinn, 2015). Shapiro and colleagues (2006) suggest that mindfulness has three principles: 1) mindfulness is “on purpose” or intentional, 2) it requires “paying attention” or attention and 3) you deploy this attention “in a particular way” or attitude. These principles can be thought of as the building blocks of mindfulness, working together to create a complete experience (Shapiro et al., 2006).

For many adherents, deliberate and intentional mindfulness practice eventually evolves into an effortless and unintentional way of being (Shapiro et al., 2006). What starts out as a practice to achieve a mindful state, turns into a characteristic or trait of oneself. One of the striking things about mindfulness is the simplicity and universality of the practice itself, merely requiring the individual to pay attention to the present moment without judgment. Vipassana teacher Joseph Goldstein used the following analogy to describe mindful practice: “It is like a mirror that clearly reflects what comes before it” (Kabat-Zinn, 2015). In other words, mindfulness allows us to understand the present moment as it is without any judgment or interpretation. This is especially beneficial to those with maladaptive or distorted cognitions that may lead to psychological disturbances (Adele & Feldman, 2004; Bishop et al., 2004; Davis & Hayes, 2011; Masicampo & Baumeister, 2007; Walsh & Shapiro, 2006). The universality of this practice allows it to be applied in various demographics and environments, giving it a heightened level of accessibility. However, this simple act has a much larger impact than what we can see at face value. While we can think of mindfulness or general attention as an innate state, it is something that many people struggle to access and master. This gives rise to activities like meditation to provide the template for a systematic practice that encourages ones to learn to be mindful (Kabat-Zinn, 2015; Shapiro et al., 2006).

Mindfulness meditation offers a host of benefits to the user that encompasses both the individual's physical and psychological health, giving it the power to have a significant and holistic impact on the individual if regularly practiced (Creswell, 2017; Keng, Smoski & Robins, 2011). Physiologically, mindfulness practice reduces several physiological markers of stress including heart rate, cortisol levels, cardiac activity, blood pressure, and triglyceride levels, as well as improvements in overall immune response and functioning (Bali & Jaggi, 2015; Berntson, Quigley, & Lozano, 2007; Davidson et al., 2003; Mendes, 2009; Pascoe, Thompson, Jenkins, & Ski, 2017). Meta-analyses of applications and outcomes of mindfulness-based interventions show that they can be effectively applied for both clinical and non-clinical symptoms to a variety of diagnoses including fibromyalgia, mixed cancer diagnoses, coronary artery diseases, obesity, and chronic pain (Grossman et al., 2004). Mindfulness-based intervention outcomes consistently produce relatively larger effect sizes across studies suggesting that mindfulness training has to potential to be an efficient practice for the management of symptoms associated with the discomfort and dysfunction that come as a result of these medical diagnoses (Grossman et al., 2004; Kabat-Zinn et al., 1987).

For the purposes of the current study, I was interested in the psychological outcomes of mindfulness practice. Mindfulness meditation can offer assistance and enhancement to the user in several areas including emotional regulation, self-moderation, objectivity, attentional control, emotional intelligence, self-awareness, and adaptability (Adele & Feldman, 2004; Bishop et al., 2004; Davis & Hayes, 2011; Masicampo & Baumeister, 2007; Walsh & Shapiro, 2006). Further, regular practice of mindfulness meditation can lead to changes in an individual's stress response through the enhancement of self-awareness, monitoring, and regulation (Guendelman, Medeiros, & Rampes, 2017; Vago & Silbersweig, 2012; Wheeler, Arnkoff, & Glass, 2017). This can be very empowering to the individual as they can achieve a new level of self-regulation that was not previously possible, which enables them toward more effective coping skills for everyday stressors (David, & Goolkasian, 2010; Tang et al., 2007; Tang, Jiang, & Posner, 2014; Zeidan et al.,2010). When we apply the mindful practice to those living high-stress lifestyles, such as healthcare and frontline workers during the pandemic, mindfulness has been suggested to be an effective intervention for prolonged stress and resulting burnout (Goodman & Schorling, 2012; Klien et al., 2020; Krasner et al., 2009). Mindfulness-based interventions (MBIs) have been increasingly integrated into treatment plans in recent years for the management of common mental health disorders such as depression and anxiety (Demarzo et al., 2015; Dimidjian & Segal, 2015; Hedman-Lagerlof et al., 2018; Plank, 2010). Several studies have revealed that MBIs are an effective way to manage and reduce symptoms of anxiety and stress, as well as the occurrence of depressive episodes (Goyal et al., 2014; Hoffman et al., 2010; Khoury et al., 2013; Piet & Hougarad, 2011; Volestaad et al., 2012). As a result, mindfulness has demonstrated efficacy in the treatment of a number of mental health disturbances and has been incorporated into several clinical applications, such as Mindfulness-Based Stress Reduction, Mindfulness-Based Cognitive Therapy, Dialectical Behaviour Therapy, and Acceptance and Commitment Therapy (Baer, 2006; King et al., 2013; Lang, 2017; Scarlett, Lang & Walser, 2016). Mindfulness can be used alone as an intervention or in combination with another treatment approach (Lang et al., 2012).

Mindfulness can also be used as a training tool to enhance general cognitive performance and flexibility (Cahn & Polich, 2006; Garrison et al., 2013; Garrison et al., 2015; Gordon, & Goolkasian, 2010; Zeidan et al., 2010). Both long-term and short-term changes have been seen with the practice of mindfulness (Lee et al., 2018). Long-term mindfulness meditation practice can lead to enhanced visuospatial abilities, attentional control, and faster reaction times in experienced meditators (Cahn & Polich, 2006; Lutz et al., 2009; Moore & Malinowski, 2012). Specifically, mindfulness practice can improve and enhance metacognition, or an individual's ability to be consciously aware of their own cognitive processing (Hussain, 2015). This carries several advantages for an individual's attentional capabilities and executive functioning (Cahn & Polich, 2006; Gordon, & Goolkasian, 2010; Zeidan et al., 2010). Experienced meditators demonstrate differences in connectivity in the executive networks of the brain associated with attention and error monitoring, as well as higher-order cognitive processing (Garrison et al., 2013; Garrison et al., 2015; Short et al., 2007). The cognitive and affective benefits experienced by the user can also be impacted by the type of meditation that is being practiced (Lutz et al., 2008). For example, focused attention and open monitoring meditations tend to be more effective for improvements in attentional capabilities, emotional management, self-reflection, and cognitive control (Lippelt et al., 2014; Tang et al., 2014). Specifically, studies assessing open monitoring meditation have shown evidence that they are more effective overall for fostering attentional control and improving performance in tasks that require ongoing attention (Ainsworth et al., 2013; Lippelt et al., 2014). The vast amount of research that has been conducted to assess outcomes of mindfulness meditation as an intervention in emotional and cognitive facets highlights the potential for therapeutic benefit and the versatility of such a practice for both physical and psychological health.

Considering the psychological changes that have been demonstrated in experienced meditators and meditative states, it is prudent to understand the neural correlates that underlie mindfulness practice to help further clarify both real-time changes and long-term changes in the brain. Some areas of interest in the brain that have been associated with the meditative practice are the prefrontal cortex, insula, and anterior cingulate cortex. Studies have shown evidence that consistent mindfulness practice may lead to increased cortical thickness in regions of the prefrontal cortex and insula, as well as differences in connectivity among neural networks (Engen et al., 2017; Lazar et al., 2005; Lee et al., 2018; Santarnecchi et al., 2014). Lee and colleagues (2018) performed a network analysis of the central executive network, salience network and default mode network, comprising what is known as the triple network. They found that connectivity between these brain regions may help facilitate mindfulness practice. Further, the authors emphasized the importance of considering the triple network in relation to mindfulness practice as these areas are often where abnormalities and dysfunction are seen in several psychiatric disorders that result in deficits in emotional regulation, decreased cognitive functioning, and abnormal saliency mapping (Lee et al., 2018; Menon, 2011; Touroutoglou et al., 2015; Udin et al., 2011; Young et al., 2017). These areas are typically associated with goal-oriented behaviours and thoughts (central executive network) (Beaty et al., 2015; Christoff et al., 2016; Kim et al., 2019; Mooneyham et al., 2016; Sridharan et al., 2008; Uddin, 2015), interoceptive perception (salience network) (Barrett and Simmons, 2015; Kim et al., 2019; Mooneyham et al., 2016) and internal thinking (default mode network) (Brewer and Garrison, 2014; Brewer et al., 2011; Fair et al., 2008; Kim et al., 2019; Mooneyham et al., 2016; Sheline et al., 2009; Sridharan et al., 2008; Uddin, 2015). Several studies have indicated that mindfulness meditation practice has the potential to deactivate the default mode network, with experienced meditators demonstrating willful control of this network (Brewer et al., 2011; Garrison et al., 2015; Simon & Engstrom, 2015; Travis & Parim, 2017). As mentioned previously, these changes in neural connections and activity can vary based on the type of meditation being practiced. In focused attention meditation, studies have demonstrated increases in brain functioning and connectivity in the anterior cingulate cortex, prefrontal cortex, and right insula compared to other forms of meditation (Botvinick et al., 2004; D'Esposito et al., 2007; Lazar et al., 2000; Manna et al., 2010). Focused attention and open monitoring have also been associated with increased activity and connectivity in the posterior insula and dorsal attention network on interoceptive attention tasks (Farb et al., 2013; Froeliger et al., 2012). Given that mindfulness practice fosters neural plasticity seen in connectivity changes amongst these networks that commonly reflect abnormalities due to psychiatric disorders, it is evident how this format of intervention and practice can potentially be a versatile tool for the treatment of common psychiatric disorders.

While the bulk of studies and reports on mindfulness meditation have emphasized the benefits of the practice it is important to consider the potential adverse effects of meditation, especially when practiced as an intervention among populations that may be vulnerable such as persons with PTSD and other psychiatric disorders. An adverse event in meditation can be defined as a harmful occurrence that is associated with the practice, but that is not necessarily a direct result of the practice (Farias et al., 2020). Some common forms of adverse events in meditation include anxiety, depression, cognitive anomalies, stress, trauma re-experience, dissociation and suicidal behaviour (Farias et al., 2020). A systematic review of meditation literature found that out of 83 studies the total pooled prevalence of adverse events was 8.3% with observational studies (33.2%) showing higher incidence than experimental studies (3.7%) (Farias et al., 2020). Zhu and colleagues (2019) conducted a study assessing trauma and stressor-related history factors impacting distress experienced during a brief mindfulness meditation practice. Participants' exposure to lifetime trauma, life stress experienced in the last year, and trauma symptoms experienced over the last year were collected. Results suggested that distress during mindfulness meditation could be anticipated based on the individual's lifetime exposure to trauma, life stress experience in the last year, and trauma-related symptoms experienced in the last month with a stronger relationship existing between distress experienced during meditation and current symptoms (Zhu et al., 2019). The possible adverse effects of meditation are essential to consider in order to provide trauma-informed care and intervention.

While many are hoping to experience the proposed physical and psychological benefits of mindfulness meditation, some struggle with the amount of attentional control that this practice requires in today's ever-changing world. This is where technologies like Electroencephalography (EEG) neurofeedback should be investigated as a training tool and learning aid to facilitate proper mindful practice and help put the individual on the right path to experiencing the benefits of mindfulness.

1.2 EEG Neurofeedback

Electroencephalography (EEG) neurofeedback provides real-time feedback of brain activity to the user. Neurofeedback is a variation of biofeedback that monitors the various metrics of brain function in real-time and presents the information back to the user (Marzbani et al., 2016). This feedback is typically presented to the user in a visual format, auditory format, or a combination of the two, reflecting some relative measure varying across time. EEG measures are often expressed as the amplitude of delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (13-30 Hz) and gamma (30-100 Hz) frequency waves, the relative dominance of which is known to correspond to various psychological states. Specifically, delta is associated with sleep, theta is associated with fatigue, alpha is associated with relaxation, beta is associated with alertness, and gamma is associated with thinking or problem-solving (Marzbani et al., 2016). However, research indicates that, at least for the alpha frequency, bands should be further separated into subsets such as upper (10-12 Hz) and lower (8-10 Hz) (Dempster, 2012). Past research has suggested that each of the subsets of the alpha range serves different purposes in selective attention and cognitive processing (Dekker et al., 2014; Klimesch, Sauseng. & Hanslmayr, 2006). Neurofeedback uses the principles of operant conditioning to train the user to control their brain toward a desired state and has been used as a training aid and intervention in the treatment of brain injuries and psychiatric disorders, demonstrating effectiveness in several areas (Demos, 2005; Marzbani et al., 2016).

Given that neurofeedback works to help the user learn attentional and cognitive control, it is similar to the goals of mindfulness. Both neurofeedback and mindfulness promote plasticity in the brain and self-regulation (Lazar et al., 2005; Pagoni & Cekic, 2007). These interventions differ, however, in that mindfulness meditation is limited to participants' subjective experience of introspection and interoception, whereas neurofeedback provides objective measures of neurophysiological states (i.e., EEG; Brandmeyer & Delorme, 2013). Most neurofeedback-based treatments are centred around the alpha, beta, delta, theta and gamma waves or a combination of certain frequency waves (i.e., alpha/theta; Dempster, 2012; Vernon, 2005). Neurofeedback interventions can be targeted toward a specific aspect of users' EEG, for example, neurofeedback paradigms designed for cognitive enhancement targeting alpha or theta waves (Zoefel et al., 2011). Cues provided by neurofeedback can be given through visual or auditory stimuli that are subtle so as not to distract the user from the task at hand (Brandmeyer & Delorme, 2013). The subtleness of these cues is important as it ensures that the feedback is not overwhelming the senses of the user and allows them to keep their attentional resources on the task (Brandmeyer & Delorme, 2013). Given that EEG has a high-quality resolution that has the capability to catch short-term oscillatory changes during meditation, it is a form of measurement that is favourable to improve the practice and potentially tailor this format of treatment to address psychiatric illness (Lee et al., 2018).

1.3 Alpha and Theta Frequencies and the Mindful Brain

1.3.1 Alpha Neurofeedback Training

One type of neurofeedback training focuses on so-called “alpha” oscillations, that is, between 8 and 12 Hz. Alpha waves are associated with states of alert relaxation, facilitating a calm state in the individual (Marzbani et al., 2016). Some suggest that the alpha frequency can be segmented into subsets, upper (10-12 Hz) and lower alpha (8-10 Hz), with upper alpha being linked to improvements in cognitive performance (Angelakis et al., 2007; Dempster, 2012). Alpha is seen most abundantly in the posterior regions of the brain (Lagopoulos et al., 2009). Alpha activity varies from person to person and may occupy an individual’s brain state in different ways. For example, some individuals display very defined alpha presence while others may appear to have very minimal alpha wave activity (Kamiya, 1969). Alpha training has been used for the purposes of pain relief, stress reduction, memory improvement, cognitive performance, and brain injuries (Marzbani et al.,2016). The most targeted bandwidth within the alpha frequency is between 7-10hz which is often used for facilitating meditative states, anxiety reduction, and improving sleep (Marzbani et al., 2016). Alpha neurofeedback training has been linked to high levels of cognitive control and improvements in mental states, such as attentional increases and reductions in anxiety (Biswas & Ray, 2019). Previous studies of the impact of alpha neurofeedback training on cognitive control have shown that participants display learning across sessions and improved performance on cognitive tasks such as mental rotation (Zoefel, Huster & Hermann, 2010). EEG studies have revealed a cessation of alpha activity when individuals are engaged in a cognitive task, known as alpha desynchronization (Aftanas et al., 2001; Stern et al., 2001). Alpha desynchronization in higher bands of the wave suggests external attention and higher-order cognitive processing. On the other hand, alpha synchronization demonstrates internal monitoring, regulation, and attention (Aftanas et al., 2001; Stern et al., 2001).

