MINDFULNESS MEDITATION AS AN INTERVENTION FOR OLDER ADULTS STRUGGLING WITH LONELINESS AND STRESS

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TITLE: Mindfulness Meditation as an intervention for older adults struggling with loneliness and stress

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Lay Abstract

This thesis explored whether mindfulness meditation can improve mental and social well-being in older adults, who often face challenges like stress, loneliness, and low mood. Twenty-six participants were randomly assigned to either a mindfulness meditation group or a brain training group. Over several weeks, they completed surveys on mood, stress, social connection, and quality of life. The mindfulness group showed greater improvements in depression and physical and emotional well-being. These findings suggest that mindfulness meditation may be a simple, low-cost way to support healthy aging and improve quality of life.

Abstract

This study investigated the effects of a mindfulness meditation intervention on psychological and social well-being in older adults. Participants (N=26) were randomly assigned to either a mindfulness meditation group or an active control group engaging in a brain training app. Assessments were conducted at five different points throughout the study. Primary outcomes included self-reported levels of loneliness, perceived stress, mindfulness (via the Five Facet Mindfulness Questionnaire), depressive symptoms (Beck Depression Inventory-II), social interaction and satisfaction (Duke Social Support Index), and quality of life (Who quality of life questionnaire). Mixed-effects models were used to examine longitudinal changes while accounting for individual variability. Results indicated that, compared to the brain training group, the mindfulness group showed a significantly greater reduction in depression and a significantly improvement in the WHO quality of life Physical and Psychological subscales.

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Abbreviation/Symbol	**Definition**
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
BDI-II	Beck Depression Inventory – Second Edition
FFMQ	Five Facet Mindfulness Questionnaire
MM	Muse Mindfulness Meditation
BT	Peak Brain Training
UCLA	University of California, Los Angeles Loneliness Scale
SPSS	Statistical Package for the Social Sciences
SD	Standard Deviation
M	Mean
p	Probability value
α	Significance level
η^2	Eta squared (effect size measure)

I, Gibbs Jr Ollivierre, hereby declare that the work presented in this thesis is my own original research and has been carried out under the supervision of Dr.Sekuler.

Introduction

Aging is marked by gradual changes in the body that produce a heightened risk of diseases and a growing need for effective interventions. Many contemporary advances in medicine focus on understanding the mechanisms of aging with the goal of increasing life expectancy and developing interventions that promote healthy aging without addressing the unique psychological challenges faced by the older adults today. Loneliness and stress predispose older adults to cognitive decline (Kuiper et al., 2015) at a frequency that highlights the need to address this vulnerability. Cognitive decline can develop into dementia that affects quality of life (Sutin et al., 2020), but it also presents an opportunity to investigate the factors of aging and reiterate the necessity for support during the process. Mindfulness meditation, a trending practice within the West that practitioners claim can improve wellbeing and mental health, could be a possible selling point to older individuals looking to remedy age related problems. However, without aids to make meditation more accessible, it is notoriously difficult to retain steady and continued practice of mindfulness meditation (Bodhi, 2005), and it may be inaccessible for people who may benefit the most. Thus, there is a need for methods to sustain this practice in order to reduce detrimental age-related comorbidity. Therefore, we studied the effectiveness of mindfulness meditation as an intervention for loneliness and stress, two factors affecting the rate of dementia diagnosis in older adults, and to examine potential characteristics that relate to the feasibility of delivering and sustaining the experience of a remote mindfulness meditation practice.

Aging and Cognition

The fear of cognitive decline is common among older adults. Severe cognitive impairment may indicate an underlying neurological disease that could lead to dementia (Murman, 2015). Dementia is linked to loss of cognitive functions (e.g., thinking, remembering, and reasoning) that interferes with a person's daily activities (Randhawa & Varghese, 2024). Individuals over the age of 60 commonly develop cognitive impairment. Although some have accepted that dementia is unavoidable with age and genetics, there are 14 modifiable lifestyle risk factors that, if eliminated, may prevent up to 45% of dementia cases worldwide (Livingston et al., 2024). These risk factors include social isolation, high cholesterol, traumatic brain injury, hypertension, depression, physical inactivity, diabetes, smoking, and excessive alcohol consumption (Livingston et al., 2020). Medical exams can help distinguish between normal aging and significant cognitive impairment, but the deterioration of cognition can be slow and go unnoticed if regular check ups are not completed (Randhawa & Varghese, 2024). Without proper monitoring and care, loneliness and stress will increase, threatening the physical and mental wellbeing of older populations by raising the likelihood of cognitive decline and dementia.

Stress & Loneliness Effects on Aging

It is critical for individuals to believe they have the necessary skills and resources to respond to stressful stimuli and be emboldened to engage in constructive problem-solving when confronting stressful situations. The mechanisms that increase stress and loneliness are closely related and mutually impactful. Stress, though often described as a negative experience, is a fundamental adaptive response that is required for successfully dealing with a myriad of daily tasks. It is only after exposure to stress for an extended period, or when the stressor becomes too severe, that physiological adaptation systems collapse (Chu et al., 2024).

Stress can worsen age-related cognitive decline by producing cumulative brain damage (Randhawa & Varghese, 2024). Unfettered stress will exacerbate a variety of age-related problems, including neurodegenerative diseases and overall aging symptoms (Goosens & Sapolsky, 2007). Furthermore, acute stress has been shown to impair emotional processing in otherwise healthy older people, potentially increasing their vulnerability to affective disorders (Everaerd et al., 2017).

Stress becomes even more hazardous as people grow older, due to an age-related decline in the ability to manage stress. As the body grows older it struggles to inhibit the production of stress hormones after repeated stressful events. This compounding stressful stimuli can possibly cause injuries to regions of the brain responsible for hormone control in turn releasing more stress hormones. If not remedied, a vicious cycle may form that, produces more stress hormones, that cause greater damage, leading to increased symptomology of stress such as; insomnia, reduced appetites, and lack of physical activity (Sapolsky et al., 1986; McEwen, 1992; Everaerd et al., 2017). These factors demonstrably increase the risk of depression and dementia (Livingston et al., 2024).

In addition to hormonal stress, perceived stress (i.e., the perception that the demand of daily life exceeds the ability to cope with those demands) can negatively impact health. Perceived stress in older people has been linked to a decline in cognitive performance, with those reporting higher levels of perceived stress performing worse on tasks requiring attention, working memory, and processing speed (Munoz et al., 2015). The increased susceptibility to stress in older adults, combined with the cognitive impairment that stress may cause, highlights it's significant impact on general health and well-being, and underlines the importance of developing effective stress management techniques.

Recent research demonstrates an association between loneliness and a tendency to engage in unhealthy behaviors like excessive drinking, excessive smoking, reduced physical activity, poor dietary habits, disrupted sleep heightened social risk awareness, diminished pleasure from positive social interactions (Ong et al., 2016). Loneliness also has been linked to an increase in depressive symptoms diminished cognitive function and increased likelihood of nursing home admission and the progression of dementia (Ong et al., 2016). It is described as an unpleasant, experience involving the perception that the quality and quantity of one's social interactions are not meeting expectations (Hawkley & Cacioppo, 2010). These unmet expectations could be related to the number of relationships, the frequency of interaction, or the intimacy or quality of those connections. Researchers have distinguished emotional loneliness from social loneliness: Emotional loneliness refers to the absence of a close emotional relationship, whereas social loneliness refers to the absence of an engaged social network (Dahlberg et al., 2022). Social isolation is defined as a lack of social interactions and a limited ability to communicate with others on a daily basis. It is possible to be alone without feeling lonely or socially isolated, and to feel lonely while with other people (Kuiper et al., 2015).

Loneliness, particularly in later age, also is closely connected with depression and higher all-cause mortality (Stek et al., 2005; Holt-Lunstad et al, 2015; Rico-Uribe et al., 2018). Loneliness in older adults is linked to a 50% greater chance of developing dementia (Kuiper et al., 2015), a 30% increased risk of incident coronary artery disease or stroke (Valtorta et al., 2016), and a 26% increased risk of all-cause mortality (Holt-Lunstad et al, 2015). Loneliness is also linked to poorer cognition scores on assessments, reduced verbal fluency, and lower backward digit span scores (Lara et al., 2019).

The combination of loneliness and stress negatively impacts cognitive function. People who are lonely and socially isolated have increased activity in their HPA axis which can cause instances of increased stress (Dunlavey, 2018). The hypothalamic-pituitary-adrenal axis (HPA) is a network that includes the hypothalamus, pituitary gland, and adrenal glands. It regulates the body's stress response while also controlling mood, digestion, immunological function, and energy but its principal function is to regulate the body's reaction to stress (Dunlavey, 2018). Conversely, the increased stress enhances the activity of the HPA axis creating a negative feedback loop–making individuals who feel lonely and isolated more likely to grow unhealthy lifestyle practices that raise stress (Yanguas et al., 2018; Munoz et al., 2015). Many of these increased behaviors and circumstances are associated with the factors that increase the risk of dementia. Demonstrating loneliness as more dire than we were willing to consider in the past and that accompanying stress will play a role in intensifying its effects if not dealt with effectively.

Dahlberg et al (2022) investigated 120 different risk factors for loneliness and found that the key risk variables consistently related to loneliness were: 1) having a small social network; 2) low levels of social activity; 3) poor self-perceived health; and 4) depression or an increase in depressive symptoms. This self-perpetuating relationship with loneliness, stress and other dementia risk factors increases the chance of dementia while also worsening the effects these conditions have on each other. These results suggest that effective intervention for these conditions are necessary to promote healthy aging as the problem continues to grow in prevalence.

A meta-analysis examining prevalence of loneliness in 113 different countries found a large proportion of the population suffer from problematic loneliness (Surkalim et al., 2022). In Canada, approximately three in ten seniors reported living alone while over a third reported feeling lonely in 2020-2021 (Ooi et al., 2023), with greater percentages among senior women and those living in larger cities (Statistics Canada, 2023). These results were acquired during the height of the pandemic where social isolation was recommended among the general population. A study examining prevalence of loneliness in 2023 using a three-item UCLA loneliness scale identified three main patterns in loneliness among Canadian older adults: stable low loneliness with 17% prevalence, fluctuating moderate loneliness with 48.8% prevalence and sustained elevated loneliness with 36% prevalence. The sustained-elevated group were more likely to live alone, had higher levels of psychological distress, and perceived a greater health risk from COVID-19 while the fluctuating-moderate group reported more health problems, greater distress, and less in-person encounters (Lara et al., 2023).

Research has identified the average expected prevalence of depression, a risk factor for dementia, among old adults to be 31.74% (Zenebe et al., 2021). The symptoms experienced by older adults are frequently accompanied by senescence-related disabilities such as apathy, cognitive impairments, and sleep disorders (Fiske et al., 2009; Flint, 2005). Recent studies have suggested depression in older populations to be underestimated, as they are more likely to describe their depressive symptoms as loneliness. This has been attributed to differences in how psychopathologies, such as stress-related disorders and depression, manifest in older adults compared to younger individuals (Fiske et al., 2009; Flint, 2005). Depression in older adults is more frequently associated with cognitive deficiencies and somatic problems than depression in younger adults (Mendonça et al., 2016). As a result, loneliness and stress-related symptoms in older adults are frequently misconstrued and not treated appropriately which in turn can increase these negative effects by those who do seek medical care and monitoring.

The effects of stress and loneliness in older adults are dire and ever growing. Without proper interventions to alleviate the elevated levels of loneliness particularly among older adults, more will continue to suffer and will suffer again in any future circumstances where widespread social isolation, like the COVID -19 pandemic, is required. Research on loneliness and depression in older individuals' stresses increased social support and interactions to combat feelings of loneliness (Pinquart & Sorensen, 2001). Alternatives or additions to common pharmacological interventions and treatments that are effective and accessible are needed to alleviate detrimental conditions that target one of the most vulnerable groups in our society.

Mindfulness Meditation

The increasing number of meditation practitioners reporting beneficial effects of meditation on general health like mood, anxiety and well-being (Cramer et al., 2016) has prompted more research into mindfulness methods. Meditators have claimed that their practice reduces stress, aids in emotional control, improves cognitive function, increases focus and attention, and improves overall mental health. These benefits are particularly evident among long-term meditation practitioners, who have received attention for their stated improvements in both physical and mental well-being (Wong, 2021). People who practice meditation for long periods of time have been found to have lower levels of worry, tension, and blood pressure (Wong, 2021). Meditation has also been found to heighten levels of attention, cognitive function, emotional regulation (Calderone et al., 2024) and to increase gray matter in areas of the brain responsible for processing sensory information, regulating emotions, and maintaining attention (Luders, 2009). These results suggest that meditation affects brain plasticity and may help to decrease age-related cognitive decline.

Previous research has found a link between mindfulness meditation and improved mental health in long term meditators, but it is unclear if beneficial effects occur in individuals who meditate for a shorter period of time. Mindfulness has been found to be negatively correlated to depressive, anxious, and stress symptomatology based on the five facets of mindfulness questionnaire (Cash & Whittingham, 2010) and mental health improvements were potentially found specifically within older adults decreasing loneliness; yet a stronger effect for reduced depression was found within the same metanalysis. Unfortunately, the quality of evidence was deemed low by Cochrane's Risk of Bias (ROB) tool and Grading of Recommendations Assessment, Development, and Evaluation (GRADE) (Teoh et al., 2021). However, more recent studies have continued to find that it is an effective alternative intervention for decreasing depression and anxiety, as well as improving quality of life and working memory (Talebisiavashani, 2024; Reangsing et al., 2021). Mindfulness also has been shown to have beneficial effects on loneliness and social interaction. EK et al., 2019 examined the effects in young adults who were new to mindfulness meditation and had to learn the practice for the first time. They found that fostering openness and acceptance toward current experiences was crucial for reducing loneliness and improving social engagement and that removing acceptance-skills training from a mindfulness intervention reduced these benefits (Ek et al., 2019). Unfortunately, it is not clear if the results obtained by Lindsay et al. would generalize to older adults.

Most studies examining the effects of mindfulness-based meditation interventions used small sample sizes and lacked follow-up assessments. Many studies also have not examined the effects of mindfulness meditation on older adults compared to an active control group, engaging in another commonly used intervention for cognitive decline and loneliness. Without an active control group, changes in self-reported scores or cognitive performance may be influenced by expectancy bias. Research on mindfulness meditation and its impact on loneliness also remains limited, underscoring the imperative for further investigation in this specific domain.

Meditation Aids

There are several challenges associated with mindfulness meditation for older adults. Firstly, accessibility poses a significant barrier because many meditation programs necessitate leaving home to attend in-person group classes, therefore hindering participation of older individuals with mobility issues or health concerns. Additionally, maintaining long-term motivation for meditation is problematic, with factors like physical discomfort from remaining still for long periods of time and self-doubt contributing to inconsistent practice (Bodhi, 2005). Overcoming these motivational barriers is crucial for promoting sustained engagement.

Recognizing the need to address these issues, meditation aids have emerged as potential solutions to some of the challenges associated with mindfulness meditation practice. Digital meditation aids are accessible in the individual's home, and their use can be adapted to a flexible schedule, addressing the barriers of reduced mobility and time constraints. To address motivation, the Muse app tracks brain activity during meditation using a brain-sensing headband and provides real-time neurofeedback to enhance focus and calmness. Such meditation aids offer valuable support, particularly for beginners struggling to maintain focus and for experienced practitioners seeking to deepen their practice (Marzbani et al., 2016). Consciousness and implicit learning theories found that awareness of relevant information is the key to learning and intentional adaptive changes, and becoming aware of implicit automatic mechanisms is a critical step in developing the ability to recognize and intervene when these automatic mechanisms are activated (Cleeremans & Jiménez, 2002), which can help mediators sustain their practice.

Although digital meditation tools hold promises for improving accessibility and may increase retention of the practice, they must be user-friendly for older adults who may struggle with technology. Addressing these challenges is essential for fostering consistent and reliable meditation practice among older adults. Robust research examining the efficacy of digital meditation tools in older persons is missing.

Objectives

Mindfulness meditation is an accessible and non-invasive intervention for remedying loneliness and stress with potential long-term benefits that could also serve as a partner to traditional therapies and pharmacological options (McEwen et al., 2015; Shapiro et al., 2018).

This thesis investigated a smartphone-based mindfulness meditation app as an intervention for lonely older adults. The primary goal of this thesis was to determine the feasibility and acceptability of this intervention in older adults and to explore what individual participant characteristics relate to meditation adherence. Another goal of this thesis was to examine preliminary data on the effect of the intervention on mental health, including loneliness, depression, and stress, relative to those engaging in an active control group. More specifically, the study evaluated the effect of the mindfulness intervention relative to that of an active control group that used a brain training app (Peak) that is thought to improve cognitive performance (Bonnechère et al., 2021).

Methods

Study Design

This study was a randomized controlled pilot study, with a two-arm parallel design and a 1:1 allocation ratio. Participants were assigned randomly to one of two groups: The main intervention (Muse-based Mindfulness Meditation group) or the active control intervention

(Brain Training group). Both groups were observed concurrently yet independently over the course of 8 weeks and an additional 16 week follow up period. Outcome measures were based on five assessment visits throughout the study and eight weekly surveys during the main intervention. Participants completed 9 surveys during assessment visits with only 6 being discussed in this thesis and one survey and a check-in form, to track their intervention activity, weekly during the main intervention.

All evaluations were conducted remotely by staff based at Baycrest and McMaster University, using telephone or computer-based assessments and mobile devices. This method allows for remote involvement from participants and some staff while maintaining scientific rigor. Participants took part in the study from the comfort of their homes by using a mobile device and computer with an internet connection. A remotely-administered study made it accessible to participants with mobility issues who would otherwise not attend in-person visits, and also allowed to broaden the study's geographic reach, allowing for a more varied sample.

Recruiting

Recruitment was carried out using social media ads across Ontario, flyers sent to agencies supporting older adults; adverts in e-newsletters for older adults; and email and phone outreach to Rotman Research Participant Database members.

Participants

This study sought older adult participants who were in good physical and mental health, were familiar with and have access to mobile technology, and had not meditated or engaged in cognitive training in the last five years. The specific inclusion criteria for enrollment were (1) an age of 60 years or older; (2) a score of 5 or higher on the 3-item Loneliness Scale, which assesses relational closeness, social connectivity, and self-perceived isolation (Hughes et al., 2004) and;

(3) access to a personal computer or laptop with an internet connection at home, as well as a mobile device (Android or iOS) compatible with the Muse and Peak applications. Necessarily, participants had to feel comfortable using mobile devices. Participants also had to be fluent in English and live in Ontario, due to restrictions in the jurisdiction of the study psychologist's license.

The exclusion criteria were evidence of cognitive impairment based on the telephone interview for cognitive status (TICS) (Ziemann et al., 2017), any psychiatric diagnoses within 90 days of study entrance; substance misuse within the previous year; lifetime diagnoses of psychosis, bipolar disorder, obsessive compulsive disorder , schizophrenia, or post-traumatic stress disorder, determined by earlier diagnoses or the clinical consultation with the study's psychologist; a diagnosis of an active cancer or another significant medical condition; significant visual impairment, hearing loss that impairs perception of the Muse app's auditory feedback (hearing aids could be used if compatible with Muse). In cases of psychiatric diagnoses prior to 90 days before study entrance, individuals needed to be on a stable dose of psychotropic or psychoactive medication for at least four weeks prior to randomization, and could not have been currently participating or recently completed another intervention study or clinical trial, and any recent meditation practice, weekly or more frequent meditation (sitting meditation, yoga, tai-chi and meditation within religious prayer) or cognitive training (e.g., Lumosity, Brain fit, Brain HQ) within the past 5 years.

Primary intervention: Mindfulness meditation

The mindfulness meditation intervention (MM) was implemented using the Muse platform, which includes the Muse app and a Muse electroencephalography (EEG) headband. The Muse headband is a battery-powered EEG wearable device that is worn across the forehead and behind the ears. It contains five dry electrodes: two frontal silver electrodes on the forehead, two conductive silicone-rubber temporal electrodes, and one reference silver electrode at a midline position on the forehead. A proprietary algorithm in Muse was employed in real time to assess whether the user was focused, aware, or mind-wandering in order to offer appropriate auditory neurofeedback to the app user.

At the start of each session, the user chose a soundscape to listen to throughout their Mind Meditation session. The soundscape is the auditory environment or ambient sounds provided during the meditation session. Neurofeedback about the state of mindfulness was provided with changes in the weather sounds within the soundscape. When the Muse algorithm detected mindfulness, the soundscape's weather became more peaceful and quieter, rewarding the user with more calm and tranquil sounds of the chosen environmental soundscape. When the algorithm determined that the user's mind was wandering, the weather sounds gradually increased in turbulence adding heavy winds, rain, and thunder; and reverting to the more hushed, quiet weather when the user returned to a mindful state. Sounds of birds tweeting were played if the user was in a mindful state for a long time. During the first 10 Mind Meditation sessions, participants completed the Muse Essentials course that included brief instructions about breath-focused mindfulness meditation and an explanation of the meaning of the weather sounds. For subsequent "Mind Meditation" sessions, participants were asked to complete unguided sessions with no instructions. Following each session, the app showed a chart illustrating the changes in focus throughout the session, represented through a "calm" score, as well as times when the bird sounds were played.

In addition to the "Mind Meditation" sessions, participants had access to a collection of eight guided meditation recordings by professional meditation instructors, focusing on topics such as acceptance, self-compassion, equanimity, and fundamental mindfulness techniques. Although participants did not receive real-time neurofeedback during the guided meditation sessions, they were able to examine a chart at the conclusion of each session with their calm score throughout the session.

Participants were requested to complete between five and seven “Mind Meditation” sessions per week, as well as to listen to four “Guided Meditation” sessions per week. “Mind Meditation” sessions started at five minutes and increased by two minutes per week, reaching 15 minutes in week 6 and continuing at 15 minutes thereafter, for a total of eight weeks. Participants were guided to set up reminders or notifications in the app to help them adhere with the program, and were asked to keep track of their sessions in a paper calendar.

Brain training: Active Control Intervention

The active control group took part in a brain training intervention (BT) that involved using a mobile app and listening to podcasts, to match the experience of using a mobile app and to control for exposure to voice content.

Participants were asked to complete "brain workout" sessions in the Peak brain training app that provides various games and puzzles that train memory, language, critical thinking, focus, problem solving, mental agility, and emotional processing. Each “brain workout” included six different exercises that took 15 minutes to complete, or longer, depending on the participant's speed. To mimic the steadily rising duration of Mind meditation sessions, participants in the control group were instructed to begin with two brain exercises per week and gradually increase the number of workouts by one each week until they reached six weekly workouts.

To replicate the meditation group's exposure to spoken voice during the guided meditation tracks, participants were also asked to listen to the podcast “A Thousand Things to

Talk About" by Andrea Parrish, four times per week. Each podcast session was delivered via a web page on REDCap that included the audio tracks to three short episodes, together lasting approximately 10 minutes.

Study Timeline

Participants began the study by reading an information sheet and discussing it with research staff over the phone. If they fit the inclusion criteria and were interested after the pre-screening phone call, a full screening e-visit (V0) was scheduled and held via Zoom. At this visit, research staff explained the study further and obtained electronic written informed consent. They then administered the Telephone Interview for Cognitive Status (TICS) with the video function turned off, followed by the demographics, medical history, and medications questionnaires, as well as a hearing speech-in-noise test. If eligible at that point, participants were asked to complete the Beck depression inventory (BDI-II) on their own, which was followed within a few days by an interview with a clinical psychologist, who screened for the mental-health exclusion criteria.

Participants who matched all inclusion criteria and did not meet any of the exclusion criteria were scheduled for the T1-PRE assessment visit. The assessment visit was conducted via Zoom and included self-report surveys to be completed via REDCap, a secure web-based tool designed to build and manage online surveys and datasets.

Within one week of T1-PRE, an orientation (V2) visit was held via Zoom, during which the RA responsible for delivering the virtual program guided the participant in installing the Muse or Peak app, signing in with the predetermined de-identified credentials for each app, and educating the participant on how to use their app and the Muse headband for the MM group. Participants were given information regarding their intervention and were required to use their app according to the schedule provided during the eight weeks of the program. The RAs checked in with participants once a week by e-surveys or by phone, if no response was received by e-survey. The survey and phone calls were used to monitor program adherence, track any adverse events or any modifications to their life that might have affected the results, as well as to offer technical help if needed.

An assessment e-visit was done after 4 weeks (T2-MID) and after 8 weeks of the intervention (T3-POST). The participants also completed an exit survey at that T3-POST visit. The exit survey included questions about general study satisfaction, satisfaction with specific aspects of the study, and participants' attitudes toward continuing their practice after the end of the intervention.

The last study phases the participants engaged in was a follow-up period that examined the continued use or adoption of meditation or control applications after the initial 8-week program. Participants were told that they could use their respective apps as much or as little as they chose for the following four months. During these four months, there were no weekly check-ins or surveys to complete. Two assessment visits were undertaken after two months (T4 - 2M) and after four months (T4 - 4M) following the end of the intervention with a final exit survey administered during the final assessment visit.

Assessments

Participants were assessed at five different time points throughout the study. T1-PRE before the main intervention, T2-MID after 4-weeks of the intervention, T3-POST at the end of the main 8-week intervention, T4-2M 2-months after the main intervention, and T5-4M 4-months after the main intervention. The following sections describe the behavioral measures and self-report questionnaires of mental health factors and state mindfulness that were used to track improvements in mindfulness related to the intervention.

Participants Characteristics

Data from participants were collected which include variables such as age, sex, gender, handedness, years of education, past medical history, medications, average income, occupation, and living situation. This information was also collected during the V0 screening and enrollment visit.

The Telephone Interview for Cognitive Status (TICS) is a standardized test for measuring cognitive function through the phone (Ziemann et al., 2017). The test was validated for older adults ages 60-98 and contains simple questions and tasks for cognitive screening. This test was administered during recruitment consent and orientation video call. Scores below 30 meet criteria to be excluded.

The Mobile Device Proficiency Questionnaire (MDPQ) is a 16-item scale, validated for use in older populations, that measures mobile device competency (Roque & Boot, 2018). Scores range from 0 to 40, with higher values signifying better proficiency. It was administered during the V0 enrollment e-visit.

Psychological Assessment

The Beck Depression Inventory II (Beck et al., 2011) is a 21-item self-report questionnaire used to screen for depression or evaluate the severity of depression symptoms. Higher scores indicated higher depressive symptoms. The BDI-II has also been shown to be sensitive to a change in depression and differentiate different grades of depression. It was administered at the enrollment visit and all study assessment visits.

The UCLA Loneliness Scale (Version 3) is a widely-used, validated 20-item scale that was designed to assess loneliness (Russell, 1996). For each item, participants rate how often they feel lonely (1: 'never', 2: 'rarely', 3: 'sometimes' or 4: 'often'). Scoring higher on the scale represents more feelings of loneliness, with a possible range between 20 and 80 (Russell, 1996). This scale was administered at all study assessment visits.

The Perceived Stress Scale or PSS-10 is the most often used psychological tool for assessing the perceived stress in one's life. It has been validated in older adults (Ezzati et al., 2014) and shown to change following mindfulness meditation in older adults as well (Oken et al., 2017). Survey questions measure how unexpected, unmanageable, and overburdened a respondent's life is. Scores of 0-13 indicate low stress, 14-26 indicate moderate stress, and 27-40 indicate high perceived stress (Nielsen et al., 2016). This was administered at all study assessment visits.