Increased frontal, parietal, and occipital alpha activity and synchrony have also been observed in meditative states as individuals become more relaxed (Arpaia et al., 2021; Cahn et al., 2013; Gil et al., 2018; Kasmatsu & Hirai, 1966; Travis, 2001). Previous studies have demonstrated that advanced meditators showed more alpha activity compared to novice meditators (Aftanas & Golochiemine, 2001; Cahn & Polich, 2006; Lee et al., 2018). Furthermore, a study of the time-course of alpha neurofeedback training by Dekker and colleagues (2014) revealed that alpha power increased both between and within neurofeedback training sessions. Between-sessions increases in alpha power were demonstrated in 10 sessions and within-sessions alpha power was seen to increase towards the beginning of the session and decrease towards the end, likely due to participant fatigue (Dekker et al., 2014). A systematic review by Lomas, Ivtzan, & Fu (2015) on the neurophysiology of mindfulness found increases in alpha and theta waves across studies. Focused attention and open monitoring meditation practices have been implicated in these findings as well (Braboszcz et al., 2017; Cahn et al., 2013; Lee et al., 2018). In addition, alpha frequencies have often been the subject of sleep studies where it has been found that the practice of meditation increases alpha power during sleep (Dentico et al., 2016). Focused attention and open monitoring meditation practice have demonstrated increased power and coherence in prefrontal and left parietal alpha activity, which is positively correlated with meditation experience (Braboszcz et al., 2017; Cahn et al., 2013; Dentico et al., 2016; Travis, 2001; Travis & Parim, 2017;). However, Braboscz and colleagues

(2017) found that open-monitoring meditation results in more alpha power and synchrony compared to focused attention meditation. Results of alpha neurofeedback training studies have not been consistent, but this can be attributed to differences in methodology such as measures and placement of electrodes (Brandmeyer & Delorme, 2013).

Early studies of alpha neurofeedback training by Joseph Kamiya (1969) found that participants could successfully be trained to distinguish between the relative dominance of alpha activity (presence vs. absence) in the EEG with great accuracy. Kamiya (1969) hypothesized that he could train people to subjectively identify when alpha oscillations were present (i.e., high in amplitude) or absent (i.e., low in amplitude) and found that they often described alpha present states as ones of concentration and/or visualization of a concept or object. Some findings of Kamiya's (1969;1978) studies are important to take into consideration for future studies of the same nature. For example, it was found that people subjectively reported that they preferred to alternate between states of alpha presence and absence because this informed their learning on the qualities of these states. It was also noted that the duration of training was important to participants' ability to distinguish between the two states (Kamiya, 1969). In Kamiya's (1969) study he identified that four sessions of alpha neurofeedback training provided sufficient time for participants to learn to discriminate between the two states (alpha present and absent) so that they could successfully navigate between the two. For adequate learning to occur, it is important to strike a balance between a training interval that is not too short or too long. Neurofeedback training sessions of short duration (i.e., under five minutes) may not be supportive of learning and adapting strategies, while overly long neurofeedback training sessions (i.e., over 60 minutes) may fatigue the participant (Ancoli & Kamiya, 1978). In general, the participant needs to be provided with an adequate amount of time where they can understand the foundational elements of each state (how they feel) so that they can assign strategies to maintain them. It is also important to consider the number of sessions the participant receives, as it is more helpful to learn to engage in multiple sessions rather than a single session (Ancoli & Kamiya, 1978; Kamyia, 1969). A study by Chow and colleagues (2017) revealed that participants practicing mindfulness meditation paired with neurofeedback showed an increased global alpha amplitude compared to the sham group. In addition, it was found that mindfulness meditation moderated the upper alpha even-related desynchronization more than a cognitive task (Stroop task) in the NFB and sham conditions. Similarly, a study by Sas & Chopra (2015) revealed that pairing EEG neurofeedback with meditation helps practitioners to achieve a deeper state of meditation, specifically in those new to the practice.

1.3.2 Theta Neurofeedback Training

Another EEG frequency and form of neurofeedback training that has been implicated in the practice of mindfulness is theta oscillations. Theta activity, found between 4 and 8hz, has been correlated with states of alertness, attentional capacities, and effective cognitive and perceptual processing (Stern et al., 2001). Theta's association with the processing of cognitive and perceptual tasks manifests itself in orienting, working memory, concentration, and emotional processing (Marzbani et al., 2016). Theta is most abundant in frontal and temporal-central areas of the brain, with increases in theta activity indicative of enhanced cognitive processing and awareness (Aftanas et al., 2001; Lagopoulos et al., 2009). Studies have revealed increases in oscillations and synchronization during complex cognitive tasks and learning tasks (de Araujo et al., 2002; Caplan et al., 2003; Ekstrom et al., 2005; Hseih et al., 2011; Kahana et al., 1999; Mizurhara et al., 2004; Raghavachari et al., 2001; Sederberg et al., 2003; Watrous et al., 2011). Frontal theta indicates the engagement of attentional and working memory processes in the prefrontal areas and anterior cingulate cortex, which influences autonomic functioning (Asada et al., 1999; Lagopoulos et al., 2009; Onton et al., 2005). When frontal theta activity increases, the sympathetic and parasympathetic measures increase as well suggesting a close relationship within the frontal neural circuitry (Braboszcz et al., 2017; Dentico et al., 2016; Kubota et al., 2001; Lagopoulous et al., 2009; Mitchell et al., 2008)

Increased theta activity has been proposed to be a unique quality specific to the meditative state itself, positively correlated with the level of experience and practice (Aftanas, 2001; Kasamatsu & Hirai, 1996; Lagopoulos et al., 2009). This enhancement of theta activity has been demonstrated across meditation types (i.e., FA, OM, TM, LK) and is strongly dependent on the experience and training of the meditator (Baijal & Srinivasan, 2010; Cahn et al., 2010; Pasquini et al., 2015). A study by Faber colleagues (2004) found that increased theta activity only appeared in the experienced meditation group, compared to novice (new) meditators. It is important to note that while both alpha and theta are present during meditative practice, they are representative of separate and distinct mental processes that independently contribute to the mindful state (Lagopoulos et al., 2009; Takashi et al., 2005). Both focused attention and open monitoring meditation result in increased theta presence, synchrony, and coherence which is associated with internalized attention and enhanced executive functioning (Lee et al., 2018; Lipelt et al., 2014; Sauseng et al., 2005). While research has revealed that mindfulness meditation has cognitive and emotional benefits, it is important to further elucidate the neural correlates of this practice. Pairing EEG/neurofeedback with meditative practice helps to better define the relationship (Lee et al., 2018).

1.4 Consumer-Grade Neurofeedback

The introduction of low-cost portable EEG systems, also known as mEEG (mobile EEG), has been an exciting addition for the scientific and consumer community as it offers the opportunity for affordable (financially), accessible, and efficient data collection. Muse by Interaxon is a consumer-grade and mobile EEG system that is marketed as an aid for mindfulness practice. Muse became commercially available in 2014 with retail prices much more affordable than that of other popular technologies on the market at the time (Stockman, 2020). This resulted in a successful entrance into the commercial market with $19 million in investments and doubled revenue each year (Korets-Smith, 2017; Stockman, 2020). In comparison to other commercially available technologies, Muse offers the purchaser the unique opportunity to learn and enhance their mindfulness practice and self-regulation using feedback (Stockman, 2020). Muse uses a variety of natural soundscapes to help guide the user into a mindful or calm brain state using audio neurofeedback. For example, in Muse's rainforest "Mind Meditation", the user starts the session listening to what sounds like a rainstorm. The user hears light rain when their brain is in a calm or neutral state. As the brain starts to wander, this light rain turns to a storm which prompts the user to know that their mind has wandered and that they need to refocus their efforts on being mindful and calm. After each session, the app creates a graph summary of the user's performance to represent the calm, active, and neutral mind during the session. Individuals are awarded birds when they can consistently maintain a calm state over a period. They also receive muse points for every second that they are in neutral (one point) and calm (three points) brain states. Lastly, they are awarded recoveries which represent the number of times that the user shifts from an active mind back to a neutral or calm state. Please note that all of the information presented in this paper about Muse's functioning can be found on their website: www.choosemuse.com. Given that Muse is a more affordable and accessible technology, it is an exciting opportunity for the scientific and non-scientific community as both a research tool and wellness aid.

However, the introduction of mEEG and devices such as Muse has not come without concerns about its use for data collection. Some of the typical concerns associated with mEEG include the quality of the hardware, event timing and marking, and electrode placement (Krigolson et al., 2017). The hardware of mEEG headsets has been called into question over the quality of the EEG data and whether it is comparable to the standards of a medical-grade EEG system (Krigolson et al., 2017). Event timing and marking have also been an area of concern as it is often not possible to use the traditional event marking and timing procedures that are used with medical-grade systems. Lastly, the electrode placement on mEEG systems differs from medical grade systems and electrode placement is often not available at locations associated with specific ERP and EEG components (Krigolson et al., 2017). These concerns surrounding low-cost portable EEG prompted several researchers to further investigate and assess the validity of these concerns.

To address the concerns of data quality, Ratti and colleagues (2017) compared two medical-grade and two consumer-grade EEG devices (including Muse). They found that while the consumer EEG systems proved to be more convenient and had a faster setup, their data quality was not equal to medical grade systems due to artifact susceptibility caused by dry electrode placement and misplacement of the headband (Ratti et al., 2017). These two factors caused low test-retest reliability and variability in the data produced by the Muse headset, which speaks to the importance of electrode placement in portable EEG devices (Ratti et al., 2017). They also noted that because consumer EEG systems are limited to one anatomical region of the brain, they would not be suitable for widespread network analyses (Ratti et al., 2017). Another study by Acabchuk and colleagues (2021) compared mindfulness scores with Muse EEG measures (claiming to measure "calm") and found a very minimal relationship between the two scores, calling into question the validity of the Muse EEG measures with regard to the neural correlates of mindful cognition. Specifically, EEG scores were not correlated with baseline levels of mindfulness or with any mental health-related improvements (Acabchuk et al., 2021). "Percent time calm" and "bird scores" (both Muse measures) were found to be highly correlated, as was expected, but there was little improvement seen in EEG scores across sessions. The authors suggested that this may be due to shifts in calibration when Muse creates a new baseline each session (Acabchuk et al., 2021). This means that if the user is becoming more mindful it may be more difficult to detect as baseline states become "calmer "each use making it increasingly hard to achieve a calm state. This will be important to consider in future studies in order to accurately assess users' progress (Acabchuk et al., 2021).

Krigolson and colleagues (2017) investigated whether it was possible to conduct ERP research without being reliant on event markers typically used in medical grade systems using the Muse headset, hypothesizing that Muse would collect comparable quality data to the medical grade EEG systems and be much more efficient at a much lower cost. They found that while ERP components did not look the same as they do in medical grade data, they were clearly seen (Krigolson et al., 2017). More importantly in the validation of low-cost portable EEG, the data was quantifiable and reliable. Follow-up studies using a larger sample in a variety of environments confirmed that Muse is an effective methodology for clinical applications (Krigolson et al., 2021). Muse is one of the only portable EEG devices that has an adjustable headband so that the user is able to fit the device adequately to the head for reading (TajDini et al., 2020). Several studies found that if researchers were struggling to get good quality data from the Muse it was often due to poor connection between the headband and electrodes, meaning that it is important to consider different head sizes, hairstyles, and inadequate placement that might impede good data collection going forward (Krigolson et al., 2017). The placement of the headband was also cited as the source behind inconsistent data and variability between sessions in a number of studies (Acabchuk et al., 2021; TajDini et al., 2020). In the current study, participants were briefed on the importance of the proper application of the headband to help alleviate the issue. Overall, Muse by InteraXon has shown to be a reasonable and efficient mEEG device for data collection that should be utilized and further validated in future studies.

1.5 Applications of Neurofeedback

1.5.1 Depression

One of the applications of neurofeedback to be considered in the current study is for the treatment and management of depression and depressive symptoms. Depression continues to be one of the leading causes of disability in the world, with one-third of patients not responding to traditional formats of treatment (Mehler et al., 2018; World Health Organization, 2017). This has led many researchers to investigate different formats of neuromodulation therapies for depression, one being EEG neurofeedback. Depressive symptoms consist of irregularities in emotional regulation, motivation, cognition, and neurological homeostasis (Linden, 2011). Neurofeedback has been demonstrated to be an effective treatment approach for depression in adults (Cheon, Koo, and Choi, 2016; Harris et al., 2021). Early studies of EEG neurofeedback and depression were based on the approach/avoidance model of emotion which asserts that appetitive and aversive emotional behaviours are promoted by the left and right frontal cortex, with decreased activity in the left frontal regions being indicative of depression (Davidson et al., 1990; Harmon-Jones et al., 2010; Henriques & Davidson, 1990; Henriques & Davidson, 1991).

This hypoactivity in the left frontal regions has been associated with an imbalance in alpha levels between the regions where the left frontal region demonstrates decreased alpha power compared to the right (Linden et al., 2014). The purpose of using neurofeedback as a form of treatment for depression would be to train the user to harness this alpha activity to help re-establish homeostasis between the two hemispheres. Most neurofeedback protocols for depression are based on the asymmetry model (Linden et al., 2014; Rosenfeld et al., 1996). Neurofeedback is particularly useful for the treatment of depression because it uses mental imagery. Using mental imagery in depression intervention has been associated with increased cognitive flexibility and positive mental stimulation (Holmes et al., 2016; Sulzer et al., 2013). A study by Linden and colleagues (2012) found that participants living with mild to moderate levels of depression who engaged in real-time fMRI neurofeedback learned to upregulate brain areas and demonstrated significant improvements in mood compared to a mental-imagery-only control group. This significant reduction in depressive symptoms was also seen in similar studies using neurofeedback (Mehler et al., 2018; Young et al., 2017). In addition, neurofeedback-assisted depression treatments have the potential to initiate long-lasting effects, with studies showing relatively stable reports of symptoms across time (Baher, 2001; Harris et al, 2021).

1.5.2 Anxiety

Another clinical application of neurofeedback intervention to be assessed in the current study is anxiety and symptoms of stress including excessive worry, restlessness, inability to concentrate, irritability, and sleep disturbances (American Psychiatric Association, 2013). Over the course of the COVID-19 pandemic, there has been a noticeable increase in the prevalence of anxiety disorders and symptoms, with the most cited barrier to treatment being accessibility and cost (Canady, 2021; Chartier-Otis et al., 2010; Vahratian et al., 2021; Russo et al., 2022). This has created a need for more research and exploration into alternative therapies and treatment approaches that would be efficacious and accessible options for reducing symptoms of anxiety. However, using neurofeedback in the treatment of anxiety disorders and symptoms of anxiety is not a recent endeavour with studies seen as early as the 1970s. Overall, it has been suggested that neurofeedback is an effective approach for the reduction of a variety of symptoms of anxiety (Bennett et al., 2020; Danskin & Walters, 1973; Dries et al., 2015; Hammond, 2005; Johnson et al., 2013; Moore, 2000; Russo et al., 2022; Tolin et al., 2020). Previous EEG studies have revealed that neural activity associated with anxious arousal has been linked to reduced alpha activity (Wise et al., 2011). Neurofeedback training can be used as a tool to help users increase their alpha activity and reduce their overall levels of anxiety. For example, an original study by Hardt & Kamiya (1978) found that highly anxious participants who were able to increase their alpha magnitude were able to induce a calming effect on themselves. Because alpha irregularities are characteristic of the psychopathological differences in anxiety, using neurofeedback to help induce healthy alpha asymmetry and teaching the individual to regulate their alpha levels can be successfully applied to manage and treat anxiety (Dias & Deusen, 2011; Kerson et al., 2009; Wang et al., 2013). A meta-analysis by Russo, Balkin, & Lenz (2022) found that effects ranged from moderate to large in the reduction of symptoms of anxiety-spectrum disorders in adults. Further, a study by Crivelli and colleagues (2019) expanded on this research using the mEEG system Muse by Interaxon to deliver a neurofeedback with mindfulness intervention for professionals in high-stress work environments with reduced levels of stress reported.

1.5.3 Trauma

Neurofeedback has also been previously used as a complementary treatment to modulate neural networks that are associated with PTSD and trauma symptoms, such as the salience network, default mode network, and executive functioning network (Kluetsch et al., 2014; Ros et al., 2013). EEG analyses from PTSD studies have revealed a relationship between alpha oscillations and spontaneous changes in networks related to common symptoms of PTSD, with PTSD generally associated with decreased alpha activity and EEG alpha asymmetry at resting state (Huang et al., 2014; Jokić-begić & Dražen Begić, 2003; Kemp et al., 2010; Lobo et al., 2015; Metzger et al., 2004; Nicholson et al., 2016). A single-session study of alpha desynchronizing neurofeedback training in PTSD patients by Kleutsch et el. (2014) suggested that after neurofeedback training there was a “homeostatic rebound” or increase displayed in participants’ alpha organization, despite being trained to lower their alpha. This study demonstrated that while the object of the training task is to increase alpha or a given frequency, this still may be achieved by training these waves in the opposite direction. As a result, it is not clear whether unidirectional or bidirectional alpha training is more beneficial to participants (Kleutsch et al., 2014; Vernon et al., 2009). However, it has been suggested that bidirectional training may be preferable because switching between enhancing and inhibiting alpha may give the user more information concerning the fundamental mechanisms and subjective feelings of each state which may enhance their ability to gain conscious control of their states (Kamiya et al., 1969; Vernon et al., 2009).

1.6 The Subjective Experience of Learning Neurofeedback

Given that the current study focuses on assessing the feasibility, satisfaction (i.e., fulfillment and pleasure), and effectiveness of an at-home neurofeedback intervention, it is important to consider how individuals learn to succeed in their neurofeedback training. Learning plays an essential role in the design of neurofeedback interventions as an inability to learn or grasp the intention of an intervention may prevent the user from experiencing the benefits of participation (Davelaar et al., 2018; Demos, 2005). One thing to consider in intervention design and success is the learning ability of participants. In neurofeedback, learning ability can be described as the change in performance seen over the course of practice (the first vs. the last session) and the change in performance seen during the session itself (Dekker et al., 2014; Dempster & Vernon, 2009; Wan et al., 2014; Zoefel et al., 2011). Several studies have found that some participants were non-learners, meaning that they were unable to learn effective strategies to achieve the goals of a given neurofeedback activity (Hanslmayr et al., 2005; Wan et al., 2014; Weber et al., 2011; Zoefel et al., 2011). Inter-individual differences have been found in learning between users as well (Hanslmayr et al., 2005; Nan et al., 2012; Wan et al., 2014; Zoefel et al., 2011).

One of the widespread challenges to participating in neurofeedback is gaining willful control of one's mind over prolonged periods of time, which can present itself as difficult to many (Davelaar et al., 2018; Wan et al., 2014). These populations have been described as non-learners, non-responders, non-performers, low aptitude users, BCI illiterate, and BCI inefficient in neurofeedback literature (Alkoby et al., 2018). In simple terms, they are not successful in regulating their brain activity and therefore may not experience the proposed benefits of a given task or intervention (Blankertz et al., 2013; Hammer et al., 2012; Kober et al., 2010). This can be described as the "neurofeedback inefficacy problem" (Alkoby et al., 2018). Consideration of the learning process and the subjective experience of learning (i.e., how users perceive their learning process) in neurofeedback is essential to the efficacy of a task or intervention.

The multi-stage learning theory of neurofeedback emphasizes the importance of subjective experience in performance and success (Davelaar et al., 2018). This theory posits that the subjective experience of the user acts as a secondary reinforcer so that eventually, even without the presence of the reward signal, the subjective experience becomes the feedback signal (Davelaar, 2018). Learning in this way helps contribute to long-term success in neurofeedback and the formation of implicit strategies for better performance. It is important to distinguish between learners (those who perform well) and non-learners (those who have poor performance) as it gives us insight into the distribution of success rates in neurofeedback interventions so that trainers can potentially provide targeted instructions to trainees to speed up the learning process and observe the therapeutic benefits sooner. We can extract a lot about the learning experience and performance of users by examining the subjective experience as this can reflect important aspects that are not readily noticeable in brain imaging and cognitive tasks (Davelaar et al., 2018; Wan et al., 2014). From previous studies, we know that is it possible for users to be able to distinguish between various brain states in accordance with their subjective experience of it, and that this can be communicated to researchers using the appropriate strategies (Davelaar et al., 2018; Edge and Lancaster, 2004; Gruzlier, 2014; Kamyia, 1969). In the current study, a measure designed to assess the subjective experience of learning in neurofeedback was piloted to clarify the elements of this experience further, and in turn, help make improvements to the neurofeedback protocol so that it better suits the learning abilities of users.

A particular study of interest in creating this measure was investigating differential subjective experiences in learners and non-learners in frontal alpha neurofeedback by Davelaar and colleagues (2018). They used an interview to qualitatively assess this phenomenon where participants reflected on their experience by rebuilding it moment by moment to see the progression of their subjective experience. Information was organized into what participants were doing (i.e., actions and strategies), their senses during the task, and executive functions that were performed. Based on the structured interviews conducted with participants, it was identified that those who performed well in the task were simply aware of something during the task, while those that struggled invested significant mental effort and used deliberate strategies to focus during the task (Davelaar et al., 2018). They described the results as a “try-sensing continuum” where successful performance (indicative of learning) enhances when shifting one’s mindset from trying or exerting oneself mentally to sensing and awareness (Davelaar et al., 2018). Some of the common themes that have been identified as being related to the subjective experience of learners helped to build the foundation for the proposed measure.

In general, it can be noted that there is a lack of consistent research tools, methodology and paradigms that can be applied to neurofeedback interventions to determine the subjective experiences of those participating that allow them to achieve success in an intervention (i.e., how they learn). In neurofeedback literature, there have been two tendencies in the measurement of subjective experience. The first is to simply interview participants and narrow down their subjective experience in the context of cognitive actions and strategies (Hinterberger et al., 2005; Kober et al., 2013; Nan et al., 2012; Nowlis & Kamiya, 1970). Responses from interviews are largely classified in terms of affect and emotion. The second method of measurement for subjective experience is questionnaires (Gruzlier, 2014). However, one problem with questionnaires is the possibility of misinterpretation of questions which may lead to inaccuracies in the assessment of subjective experience (Davelaar et al., 2018). Several studies have found that there was room for interpretation in both open-ended and interview-style questions and that this was majorly influenced by the context of the neurofeedback task (Davelaar et al., 2018; Gruzlier, 2014; Kober et al., 2013). For example, when Kober and colleagues (2013) asked participants to recollect their experience and the strategies that they had used, they found that those using no specific strategy were classified as successful learners meaning that they could have been doing nothing at all or they could have used multiple strategies to complete the task. The contrast between these two approaches that seemingly arrive at the same answer highlights the importance of considering context when posing questions to participants in neurofeedback. It is important to be specific with the wording of questions so that the responder has a clear idea of what is being asked and that there is little room for misinterpretation. Another methodological issue identified by researchers was the time interval between participation and recall as this can be significantly impacted by memory decay, as well as giving the participants notice that they will be asked to recall their experience after the practice to allow them to prepare to recount their experience (Davelaar et al., 2018; Edge & Lancaster, 2004). To date, there is no standardized methodology for detailing the subjective experience of the user in neurofeedback (Davelaar et al., 2018).

1.6.1 Cognitive Effort

One of the noted concepts in the neurofeedback literature on learning and performance is effort or the conscious exertion of power. It is important to note that effort can be in a physical context or cognitive (mental) context (Kafner, 1992). For the purposes of the current study and the practice of neurofeedback, we will be focused on cognitive effort. Cognitive effort can be described as the extent of organized cognitive processing that an individual engages in during a task (Paas & Marrieboer, 1993). We can use the concept of cognitive effort to explain performance, the "cognitive costs" of learning, and individual effectiveness in a task. Cognitive effort is of limited capacity and has a direct impact on the speed of information processing and resulting performance on a task (Humphreys & Revelle, 1984; Kahneman, 1973). While many consider cognitive effort to be a hypothetical construct, it is still a subjective state that individuals have some level of awareness and ability to reflect on (Ambrose & Kulik, 1999;

Davelaar et al., 2018; Humphreys & Revelle, 1984; Khodakarami & Firoozabadi, 2020; Locke & Latham, 2004; Pinder, 1998). For example, if we perceive we are exerting a lot of mental effort to complete a task we would identify it as “trying hard”. Researchers propose that one’s perceived mental effort can be influenced by their level of skill or practice with a task (i.e., using less effort with a task once they are familiar with it) and the perceived difficulty of the task (i.e., exerting more effort when they believe that the task is “hard”) (Anderson, 1982; Carver & Scheier, 1998; Fitts & Posner, 1967; Yeo & Neal, 2008). Previous studies assessing cognitive effort in the context of neurofeedback found that exerting intense mental effort resulted in less success in neurofeedback and that this form of exertion may hinder performance (Davelaar et al., 2018; Khodakarami & Firoozabadi, 2020). Khodakarami & Firoozabadi (2019) revealed that unconscious learning, or learning without exerting deliberate effort, leads to better performance in their neurofeedback task. This premise that little effort may be needed to willfully control one’s brain directly contrasts with what one would naturally think they need to do to “control” their brain.

1.6.2 Strategy

Another factor of interest in the subjective experience of learning in neurofeedback is strategy, which can be described as a plan or action that is used to achieve the desired goal. In the context of neurofeedback, an individual may use a specific mental strategy, or a variety of mental strategies, to help willfully control their brain and enhance their performance (Davelaar et al., 2018; Kober et al., 2013). The concept of strategy in neurofeedback is not often studied, however, it remains a crucial part of the subjective experience of the user. Traditionally, the user is simply given instructions to help guide them in the task (Kober et al.,2013). Studies that have investigated strategy in neurofeedback have revealed some common themes. First, it was noted that the use of positive strategies such as positive thinking or positive emotion may lead to better performance (Angelakis et al., 2007; Rubik, 2011; Nan et al., 2012). The other successful strategy identified among studies was no explicit mental strategy, meaning that the user was not consciously aware of a strategy (Birbaumer, Ruiz & Sitaram., 2013; Kober et al., 2013; Neumann & Birbaumer, 2003; Khodakarami & Firoozabadi, 2020; Witte et al., 2013). Khodakarami & Firoozabadi (2020) found that participants often used multiple strategies in neurofeedback practice, but that the same strategy wasn't always successful across sessions. By the final task, they found that participants didn't adopt a strategy and that because they were using less mental effort, they were less fatigued and were able to willfully control their brain activity. Participants also reported this final (successful) session was the most "comfortable" and "desirable" for their experience (Khodakarami & Firoozabadi, 2020). These findings agree with theories of neurofeedback learning that suggest it is more like acquiring a skill that we learn through trial and error and that becomes stored in our implicit memory for future use (Birbaumer et al., 2013; Kober et al., 2013). The right mental strategy can help enable learning in neurofeedback users and can fast-track the process of learning (Khodakarami & Firoozabadi, 2020).

1.6.3 Sense of Agency

One of the main purposes of neurofeedback is for the user to learn to regulate one's brain activity (Demos, 2005). In order to achieve this sense of control, the user needs to perceive that their actions are having some sort of an effect on the neurofeedback protocol (Ninaus et al., 2013). Neurofeedback literature refers to this sense of control as the agency or the belief and awareness that the individual is causing the action (Gallagher, 2000). For example, a user would be demonstrating a sense of agency when they know that their actions to take control of their brain are resulting in reward signals. Our sense of agency plays an essential role in our sense of self and allows us to distinguish what action is caused by ourselves and what action is caused by outside factors (Gallagher, 2000; Newen & Vogeley, 2003). A study by Ninaus and colleagues (2013) found that those who reported that they tried to "get control" of their brain during the task showed activation in the anterior insular and cingulate cortex, identified areas associated with self-agency. These findings suggest that self-agency plays a role in an individual's ability to perform during a neurofeedback task (Ninaus et al., 2013; Sperduti et al., 2011).

1.6.4 Awareness: Internal and External

Awareness can be difficult to measure given that it requires the individual to be consciously aware of their own experience and report the phenomena sufficiently by assigning verbal labels to the experience (Michel, 2017). In the context of research, participants are going to be aware of different aspects of an experiment. For neurofeedback, "awareness" can mean being aware of internal sensations, the fact that one is being trained, awareness of one's actions to perform, and awareness of the relationship between brain state and reward signals (Brener, 1977; Fredrick, 2016; Ramos et al., 2016; Shibata et al., 2019). Awareness can be categorized into internal awareness (i.e., physical sensations, thoughts, and feelings) and external awareness (i.e., distractions from the environment, noticing the temperature of the room). Some theorists posit that learning in neurofeedback takes place as an implicit process, that is not in our conscious awareness. In other words, we do not need awareness for success in an intervention and learning occurs without our direct knowledge (Amano et al., 2016; Birbaumer et al., 2013; Shibata et al., 2019). This view would deem the acquisition of cognitive control in neurofeedback as motor skill learning, which does not require our subjective awareness of the task (Birbaumer et al., 2013). However, other theories have suggested that neurofeedback is more of an explicit and instrumental learning process, where we require some level of awareness to successfully acquire the skill (Birbaumer et al., 2013; Lovibond & Shanks, 2002; Mitchell et al., 2009). It has been proposed that the early stages of learning in neurofeedback are predominantly explicit, whereas the more advanced stages of learning are implicit (Taylor et al., 2014). Due to the debate surrounding awareness, Munoz-Moldes & Cleeremans (2020) emphasize the importance of considering how awareness is being measured, how instructions for the task are delivered to participants, and the type of learning situation that the neurofeedback task is presented in (passive vs. active). They also note that we should not dismiss the explicit awareness of users in neurofeedback as they are often aware of the relationship between their brain state and the neurofeedback signal and must use their explicit awareness to judge this (Munoz-Moldes, 2020). Lutterveld and colleagues (2017) investigated the subjective experience of mindfulness meditation and neurofeedback and found that participants who were able to subjectively report their experience of "effortless awareness" had better performance in a neurofeedback task (Lutterveld et al., 2017). Edge and Lancaster (2004) suggested that the best performance in neurofeedback that would enhance learning would be one where the user is relaxed, but not so relaxed that they become unaware of the task they were participating in.

1.6.5 Motivation

In a general sense, it is known that when we have an investment in something (i.e., compensation), we are more likely to be motivated to perform well. The concept of motivation can also be applied in the context of performance in neurofeedback, or the degree to which the "participant is motivated to participate" (Dagleau, 2021). Motivation sources for neurofeedback can be intrinsically or externally driven depending on the reasons for participating (Dagleau, 2021). For example, a student participating in a neurofeedback intervention may be more motivated to participate and perform knowing that they will be receiving a credit for their participation. Previous studies have found that state motivation can influence the outcomes of a neurofeedback task and that this motivation was influenced by “perceived challenge”, “interest”, and “fear of incompetence” (Kleih et al., 2011; Kleih, 2013; Nijober et al., 2010). Better performance was found to be positively correlated with “perceived challenge”, while performance was hindered by “fear of incompetence” (Klieh, 2013). In addition, it was found that when researchers emphasized the importance of interest in the neurofeedback task their motivation increased, as well as their motor learning of the skill (Deci & Ryan, 2008). Based on these findings, researchers have suggested that motivation be encouraged in users to enhance their performance and learning outcomes (Alkoby et al., 2018; Nijober, 2008; Nijober et al., 2010).