The Duke Social Support Index (DSSI-10) is a 10-item survey used to measure two factors of social support in older adults: social satisfaction, which assesses the individual satisfaction with social support, and social interaction, which relates to the quality of the individual's social network (Pachana et al., 2008) . Higher scores indicate higher social support. Lower DSSI scores are associated with poor self-reported health status and poor self-reported quality of life (Wardian et al., 2013). Living alone is associated with lower DSSI-10 scores, which suggests that the DSSI-10 may be used to assess social support in a variety of adult populations (Wardian et al., 2013). The final items of the DSSI survey were modified to account for the rise of virtual meetings and videoconferencing during the pandemic. The ninth item, "How many times did you talk to someone—friends, relatives, or others—in the past week (either they called you, or you called them)?", was asked separately for phone and video calls (via Skype or WhatsApp). The tenth item: "How often did you attend meetings of clubs, religious groups, or other organizations you belong to in the past week (not including work)?" was asked separately for in-person and virtual attendance. The final score for each question was determined by the higher of the two scores. This survey was administered at all study assessment visits.

The WHOQOL-BREF is a 26-item questionnaire with items rated on a 5-point scale and is an abbreviated version of WHO quality of life questionnaire (WHOQOL-100), that evaluates quality of life with five subscores: physical, psychological, social, environmental and general. Higher scores represented higher quality of life in each sub score. It is a reliable and valid tool for measuring quality of life (The WHOQOL Group, 1998). This questionnaire was administered during the pre, post and four-month assessment visits.

Mindfulness

The Five Facet Mindfulness Questionnaire (FFMQ-SF) is a 24-item survey that measures five dimensions of dispositional mindfulness: observing, describing, acting with awareness, non-judgment, and nonreactivity to inner experience (Bohlmeijer et al., 2011). Items are scored on a five-point scale (1 = never or very rarely true, 5 = very often or always true). Higher scores imply a higher level of mindfulness. This survey was administered at all assessment visits.

Intervention Acceptability & Adherence

Other assessments

A Credibility and Expectancy Questionnaire (CEQ) (Devilly & Borkovec, 2000) was given to participants at three time points: after the participant was allocated to an intervention, after the end of the main intervention, and at the end of the 4-months follow-up period. The questionnaire measures two factors: Credibility, which assesses the perceived credibility of the intervention, consisting of the first three questions, and Expectancy, which assesses the perceived expectancy of the intervention, consisting of the final three questions. The CEQ has been utilized to evaluate the expectancy and credibility of mindfulness meditation with older adults (Polsinelli et al., 2020). Here, it was used to determine whether participant expectations were the same across both intervention situations.

Participants were sent weekly email reminders to complete a check-in survey which asked them to report how many meditation or brain training sessions they completed per week, as well as to report any adverse events or changes to their health or lifestyle (e.g. starting a new exercise routine). Participants also used a paper calendar to keep track of the number and duration of their Muse and Peak sessions. Muse sessions were also automatically tracked by Muse and made available to study staff via the MuseConnect researcher portal. Adherence was assessed by comparing completed sessions to the program requirement.

Participants had contact with research staff for assistance with technical concerns, which were also documented and quantified as part of the feasibility assessments of the study. The same analysis was done following the main intervention phase during the follow-up period, where research assistants kept track of participants' app usage, despite the fact that there was no fixed number of engagements with the app required to be done weekly. We expected to see higher participation rates in participants who adhered to the program during the main intervention phase.

The following measures were also measured but are not discussed or presented within this thesis. The Ecological Momentary Assessments (EMA) was used to repeatedly sample participants' behaviors and experiences as they occurred in their natural setting, aiming to reduce recall bias, increase ecological validity, and study microprocesses impacting behavior in natural settings. EMA studies use technology sensors to collect data, and are shown to be reliable, valid, and less prone to random error variation (Shiffman et al., 2008; Moskowitz & Young, 2006). Questions prompted during the EMA were “Since you completed the last survey, how many social interactions have you had?", “At this moment, how stressed do you currently feel?” on a 7-point scale, from 1(not at all) to 7 (extremely). At the end of each day, participants answered “How lonely did you feel today?” using a visual analog slider scale from 1 (not at all) to 7 (extremely)). The EMA was sent out at 4 random times throughout the day and once at the end of the day for 3 days after each assessment visit.

Each assessment visit also included the administration of the 8-item PROMIS Sleep Disturbance questionnaire, that assesses sleep quality using a five-point scale. This sleep scale was chosen because of sleep's link to stress and loneliness, both of which have been shown to have a negative impact on sleep quality (Hom et al., 2020; Nollet et al., 2020).

Behavioural & cognitive tasks

The following four tasks were also administered via a Zoom session with participants at all five assessment time points to evaluate changes in mindfulness, attention, working memory, and episodic memory.

The breath counting task is a behavioral measure of mindfulness that has shown strong reliability and construct validity, as well as being sensitive to mindfulness training (Levinson et al., 2014). Participants were instructed to sit on a chair, breathe normally, and silently count their breaths from 1 to 21 for a total of 15 minutes, pressing one button for each count 1 to 20, and another button for each count of 21. The task was delivered through a custom script running on Pavlovia.

In the sustained attention to response task (SART), participants viewed digits on a screen and responded to all except '3'. SART measures attention and response inhibition. SART performance was quantified by error rates and response time variability, and better results have been linked to mindfulness meditation with long-term improvements (Zanesco et al., 2018).

In the multiple object tracking (MOT) task, participants tracked three of eight identical moving balls for 8 seconds, and performance was assessed by estimating the speed at which all three targets were tracked with 50% accuracy (Legault et al., 2013).

Finally, the Hopkins Verbal Learning Test-Revised (HVLT) was administered by RAs via Zoom. This is a test of verbal learning and memory that requires participants to recall lists of words immediately and following a delay. Verbal memory declines in socially isolated older adults but has been shown to improve with interventions like mindfulness-based interventions (Wetherell et al., 2017).

Randomization

Following V1 assessment visits, a random number generator in R created a random series of integers 1 and 2 using block randomization, with block sizes randomly determined between 4 and 6. This sequence determined whether each participant was assigned to the MM or the BT program. The random sequence was created by study staff who were not engaged in the administration of the intervention or the assessment of the result and uploaded in a randomization module in REDCap. Once each participant had been enrolled in the study, they were randomized in REDCap by the intervention RA, who then sent them the appropriate program materials by mail, to ensure they were available for their onboarding visit.

Blinding

The assessments were carried out by research assistants (RAs) who were unaware of the participants' intervention group. Participants were instructed not to discuss the content of their program with the RA who performed the assessment visits to ensure that their program assignment did not become known to the testing staff. Researchers who analyzed the data were provided with a table containing participant IDs and whether they were in condition A or B. Only at the end of the study was the mapping of condition A vs. B to MM vs. BT unblinded to all.

Analysis and Data collection

Data from the Muse app group was analyzed to identify factors that influenced consistent engagement with mindfulness meditation. Additionally, prevalent characteristics and recurring patterns exhibited by participants who had higher usage and elevated positive experiences were explored. The statistical analysis used includes linear mixed models to examine longitudinal changes. When a significant main effect or interaction was found, a simple main effects analysis was conducted to assess time effects within each group. Additionally, ANCOVA was used to compare group differences at specific time points while controlling for baseline scores. Analysis also included independent T-tests comparing CEQ questionnaires between both groups, to assess participants perception of their assigned intervention. All statistical analysis was conducted using RStudio.

Adherence to the program was measured by calculating the number of sessions recorded in the weekly calendars, corroborated with data collected from the Muse app or data collected from the Peak app. Adherence to study assessments was measured by tracking the number of completed assessment visits. Adherence and feasibility rates were calculated based on active participants only. If a participant withdrew from the study at any point, their remaining assessment visits, tests, and calendar entries were not considered incomplete but were excluded from the calculations.

Results

A total of 481 people were identified as potential leads, of which 281 individuals were pre-screened, resulting in 228 exclusions (94 declined, 102 ineligible, and 32 lost to follow-up, LTFU) and 53 potentially eligible participants. Following additional screening and consent, 28 were excluded (5 declined, 21 were ineligible, and 1 LTFU). Major reasons for ineligibility were already practicing meditation or cognitive training, not scoring high enough on the 3-item loneliness questionnaire, and mental health conditions. Reasons for declining were mainly due to length and time commitment of the study, not thinking that the study was for them, not having the right technology, and some individuals thought that the compensation was not enough. Finally, 26 participants were enrolled and randomly assigned to one of two groups: Muse Meditation (MM) (n = 13) and Brain Training (BT) (n = 13). These 26 participants made up 9.25% of individuals pre-screened and 49% of participants who underwent full screening.

Table 1. *Participant Demographics and Characteristics by Group. Means, standard deviations (SD), and ranges [min, max] are reported for continuous variables, and counts and percentages (%) are reported for categorical variables. MDPQ = Mobile device proficiency questionnaire; TICS = Telephone Interview for Cognitive Status.*

Sample Characteristics	Participants n(%)		
	Brain Training n = 13	**Muse Meditation n = 13**	**Total n=26**
Age	70.46 (7.76) [60, 86]	70.02 (6.19) [61, 81]	
60-69	6 (46.15%)	6 (46.15%)	12 (46.15%)
70-79	6 (46.15%)	6 (46.15%)	12 (46.15%)
80–89	1 (7.69%)	1 (7.69%)	2 (7.69%)
Gender			
Males	2 (15.38%)	3 (23.08%)	5 (19.23%)
Females	11 (84.62%)	10 (76.92)	21 (80.77%)
Marital status			
Married	4 (30.77%)	2 (15.38%)	6 (23.08%)
Single	2 (15.38%)	4 (30.77%)	6 (23.08%)
In a relationship & living apart	0 (0%)	2 (15.38%)	2 (7.69%)
Widowed	2 (15.38%)	3 (23.08%)	5 (19.23%)
Divorced	4 (30.77%)	2 (15.38%)	6 (23.08%)
Education			
Secondary school diploma	1 (7.69%)	0 (0%)	1 (3.85%)
Non-university certificate/ diploma from a college, CEGEP, etc.	4 (30.77%)	3 (23.08%)	7 (26.92%)
University certificate below bachelor's level	0 (0%)	1 (7.69%)	1 (3.85%)
Bachelor's degree	3 (23.08%)	2 (15.38%)	5 (19.23%)
University degree above bachelor's (Master's, PhD, MD)	3 (23.08%)	6 (46.15%)	9 (34.62%)
Other	1 (7.69%)	1 (7.69%)	2 (7.69%)

Race/Ethnicity			
Black (eg African, Afro-Caribbean, African Canadian)	0 (0%)	1 (7.69%)	1 (3.85%)
East Asian	1 (7.69%)	0 (0%)	1 (3.85%)
South Asian	1 (7.69%)	0 (0%)	1 (3.85%)
White	10 (76.92)	11 (84.62%)	21 (80.77%)
Other	1 (7.69%)	0 (0%)	1 (3.85%)
Prefer not to say	0 (0%)	1 (7.69%)	1 (3.85%)
Average Income			
0 - $29,999	2 (15.38%)	2 (15.38%)	4 (15.38%)
$30,000 - $49,999	2 (15.38%)	3 (23.08%)	5 (19.23%)
$50,000 - $69,999	1 (7.69%)	0 (0%)	1 (3.85%)
$70,000 - $99,999	3 (23.08%)	3 (23.08%)	6 (23.08 %)
$100,000 - $149,999	1 (7.69%)	2 (15.38%)	3 (11.54%)
$150,000 or more	0 (0%)	1 (7.69%)	1 (3.85%)
Prefer not to answer/ No Response/ Did Not Know	4 (30.77%)	2 (15.38%)	6 (23.08%)
Occupation			
Retired	9 (69.23%)	11 (84.62%)	20 (76.92%)
Employed Full-Time	3 (23.08%)	1 (7.69%)	4 (15.38%)
Volunteering	1 (7.69%)	0 (0%)	1 (3.85%)
Caregiver	0 (0%)	1 (7.69%)	1 (3.85%)
Other	0 (0%)	1 (7.69%)	1 (3.85%)
MDPQ Score	35.22 (5.45) [23, 39.5]	33.19 (3.93) [25.5, 38.5]	34.24 (4.77)
3-item Loneliness Scale Score	6.83 (1.26)	6.92(1.32)	6.87 (1.29)
TICS Score	35.33 (2.80)	35.92 (2.83)	30.65(6.06)