The measure piloted in the current study will assess the subjective experience of learning in neurofeedback to further clarify what factors distinguish learners from non-learners in a task. This has implications for the usefulness and clinical utility of neurofeedback practices and interventions and allows neurofeedback practitioners to design an intervention in such a way that users can learn the task and benefit from it. While we can measure learning through cognitive tasks and brain imaging, we have yet to establish a solid methodology for the measurement of the individual’s subjective experience of learning during a neurofeedback intervention (Davelaar et al., 2018). Building on some of the factors that have been identified in neurofeedback literature, this measure will assess the factors of cognitive effort, strategy, sense of agency, internal and external awareness, and motivation. Based on the previous literature, it can be hypothesized that those who are successful in neurofeedback tasks, also known as learners, will demonstrate the common traits of less cognitive effort, implicit strategy taking, increased sense of agency, elevated awareness, and high scores of motivation.

1.7 Pairing Consumer-Grade Neurofeedback with Meditation as an Intervention

Neurofeedback and mindfulness may share some of the same foundational elements of attentional and cognitive control, as well as an ability to enact changes in neural connectivity (Lazar et al.,2005; Pagoni & Cekic, 2007). Previous studies have demonstrated that pairing the two practices together can help the user achieve a deeper meditative state and experience greater and more sustainable benefits (Chow et al., 2017; Sas & Chopra, 2015). While some studies have assessed pairing mindfulness and neurofeedback in the context of consumer-grade EEG devices, there is still much room for exploration and further validation of incorporating these devices for clinical application. The purpose of the current study was to assess the feasibility, satisfaction, and effectiveness of an at-home mindfulness program using a consumer-grade neurofeedback device, Muse by InteraXon. I wanted to assess whether this format of intervention was feasible, which for this proof-of-concept question was assessed via participants' ability to successfully take the Muse headset home with them and engage in multiple sessions. It was also hypothesized that the participants in the mindfulness with neurofeedback (experimental) group would report significantly higher satisfaction scores (i.e., more satisfied) than the control group. Finally, it was hypothesized that participants' self-report outcomes assessed pre-and-post intervention would differ between neurofeedback and non-neurofeedback conditions, suggesting a benefit to pairing neurofeedback with mindfulness.

Chapter 2: Method

2.1 Participants

Participation was open to individuals between the ages of 18 and 65 years of age. A total of 40 participants enrolled in the study, with 19 participants being randomly assigned to the mindfulness with neurofeedback group and 21 being assigned to the guided meditation group (control). However, 6 participants did not complete the study. 34 participants completed the study, with 17 in the mindfulness with neurofeedback group and 17 in the control group. Participants were recruited via posts to social media platforms such as Facebook and from posters on campus. A sample of the recruitment post is included below:

You are invited to participate in a research study about the psychotherapeutic effects of an at-home neurofeedback intervention for mental health and well-being. In this study, you will complete a 4-day mindfulness-based program where you engage in 2 5-minute sessions of a mindfulness activity and complete questionnaires. Each session will take approximately 10 minutes to complete and approximately 20 minutes per day. Participants will be entered into a prize draw for a chance to win one of three $100 Amazon gift cards. If interested, please contact ***mindful@uwo.ca*** *for further details.*

Before beginning the study, participants gave their informed consent. All participants were fluent in English, which was necessary in order to communicate with the research team and understand the meditation sessions. Participants also had to have access to Wi-Fi to receive email communications and do their mindful sessions. Those that were assigned to the control (guided meditation) group needed to have access to a phone or laptop to participate. Individuals experiencing a significant hearing impairment that would prevent them from listening to information delivered through mobile phone speakers were excluded from participation. Participants who completed the study were entered into a prize draw for a chance to win one of three $100 Amazon gift cards. Ethics approval was received from the Research Ethics Board (REB) at Western University (the letter of approval can be found in Appendix B).

2.2. Materials

2.2.1 Muse

The Muse headset (by Interaxon) is a commercial wearable device designed for the practice of meditation with neurofeedback (https://choosemuse.com). This device provides guided meditation to the user via audio neurofeedback to give them insight into their current brain state. Users can listen to a variety of soundscapes and can learn to control their brain state as noise within the simulations gets quieter or louder to reflect brain waves. Muse has 7 sensors in total including two forehead sensors, three reference sensors, and two Smartsense conductive rubber ear sensors (www.choosemuse.com). The two sensors located on the forehead are meant to be analogous to AF7 and AF8 and are intended to measure activity in the frontal lobe. The other two electrodes are located above each ear are meant to be analogous to TP9 and TP10 and are intended to measure activity in the temporal lobe (Krigoloson et a., 2021). There are also three reference sensors that sit in the middle of the forehead (analogous to Fpz) (Krigolson et al., 2021). All of the information presented about Muse's EEG capabilities is proprietary to Muse (InteraXon) and can be found on their website: www.choosemuse.com. Muse is one of the only consumer-grade EEG headsets that has an adjustable headband, which promotes adequate reading regardless of head shape. Muse uses the data collected from these electrodes to report on the user's performance including muse points, recoveries, and birds.

2.2.2 Guided Meditation

Participants in the guided meditation (control) group listened to a focused attention meditation recording for their mindful session. Ruby Nadler's "3-minute mindfulness of the

Breath Practice" meditation recording was used, which can be found on SoundCloud. In total, the meditation was four minutes and 40 seconds. Participants were guided in a meditation focusing on the breath and the sensation of breathing. The link for the guided meditation link can be found below:

https://soundcloud.com/rubynadler/3-minute-mindfulness-of-the-breath-practice?utm_source=clipboard&utm_medium=text&utm_campaign=social_sharing

2.3. Measures

2.3.1 Demographics

Before starting the program, several demographic characteristics were collected from participants including gender, education, and history of experience with mindfulness and related activities (i.e., meditation, yoga, and tai chi).

2.3.2 Five Facet Mindfulness Questionnaire (FFMQ)

Mindful traits were measured pre- and post-intervention (on day one and day four, respectively) using the Five Facet Mindfulness Questionnaire by Baer & colleagues (2006). This measure is intended to assess trait mindfulness, or how mindful an individual tends to be in everyday life. The FFMQ comprises 39 items rated on a Likert Scale, ranging from *1 (never or very rarely true)* to *5 (very often or always true)*. The FFMQ assesses the five facets of mindfulness including *observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience* (Baer et al., 2006). This measure demonstrates good internal consistency (alpha) across several samples and "significant relationships with a variety of constructs related to mindfulness" (Baer et al., 2006; Baer et al., 2008; Baer et al., 2012).

2.3.3 Depression, Anxiety and Stress Scale (DASS-21)

The Depression, Anxiety, and Stress Scale (DASS-21) was administered pre and post intervention (before day one and after day four, respectively). This measure was used to assess levels of anxiety, depression, and stress. DASS-21 consists of 42 self-report items scored on a 4-point Likert Scale of *0 (Did not apply to me at all) to 3 (Applied to me most of the time)*. The respondent answers each item based on how they have felt in the last week (Lovibond & Lovibond, 1995). DASS-21 is used in a variety of settings, such as research and clinical, and has been shown to be a reliable and valid measure (Crawford & Henry, 2003).

2.3.4 Trauma Symptom Checklist (TSC-40)

The Trauma Symptom Checklist - 40 (TSC-40) was distributed pre-and post-intervention (before day one and day four, respectively). This measure was used to assess for the presence of trauma symptoms before and after completing the intervention. The TSC-40 consists of 40 items rated on a 4-point Likert scale of *0 (Never) to 3 (Often)*. The TSC-40 has six subscales including Dissociation, Anxiety, Depression, Sexual Abuse Trauma (SATI), Sleep Disturbances, and Sexual Problems (Briere & Runtz, 1989). However, for the purposes of this study, the sexual problems subscale and elements of the SATI subscale have been removed as their topics were not relevant to the present research. The TSC-40 demonstrates construct, criterion-related ad convergent validity (Zlotnik et al., 1996).

2.3.5 Positive and Negative Affect Schedule (PANAS)

The Positive and Negative Affect Schedule (PANAS) was administered after each mindful session over the course of the four days (twice per day, eight times total). PANAS consists of 10 items that are rated on a 5-point Likert Scale, ranging from *1 (not at all) to 5 (very much)*. This measure is designed to measure aspects of both negative and positive mood states (Watson et al., 1988). PANAS has been found to have good psychometric properties including very good internal consistency for both positive (0.86-0.90) and negative (0.84-0.87) affect scales, as well as convergent validity and discriminant validity (Maygar-Moe, 2009).

2.3.6 Toronto Mindfulness Scale (TMS)

The Toronto Mindfulness Scale (TMS) was administered after each mindfulness session in the control group (guided meditation). The measure was intended to assess state mindfulness traits, or how mindful participants felt during their mindfulness session. TMS consists of 13 self-report items scored on a 5-point Likert Scale of *0 (Not at all) to 4 (very much).* The respondent is prompted to respond based on what they have just experienced and/or what they are currently experiencing (Lau et al., 2006). This measure was designed to be brief and minimally intrusive to avoid providing impeding individual recall of their experience. TMS has demonstrated favourable psychometric properties, with high levels of internal consistency and validity, and has been found to be a useful instrument in assessing outcomes in those participating in mindfulness-based interventions (Lau et al., 2006).

2.3.7 Subjective Experience of Learning in Neurofeedback (SEOLIN)

The Subjective Experience of Learning in Neurofeedback (SEOLIN) was used after each mindful session in the experimental (mindfulness with neurofeedback) group (eight times total). The SEOLIN was administered upon completion of the meditation session so that there were no obstacles to the recall of the participants' experience of neurofeedback (i.e., memory decay). The purpose of administering the SEOLIN after each session was to assess for reliability across sessions. SEOLIN was created by the author with the intention to assess the subjective experience of learning in neurofeedback. The rationale for such a measure is detailed in the introduction of this paper. SEOLIN consists of 35 items scored on a 6-point Likert Scale of *1 (Strongly Disagree) to 5 (Strongly Agree)*. SEOLIN is composed of 6 subscales including cognitive effort (7 items), strategy (5 items), sense of agency (6 items), awareness: internal and external (11 items), and motivation (6 items). As mentioned previously, the current study was used as an opportunity to assess the psychometric properties of SEOLIN (i.e., reliability) and will be discussed further in the Discussion portion of this paper.

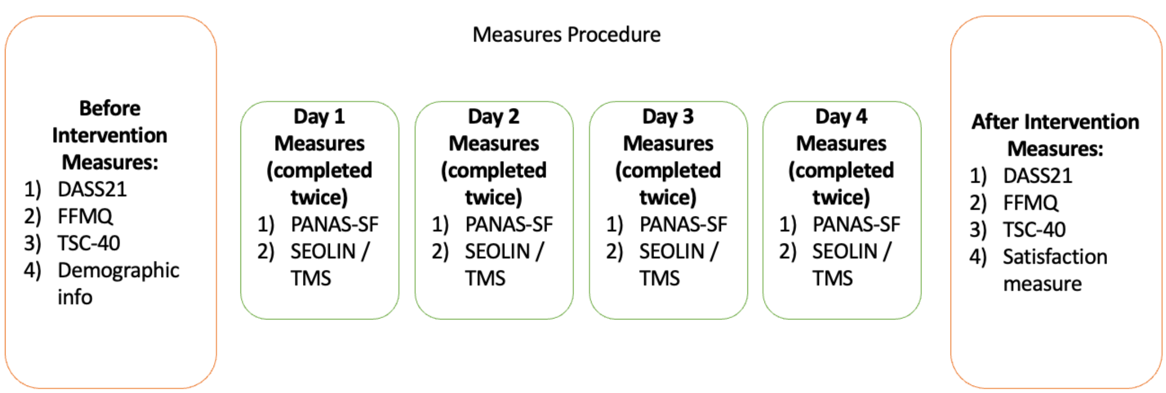
2.3.8 Satisfaction measure

Upon completion of the program (within 24 hours of the last session) a satisfaction measure was included in the post-intervention measures. The satisfaction measure consisted of one question asking, "*Please rate your overall satisfaction with this format of intervention*". Participants were asked to respond on a 5-point Likert Scale of *1 (Very Dissatisfied) to 5 (Very Satisfied).*

A visual representation of how the measures were distributed can be found in Figure 1 below.

Figure 1.

Procedural Layout of Measures.



2.4 Recruitment and Research Design

Through recruitment announcements posted to Facebook groups affiliated with Western University (London, ON, CA), prospective participants were provided with the contact information for the research team and were invited to contact the team if they wished to participate. Upon initiation of contact, participants were assigned to one of two groups: 1) meditation with neurofeedback, and 2) guided meditation (control). Initially, researchers tried to use random assignment for groups, however, this was not found to be possible as participants had to be assigned based on their access to campus (such as being able to pick up a Muse device). As participant recruitment was done during the summer, there were not many participants available on Western's campus. Upon the initiation of contact, the research team sent an email to participants containing a link to the letter of information and consent. Participants were given the opportunity to review the letter of information and complete the consent form via Qualtrics (an electronic survey platform). Once participants had confirmed their consent to participate and registration was complete, another email was sent to briefly review the letter of information and go over expectations and instructions for participation. For the experimental group (mindfulness with neurofeedback), a brief in-person meeting was scheduled to deliver the Muse device and accompanying equipment (i.e., iPad) to participants. At this time another brief meeting was scheduled to return the equipment to the research team after completing the program. Before starting the intervention, participants were sent an email with links to complete their baseline measure surveys. These measures consisted of basic demographic information, questions about previous mindfulness and/or meditation experience, the Depression, Anxiety and Stress Scale (DASS-21), the Five Facet Mindfulness Questionnaire (FFMQ), and the Trauma Symptom Checklist (TSC-40).

In the experimental and control group, participants engaged in two sessions of mindfulness activity per day, with one session being completed in the morning and the other in the evening (eight sessions total). A visual representation of the procedure for the current study can be found in Figure 2 below. To remind participants that it was time to complete their session, an email was sent at 8 am and 3 pm (EST) containing instructions, as well as links to complete their surveys after the session. Participants were given a four-hour window of time to complete their sessions (i.e., “Please complete your session between 8 am and 12 pm.”). Participants were asked to do the following in each of the conditions:

2.4.1 Meditation with Neurofeedback (Condition 1)

Participants completed a series of two five-minute meditation sessions (using Muse by Interaxon) over the course of four days. Over the four days, participants did one session of neurofeedback in the morning (8 am EST) and one in the evening/afternoon (3 pm EST). Participants engaged in five-minute sessions of Muse’s “Mind Meditations”. During the session, Muse provides auditory feedback to the user to help guide them towards a “calm” state. Muse’s soundscape is meant to resemble natural surroundings (i.e., rain). For example, participants begin the practice by listening to what sounds like rainy weather representative of the brain's “resting state”. As they progress through practice, they will either hear the rain lighten when their brain is in a “calm state”, or they will hear the rain get heavier when their mind starts to wander. The heavy rain signals to the participants that their mind has wandered and that they need to take action to return to a calm state. After each session, participants completed two measures designed to assess their subjective experience during the neurofeedback session and their affective state (SEOLIN and PANAS, respectively). Each session took approximately 10-15 minutes (meditation and measures) to complete, totalling 20-30 minutes per day.

2.4.2 Guided Meditation (Condition 2/Control)

Participants completed a series of two five-minute meditation sessions over the course of four days. Over the four days, participants engaged in one meditation session in the morning (8 am EST) and one session in the afternoon/evening (3 pm EST). Participants practiced five-minute guided meditation sessions. Instructions on how to engage in focused attention meditation were included in the reminder email to help guide participants in their meditation. The instructions included the following:

> *"Please find a space where you are comfortable. Take a deep breath and release all of your current preoccupations or concerns. Bring your awareness to the present moment and attempt to hold it there for this 5-minute meditation. You will be listening to naturalistic sounds. If you feel your attention wander, that is okay. Simply bring your awareness back to the current moment and continue with your practice. This may happen several times throughout your practice. This is completely normal and acceptable. Please notice that your mind has wandered, acknowledge it, and bring your awareness back to the present moment."*

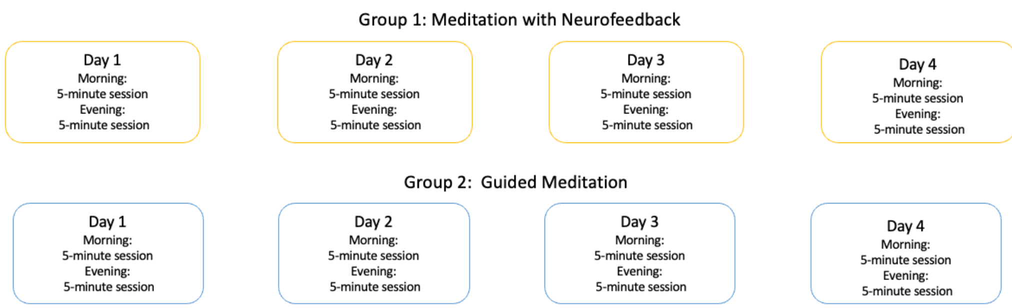
After each session, participants completed two measures designed to assess their awareness during the session and their affective state: The Toronto Mindfulness Scale (TMS) and The Positive and Negative Affect Schedule (PANAS). Each session took approximately 10-15 minutes (meditation and measures), totalling 20-30 minutes per day.

After completing the four days of sessions, participants were sent an email to prompt them to complete their post-program questionnaires, including The Five Facet Mindfulness Questionnaire (FFMQ), The Depression, Anxiety and Stress Scale (DASS-21), The Trauma

Symptom Checklist (TSC-40), and a satisfaction measure. Participants were asked to complete their post-program measures within 24 hours of their final mindful session.

Figure 2.

Mindfulness Program Procedure.



Note. Procedural layout for mindfulness conditions: neurofeedback and control.

2.5 Analyses

Data was organized and cleaned in Excel and imported to Jamovi (version 2.3.13). A series of mixed ANOVAs were performed on pre- and post-intervention data, as well as across session data. Reliability and correlational analyses were performed on the piloted measure: the subjective experience of learning in neurofeedback.

Chapter 3: Results

3.1 Participant Demographics

A total of *N*=34 participated in the current study, with *n*=17 participants being assigned to the neurofeedback (experimental) group, and *n*=17 participants being assigned the guided meditation (control) group. Please see Table 1 for a breakdown of demographics.

Table 1.

Demographic Information.

Gender	*Group*	*Percentage of Total*

Male	NFB Control	18.2% 6.1%
Female	NFB Control	36.4% 36.4%
Other	NFB Control	0% 3.0%
Student Status	**Group**	**Percentage of Total**
Full Time	NFB Control	15.2% 12.1%
Part Time	NFB Control	3.0% 0.0%
Not Applicable	NFB Control	12.1% 6.1%
Other	NFB Control	24.2% 27.3%
Meditative or Contemplative Experience	**Group**	**Percentage of Total**
Yes	NFB Control	27.3% 27.3%
No	NFB Control	18.2% 27.3%
Frequency of Meditative Practice	**Group**	**Percentage of Total**
1-3 months	NFB Control	27.8% 22.2%
6 -12 months	NFB Control	11.1% 5.6%
1-2 years	NFB Control	5.6% 5.6%
3+ years	NFB Control	5.6% 16.7%

Note. Demographic information collected from experimental and control groups.

3.2 Feasibility as an intervention

One of the primary goals of the current study was to determine the feasibility of an at-home mindfulness program with neurofeedback using consumer-grade EEG. A control group participated in an at-home guided meditation program. Feasibility was examined through overall engagement with the program and the degree to which the program was completed (satisfactory completion). Thirty-four participants were assigned to complete eight sessions over the course of four days (two sessions per day). In the mindfulness with neurofeedback group (experimental group, n=17) participants completed an average of seven sessions (M=7.06, SD=1.56), totalling approximately 35 minutes (M= 35.30, SD=7.80) of meditation practice. Participants in the mindfulness with neurofeedback group had a minimum engagement of 15 minutes or three sessions, and a maximum engagement of 40 minutes or eight sessions. In the guided meditation control group (*n*=17) participants completed an average of seven sessions (*M*=7.85, *SD*=0.38), totalling approximately 39 minutes (*M*=39.20, *SD*=1.88). Participants in the guided meditation group had a minimum engagement of 25 sessions or five sessions, and a maximum engagement of 40 minutes or eight sessions.

Overall, participants were able to complete 88% of their intervention on average in the mindfulness with neurofeedback group, with 32.4% or 11 participants completing the full length of the intervention. In the guided meditation group, an average of 96% of the intervention was completed, with 41.2% or 14 participants completing the full length of the intervention. To determine if the differences between means in each of the groups was statistically significant, an independent t-test was performed. To determine if completion rates between groups were statistically significant, an independent samples t-test was performed. Completion of the intervention and overall engagement in meditation with neurofeedback (*n*=17) did not significantly differ from participants who engaged in a guided meditation program (*n*=17), t (32) = -1.53, p = 0.135, d=-0.654.

3.3 Pre-Post-Intervention Measures

3.3.1 Depression, Anxiety, and Stress Scale (DASS-21)

To evaluate the hypotheses that pairing neurofeedback with mindfulness meditation would improve well-being across time more effectively than meditation alone, participant scores on the DASS-21 for each condition were compared at time one (pre-intervention) and time two (post-intervention). To determine if there were any significant differences between groups at the start of the program, an independent samples t-test was performed on each of the subscales (please see Table 2). A factorial repeated measures ANOVA with intervention (neurofeedback or guided meditation) as the between-subjects factor and time (pre-intervention and post-intervention) as the within-subjects factor was conducted on scores for each of the three subscales: stress, anxiety, and depression. The ANOVAs were performed on each of the subscales separately. Table 3 displays mean scores and standard deviations between groups pre and post-intervention.

Stress. Before the start of the program, there were no significant differences in stress subscale scores between groups, t (28) =0.813, p=0.423. The effect of time (pre and post intervention) within groups on stress scores was not statistically significant; F (1, 27) =0.538, p=0.071. Despite not reaching statistical significance, the effect of time on stress score was moderately large, $\eta^2 = 0.116$. The interaction between time and group on stress scores within groups was not statistically significant and had a small effect; F (1, 27) =0.640, p=0.659, η^2= 0.023. Between subjects, the main effect of the group on stress score was not statistically significant and had a small effect; F (1, 27) =1.36, p=0.254, η^2=0.048[1]. Pre- and post-intervention, the stress subscale demonstrated good reliability (α = 0.861).

Anxiety. Before the start of the program, there were no significant differences in anxiety subscale scores between groups, t (28) =-0.061, p=0.952. The effect of time (pre and post) within groups on anxiety scores was not statistically significant with a small effect; F (1, 28) =0.198, p=0.659, η^2=0.007. The interaction between time and group on anxiety scores was not statistically significant; F (1, 28) = 1.215, p=.279, η^2=0.042. Between subjects, the main effect of group on anxiety scores was not statistically significant; F (1, 28) =0.150, p=0.659, η^2 =0.005. Pre- and post-intervention, the anxiety subscale demonstrated good reliability (α = 0.835).

[1] Due to incomplete responses, some participants were omitted from this portion of the analysis (n=1).

Depression. Prior to the start of the program, there were no significant differences in depression scores between groups, t (28) =-0.387, p=0.702. The effect of time (pre and post) within groups on depression scores was not statistically significant; F (1, 28) =3.421, p=0.083. Despite not reaching statistically significant, the effect of time on depression score was moderately large, η^2 =0.104. The interaction between time and group on depression scores was not statistically significant and had a small effect; F (1, 28) =0.573, p=0.455, η^2=0.020. Between subjects, the main effect of group on depression scores was not statistically significant and had a small effect; F (1, 28) =0.018, p=0.893, η^2=0.002. Pre- and post-intervention, the depression subscale demonstrated good reliability (α = 0.898).

3.3.2 Five Facet Mindfulness Questionnaire (FFMQ)

To evaluate the hypothesis that pairing neurofeedback with mindfulness meditation would improve mindful traits across time more effectively than meditation alone, the scores on the FFMQ for participants for each condition were compared at time one (pre-intervention) and time two (post-intervention). To determine if there were any significant differences between groups at the start of the program, an independent samples t-test was performed on each of the subscales (please see Table 2). A factorial repeated measures ANOVA with intervention (neurofeedback or guided meditation) as the between-subjects factor and time (pre-intervention and post-intervention) as the within-subjects factor was conducted on scores for each of the five subscales: observing, describing, acting with awareness, non-reactivity, and non-judging. The ANOVAs were performed on each of the subscales separately. Table 4 displays mean scores and standard deviations between groups pre-and post-intervention.

Observing. Prior to the start of the program, there were no significant differences in observing scores between groups, t (28) = -1.63, p=0.114. The effect of time (pre-and-post intervention) within groups on observing scores was statistically significant; F (1, 28) =6.44, p=0.017. Time had a large effect on observing score, η^2= 0.187. The interaction between time and group on observing scores was not statistically significant; F (1, 28) =2.82, p=0.104. Despite not reaching statistical significance, the effect of the interaction between time and group had a moderate effect, η^2= 0.092. Between subjects, the main effect of group on observing scores was not statistically significant and had a small effect; F (1, 28) =1.04, p=0.317, η^2=0.036. Pre- and post-intervention, the observing subscale demonstrated good reliability (α = 0.851).

Describing. Prior to the start of the program, there were no significant differences in describing scores between groups, t (28) =1.06, p=0.299. The effect of time (pre-and post-intervention) within groups on describing scores was not statistically significant; F (1,28) =0.051, p=0.822. Despite not reaching statistical significance, time had a moderate effect on describing scores, η^2= 0.093. The interaction between time and group on describing scores was not statistically significant and had a small effect; F (1,28) =0.003, p=0.956, η^2=0.002. Between subjects, the main effect of group on describing scores was not statistically significant; F (1, 28) =0.882, p=0.356, η^2=0.031. Pre- and post-intervention, the describing subscale demonstrated good reliability (α = 0.822).

Acting with Awareness. Prior to the start of the program, there were no significant differences in acting with awareness scores between groups, t (28) =-0.265, p=0.793. The effect of time (pre-and post-intervention) within groups on acting with awareness scores was not statistically significant and had a small effect; F (1, 26) =0.155, p=0.697, η^2= 0.006. The interaction between time and group on acting with awareness scores was not statistically significant and had a small effect; F (1, 26) =0.003, p=0.956, η^2=0.000. Between subjects, the main effect of group on acting with awareness scores was not statistically significant; F (1, 26)

=0.016, p=0.736, η^2=0.004[3]. Pre-and post-intervention, the acting with awareness subscale demonstrated good reliability (α = 0.857).

Nonjudging. Prior to the start of the program, there were no significant differences in nonjudging scores between groups, t (28) =0.188, p=0.852. The effect of time (pre-and post-intervention) within groups on nonjudging scores was statistically significant; F (1, 27) =4.42, p=0.045. Time had a large effect on nonjudging scores, η^2= 0.141. The interaction between time and group on nonjudging scores was not statistically significant and had a small effect; F (1, 27) =1.48, p=0.220, η^2=0.055. Between subjects, the main effect of group on nonjudging scores was not statistically significant; F (1, 27) =0.065, p=0.801, η^2=0.002[2]. Pre-and post-intervention, the nonjudging subscale demonstrated good reliability (α = 0.814).

Nonreactivity. Prior to the start of the program, there were no significant differences in nonreactivity scores between groups, t (28) =0.973, p=0.339. The effect of time (pre- and post-intervention) within groups on nonreactivity scores was not statistically significant and had a small effect; F (1, 28) = 0.605, p=0.433, η^2=0.021. The interaction between time and group on nonreactivity scores was not statistically significant; F (1, 28) =0.027, p=0.220, η^2=0.001. Between subjects, group's main effect on nonreactivity scores was not statistically significant and had a small effect; F (1, 28) =0.065, p=0.801, η^2=0.040. Pre- and post-intervention, the nonreactivity subscale demonstrated acceptable reliability (α = 0.708).

3.3.3 Trauma Symptom Checklist (TSC-40)

To test the hypothesis that pairing neurofeedback with meditation would improve wellbeing across time more effectively than meditation alone, the scores on the TSC-40 for

[2] Due to incomplete responses, some participants were omitted from this portion of the analysis (n=1).

participants for each condition were compared at time one (pre-intervention) and time two (post-intervention). To determine if there were any significant differences between groups at the start of the program, an independent samples t-test was performed on each of the subscales (please see Table 2). A factorial repeated measures ANOVA with intervention (neurofeedback or guided meditation) as the between-subjects factor and time (pre-intervention and post-intervention) as the within-subjects factor was conducted on scores for each of the two subscales: dissociation and sleep problems. The subscales of depression, anxiety, sexual abuse trauma index, and sexual problems were excluded from analysis due to redundancy (depression and anxiety were assessed in DASS-21) and relevancy to the current study (sexual problems and sexual abuse trauma index). The ANOVAs were performed on each of the subscales separately. Table 5 displays mean scores and standard deviations between groups pre-and post-intervention.

Dissociation. Prior to the start of the program, there were no significant differences in dissociation scores between groups, t (28) =-0.475, p=0.638. The effect of time (pre and post) within groups on dissociation scores was not statistically significant; F (1, 28) =2.571, p=0.120. Despite not reaching statistical significance, time had a moderate effect on dissociation scores, η^2= 0.084. The interaction between time and group on dissociation scores was not statistically significant and had a small effect; F (1, 28) =0.639, p=0.431, η^2= 0.022. Between subjects, the main effect of group on dissociation scores was not statistically significant and had a small effect; F (1, 28) =0.043, p=0.887, η^2= 0.002. Pre- and post-intervention, the dissociation subscale demonstrated good reliability (α = 0.846).

Sleep Disturbances. Prior to the start of the program, there were no significant differences in sleep disturbances scores between groups, t (28) =0.874, p=0.390. The effect of time (pre and post) within groups on sleep disturbance scores was not statistically significant and had a small effect; F (1,27) =2.77, 1, p=0.987, η^2=0.000. The interaction between time and group on sleep disturbance scores was not statistically significant and had a small effect size; F (1,27) =0.039, p=0.565, η^2= 0.012. Between subjects, the main effect of group on sleep disturbance scores was not statistically significant and had a small effect; F (1, 27) =0.677, p=0.418, η^2=0.024. Pre- and post-intervention, the sleep disturbances subscale demonstrated questionable reliability (α = 0.668).

Table 2.