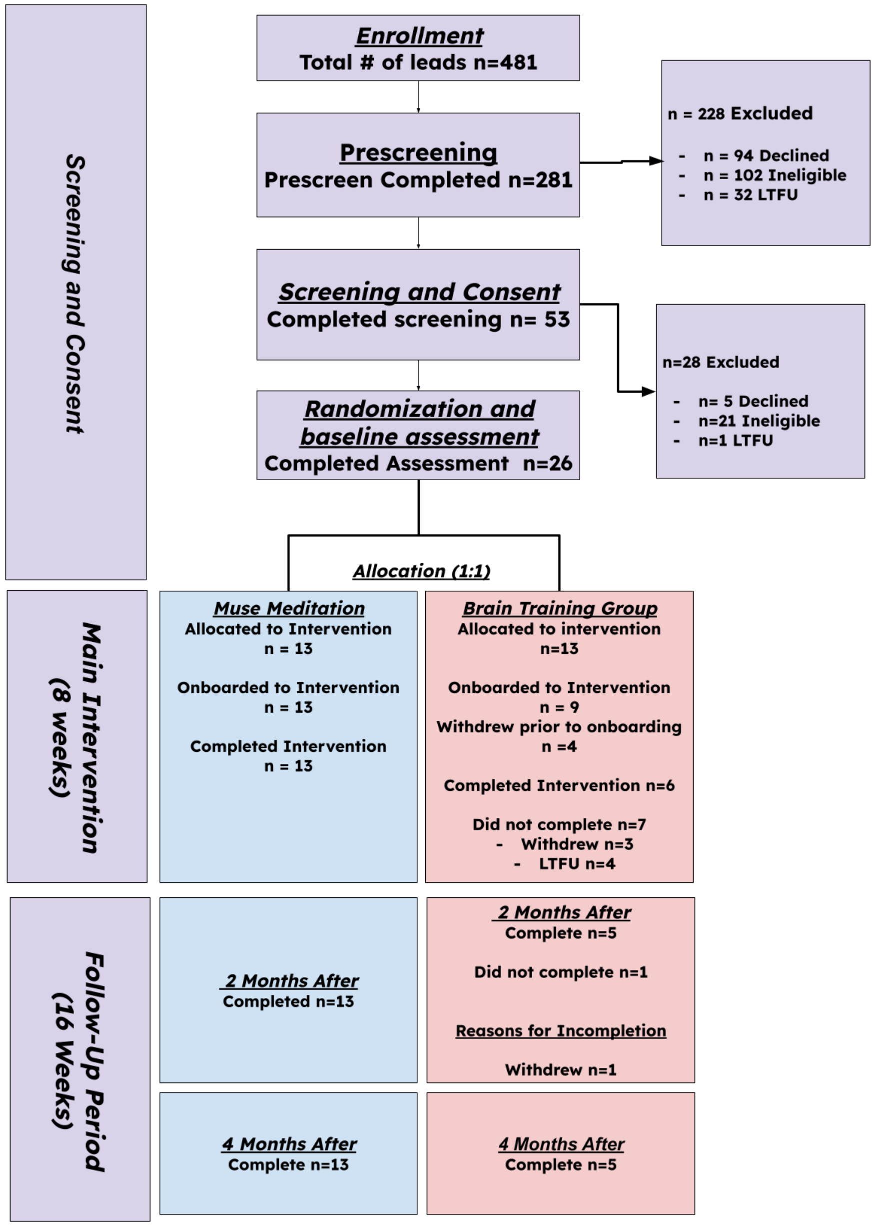

Figure 1.CONSORT Flow Diagram. Participant Flow Through the Study by Group. The diagram outlines the number of participants at each stage, including enrollment, screening, randomization, intervention completion, and follow-up. Counts are reported for the Muse Meditation and Brain Training groups. LTFU = Lost to follow-up.

Table 1 shows the demographics of enrolled participants. The average age and the age range of participants in the Brain Training group (mean = 70.46, SD = 7.76) and the Muse Meditation group (mean = 70.02, SD = 6.19) were similar. Older adults frequently experience age-related loneliness and cognitive impairments, and similar age distributions imply that both groups face comparable risks, allowing for more direct comparisons of intervention impacts on age-sensitive outcomes. Most participants were female, with similar proportions across both groups. Similar gender proportions mean that differences found in outcome will not be confounded by differences across men and women. There were no major differences in marital status between the two groups, which suggests that social support, which may have an influence on loneliness and stress levels, was comparable across groups.

Educational backgrounds also were similar in the two groups, with 30.8% of Brain Training participants (n = 4) and 23.1% of Muse Meditation participants (n = 3) having a non-university certificate or diploma. In the Brain Training group, 7.7% (n = 1) had a secondary school certificate, whereas none in the Muse Meditation group. A bachelor's degree was held by 23.1% in Brain Training (n = 3) and 15.4% in Muse Meditation (n = 2), however higher degrees (e.g., Master's, PhD) were more numerous in the Muse Meditation group (46.2%, n = 6) than in Brain Training (23.1%, n = 3). Participants in this study were mostly highly educated with 53.85% of participants having a bachelor's degree or higher. These levels of educational attainment aid in observing the differences in both groups' educational levels to determine whether they may have a role in the study findings.

The racial/ethnic distribution was primarily white, with 76.9% of participants in Brain Training (n = 10) and 84.6% in Muse Meditation (n = 11). One person in each group had indicated "Other." In the Brain Training group, one participant identified as East Asian (7.7%) and one as South Asian (7.7%), but in the Muse Meditation group, one person identified as Black (7.7%) and one decided not to reveal their race.

Income levels were also similar among both groups. In Brain Training, 15.4% of participants (n = 2) reported salaries between $0 and $29,999, whereas 15.4% (n = 2) reported incomes between $30,000 and $49,999, with a similar range in Muse Meditation. The middle- and higher-income levels were likewise comparable, with $70,000-$99,999 being the most prevalent in both groups (23.1%, n = 3 in each). These income parallels are relevant, since socioeconomic characteristics might influence access to resources that impact stress and well-being, potentially affecting responses to each intervention.

Most participants were retired, accounting for 69.2% in Brain Training (n = 9) and 84.6% in Muse Meditation (n = 11). Employment status varied somewhat, with 23.1% working full-time in Brain Training (n = 3) and only 7.7% in Muse Meditation (n = 1). Having a predominantly retired sample focuses our analysis by limiting possible disparities in occupational stress that translates to more attention to how each intervention affects stress and loneliness.

The Brain Training group got an average score of 6.83 (SD = 1.26) on the three-item loneliness scale, whereas the Muse Meditation group scored 6.92 (SD = 1.32). Participants were required to score at least 5 out of 9 to be included, thus both groups were moderately lonely at the outset, allowing for an assessment of intervention effects on loneliness without baseline bias.

The TICS (Telephone Interview for Cognitive Screening) results were comparable, with the Brain Training group scoring on average 35.3 (SD = 2.80) and Muse Meditation getting 35.9 (SD = 2.83). Participants with a score of 30 or less were not included. These cognitive screening scores indicate that all groups had equal baseline cognitive performance, decreasing the possibility that cognitive differences might influence participants' participation with brain training or meditation activities, or alter outcome measures of loneliness and stress.

The Mobile Device Proficiency Questionnaire (MDPQ) ratings proved comparable between the groups, with BT group averaging 33.6 and MM group 35.6 out of a maximum score of 40. This closeness shows that both groups were equally comfortable and skilled in using mobile devices, which is critical for remote research dependent on app-based treatment technologies. High mobile device proficiency increases the likelihood that participants will be able to access and interact with their assigned treatments successfully, reducing the possibility of engagement disparities caused by technical difficulty.

In conclusion, the Brain Training and Mindfulness Meditation groups had similar demographic characteristics which allows for a more accurate assessment of the effectiveness of brain training vs mindfulness meditation in reducing loneliness and stress by removing any confounding factors.

Figure 1 shows the CONSORT flowchart, which depicts the flow of participants through the study, illustrates the differences in recruitment, retention, and provides some insight into participant engagement in the two intervention groups during the study. The MM group had a very high retention rate, with all 13 individuals (100%) completing the 8-week intervention and the 2 and 4-month follow-up assessments. In comparison, just 9 participants in the BT group were onboarded to the intervention, as 4 (31%) participants withdrew from the study before onboarding. A total of 6 (46%) participants completed the 8-week intervention while 3 (23%) withdrew or were LTFU during the intervention. Participants who withdrew before onboarding found the study too involved requiring too much commitment with the amount of assessment visits and contact, too much record keeping and too with little compensation. During the follow-up period, no members of the MM group withdrew while the BT group lost one participant, leaving 5 (38%) by the end of the study.

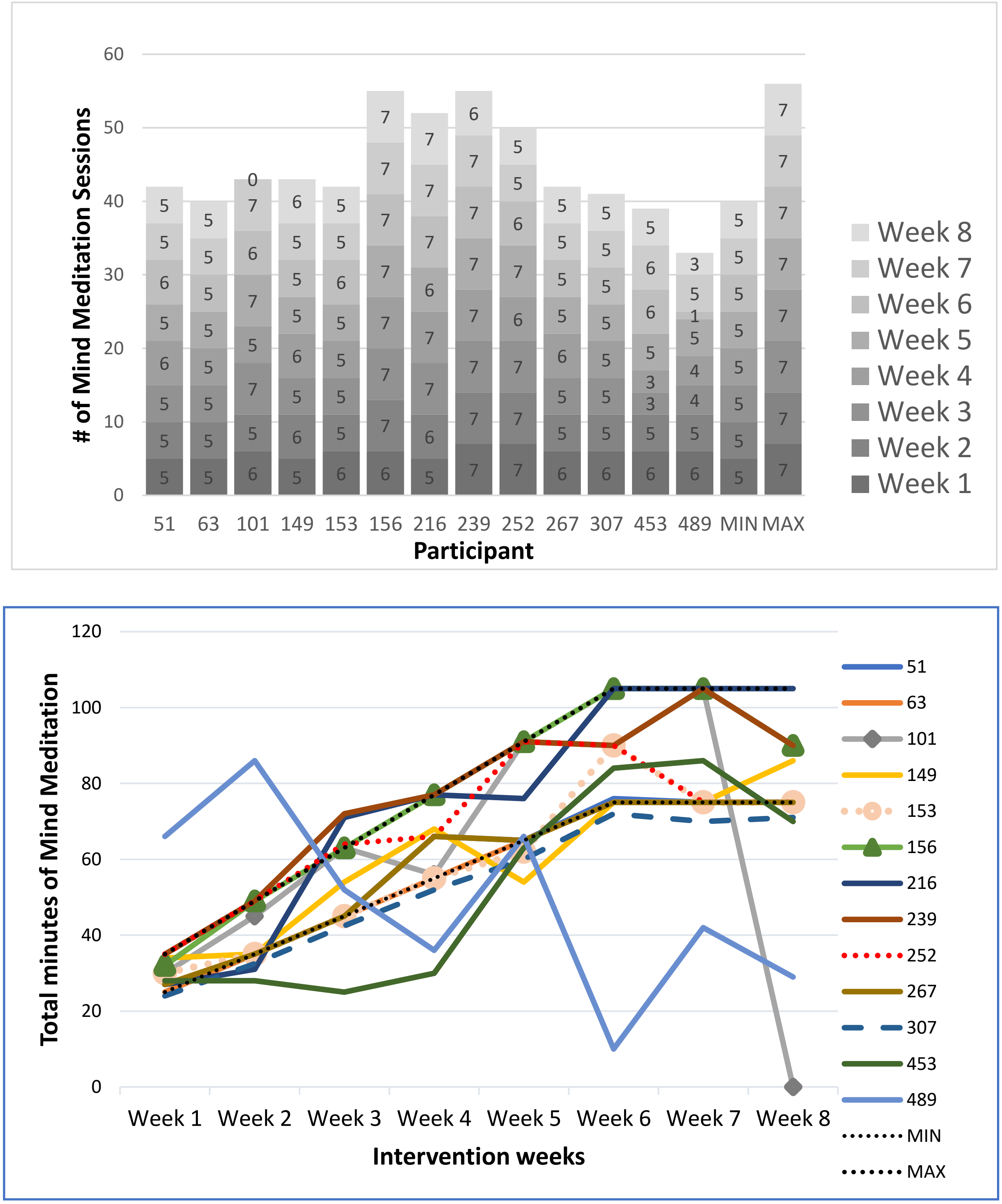

Figure 2. (A) Number of Mind meditations completed each week during the 8-week intervention for each participant. (B) Total minutes of Mind meditation each week during the 8-week intervention. The minimum and maximum number of sessions and total time is shown with MIN and MAX, respectively.

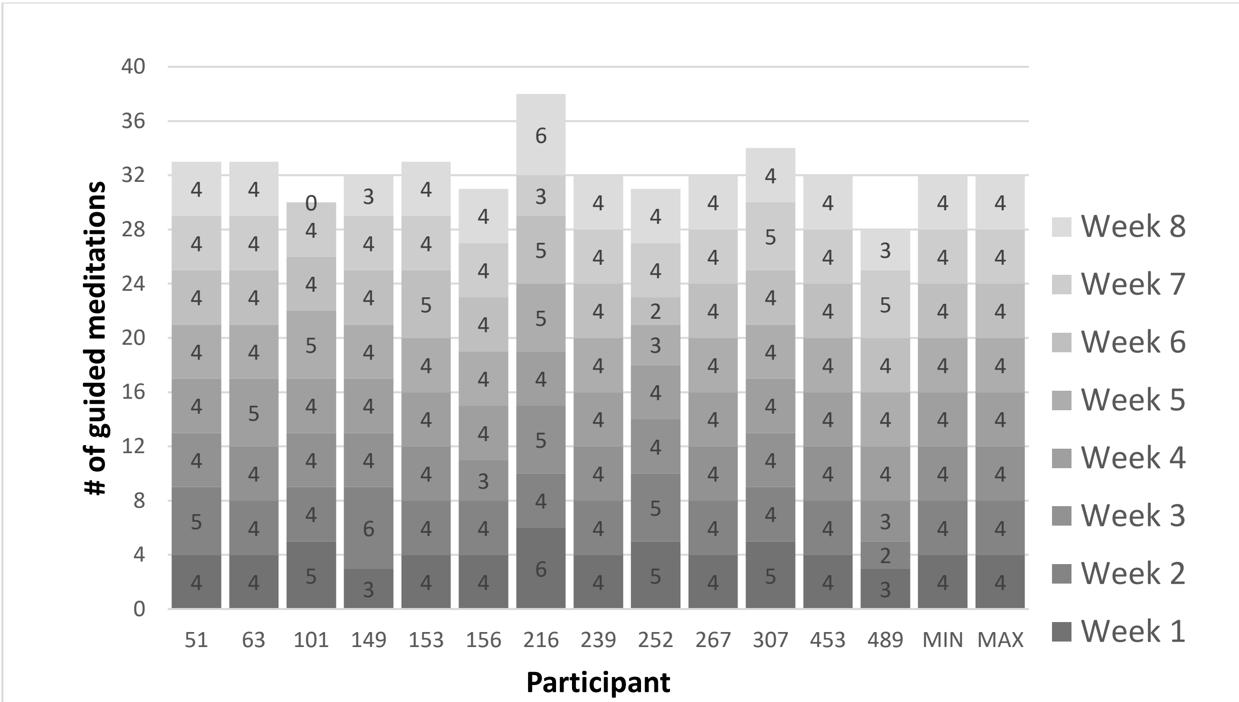

Figure 2. Number of guided meditations completed each week during the main intervention for each participant. The required number of sessions is shown in MIN and MAX columns.