Pre-Intervention Score Mean Differences between Experimental and Control Groups.

	df	*t*	*p*	*d*
DASS-21				
Stress	28	0.813	0.423	0.300
Anxiety	28	-0.061	0.952	-0.023
Depression	28	-0.387	0.702	-0.142
FFMQ				
Observing	28	-1.63	0.114	-0.601
Describing	28	1.06	0.299	0.390
Acting with Awareness	27	-0.265	0.793	-0.10
Nonjudging	28	0.188	0.852	0.069
Nonreactivity	28	0.339	0.973	0.359
TSC-40				
Dissociation	28	-0.475	0.638	-0.175
Sleep Disturbances	28	0.874	0.390	0.322

Note. Pre intervention mean differences between experimental and control groups on the DASS-21, FFMQ, and TSC-40.

Table 3.

Depression, Anxiety, and Stress Scale (DASS21) Pre- and Post- Intervention.

	Neurofeedback (*n*=17)				Control (*n*=13)			
	Pre		Post		Pre		Post	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Stress	28.8	7.38	27.9	7.12	26.8	6.08	24.5	4.01
Anxiety	21.9	4.91	22.5	8.96	22.0	5.60	20.6	5.44
Depression	24.5	7.50	23.5	9.26	25.5	7.49	23.2	7.81

Note. DASS21 means and standard deviations pre- and post-intervention.

Table 4.

Five Facet Mindfulness Questionnaire (FFMQ) Pre- and Post- Intervention.

	Neurofeedback (*n*=17)				Control (*n*=13)			
	Pre		Post		Pre		Post	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Observing	23.5	4.86	26.1	5.01	26.2	4.21	26.8	5.20
Describing	25.4	4.39	26.4	5.43	23.8	3.96	25.1	4.65
Acting with Awareness	19.4	5.93	19.6	5.32	20.0	5.85	20.4	4.09
Nonjudging	26.4	4.62	27.4	6.03	26.0	7.36	29.2	8.51
Nonreactivity	19.6	4.01	20.4	4.83	18.3	3.33	18.8	4.40

Note. FFMQ means and standard deviations pre- and post- intervention.

Table 5.

Trauma Symptom Checklist (TSC-40) Pre- and Post- Intervention.

	Neurofeedback (*n*=17)				Control (*n*=13)			
	Pre		Post		Pre		Post	
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dissociation	12.5	4.09	12.1	4.38	13.2	3.63	11.9	2.75
Sleep Problems	16.4	5.04	15.8	4.52	14.8	4.16	15.1	4.78

Note. TSC-40 scores and factorial repeated measures ANOVA results pre- and post-intervention.

3.4 Across-Session Mood Changes between Experimental and Control Group

To evaluate the hypothesis that pairing neurofeedback with meditation would improve well-being across time more effectively than meditation alone, the scores on the PANAS for participants from each condition were compared from the first to the last session, eight-time points in total. Means and standard deviations across sessions for positive and negative scores can be found in Tables 6 and 7. A factorial repeated measures ANOVA with intervention (neurofeedback or guided meditation) as the between-subjects factor and time (session one to eight) as the within-subjects factor was conducted on scores for each of the two subscales: positive and negative. The ANOVAs were performed on each of the subscales separately. To overcome a violation of the sphericity norm, a Greenhouse Geiser correction was applied to the analysis of positive and negative scores across sessions. The effect of time (first to last session, 8 sessions total) on positive scores within groups was found to be statistically significant; F (1, 133) =3.07, p=0.026, representative of a large effect (η^2=0.139). The interaction between time and group on positive scores within groups was not statistically significant; F (1, 133) =1.91, p=0.126. However, the interaction between time and group demonstrated a moderate effect, η^2=0.91. Between subjects, the main effect of group on the positive score was found to be statistically significant; F (1, 19) =6.11, p=0.023. Across sessions, the positive score subscale demonstrated excellent reliability (α = 0.98), representative of a large effect (η^2=0.24). For negative scores across sessions, the effect of time (over 8 sessions) within groups was statistically significant; F (1, 140) =5.572, p=<.001. The effect of time on negative score had a large effect, η^2=0.218. The interaction between time and group on negative scores within subjects was not statistically significant; F (1, 140) =0.806, p=0.521, η^2=0.039. Between subjects, the main effect of group on negative scores over time was found to be statistically significant; F (1, 20) =6.30, p=0.021. The effect of group on negative score had a large effect, η^2=0.240. Across sessions, the negative score subscale demonstrated excellent reliability (α = 0.98).

Further to the analysis of positive and negative scores, another factorial repeated measures ANOVA was performed comparing every participant's first and last session regardless of how many sessions were completed (i.e., if all eight were not completed). A factorial repeated measures ANOVA with intervention (neurofeedback or guided meditation) as the between-subjects factor and time (first and last session) as the within-subject factor was conducted on scores for each of the two subscales: positive and negative. The effect of time (first and last session) on positive scores within groups was statistically significant; F (1,30) =9.89, p=0.004. Time demonstrated a large effect on positive score, η^2=0.248. The interaction between time and group on positive scores in the first and last session was not statistically significant; F (1,30) =2.026, p=0.873, η^2=0.01. Between subjects, the main effect of group on positive scores between the first and last session was found to be statistically significant; F (1, 30) =6.11, p=0.019. Group had a large effect on the positive score, η^2=0.169. The effect of time (first and last session) on negative scores within groups was statically significant; F (1, 32) =16.811, p=<.001. Time demonstrated a large effect on the negative score, η^2=0.344. The interaction between time and group within subjects on negative score was not statistically significant F (1, 32) =0.113, p=0.739, η^2=0.004. Between subjects, the main effect of group on negative scores was not statistically significant; F (1,32) =2.07, p=0.160. The effect of group on the negative score was moderate, η^2=0.061. Figures 3 and 4 display positive and negative scores across sessions between experimental and control groups.

Table 6.

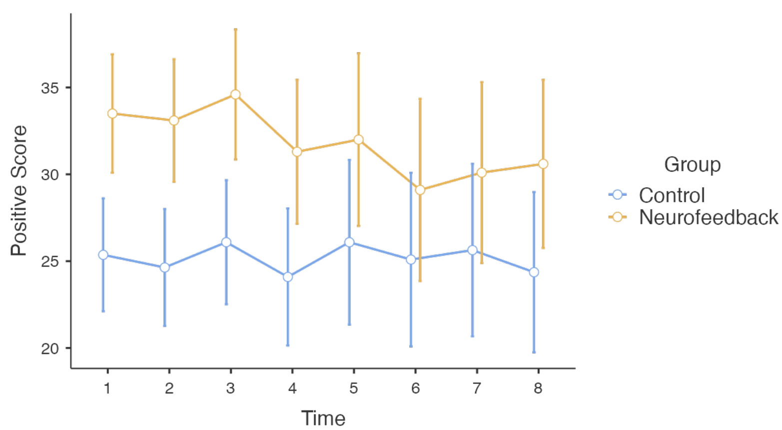
Positive Scores Across Sessions.

	Group	1	2	3	4	5	6	7	8
Mean	NFB	33.5	33.3	34.6	31.4	32.0	29.4	30.2	30.4
	Control	25.9	25.3	26.5	25.5	26.8	25.0	26.2	24.4
SD	NFB	4.97	5.20	5.29	5.53	5.91	5.38	5.78	6.00
	Control	4.97	5.06	5.72	7.16	8.33	9.39	9.20	8.13

Note. Means and SD's for positive scores across sessions for experimental and control groups.

Figure 3.

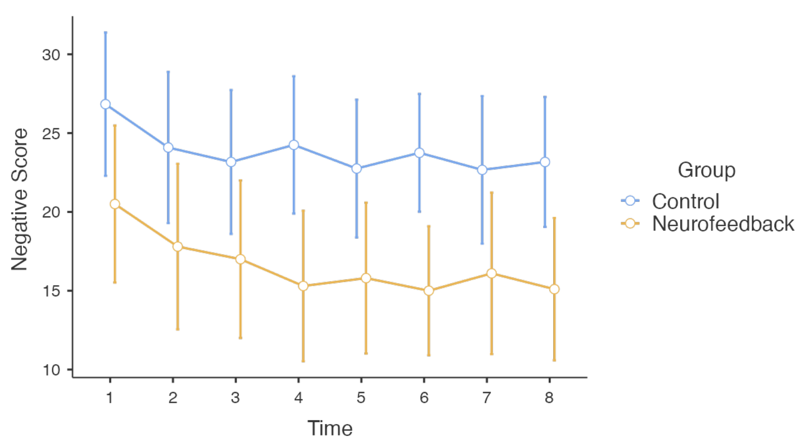
Positive Scores Across Sessions.



Note. Mean Positive scores across sessions between experimental and control groups.

Figure 4.

Negative Scores Across Sessions.



Note. Mean Negative scores across sessions between experimental and control groups

Table 7.

Negative scores across sessions.

	Group	1	2	3	4	5	6	7	8
Mean	NFB	25.9	23.2	23.2	23.4	21.9	22.9	21.9	22.4
	Control	20.4	18.0	17.2	15.3	16.0	15.7	16.3	15.3
SD	NFB	8.36	8.48	9.21	9.29	9.00	8.14	8.96	8.68
	Control	6.56	7.22	4.67	3.74	4.36	3.72	5.76	3.64

Note. Means and SDs for negative scores across sessions for experimental and control groups.

3.5 Toronto Mindfulness Scale in the Control Group

To assess potential improvements in mindful states in the control (guided meditation) group, scores from the TMS were compared at the first (time one) and the last (time two) session. The Toronto Mindfulness Scale is scored by calculating the sum of items related to decentering and curiosity, with each subscale including 6 items (minimum score = 6, maximum score = 24). A factorial repeated measures ANOVA using time (first and last session) as the within-subjects factor was conducted on scores for each of the two subscales: curiosity and decentering. The ANOVAs were performed on each of the subscales separately. The difference in mean curiosity scores between the first and last session was not statistically significant; F (16,1) =0.007, p=0.933, η^2=0.00. Across sessions, the curiosity subscale demonstrated excellent reliability (α = 0.95). Further, mean decentering scores between the first and last sessions were not statistically significant, F (15,1) =0.228, p=0.640, η^2=0.015. Across sessions, the decentering subscale demonstrated excellent reliability (α = 0.96).

3.6 Outcomes in the Meditation with Neurofeedback Group

Data collected from the Muse application including Muse points, birds, and recoveries between the first and last session were assessed by performing a paired samples t-test using Wilcoxon rank test to address a normality violation. Muse points are awarded for every minute spent in a neutral (resting) or calm (deep focus on breath) brain state, with one point awarded for every second neutral and three points awarded for every second in a calm state. Birds are awarded when the individual finds a deep, restful state that they can hold for an extended period. Recoveries are awarded when the individual notices that their mind has wandered and are able to re-establish their focus and return to a mindful state[3]. There was not a significant difference in muse points achieved between the first session (M=851.00, SD=1145.12) and the last session (M=471.71, SD=121.39), t (16) =1.07, p=0.300, d=0.260. Muse points demonstrated poor reliability (α=0.026). Similarly, there were no significant differences found between birds achieved in the first (M=18.63, SD=23.42) and last (M=9.19, SD=10.23) sessions; t (16) =1.20, p=0.247, d=0.292. Bird scores demonstrated poor reliability (α =0.048). Lastly, there was no significant difference found between recoveries recorded during the first (M=19.41, SD=42.47) and last (M=6.76, SD=5.57), t (15) =1.47, p=0.163, d=0.367. Recoveries demonstrated poor reliability (α =0.030).

3.6.1 Subjective Experience of Learning in Neurofeedback (SEOLIN) Reliability Analysis

The current study served as an opportunity to pilot SEOLIN and assess the reliability of the measure. To determine if the SEOLIN subscales were reliable, participants were asked to complete the measure after each of their sessions, totalling eight responses from each participant, and N=120 responses total. A reliability analysis was then performed. The cognitive effort subscale consisted of seven items (α =0.853), the strategy subscale consisted of five items

[3] Please note that the description of these points is proprietary to Muse and is not the authors own interpretation.

(α=0.563), the sense of agency scale consisted of six items (α= 0.825), the internal awareness scale consisted of six items (α=0.352), the external awareness subscale (α= 0.540), and the motivation subscale consisted of (α=0.656). Sense of agency and cognitive subscales showed good reliability, while internal awareness, external awareness, strategy, and motivation showed questionable and poor reliability.

3.6.2 SEOLIN Across Sessions

To assess the Subjective of Experience of Learning in Neurofeedback, the variables of sense of agency (SA), cognitive effort (CE), strategy, internal awareness (IA), external awareness (EA) and motivation were assessed at participants' first and last neurofeedback session. A paired-sample t-test was performed to compare SA, CE, Strategy, IA, EA, and motivation in the first and last sessions. For SA, there was no significant difference in score for the first SA (M= 18.4, SD=3.48) and last SA (M=18.1, SD=3.18) scores; t (16) = 0.231, p=0.820 d=0. 06. For CE, there was not a significant difference in score for the first CE (M=22.9, SD=2.99) and last CE (M=22.5, SD=2.15) score; t (16) =0.641, p=0.530, d=0.156. There was no significant difference in scores for strategy scores between the first (M=16.8, SD=2.53) and last (M=16.2, SD=2.63) session, t (16) =1.000, p=0.332, d=0.243.. There was no significant difference in scores for IA between the first (M=19.4, SD=3.02) and last (M=20.2, SD=2.11), t (16) =-1.024, p=0.321, d=-0.248. There was no significant difference in scores of EA between first (M=16.6, SD=1.80) and last (M=15.9, SD=2.16) sessions, t (16) =1.461, p=0.163, d=0.354. Lastly, there was non-significant differences found in scores of motivation between first (M=20.5, SD=2.98) and last (M=20.5, SD=2.58) last, t (16) =0.098, p=0.923, d=0.023.

3.6.3 Correlational Analysis between Muse performance and SEOLIN

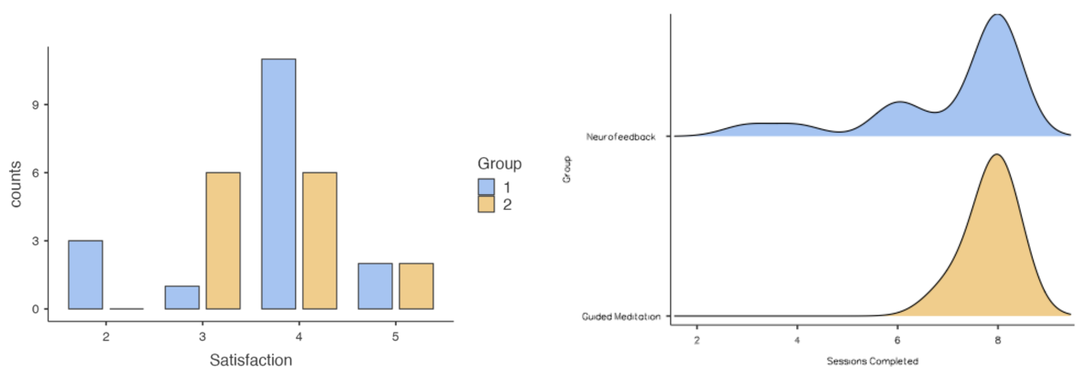
To assess hypotheses about the relationship between neurofeedback performance and scores on the SEOLIN subscales, a correlational analysis was performed. Sense of agency was found to have a moderately positive correlation with muse points (*r* (20) =0.238, *p*=<0.009) and birds (*r* (120) =0.352, *p*=<.001) which was statistically significant. Higher muse points suggest that the individual can achieve a neutral or calm brain state with more frequency, with increasing points suggesting an increased ability to achieve calm brain states. Birds are awarded when this calm state is sustained over time. However, a sense of agency was not found to have a notable relationship with recoveries (*r* (120) =-0.002, *p*=0.987). Cognitive effort was found to have a very minimal relationship with muse points (*r* (120) =0.003, *p*=0.974), recoveries (*r* (120) =-0.100, *p*=0.276, and birds (*r* (120) =0.001, *p*=0.992). Similarly, strategy was not found to have a notable relationship with muse points (*r* (120) =0.107, *p*=0.248), recoveries (*r* (120) =-0.001, *p*=0.990), and birds (*r* (120) =0.106, *p*=0.251). Internal awareness was found to have minimal relationship with muse points (*r* (120) =0.104, *p*=0.261), recoveries (*r* (120) =-0.020, *p*=0.829, and birds (*r* (120) =0.091, *p*=0.330. Further, external awareness had negligible relationship with muse points (*r* (120) =0.041, *p*=0.657), recoveries (*r* (120) =0.036, *p*=0.693), and birds (*r* (120) =-0.031, *p*=0.734. Lastly, motivation was found to be insignificant in relationship to muse points (*r* (120) =0.072, *p*=-0.435), recoveries (*r* (120) =0.024, *p*=0.796), and birds (*r* (120) =0.036, *p*=0.699).

3.7 Satisfaction

Researchers were interested in determining the overall satisfaction of applying mindfulness with neurofeedback using consumer-grade EEG in the context of an at-home intervention. As a comparison, satisfaction ratings were also collected in the control group, who practiced guided meditation. In the mindfulness with neurofeedback group (*n*=17), an average satisfaction of *M*= 3.71 (*SD* = 0.920) was reported. In the guided meditation group (*n*=14) an average of *M*=3.71 (*SD*=0.726) was reported. More than half of the participants (*n*=11, 64.7 % of group 1 respondents) in the mindfulness with neurofeedback group responded with a rating of 4 indicating that they were satisfied with this format of intervention. In the guided meditation group, most responses were equally split between 3 and 4 (*n*=12, 85.7% of group 2 respondents), indicating a neutral and satisfied ranking respectively. To determine if the difference between the two groups was significant, an independent samples t-test was conducted. Participants who engaged in mindfulness with neurofeedback did not significantly differ in their satisfaction when compared to their guided meditation group, $t(29)=-0.028$, $p=0.978$, $d=-0.010$. A distribution of group satisfaction scores can be found in figure 5.

Figure 5.

Group Satisfaction Scores.



Note. Distribution and density of satisfaction scores for the experiment (neurofeedback with mindfulness, 1) and control (guided meditation, 2) groups.

Chapter 4: Discussion

4.1 Evaluating Research Objectives

The purpose of the current study was to assess the feasibility, satisfaction (i.e., fulfillment and pleasure), and effectiveness of a mindfulness intervention using consumer-grade EEG. I hypothesized that pairing consumer-grade EEG neurofeedback with mindfulness (using Muse by

InteraXon) through a remote and self-driven intervention would be feasible, which for this proof-of-concept was confirmed through the satisfactory completion of the program. For the purposes of this study, “satisfactory completion” was defined as successfully taking the Muse device out of the laboratory setting, into participants' own schedules and homes, and completing multiple meditation sessions. Success in using Muse at home to practice mindfulness would confirm that this format of intervention is possible as a remote and self-administered intervention. As a control, a second group of participants engaged in a remote guided meditation program.

After evaluating completion rates, it was determined that participants in neurofeedback and control groups completed an average of seven out of the eight assigned sessions. Averages of group completion suggest that participants were successfully able to engage in both forms of remote and self-administered intervention, regardless of group type. Of specific interest to my hypotheses, it was determined to be plausible for participants to take the Muse EEG device outside of a laboratory and apply it within their own unique settings. There were no differences found between groups in regard to completion. This initial confirmation of feasibility facilitates the need for future studies using a consumer-grade EEG intervention, carried out on a much larger scale to gain a better understanding of attrition and completion rates, as well as the practicality of using such a device for at-home intervention. Completion rates in the current study further validate Muse’s ability to be used as an efficient, effective, and low-cost research aid that can be used in a multitude of non-laboratory settings (Korets-Smith, 2017; Krigolson et al., 2017; Krigolson et al., 2021; Ratti et al., 2017; Stockman, 2020)

Another purpose of the current study was to assess satisfaction rates with an at-home intervention using consumer-grade EEG. In the context of the current study, satisfaction referred to the degree that participants found the intervention met their expectation and the pleasure that they derived from participation. Researchers hypothesized that participants in the meditation with neurofeedback group would rate their intervention as more satisfying than non-neurofeedback groups. However, predictions were not supported by participant responses with neurofeedback and control groups reporting similar levels of satisfaction. While this is not supportive of initial hypotheses, , it does suggest that the addition of neurofeedback did not lessen satisfaction levels with mindfulness practice. Participants were asked to respond on a 5-point Likert scale, with 1 indicating “Extremely Dissatisfied” and 5 representing “Extremely Satisfied”. When assessing the distribution of satisfaction scores, 64% of participants in the neurofeedback group reported that they were satisfied with the intervention in comparison to 42% of control participants suggesting a slight preference for neurofeedback with mindfulness. However, it is important to note that 18% of participants in the neurofeedback group reported that they were dissatisfied with their format of the intervention. Dissatisfaction was not reported in the control group. A distribution of Satisfaction scores can be found in Figure 5.

For future research, it would be imperative to evaluate the reasoning behind satisfaction reports to clarify the strengths and weaknesses of pairing neurofeedback with mindfulness. One line of questioning to be assessed is whether the addition of feedback during mindfulness practice impacts the individual's level of satisfaction. That is, participants in the neurofeedback group received feedback whereas the guided meditation group did not. In the Muse application, participants are rewarded for good performance with pleasant audio feedback and the sound of birds chirping. At the end of the session, they receive another level of feedback by way of muse points, birds, and recoveries. This adds a level of goal-seeking and gamification to the practice that traditional mindfulness does not inherently possess. For example, an individual that engages in a session where they hear pleasant audio and the sounds of birds chirping followed by impressive scores may feel differently about the activity compared to an individual that heard stormy audio their entire session and received scores that were not what they wanted to achieve. Pleasant audio and holding a calm state long enough to hear birds are one of the goals users strive for during the mindful session. Feedback in any form is an important part of goal formation and propelling an individual toward the desired goal (Bandura et al., 1991; Festinger, 1954; Fishbach et al., 2010). Feedback (positive or negative) when learning contributes to an individual's success in mastering a skill or practice (Fishbach et al., 2010). Most motivation theories (i.e., reinforcement theories, expectancy theories) stress that positive feedback is more effective in encouraging good performance and one’s self-efficacy in that task in comparison to its negative counterpart (Atkinson, 1964; Fishbach et al., 2010; Zajonc & Brickman, 1969). In contrast, other motivation theorists (i.e., self-regulation theories) believe that negative feedback helps individuals to apply different strategies and use more effort in order to get positive feedback, and therefore plays an essential role in learning and task success (Carver & Scheier, 1998; Fishbach et al., 2010; Higgins, 1987; Powers, 1973). A review by Fishbach and colleagues (2010) found that positive or negative feedback have the potential to induce mood states within the person, suggesting that positive feedback induces positive mood and adoption of helpful strategies and vice versa. Therefore, it is possible that the feedback that participants receive from the Muse application has the potential to influence an individual's mood toward the activity and intervention. It would be informative to include some open-ended questions to participants about feelings toward this type of intervention to identify common themes (i.e., what they enjoyed about consumer-grade EEG, what they disliked etc.).

I hypothesized that pre-and-post intervention measures would differ between experimental (neurofeedback) and control (guided meditation) groups, suggesting an added benefit to pairing mindfulness with neurofeedback. Participants were assessed using the Depression, Anxiety, and Stress Scale (DASS-21), the Five-Facet Mindfulness Questionnaire (FFMQ), and the Trauma Symptom Checklist (TSC-40) before and after the intervention. However, the data did not support this hypothesis. These results suggest that participants did not necessarily benefit on measures of depression, anxiety, and trauma as a result of participation, nor did the addition of neurofeedback enhance their experience. This information disagrees with previous research that asserts mindfulness as an effective treatment and management system for common mental health disturbances (i.e., anxiety, depression, PTSD) and its incorporation into several clinical applications (Baer, 2006; Demarzo et al., 2015; Dimidjian & Segal, 2015; Hedman-Lagerlof et al., 2018; King et al., 2013; Lang, 2017; Plank, 2010; Scarlett, Lang & Walser, 2016). Similarly, in neurofeedback literature, many studies have indicated the psychological and neurological benefits of neurofeedback training for depressive, anxious, and trauma-related symptoms (Bennett et al., 2020; Cheon, Koo, and Choi, 2016; Danskin & Walters, 1973; Dries et al., 2015; Hammond, 2005; Harris et al., 2021; Johnson et al., 2013; Kluetsch et al., 2014; Moore, 2000; Ros et al., 2013; Russo et al., 2022; Tolin et al., 2020). However, the lack of significance in the current results may be attributed to the small sample size or the short duration of the intervention. Within groups, significant differences in observing and nonjudging scores were observed between pre- and post-intervention scores. This agrees with previous findings that awareness and mindful traits increase with the amount of mindful practice an individual engages in (Guendelman, Medeiros, & Rampes, 2017; Vago & Silbersweig, 2012; Wheeler, Arnkoff, & Glass, 2017). Similar to the findings of Acabchuk and colleagues (2021), there was no relationship found between scores provided by the Muse application (muse points, birds, and recoveries) and outcomes on the FFMQ. This suggests that there is a need for further investigation into the relationship between muse scores and mindful traits to determine if Muse EEG measures are representative of the mindful experience both psychologically and neurologically.

Further to my hypotheses that there would be differences in group means on affective measures, I also examined the positive and negative scores on the PANAS across sessions. Positive scores were significantly different between groups, with the neurofeedback group consistently scoring higher on positive mood. Regardless of group, there was a significant effect of time on positive mood suggesting that all participants experienced a shift in affect as a result of participation. While there was a slight decrease in positive mood over time in the neurofeedback group, scores remained consistently high across sessions. Similarly, negative scores were found to be significantly different over time between neurofeedback and control groups. Neurofeedback participants consistently scored lower on measures of negative mood. There was also a significant effect of time on measures of negative mood in both groups with scores decreasing steadily over time, suggesting that regardless of group participants experienced improvements in negative mood. The results of this analysis indicate that the neurofeedback group scored significantly higher on positive mood and lower on negative mood scales across sessions compared to the control group, supporting researchers' hypotheses that neurofeedback may add benefit to practice and outcomes in a mindfulness intervention. This information supports the body of growing research promoting the affective benefits of mindfulness practice, as well as suggesting an added enhancement when neurofeedback is incorporated (Chow et al., 2017; Sas & Chopra, 2015). At their roots, mindfulness and neurofeedback both work on the concepts of attentional and cognitive control (Cahn & Polich, 2006; Gordon, & Goolkasian, 2010; Lazar et al., 2005; Pagoni & Cekic, 2007; Zeidan et al., 2010). Some studies have suggested that pairing neurofeedback and mindfulness in intervention helps the individual to reach a deeper state of meditation and experience increased and sustainable benefits (Chow et al., 2017; Cirvelli, Fronda, and Balconi, 2019; Hunkin, King, and Zajac, 2021; Lazar et al., 2005; Pagoni & Cekic, 2007; Sas & Chopra, 2015). While mindfulness in general has been found to increase positive mood states, the addition of neurofeedback allows the individual to gain more information about their current brain state via feedback (Jiminez, Niles, & Park, 2010; Kiken, Lundberg, & Fredrickson, 2017). This feedback (positive or negative) helps the user to gain a clearer understanding of where their mind needs to be in order to reach a mindful state. With traditional guided meditation, there is no immediate feedback to guide the user which may result in a failure to achieve or reach an optimal mindful state. While this sample size is small and not generalizable to a larger population, it provides some preliminary support that pairing mindfulness with neurofeedback may provide benefits to the individuals learning to be mindful. Results indicate that between experimental and control groups there is some element that has a significant impact on positive and negative mood, which for the purposes of experimental design was the addition of neurofeedback to meditation. The increased mood experienced in the mindfulness with neurofeedback group could also be a result of expectancy, meaning that participants expected to have elevated mood simply because they were assigned to the neurofeedback condition and suspected that it may carry some advantage. It would be beneficial to further parse out the differences between groups to determine if there may be other factors that may influence positive and negative moods that cannot be attributed to neurofeedback.

The current study piloted the measure called the “The Subjective Experience of Learning in Neurofeedback” which is intended to measure the qualities that contribute to success and learning in a neurofeedback training paradigm. Variables that contribute to success or learning include cognitive effort, strategy, sense of agency, internal and external awareness, and motivation. It was hypothesized that participants who performed well during their neurofeedback session (reflected in their muse points, recoveries, and birds) would demonstrate low cognitive effort, implicit strategies, elevated sense of agency, and high motivation. However, correlational analyses revealed that there was very minimal relationship between these factors and the data reported from the Muse application. As a follow-up, a reliability analysis was then performed on each of the subscales. Sense of agency and cognitive effort demonstrated good reliability, while the remainder of the subscales had questionable to poor reliability. To use data from the SEOLIN in future research, each of the subscales need to be revised and adjusted to produce more reliable results. The SEOLIN consists of 35 items, which should be condensed in future studies to alleviate the burden of completing a larger measure. As this measure was intended to assess the subjective experience of the neurofeedback that the participants had just engaged in, it is important to alleviate any burden on the individual that may impede their ability to accurately recall their session. Previous research assessing the subjective experience of learning noted the issue of memory decay and the inability to recall presented a barrier to extracting important elements of the experience (Davelaar et al., 2018; Edge & Lancaster, 2004). A 10-15 item survey would be less cumbersome to complete and would still provide pertinent information on the subjective experience. It would be beneficial to do another pilot of this measure (with revised content) on a larger scale to further assess reliability, as the current study was too underpowered to provide a fully accurate assessment.

4.2 Recommendations and Future Directions

To enhance the generalizability of these results, it is important to carry out similar studies on a much larger scale to determine the feasibility of consumer-grade EEG and at-home mindfulness interventions across various demographics and populations. More importantly, it is essential to determine if this format of intervention is helpful and useful as a clinical tool for mental health and well-being. Since consumer-grade EEG is a mobile form of EEG, it would be valuable to carry out such studies in a variety of environments as well. For example, the medical community and front-line workers (i.e., nurses, emergency room staff, and first responders) may stand to significantly benefit from a portable device such as Muse. As the pandemic continues to negatively impact our healthcare system, professionals in the field have remained under significant stress for prolonged periods of time (Klien et al., 2020). Previous research has revealed that maintaining a mindfulness practice changes an individual stress response in a positive way. For example, individuals have been found to have stronger self-awareness, monitoring and regulation as a result of their regular practice which assists in managing oneself in a high stress environment (Goodman & Schorling, 2012; Guendelman, Medeiros, & Rampes, 2017; Krasner et al., 2009; Klien et et al., 2020; Tang et al., 2007; Tang, Jiang, & Posner, 2014; Vago & Silbersweig, 2012; Wheeler, Arnkoff, & Glass, 2017; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). Given the long shifts and intense work schedules that frontline healthcare workers face, it is essential to have portable and accessible options that enhance mental health and well-being regardless of schedule or environment. Muse and other consumer-grade EEG headsets offer these qualities and have the potential to enhance phycological and cognitive well-being which in turn helps them perform better in their careers (Adele & Feldman, 2004; Bishop et al., 2004; Davis & Hayes, 2011; Masicampo & Baumeister, 2007; Walsh & Shapiro, 2006). In relation to portability and accessibility, consumer-grade devices like Muse can reach communities that may be more remote and have less access to institutions for psychological health care.