Adherence Main Intervention

Figure 2 provides a visualization of the Mind meditation adherence exhibited by each participant. Participants were requested to complete between five and seven Mind meditation sessions per week, starting with 5 minutes per session and increasing the session length by 2 minutes every week, until 15 minutes was reached. The MM group met the required number of sessions on most weeks, Most participants followed program requirements to increase the meditation session length, with 4 participants not adhering to the required duration on at least one week In sum, 77% of participants completed the required number of Mind meditations during all eight weeks, and 69% of participants adhered to the length of sessions required on all eight weeks. The mean number of sessions of the weekly mind meditation was 5.71 and the standard deviation yielded 0.50.

The brain training group had significant withdraw during the main intervention. Based on the 13 participants who participated in the control group, 4 dropped before onboarding, leaving 9 participants in the brain training group when examining adherence. From those 9 participants only 3 completed the main intervention required program (33%)

Mean adherence, defined as the percentage of weeks in which participants completed their assigned practice was 97% for mind meditation and 89% for the guided meditations. In the brain training group (not shown), 91% of participants adhered to the required number of brain training sessions across all weeks, and 66% of participants listened to the required number of podcasts on all weeks.

Figure 3 depicts the number of guided meditation sessions completed by each participant in the MM group every week. Nine participants completed the required number of guided meditation sessions across eight weeks, and 7 participants listened to at least 4 guided sessions in each week, resulting in 53% of participants totally adhering to the requirements for guided meditations. Adherence varied somewhat across weeks, with week 4 seeing everyone complete the required number of sessions, and all other weeks having between 1 and 3 participants completing fewer sessions. We also note that nine participants listened to more than four guided sessions on at least one week. The mean score of the weekly guided meditation was 4.03 and the standard deviation was 0.739.

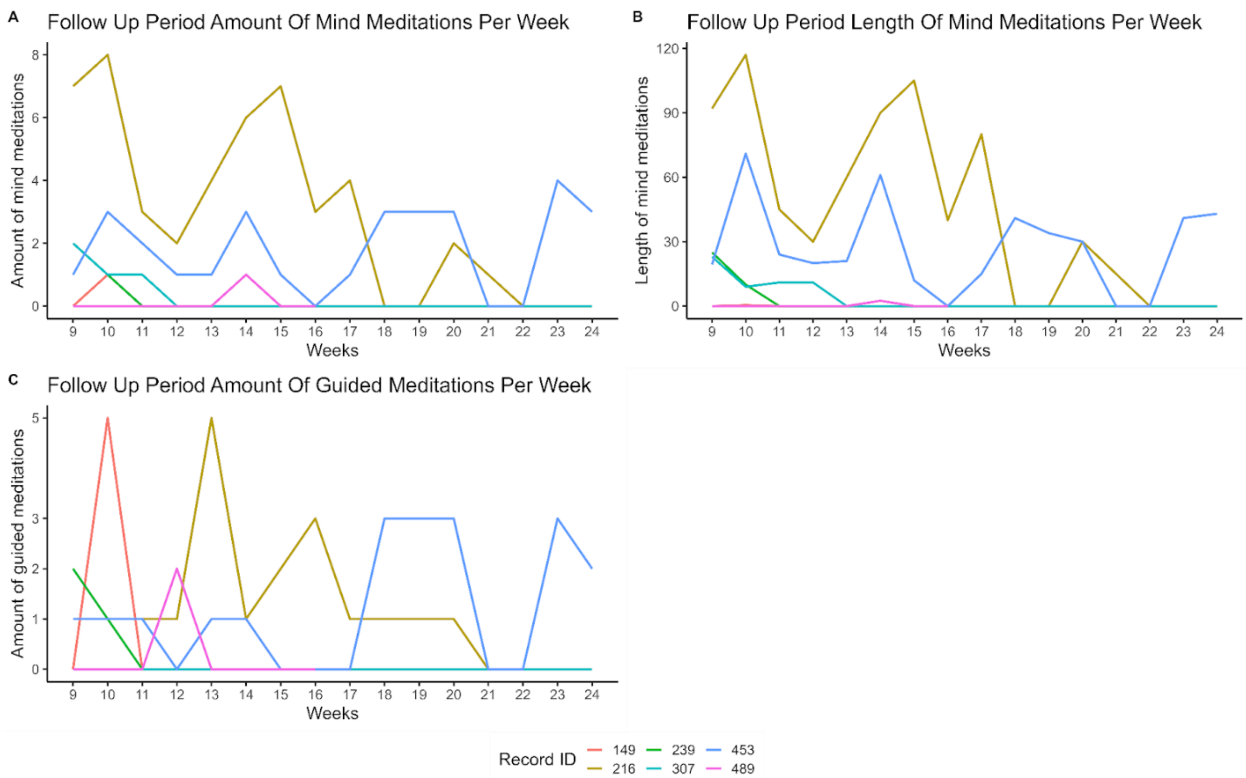

Figure 3. (A) Number of mind meditations completed each week during the follow-up period. (B) Length of mind meditations completed each week during the follow-up period. (C) Number of guided meditations completed each week during the follow-up period. Meditation during the follow-up period was optional. Participants not shown completed zero sessions during follow-up.

Continued engagement with programs in the optional follow-up period

Figure 4 shows the engagement with Muse meditation during the sixteen-week follow-up period, in which in which meditation was optional. Six out of 13 MM participants completed at least one Muse session, while the rest (54%) did not use the Muse at all during the follow-up period. The mean number of mind meditations completed (Figure 4, A) was 0.96 with a standard deviation of 1.75. The mean number of guided meditation (Figure 3) was 0.56 with a standard deviation of 1.08, and the mean length of mind meditation per week (Figure 4, B) was 13.8 with a standard deviation of 26.2. We identified some possible trends among those who took part in the follow-up period. Participants 216 and 453 demonstrated significant activity during the follow-up phase, with participant 216 showing greater activity during the first two months, and declining in the second two months, while 453 maintained a consistent level of engagement throughout the follow-up period. Meanwhile, the remaining participants displayed more sporadic points of activity, engaging only once or twice during the follow-up period.

Study Satisfaction

All participants in the MM group and 6 in the BT group completed an exit survey at the end of the 8-week intervention and provided ratings on their satisfaction with various aspects of the study on a scale of 0 to 100. Overall satisfaction with the research study was 66.5±24.4, with participants in the MM group being more satisfied with their program study (72.9 ± 17.2, range: 43-98) than those in the brain training group (54.4 ± 32.0, range: 0-90). Satisfaction with study conduct was relatively high (75.2 ± 16.3), while there was lower satisfaction with assessment visits (62.1 ± 27.3) and ecological momentary assessments (EMAs) (55.6 ± 25.5). Participants thought that assessment sessions were too long and that it was difficult to reply to the small 45-minute EMA window, especially because they did not always have their phone close. One participant stated, "I do not keep my phone on my person, so the in-the-moment surveys were hardly ever answered in the short time that was given."

According to feedback about the assessment visits, participants found some questions were unrelated to their experiences, and that documenting sessions on their program calendars was time-consuming. Some participants had some difficulty with the app, with three out of thirteen requiring assistances with the Muse app after a software update changed the UI. Despite these limitations, many users enjoyed using the Muse app, calling the neurofeedback "interesting" and believing they benefited from the program while some participants questioned the relationship between their intervention and reduced loneliness.

Onboarding/orientation satisfaction and program frequency/duration satisfaction were positively assessed (80.5 ±14.2, range: 50-100) . When comparing satisfaction with administered programs, the MM group gave high scores for the Mind Meditation (85.9 ± 15.1, range: 50-100) and lower satisfaction with the guided mediations (58.5 ± 32.4, range: 7-100). The BT group displayed high satisfaction for the Peak brain workouts (91.1 ± 9, range: 79-100) and much lower satisfaction for the podcasts (41.4 ± 30.8, range: 0-75).

Participants had varying experiences with the meditation component of the study. While some participants found the program fun and useful, such as assisting with sleep troubles or serving as a "lifesaver" for individuals living alone, others struggled to stay engaged. Five out of 12 individuals reported concerns with the Muse headband, such as poor signal connection or discomfort, whereas one reported no problems. Seven individuals planned to continue meditating with the Muse app after the trial, while others were hesitant or unwilling to continue owing to a perceived lack of effect. Participants mentioned relaxation, peace, and enhanced social interaction as benefits, with some incorporating meditation into their daily practice.

Below we focus on several participants specifically to examine what factors may have influenced their engagement with the program during the main intervention and/ or the follow-up period.

Participant 453: This participant exhibited higher activity than other participants during the follow up period, completing between 0-4 Mind meditations and 0-3 guided meditations per week throughout the four months, with some weeks seeing greater activity than others During the main intervention they struggled a bit more with adhering to the mind mediation practices but completed all guided mediations for 8 weeks. This participant displayed high scores in the exit survey and described good satisfaction with the study and had no suggestions to improve the experience of the study. Their high satisfaction scores remained through the follow up period. Scoring the overall satisfaction MILOA study an 88, the frequency of the study assessment a 90, length of follow up period 84 and the technical support during the follow up period a 96.

Participant 216: This participant exhibited good adherence to the mindfulness practice and regularly did more than required. They continued the meditation practice during the follow up and showed one of the most active engagements with the app during that period. They rated many aspects of the study well and recommended the Muse app and mindfulness meditation practice to others and gave higher ratings to all aspects of the in their final exit survey after the follow up period. They did however mention fluctuations and life changes inducing stress during the study period in their surveys. While still maintaining relatively average yet consistent PSS scores, participant 216 revealed details of life-induced stressors on their exit surveys Unexpectedly, the study appeared beneficial to them despite their life's turbulence, hinting at the potential for stress management as a motivation to commit to meditation with Muse longer. They did nonetheless express enjoyment and blamed time constraints as a factor behind their Muse app engagement.

Participant 252: During the main intervention, this participant showed full adherence to Mind meditation but had listened to less than four guided meditations on some weeks and chose to not continue using the Muse device during the follow up period. This participant displayed high satisfaction with the conduct of study, onboarding and introduction as well as satisfaction with the user guide and study calendar but expressed disapproval with the in-the-moment surveys. In the suggestions for improvements, they mentioned that the requirement to listen to four guided meditations per week was too much, especially considering the limited choice of tracks, which meant that they had to repeatedly listen to the same ones. They found that the guided meditations were 'filled with jargon' and were not relatable to them, which made them lose interest quickly. They enjoyed the experience of meditating with the Muse and the feedback it provided, just not with the addition of vocal guidance from the guided meditation. Their end of study survey expressed that their engagement was due to their unlimited leisure time.

Participant 101: This participant showed good adherence to Mind and guided meditations during weeks 1 – 7, but stopped meditating in week 8 because they had no access to internet, and they did not engage with the app in the follow-up period. In their exit surveys, they rated the meditation app very highly, but revealed that they did not feel that meditation had an impact on them in their everyday life and that is why they would not continue with meditation. Their overall study satisfaction was very high after the main intervention, but was quite low at the final exit survey at the end of the follow-up period. The dissatisfaction was due to changes in staff throughout the study, which caused delays in communication with the participant. Although their outcome measures continued to improve after the main intervention, hinting at external influences possibly shaping their scores.

Participant 153: This participant adhered to the required schedule throughout the eight weeks, but chose not to continue meditating in the follow up period. Their satisfaction with the overall study, the mind meditations, and the guided meditations, and several other study aspects was neutral (50). They did not see the relationship between the program and loneliness, and were irked by some technical issues during the study. They also reported that increasing the meditation length up to fifteen minutes was difficult for them. They reported that it was unlikely they would continue meditating as they enjoy mind-wandering and did not like to be asked to stop doing it. In their final exit survey, they reported that they lost interest in continuing meditating, but they picked up one exercise in the study that they continue, which is labeling when they are judging and that allows them to reset their attitude.

Participant 156: This participant showed daily engagement with the Muse app during the main intervention, but did not continue meditating during follow-up. In the exit survey, they reported high satisfaction with the Muse meditations and the headband but disliked the guided meditations due to their voices. They were relatively satisfied with the overall study (63/100), but were quite dissatisfied with the frequency and duration of assessment visits (22/100), deeming them too long. In their final exit survey, the participant conveyed dissatisfaction with the time commitment required by the study, the length of the follow-up period, and the study overall. They attributed their adherence to the program to the fact that they committed to the study and would not break the commitment.

Participant 239: This participant had strong engagement with the Muse app during main intervention, completing meditations almost daily. They expressed overall good satisfaction with the study (76/100), providing high ratings for the Muse app, Mind and guided meditations, and lower ratings for assessment visits and in-the-moment surveys. They participated in the follow up period but had little activity during the time, completely dropping off after the first 2 weeks. In their exit survey, they mentioned that their goal was to complete the eight weeks, and afterwards their circumstances changed, and they dropped off from doing it regularly in the follow up period. However, they expressed that they experienced positive effects from meditating when one does it diligently.