Future studies may consider using consumer-grade EEG at home for a longer duration of time to get a more accurate representation of long-term electrophysiological and psychological changes that may occur with regular practice. Previous studies assessing neurological changes associated with mindfulness have indicated that regular and continued practice has the potential to enact long-term change in the brain (Aftanas & Golochiemine, 2001; Cahn & Polich, 2006; Lazar et al., 2005; Lee et al., 2018; Pagoni & Cekic, 2007). To experience these changes, consistency in practice is key. Further, follow-up assessments of electrophysiological and psychological measures collected at the one-month, three-month, six-month, and one-year periods would provide an estimate of how long changes are maintained after a longer-duration neurofeedback program. It is important to note that Muse is a good candidate for this type of study. Muse collects electrophysiological data as the user practices and tracks progress, which can also be exported and assessed using EEG analysis platforms (i.e., MatLab). While the current study did not analyze electrophysiological data from the Muse software due to time constraints, it would be very informative to deploy this type of data collection and analysis in future studies. Both mindfulness and neurofeedback have demonstrated the ability to alter connectivity and neural patterns in the brain with continued practice (Lazar et al., 2005; Pagoni & Cekic, 2007). A systematic review by Gotnik and colleagues (2016) found that approximately 8 weeks of mindfulness-based training alters activity and connectivity in several regions of the brain including the prefrontal cortex, cingulate cortex, insula, amygdala, and hippocampus. Individuals that have practiced meditation for serval years or more even show significant changes in the structure and function of the brain that is not seen in their non-meditating counterparts (Brewer et al., 2011; Garrison et al., 2015; Holzel et al., 2008; Lazar et al., 2005; Luders, Toga, Lepore & Gaser, 2009; Pagoni & Cekic, 2007; Simon & Engstrom, 2015; Travis & Parim, 2017). These changes foster enhancements in meta-awareness, appraisal, memory, emotional regulation, and bodily awareness processes (Boccia, Piccardi, & Guariglia, 2015; Davis & Hayes, 2011; Fox et al., 2014; Manna et al., 2010). Similarly, neurofeedback has demonstrated the capacity to incite changes in the structure and function of the brain that can last weeks to years (Amano et al., 2016; Rance et al., 2018; Subramanian et al., 2011; Yoo et al., 2007). A study using a consumer-grade EEG device over a longer period would help further assess the benefit of pairing neurofeedback and mindfulness together while tracking electrophysiological changes over time.

An area of expansion to consider for future studies would be the addition of a sham neurofeedback condition. Sham feedback provides a valuable control for the experimental design and would help determine if the feedback provided by the consumer-grade EEG device is indeed a useful addition to mindful practice. Sham feedback would allow experimenters to simulate a neurofeedback training session so that the participant believes they are getting an accurate depiction of their current brain state when in reality they are getting random feedback. This could be achieved by coordinating a setting on a consumer-grade device application (i.e., Muse’s app) that allows the user to engage in what appears to be a neurofeedback session, but with sham feedback. If neurofeedback does in fact aid mindfulness practice and learning to master it, then we should see clear differences in groups across time. According to the multi-stage learning of neurofeedback, accurate feedback is essential as a primary reinforcer of the individual’s subjective experience (Davelaar, 2018). With this in mind, accurate feedback in combination with mindfulness practice should contribute to the long-term success of the intervention and sustained cognitive and neurological effects.

Another valuable comparison that is recommended to be included in future studies is a comparison group using medical-grade EEG. One of the commonly cited concerns surrounding consumer-grade devices in EEG research is how well they compare to medical-grade EEG devices (Krigolson et al., 2017). Directly comparing consumer-grade and medical-grade EEG in the context of practicing mindfulness meditation will allow researchers to determine if the electrophysiological data provided by consumer-grade devices meet the standards or similar conclusions of medical-grade EEG recordings. For consumer-grade EEG to be an effective research tool in the future, it is essential that it is providing the same or similar results as the medical grade device. It would be beneficial not only to track the progress of neural changes across sessions, but to see how the progression compares in consumer-grade and medical-grade EEG devices. This could be achieved by conducting a study similar to the present one, where one group practices mindfulness using a medical-grade EEG system and the other practices mindfulness using a consume-grade EEG headset.

Future studies could use consumer-grade EEG to carry out more in-depth analyses on the neural correlates underlying mindfulness meditation and the progression of the mindful brain. Two commonly associated elements of EEG recordings during mindfulness meditation are alpha and theta. Increases in frontal, parietal, and occipital alpha synchrony and activity have been recorded in meditative states, with experienced meditators exhibiting enhanced alpha activity (Aftanas & Golochiemine, 2001; Cahn & Polich, 2006; Lee et al., 2018). Similarly, theta waves have been proposed as one of the unique qualities of the mindful state that is positively correlated with experience and practice (Kasamatsu & Hirai, 1996; Aftanas, 2001; Lagopoulos et al., 2009). An investigation of how alpha and theta change across sessions would help identify the progression of neural changes displayed with regular meditation practice. While researchers have unearthed some parts of the meditative experience, there is still much to be known about neural correlates underlying this practice. Further to the analyses of theta and alpha, consumer-grade EEG could be used to investigate other neural elements of mindfulness as well. Connectivity among neural networks that have been found to be impacted by regular mindfulness practice including the default mode network, central executive network, and saliency network (Udin et al., 2011; Touroutoglou et al., 2015; Young et al., 2017). Muse has the option to attach an auxiliary electrode that would be useful in this type of connectivity assessment, allowing researchers to select the region they would like to monitor. Using a similar experimental design to the current study, it would be possible to monitor connectivity practices as the user engages in sessions.

A final recommendation for future studies would be to collect electrophysiological data across groups regardless of whether they were participating in neurofeedback training. This helps further elucidate the level of electrophysiological change participants are experiencing for mindfulness practice alone. This could be achieved by sending all participants home with a consumer-grade EEG headset that they wear for all their meditation practice, regardless of whether they are doing neurofeedback. A comparison can then be made between neurofeedback and non-neurofeedback groups by evaluating EEG recordings across time points. This may allow us to pinpoint what advantage there is to combining mindfulness with neurofeedback and identifying any surpluses that users may experience as result (i.e., faster learning, deeper meditation).

4.3 Limitations and Considerations

As with most studies, the design of the current study was subject to limitations. Given that the study was a proof-of-concept for the feasibility, satisfaction, and effectiveness of this format of intervention, the hypotheses and objectives were broad in nature. Researchers simply wanted to determine if this format of intervention was well received by participants and able to be carried out in the manner that was intended. The current study had a small sample size of *N*=34. As a result, the outcomes of the current study are underpowered and may not be generalizable to the broader population. Due to the lack of electrophysiological data, the results cannot confirm if pairing mindfulness with neurofeedback led to electrophysiological changes in the brain. The results of the study would be stronger if we were able to compare subjective reports from participants with objective measures (i.e., electrophysiological data). Finally, due to time constraints and several obstacles encountered by researchers, it was beyond the scope of the study to carry out some aspects in more detail and on a grander scale. While the noted limitations of the study may have impacted the results and analysis, they are still valid and informative to the future studies.

As a feasibility study, I wanted to assess the effectiveness and utility of different formats of at-home mindfulness programs for mental health and wellbeing. In the process of carrying out the study, several obstacles were identified that should be considered in future studies of a similar nature, as there is still plenty to explore in this area of research. One of the main issues encountered during the current study was collecting participants that were available for a 4-day intervention. Many participants mentioned that a 4-day study with morning and evening sessions was difficult to integrate into their lifestyle. For example, some individuals worked irregular shifts (i.e., alternating between day and night shift), had obligations in the mornings and evenings, and had busy lifestyles. One of the drawbacks to a fixed schedule is that, while it provides an element of experimental control, it may become cumbersome to the individual and result in them viewing their sessions as a chore or task that they are obligated to do. This may interfere with the therapeutic and enjoyable nature that was intended for this type of program and may present as a confounding factor to the intervention's success. Future studies may benefit from integrating a more variable schedule that can be individually tailored to the participant's lifestyle. In addition, it would be helpful to assess more naturalistic ways of data collection for this format of intervention. Perhaps having participants do their sessions at their own leisure (i.e., instructing them to do two sessions at any point in the day that is convenient to them) might reflect how they would use a consumer-grade EEG device in everyday life and provide more realistic results.

Future studies should consider the usability and accessibility of Muse and portable EEG in the context of culture. For example, participants entering the current study notified researchers that they would not be good candidates for the Muse group as they wear religious coverings that would prevent the Muse headset from having contact with the skin where sensors are located. Skin contact is essential to the Muse's ability to read electrophysiological activity and would negate the purpose of neurofeedback if not worn properly. Future research and innovation should consider ways in which Muse can be made more accessible and useful to members of religions and other spiritual beliefs that may require garments.

A significant limitation of this format of intervention is its reliance on wireless networks and the internet. Without wireless networks, the consumer-grade EEG headset becomes unusable and therefore not accessible to the individual. This can limit some of the environments that Muse and other consumer-grade EEG deivces can be used in. This reliance on wireless networks deviates from the traditional practice of mindfulness mediation that was established centuries ago, where you simply just needed to engage your awareness of the current moment regardless of where you were in time or space. In the future, it would be beneficial to see expansions and improvements to mobile-EEG software and technology that allows for use regardless of access to wireless networks.

4.4 Conclusion

The objective of the current study was to assess the feasibility, satisfaction (i.e., fulfillment and pleasure), and effectiveness of an at-home mindfulness program using consumer-grade EEG, and to identify any benefits that arose as a result of pairing mindfulness with neurofeedback. I hypothesized that this format of intervention would be feasible and more satisfying to participants than non-neurofeedback groups. The results supported the feasibility of at-home neurofeedback with mindfulness as an intervention. However, satisfaction reports did not support researchers' predictions that participants would rate neurofeedback with mindfulness more highly than controls. There was also some evidence that the addition of neurofeedback to mindfulness helped promote positive mood and reduce negative affect. It is the researcher's hope that this intervention can be delivered on a larger and more representative scale in future studies incorporating longer durations, sham conditions, and electrophysiological analysis.

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Appendix A: The Subjective Experience of Learning in Neurofeedback (SEOLIN) Measure

5-point Likert scale (1- strongly disagree, 5- strongly agree)

Cognitive Effort (7 items)

	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
1. I did not have to put any effort into completing this task. R					
2. I had to use a lot of mental energy to complete this task.					
3. I had to work hard to complete this task.					
4. I felt like doing neurofeedback came naturally to me.					
5. I approached this task with a sense of ease.					
6. It was easy to complete this task.					
7. I felt like I had to try harder because I did not feel confident in my ability to complete this task. R					

Strategy (5 items)

	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
8. I felt like I found a strategy to meet the goals of this task.					
9. I tried different techniques to see what would work to control my brain state.					
10. I did not use any dedicate strategy to complete this task. R					
11. I used the same technique throughout the task to control my brain.					

12. I found a plan that I felt worked to control my brain in the task.					

Sense of Agency (6 items)

	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
13. I was in control of my brain during the task.					
14. I was able to regulate my brains activity during the task.					
15. I did not know what was going on in my brain during the task. R					
16. I knew how to meet the desired goals of the task through controlling my brain.					
17. I found it difficult to regulate my brain activity. R					
18. I think I was able to change my brain state in a way that helped me complete the task.					

Awareness (11 items)

Internal Awareness (6 items)

	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
19. I was aware of my inner experiences during the task.					
20. I was unaware of the sensations in my body during the task.R					
21. I noticed my thoughts during the task but did not interfere with them (TMS, 2006).					
22. When doing the task, my mind easily wandered off and I kept getting distracted (FFMQ, 2016). R					

23. I felt aware of the physical sensations in my body during the task (i.e., breathing, heart rate).					
24. I paid attention to how my thoughts and emotions affected the feedback I got during the task (FFMQ, 2016).					

External Awareness (5 items)

	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
25. I paid attention to sounds in my environment such as clocks ticking, birds chirping, or cars passing (FFMQ, 2016).					
26. I noticed visual elements of the neurofeedback task, such as colours, shapes, patterns or lights (FFMQ, 2016).					
27. I was not aware of what was going on in my environment during the neurofeedback task. R					
28. I felt distracted by my environment during the neurofeedback task. R					
29. I remained curious about the nature of each experience as it arose in the task (TMS, 2006).					

Motivation (6 items)

	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
30. I was fascinated by the process of neurofeedback.					
31. I was interested in the prospect of controlling my own brain.					
32. I felt that I was distracted by my environment easily because I was not interested in the task. R					

33. I did not find neurofeedback to be an engaging task. R					
34. I felt like I wanted to perform well for this task because I am being compensated for it.					
35. I did not feel obligated to perform well on this task. R					

The SEOLIN is scored by average each of the subscales. Please note that some items are reverse scored (indicated by the “R” beside them).

Appendix B: Ethics Approval

Western Research

Date: 12 May 2022

To: Dr. John Paul Minda

Project ID: 120564

Study Title: The Psychotherapeutic Effects of Consumer-Grade EEG Neurofeedback with Mindfulness on Mental Health and Wellbeing

Short Title: Neurofeedback and Wellbeing

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: June 3 2022

Date Approval Issued: 12/May/2022 11:14

REB Approval Expiry Date: 12/May/2023

Dear Dr. John Paul Minda

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study.**

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Pre-Program Questionnaires 120654	Online Survey	06/Mar/2022	1
Group 1 Daily Surveys 120564	Online Survey	06/Mar/2022	1
Group 2-4 Daily Surveys 120564	Online Survey	06/Mar/2022	1
Post-Program Questionnaires 120564	Online Survey	06/Mar/2022	1
Recruitment Poster - CLEAN -120564	Recruitment Materials	18/Apr/2022	2
LOI and Consent 120564 CLEAN	Written Consent/Assent	18/Apr/2022	2

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
TRA_QUALTRICS	Technology Review document	25/Feb/2022	1
Supplementary Figures 120564	Supplementary Tables/Figures	06/Mar/2022	1
Mental Health Resources 120564	Other Materials	06/Mar/2022	1

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

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

Sincerely,

Curriculum Vitae

Madeline Slack – Curriculum Vitae

Research Cluster
Cognitive, Developmental and Brain Sciences

Year in Program
Year 2

Thesis Supervisor(s)
Dr. Paul Minda

Advisory Committee
Dr. Laura Batterink
Dr. Lindsay Nagamatsu

Research Activities

Assisted Undergraduate Student with Honours Thesis	September 2020- April 2021
EEG Analysis Research Group	November 2020 – April 2021
Chapter Co-Author	July 2021

- P.Frewen, Bao, Z., Schaffer, S. (In Press). Meditation Breath Attention Scores (MBAS) *Handbook of Assessment in Mindfulness Research*. Springer.

Required Courses

PSYCHOL 9223A – Neuroimaging of Cognition	September 2020- December 2020
PSYCHOL 9540 – Research Design and Statistical Modelling	September 2020- April 2021
PYSCHOL 9251Y – CDBS Seminar	September 2020 – April 2022
PSYCHOL 9260B – CDBS Proseminar	January 2021- April 2021
PSYCHOL 9545 – Test Measurement Construction	September 2021-December 2021

Other Activities

PSYCHOL 2820 Teaching Assistantship	September 2020-April 2021
Open Instructional Skills Workshop Online	September 2020
PSYCHOL 1003a Teaching Assistantship	September 2021-December 2021
PSYCHOL 1003b Teaching Assistantship	January 2022- April 2022