Participant 489: This participant showed inconsistent adherence during the main intervention across the weeks, and took part in the follow up period but had very little engagement during that time. They expressed high satisfaction with the study overall, and with the Mind meditations, although they showed lower satisfaction with guided meditations. They said that Muse helped them from feeling lonely and changing their thought pattern after the loss of family members and friends and being stuck in lockdown due to Covid-19. They also reported high satisfaction with the study at the end of the follow-up period. As a potential explanation for their low activity during the follow up, they expressed that they relied on the reminder emails and having to fill out the calendar to remember to complete their meditations during the main intervention. Given that no reminders were sent during the follow-up, their engagement was reduced in the follow up period, despite them feeling that meditation was useful to them.

Depression, Stress & Loneliness Results

Considering that 26 participants enrolled within the study, a total of 130 assessment visits would have been conducted if all participants completed five assessment visits. However, due to withdrawals before and during the main intervention and some visits being missed, a total of 101 assessment visits were conducted: 36 for the brain training group and 65 for the mindfulness group. Out of those visits, all three outcome measures were completed in the brain training group and 64 were completed in the mindfulness group.

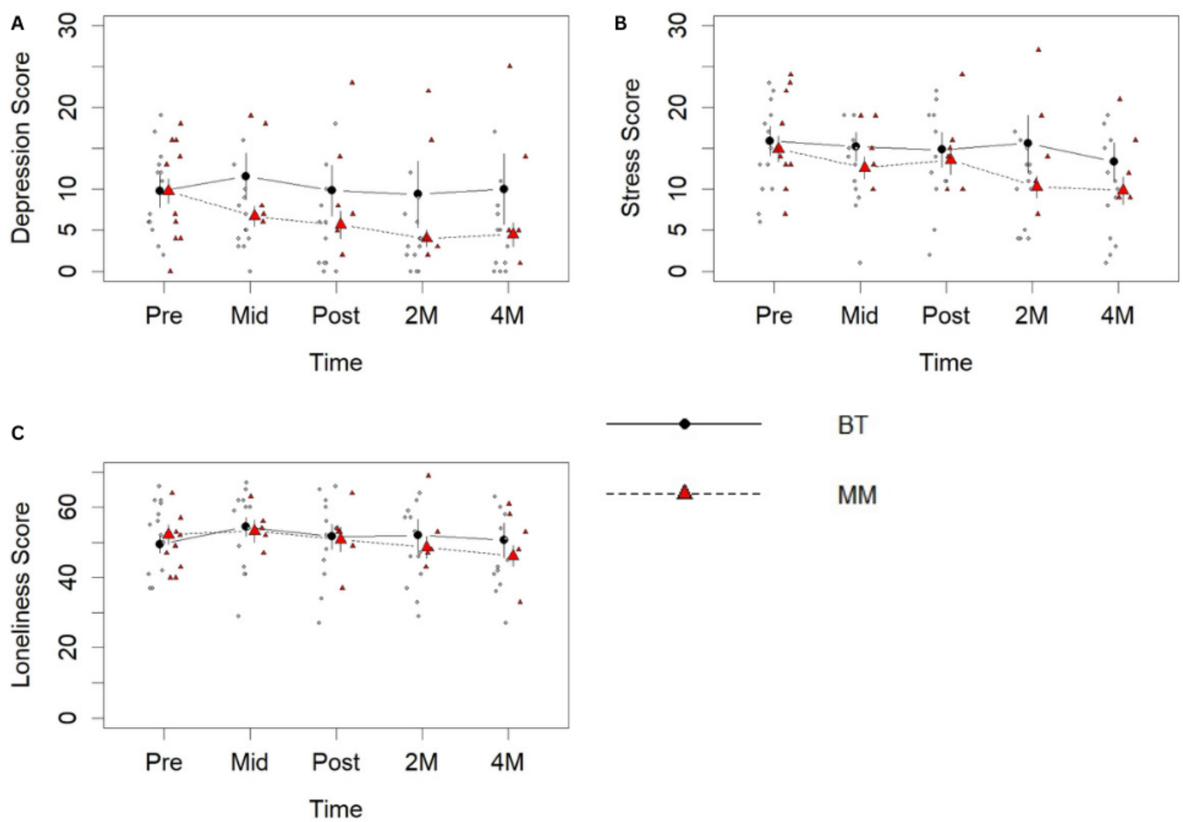

Figure 4. (A) BDI-II (Beck depression inventory) scores across the entire study at each assessment visit. (B) PSS-10 (Perceived stress survey) scores across the entire study at each assessment visit (C) UCLA loneliness scores across the entire study at each assessment visit

Table 2. *Mixed-effects model results for Depression), Stress, and Loneliness scores (Figure 5).*

Scale	Effect	NumDF	DenDF	F-value	p-value	Effect Size (η^2)	95% CI
Depression (BDI)	Intercept	1	64	44.13	<0.0001	-	-
	Group	1	21	2.66	0.1181	0.11	[0.00, 1.00]
	Time	4	64	7.89	<0.0001	0.33	[0.15, 1.00]
	Group × Time	4	64	3.13	0.0204	0.16	[0.02, 1.00]
Stress (PSS)	Intercept	1	64	189.19	<0.0001	-	-
	Group	1	21	3.30	0.0836	0.14	[0.00, 1.00]
	Time	4	64	3.95	0.0063	0.20	[0.04, 1.00]
	Group × Time	4	64	1.35	0.2619	0.08	[0.00, 1.00]
Loneliness (UCLA)	Intercept	1	64	641.14	<0.0001	-	-
	Group	1	21	0.07	0.7889	0.003	[0.00, 1.00]
	Time	4	64	4.35	0.0036	0.21	[0.05, 1.00]
	Group × Time	4	64	0.32	0.8659	0.02	[0.00, 1.00]

Table 3. *Simple main effect of time on Depression, Stress, & Loneliness scores for each group (Figure 5).*

Scale	Group	NumDF	DenDF	F-Value	p-value	Effect Size (η^2)	95% CI
Depression (BDI-II)	MM	4	47	10.54	<0.0001	0.47	[0.27, 1.00]
	BT	4	17	0.58	0.6788	0.12	[0.00, 1.00]
Stress (PSS)	MM	4	47	4.52	0.0036	0.28	[0.07, 1.00]
	BT	4	17	0.44	0.7808	0.09	[0.00, 1.00]
Loneliness (UCLA)	MM	4	47	3.78	0.0095	0.24	[0.04, 1.00]
	BT	4	17	0.68	0.6149	0.14	[0.00, 1.00]

Depression Results

The effects of group mindfulness meditation (MM) vs. brain training (BT) on depression (BDI-II scores) were analyzed using a linear mixed-effects model (LME) with Group (MM vs. BT) and Time (Pre, Mid, Post, 2M, 4M) as fixed factors, and participant as a random factor. Effect size was expressed as eta-squared (η^2). The results of the linear mixed effect model are shown in Table 2. The model included group (BT vs. MM), time, and their interaction as fixed effects, with random intercepts for participants. The interaction between Time and Group was statistically significant, ($F(4, 64) = 3.13$, $p = 0.020$). To further explore the interaction, the simple main effects of time were analyzed separately for each group (see Table 3). In the MM group, there was a significant effect of time on depression scores ($F(4, 47) = 10.54$, $p < 0.0001$, $\eta^2=0.47$). The effect of time was not significant in the BT group ($F(4, 17) = 0.58$, $p = 0.6788$, $\eta^2=0.12$). The results suggest that the MM group, but not the BT group, experienced a significant reduction in depression scores over time.

We also evaluated group differences at each time point (Mid, Post, 2M, and 4M) with ANCOVA models that included baseline depression scores as a covariate to control for differences in baseline depression. The results are summarized in Table 4. The MM group had lower depression scores compared to the BT group after controlling for baseline at all assessment time points, except at Post ($p = 0.051$). The largest group difference was observed at the 4M time point, with depression scores in the MM group being 5.84 units lower than in the BT group ($p = 0.0430$). This indicates that the reduction in depression in the MM group was maintained up to four months following the end of the intervention.

Table 4. *ANCOVA results for group differences at each time point on BDI-II, PSS, and UCLA scales.*

Outcome Measure	Timepoints	Effect	Num DF	Den DF	F	p	Effect Size (η^2)	95% CI	Difference (MM - BT)
Depression (BDI-II)	Mid	Baseline	1	15	22.48	0.0003	0.60	[0.30, 1.00]	
		Group	1	15	9.29	0.0082	0.38	[0.08, 1.00]	-5.17
	Post	Baseline	1	15	14.93	0.0015	0.50	[0.18, 1.00]	
		Group	1	15	4.48	0.051	0.23	[0.00, 1.00]	-4.85
	2M	Baseline	1	15	12.73	0.0028	0.46	[0.14, 1.00]	
		Group	1	15	6,69	0.0206	0.31	[0.03, 1.00]	-5.65
	4M	Baseline	1	15	12.24	0.0032	0.45	[0.13, 1.00]	
		Group	1	15	4.89	0.0430	0.25	[0.01, 1.00	-5.84
Stress (PSS-II)	Mid	Baseline	1	15	22.31	0.0003	0.60	[0.29, 1.00]	
		Group	1	15	3.05	0.1011	0.17	[0.00, 1.00]	-2.79
	Post	Baseline	1	15	6.48	0.0224	0.30	[0.03, 1.00]	
		Group	1	15	0.70	0.4154	0.04	[0.00, 1.00]	-2.15
	2M	Baseline	1	15	6.13	0.0257	0.29	[0.02, 1.00]	
		Group	1	15	4.58	0.0491	0.23	[0.00, 1.00]	-5.47
	4M	Baseline	1	15	7.86	0.0134	0.34	[0.05, 1.00]	
		Group	1	15	2.13	0.1652	0.12	[0.00, 1.00]	-3.75
Loneliness (UCLA)	Mid	Baseline	1	15	26.36	0.0001	0.64	[0.35, 1.00]	
		Group	1	15	0.05	0.8224	0.003	[0.00, 1.00]	0.79
	Post	Baseline	1	15	19.14	0.0005	0.56	[0.25, 1.00]	
		Group	1	15	0.22	0.6476	0.01	[0.00, 1.00]	-1.81
	2M	Baseline	1	15	16.99	0.0009	0.53	[0.21, 1.00]	
		Group	1	15	0.15	0.7055	0.01	[0.00, 1.00]	-1.60
	4M	Baseline	1	15	13.11	0.0025	0.47	[0.15, 1.00]	
		Group	1	15	0.42	0.5267	0.03	[0.00, 1.00]	-2.78

Stress Results

Figure 5B shows the PSS-10 mean scores of both groups across time. The average scores in the MM group remained stable during the main intervention, but showed a slight drop at the 2M and 4M follow up points. The PSS linear mixed model results shown in Table 2 found a significant main effect of time ($F(4, 64) = 3.95$, $p = 0.0063$), signifying stress scores changed over time, but neither the main effect of group nor the Group *x* Time interaction were significant, suggesting the effect of time on stress did not differ significantly between groups. Results of the ANCOVA analysis at each time point revealed that, controlling for baseline perceived stress, the MM group had lower stress scores compared to the BT group at the 2M time point only ($F(1, 15) = 4.58$, $p = 0.0491$; see Table 4). Pairwise comparisons of estimated marginal means were conducted across five time points (Pre, Mid, Post, 2-month follow-up, and 4-month follow-up) within each intervention group using Bonferroni-adjusted p-values to correct for multiple comparisons (10 tests) to decompose the main effect of time. In the MM group, significant decreases were observed from Pre to the 2-month follow-up ($t(47) = 3.25$, $p = .0212$) and from Pre to the 4-month follow-up ($t(47) = 3.58$, $p = .0082$) suggesting a possible gradual yet significant reduction in stress. No other pairwise comparisons reached significance after adjustment (e.g., Pre vs. Mid: $t(47) = 1.63$, $p = 1.00$). In contrast, for the Brain Training (BT) group, no significant differences were found between any time points following Bonferroni correction (all $p = 1.00$).

Loneliness Results

Figure 5C shows the UCLA mean scores for both groups remained stable for most of the study, declining slightly during the follow up period. The mixed model analysis found a significant main effect of time ($F(4, 64) = 4.35$, $p = 0.0036$), but the main effect of group and the Group x Time interaction were not significant. Results of the ANCOVA analysis are shown in Table 4: At all time points, group differences were not statistically significant ($p > 0.05$), indicating that the BT and MM groups did not differ significantly in loneliness scores after controlling for baseline scores. A pairwise comparison within each group was conducted to examine the main effect of time, as there was no significant Group × Time interaction. Bonferroni-adjusted pairwise comparisons of estimated marginal means were conducted across five time points (Pre, Mid, Post, 2-month follow-up, and 4-month follow-up) within each group to examine changes in loneliness scores. In the MM group, a significant decrease was observed from Mid to the 4-month follow-up ($t(47) = 3.42$, $p = .0130$). Although the comparison between Pre and 4-month follow-up approached significance ($t(47) = 2.94$, $p = .0511$), it did not reach the adjusted threshold. No other comparisons were statistically significant after correction. In contrast, the Brain Training (BT) group did not exhibit any significant changes between time points (all $p = 1.00$). These results indicate that the MM intervention was associated with a gradual but significant reduction in loneliness, while no such trend was observed in the BT group.

Quality Of Life Results

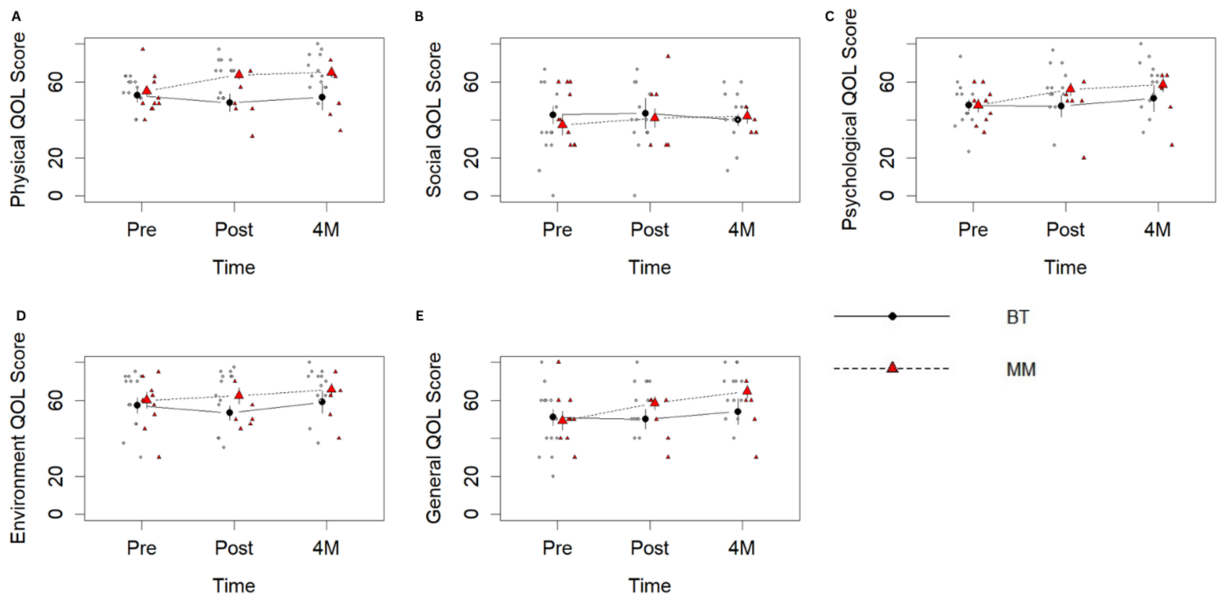

Figure 5. Results of the WHOQOL-BREF quality of life survey at Pre, Post, and 4-month follow-up visit are shown for five subscales: (A) Physical (B) Social (C) Psychological (D) Environmental, and (E) General. Mind meditation group labeled as MM in green and brain training group labeled BT in purple. Each group mean line is displayed with points during the pre post and 4-month assessment visits.

Table 5.

Linear Mixed Model Results for WHO Quality of Life Measures

Scales	Effect	NumDF	DenDF	F	P	Effect Size η^2	95% CI
QOL Physical	Intercept	1	33	965.85	<0.0001	-	-
	Group	1	21	6.44	0.0191	0.23	[0.02, 1.00]
	Time	2	33	4.57	0.0177	0.22	[0.03, 1.00]
	Group × Time	2	33	4.55	0.0180	0.22	[0.03, 1.00]
QOL Social	Intercept	1	33	183.09	<0.0001	-	-
	Group	1	21	0.18	0.6722	0.009	[0.00, 1.00]
	Time	2	33	0.64	0.5361	0.04	[0.00, 1.00]
	Group × Time	2	33	0.21	0.8085	0.01	[0.00, 1.00]
QOL Psychological	Intercept	1	33	468.66	<0.0001	-	-
	Group	1	21	1.30	0.2675	0.06	[0.00, 1.00]
	Time	2	33	9.93	0.0004	0.38	[0.15, 1.00]

Scales	Effect	NumDF	DenDF	F	P	Effect Size η^2	95% CI
	Group × Time	2	33	2.19	0.1279	0.12	[0.00, 1.00]
QOL Environmental	Intercept	1	33	470.56	<0.0001	-	-
	Group	1	21	1.64	0.2139	0.07	[0.00, 1.00]
	Time	2	33	2.62	0.0875	0.14	[0.00, 1.00]
	Group × Time	2	33	2.79	0.0757	0.14	[0.00, 1.00]
QOL General	Intercept	1	33	489.34	<0.0001	-	-
	Group	1	21	1.45	0.2417	0.06	[0.00, 1.00]
	Time	2	33	5.19	0.0110	0.24	[0.04, 1.00]
	Group × Time	2	33	1.76	0.1875	0.10	[0.00, 1.00]

Table 6.
Simple main effects of time on WHOQOL by group

Scale	Group	NumDF	DenDF	F	P	Effect size η^2	95% CI for η²
QOL Physical	MM	2	24	8.42	0.0017	0.41	[0.14, 1.00]
	BT	2	9	0.52	0.6108	0.10	[0.00, 1.00]
QOL Psychological	MM	2	24	10.17	0.0006	0.46	[0.19, 1.00]
	BT	2	9	1.71	0.2351	0.28	[0.00, 1.00]
QOL General	MM	2	24	6.02	0.0076	0.33	[0.07, 1.00]
	BT	2	9	0.13	0.876	0.03	[0.00, 1.00]

Table 7.
ANCOVA Results for Group Differences at Each Time Point

Outcome measure	Time Point	Effect	NumDF	DenDF	F	p	Effect Size η^2	95% CI for η²	Group Difference (MM - BT)
QOL Physical	Post	Baseline	1	16	11.54	0.0037	0.42	[0.11, 1.00]	
		Group	1	16	9.57	0.0070	0.37	[0.08, 1.00]	12.68
	4M	Baseline	1	15	1.26	0.2786	0.08	[0.00, 1.00]	
		Group	1	15	4.60	0.0488	0.23	[0.00, 1.00]	12.57
QOL Psychological	Post	Baseline	1	16	33.20	<0.0001	0.67	[0.41, 1.00]	
		Group	1	16	5.68	0.0299	0.26	[0.02, 1.00]	9.01
	4M	Baseline	1	15	9.27	0.0082	0.38	[0.08, 1.00]	
		Group	1	15	0.80	0.3843	0.05	[0.00, 1.00]	5.42
QOL General	Post	Baseline	1	16	2.77	0.1154	0.62	[0.33, 1.00]	
		Group	1	16	2.12	0.1642	0.14	[0.00, 1.00]	9.78
	4m	Baseline	1	15	0.72	0.4081	0.05	[0.00, 1.00]	
		Group	1	15	2.53	0.1326	0.14	[0.00, 1.00]	11.21

WHOQOL Results

Considering the 26 enrolled participants and the withdrawals throughout the study, a total of 62 assessments of WHOQOL should've been conducted (23 in the BT group, 39 in the MM group). Two assessments in the BT group had missing data, and all were completed in the MM group.

QOL graphs revealed a diverging relationship between the two groups in the QOL physical subscale (Figure 6, A). Both groups began at a similar mean at the Pre visit and then diverged after the main intervention, at Post, while towards the final 4-month assessment visit the gap between the two groups reduced, a significant gap between both means remained present at the end of the study. The QOL social subscale (Figure 6, B) was consistent and both groups shared very similar scores in the pre, post and 4-month assessments. The QOL psychological subscale (Figure 6, C) and QOL general subscale (Figure 6, E) also began with similar scores in the beginning and diverged in the post and 4-month assessment visit but to a lesser degree then the QOL physical graph. Both groups in the QOL environmental (D) had consistent and similar scores.

Data for all WHOQOL-BREF subscales were analyzed with a linear mixed model with the effect of Time, Group, and Time x Group interaction (Table 5). For the Physical subscale, the main effects of group ($F(1, 21) = 6.44$, $p = 0.0191$) and time ($F(2, 33) = 4.57$, $p = 0.0177$) were significant, as was the Group × Time interaction ($F(2, 33) = 4.55$, $p = 0.0180$). Exploring further with a simple time effect analysis shown in Table 6 found a significant effect of time ($F(2, 24) = 8.42$, $p = 0.0017$) in the MM group but not the BT group. An ANCOVA for group differences shown in Table 7 using the baseline scores as a covariate found significance group differences in Post ($F(1, 16) = 9.57$, $p = 0.0070$) and 4M ($F(1, 15) = 4.60$, $p = 0.0488$) timepoints. This analysis indicates that the MM group, but not the BT group, experienced a significant improvement in QOL (Physical) scores up to 4 months following the end of the intervention.

A linear mixed model on the psychological health subscale found a significant main effect of time ($F(2, 33) = 9.93$, $p = 0.0004$), but the main effect of group and the group x time interaction were not significant (Table 5). Analysis of the simple main effects of time (Table 6) found a significant effect of time in the MM group ($F(2, 24) = 10.17$, $p = 0.0006$, $\eta^2=0.46$). When examining group differences at each time point, controlling for Pre (Table 7), there was a significant group difference at Post ($F(1, 16) = 5.68$, $p = 0.0299$), with the average in the MM group being 9.01 units higher than the BT group. There was no group difference at 4M. These results indicate psychological QOL was improved with MM at the end of the main intervention, but the effect did not last after 4-months follow-up.

The linear mixed model on the general health subscale found a significant main effect of time ($F(2, 33) = 5.19$, $p = 0.0110$), but the main effect of group and the group x time interaction were not significant (see Table 5). Our ANCOVA analyses failed to find a significant group difference at any time point (Table 7). The linear mixed model shown in Table 5 found that the social and environment WHO quality of life scales showed no significance in main effect of group, time and Group x Time interaction.

Social Support Index Results

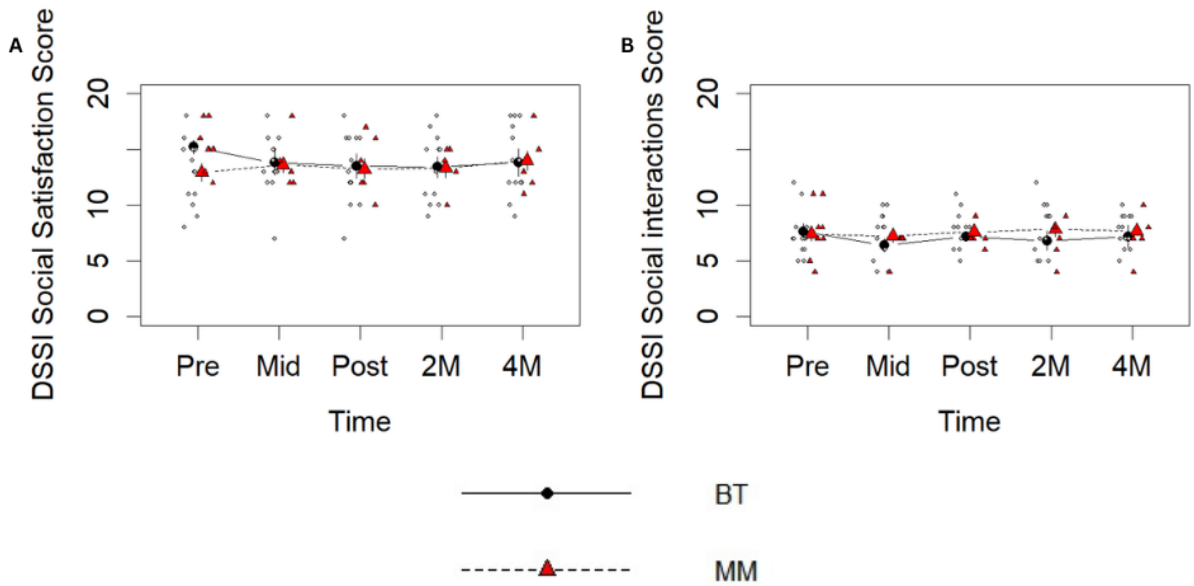

Figure 6. Duke Social Support index (DSSI-10) scores across the entire study at each assessment visit for the Social Satisfaction subscale (A) and the Social Interactions subscale (B). Mind meditation group labeled as MM in green and brain training group labeled BT in purple. Each group mean line is displayed with points during the pre mid, post, 2-month and 4-month follow-up visits.

Table 8

Linear Mixed Model Results for DSSI subgroup measures (Figure 7)

Subscales	Effect	NumDF	DenDF	F	P	Effect Size	95% CI
Satisfaction	Intercept	1	64	397.47	<.0001	-	-
	Group	1	21	0.01	0.9342	3.32e-04	[0.00, 1.00]
	Time	4	64	0.88	0.4797	0.05	[0.00, 1.00]
	Group:Time	4	64	0.16	0.9583	9.83e-03	[0.00, 1.00]
Interactions	Intercept	1	64	719.26	<.0001	-	-
	Group	1	21	1.20	0.285	0.05	[0.00, 1.00]
	Time	4	64	0.76	0.556	0.05	[0.00, 1.00]
	Group:Time	4	64	1.30	0.279	0.08	[0.00, 1.00]

From the initial 26 participants enrolled within the study, due to withdrawal before and during the main intervention a total of 101 assessment visits should've been conducted, 36 assessment visits for the brain training group and 65 for the mindfulness group. Out of those visits 31 DSSI outcomes were completed in the brain training group and 64 were completed in the mindfulness group.

Both groups shared very similar scores with exception of the pre assessment visit where a more pronounced difference can be seen. Figure 7A shows the social satisfaction subscale which was consistent. Figure 7B revealed a consistent relationship between both groups in the amount of social interaction subscale. They both began at similar means during the pre assessment visit and remained quite consistent compared up until the 4 month follow up time point visit. The data in Figures 7A & B were analyzed with linear mixed-effects models. For either subscale, the main effects of group, time and Group x Time interaction were not significant (Table 8).

Mindfulness Results

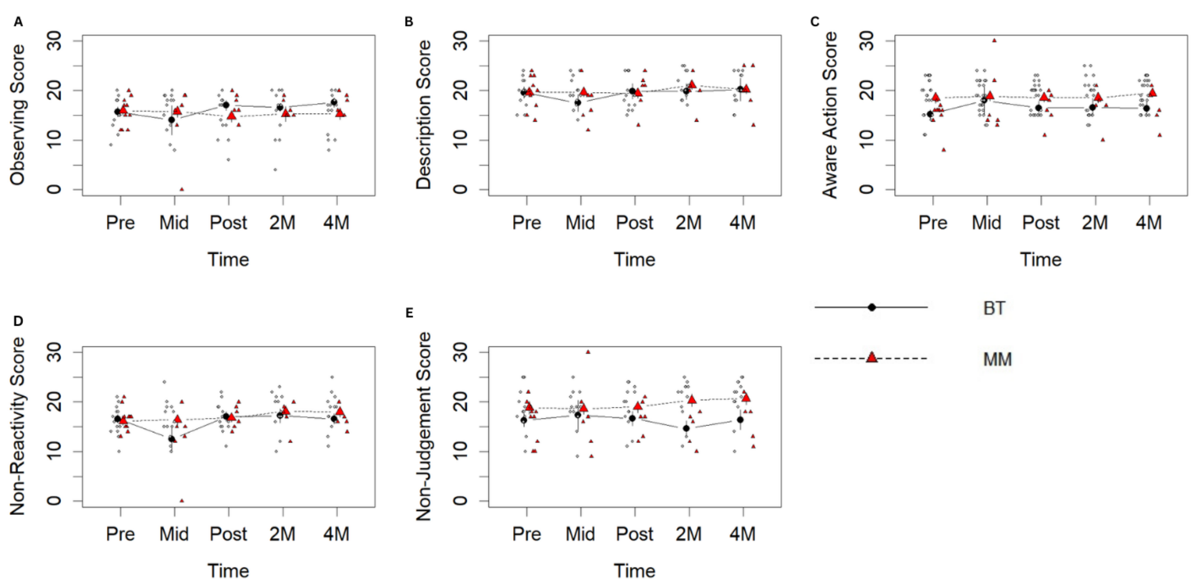

Figure 8. Five Facet Mindfulness Questionnaire (FFMQ) results for both groups across all assessment visits are shown separately for each facet: A) Observation, B) Description C) Aware Actions D) Non-Reactivity E) Non-Judgemental. The Mindfulness group

(MM)is labeled as red triangles, and the brain training group is labeled as black circles. Each group mean line is displayed with points during the pre, mid, post, 2 month and 4-month assessment visits.

Table 9.
Linear Mixed Models for all FFMQ subgroups

Subscales	Effect	NumDF	DenDF	F	P	Effect Size η^2	95% CI
Non-Reactivity	Intercept	1	65	589.40	< .0001	-	-
	Group	1	21	1.14	0.2977	0.05	[0.00, 1.00]
	Time	4	65	3.54	0.0113	0.18	0.218
	Group:Time	4	65	2.81	0.0323	0.15	[0.00, 1.00]
Aware Actions	Intercept	1	65	724.38	<.0001	-	-
	Group	1	21	3.75	0.0663	0.15	[0.00, 1.00]
	Time	4	65	0.78	0.5411	0.05	[0.00, 1.00]
	Group:Time	4	65	0.53	0.7157	0.03	[0.00, 1.00]
Non-Judgemental	Intercept	1	65	457.51	<.0001	-	-
	Group	1	21	1.98	0.1742	0.09	[0.00, 1.00]
	Time	4	65	2.36	0.0627	0.13	[0.00, 1.00]
	Group:Time	4	65	1.23	0.3054	0.07	[0.00, 1.00]
Description	Intercept	1	65	1055.54	<.0001	-	-
	Group	1	21	0.28	0.6037	0.001	[0.00, 1.00]
	Time	4	65	2.00	0.1055	0.11	[0.00, 1.00]
	Group:Time	4	65	1.05	0.3900	0.06	[0.00, 1.00]
Observation	Intercept	1	65	387.68	< .0001	-	-
	Group	1	21	0.03	0.86	0.001	[0.00, 1.00]
	Time	4	65	0.60	0.67	0.04	[0.00, 1.00]
	Group × Time	4	65	1.66	0.17	0.09	[0.00, 1.00

Table 10
Simple Main Effects on FFMQ Non-reactivity subscale by group

Scale	Group	NumDF	DenDF	F-value	P-value	Effect size η^2	95% CI
Non-Reactivity	MM	4	47	3.507	0.014	0.23	[0.03, 1.00]
	BT	4	18	2.226	0.107	0.33	[0.00, 1.00]

Table 11.
ANCOVA Results for Group Differences at Each Time Point in the FFMQ subscales (Figure 8)

Outcome measure Subscale	Time Point	Effect	NumDF	DenDF	F	P	Effect Size η^2	95% CI	Difference (MM - BT)
Non-Reactivity	Mid	Baseline	1	16	5.96	0.027	0.27	[0.02, 1.00]	
		Group	1	16	5.20	0.037	0.25	[0.01, 1.00]	-1.68
	Post	Baseline	1	16	48.61	<.0001	0.75	[0.54, 1.00]	
		Group	1	16	1.55	0.2313	0.09	[0.00, 1.00]	0.58
	2M	Baseline	1	14	6.82	0.020	0.33	[0.04, 1.00]	
		Group	1	14	0.66	0.4303	0.04	[0.00, 1.00]	2.81
	4M	Baseline	1	15	14.59	0.002	0.49	[0.17, 1.00]	
		Group	1	15	2.59	0.1281	0.15	[0.00, 1.00	2.59

FFMQ Results

From the initial 26 participants enrolled within the study, due to withdrawal before and during the main intervention a total of 101 assessment visits should've been conducted, 39 assessment visits for the brain training group and 65 for the mindfulness group. Out of those visits 31 FFMQ outcomes were completed in the brain training group and 64 were completed in the mindfulness group.

Figure 8 shows the scores on the five facets of trait mindfulness at the five assessment points for the two groups. Overall, the data are similar across the two groups in all the subscales and relatively stable across time.

The results of a linear mixed effects analysis for all the subscales are shown in Table 9. The non-reactivity subscale is the only subscale that showed a significant main effect of time ($F(4, 65) = 3.536$, $p = 0.011$), and a significant Group x Time interaction ($F(4, 65) = 2.814$, $p = 0.032$). Examining the effect of time separately for each group (Table 10) revealed a significant effect in the MM group ($F(4, 47) = 3.507$, $p = 0.014$, $\eta^2 = 0.23$), but not the BT group ($F(4,18)=2.26$, $p = 0.107$, $\eta^2 = 0.33$), although the estimated effect sizes were similar. Examining group differences at each time point, controlling for baseline (Table 11), revealed a statistically significant difference at the Mid time point only, where the BT group showed lower non-reactivity than the MM group which was increase in the MM group form Pre to Post assessment visits, but this trend was not maintained at other time points. Even though not all group differences are statistically significant, the pattern is consistent with improvement in MM's Non-Reactivity scores from Pre to Mid.

The Non-judgemental subscale showed a slight trend of increasing scores across time in the MM group and decreasing scores in the BT group, but neither the main effect of time, nor the time x group interaction were significant. No other significant effects or interactions were found for any other subscales (Table 9).

CEQ Results

Table 12

The Credibility and Expectancy Questionnaire (CEQ) scores for the Brain Training and Mindfulness Meditation groups at baseline, Post, and 4M follow-up visits. Scores are provided for Credibility and Expectancy subscales separately at each time point.

	N = 21	**Peak**	**Muse**	**T-test**
Credibility Baseline	MM = 13 BT = 8	53.79 (16.08)	62.13 (26.25)	T = 0.80, p < .05
Expectancy Baseline		45.87 (19.22)	57.7 (26.11)	T= 1.08, p < .05
Credibility Post	MM = 13 Peak = 6	52.77 (19.33)	60.33 (21.22)	T= 0.740, p < .05
Expectancy Post		33.61 (30.80)	46.28 (29.08)	T= 0.880, p < .05
Credibility 4M	MM = 13 BT = 5	62.13 (18.11)	62.23 (24.91)	T= 0.170, p < .05
Expectancy 4M		43.67 (28.80)	53.05 (27.90)	T= 0.634, p < .05

Table 12 shows the results of the credibility and expectancy questionnaire completed at three time points during the study. Immediately after they were introduced to their programs, the credibility of the two programs were similar (MM: 62.13 (26.25), BT: 53 (16.1), and were slightly higher than the expectancy ratings (MM: 53.79 (16.08) 45.87(19.22), BT: 45.87(19.22)), which also did not differ significantly across groups. Immediately after the 8-week program, there was a small decline in credibility ratings and a larger decrease expectancy rating in both groups, but there was no group difference in the scores for either subscale.

Finally, the credibility and expectancy scores at the end of the 4-month period also did not differ across groups. These results indicate that the active control condition was similarly credible, on average, as a program for improving brain health, as the mindfulness meditation program. That said, it is important to note that the results showed large individual differences across participants in both groups.

Discussion

The current study assessed the impact of a mindfulness meditation intervention on a variety of psychological and social outcomes, such as stress, loneliness, mindfulness, social interaction and satisfaction, depression and quality of life. In hopes to discover a accessible and non-invasive mental health interventions for aging populations by evaluating feasibility, acceptability, and preliminary efficacy of a smartphone-based mindfulness meditation app for lonely older adults. Our findings provide insight into the potential of digitally administered mindfulness meditation to address mental health concerns.

Feasibility and Acceptability

Results from the adherence data collected found that the Mindfulness intervention exhibited high feasibility and adherence in older adults. The MM group had no withdrawal through the entirety of the study with a 100% retention rate, compared to the BT group which experienced 50% retention rate, losing more than half of its participants by the end of the study. This difference in retention rates suggests a greater appeal for mindfulness meditation in our participants and confirms that the intervention is feasible. Further evidence of remote mindfulness practice feasibility can be seen when examining adherence in both mind and guided meditation practice adherence. During the main intervention phase of the study, participants adhered 77% to the mind meditation schedule and 73% with the guided meditation schedule suggesting a high acceptability with the mindfulness practice. Both mind and guided meditation had similar adherence within the MM group suggesting a small difference if any of feasibility and acceptability of both mindfulness practices. Although mainly positive reviews were given for the mindfulness practice some qualitative feedback has showed that the Muse headband created some challenges, as indicated in the exit surveys where five participants expressed discomfort while using the device and a poor-quality connection between the Muse headband and the accompanying app, possibly hindering usage of the meditation aid. Three out of 13 MM participants found navigating the muse app difficult after UI updates. Both groups also communicated dissatisfaction with the overall time commitment of the interventions. Participants also said that keeping up with their intervention, documenting their progress, by filling in calendars with their activity, and completing surveys, was burdensome and time consuming, which may have impacted their engagement with their respective interventions, but many participants found it still helpful in keeping track of their practice.

Examining specific participants' exit surveys for reasons behind their adherence to the program and self reported benefits revealed several interesting trends. The engagement of participant 453 engagement in the MM group was on par with requirements given each week. Their survey scores had positive outcomes as the study progressed. In their exit survey, this participant stated an improved quality of life attributed to the study. Despite such positive responses, they experienced phases of non-engagement in the follow-up period, which they attributed to travel and illness. This participant expressed that under the circumstance of no travel and good health, they would have engaged more with Muse.

Participant 239 participated in the follow up period but had little activity during this time completely dropping off engagement after the first 2 weeks. During the main intervention they had weeks where they were doing more than the required practice. In their exit survey, participant 239 expressed positive effects from meditating when done diligently but mentioned a change in their circumstances when they stopped doing it regularly. This claim strengthens, the idea that consistency in the environment may be important to retaining mindfulness practice.

Participants displaying significant activity and beneficial assessment scores often had elevated DSSI scores or reported appreciation for the check-in and assessment visits. These observations suggest participants who have a higher number of social interactions are also more positively inclined towards mediations. Previous studies found that including more social support, encompassing friends, family, or study staff, improved practice retention and helped people benefit from mindfulness (Galante et al., 2021). Stability in life is another factor that could be correlated with mindfulness practice retention. Having a set routine or stable situation physically, socially and emotionally can help keep a consistent practice of meditation.

Participants who experienced positive outcomes, both in terms of assessment scores and perceived benefits, cited social interactions, such as check-ins and assessment sessions, as the determining factors for adherence. This finding implies that integrating social support into mindfulness programs may enhance practice retention and overall effectiveness. Additionally, the stability in participants' lives appeared to be a potential influence on their mindfulness practice whether this stability was good or bad, as long as it was consistent. Specifically, we found that participants with more consistent routines and environments seemed better suited to maintain consistent engagement, whereas perceived changes in environment and surroundings often led to fluctuations or discontinuations in the practice.

Mental Health Outcomes

Preliminary analysis of the outcomes in this pilot study revealed that Mindfulness meditation had a greater effect on mental health compared to the active control group. Depression scores in the MM group showed a significant improvement over time, in comparison to the BT group, with the difference continuing up to four-months after the end of the main intervention. This finding agrees with previous research indicating that mindfulness practices can reduce depressive symptoms in older adults (Talebisiavashani, 2024; Reangsing et al., 2021) However, they had no effect on other cognitive measures and found mindfulness-based interventions shorter than eight weeks showed greater benefits for anxiety and quality of life which coincides with our findings.

Measures of perceived stress and loneliness revealed a more modest effect of time that did not differ significantly between groups, suggesting both stress and loneliness may be less affected by mindfulness than depressive symptoms. A larger sample size is needed to detect the effects, or the effect may be similar in both groups. These results could imply that a longer main intervention period may be required to find a significant effect or that the MM and BT group have similar effects in mitigating stress and loneliness symptoms. The absence of a significant difference between groups could be attributable to the specific measures employed to measure perceived stress and loneliness: although the PSS and UCLA are reliable and valid they may not have been sensitive enough to find differences between groups or individual differences in responsiveness to the intervention. As stated earlier, participating in one of the interventions, rather than participating in a specific intervention, may explain the results found within the main intervention. The increase in social interaction resulting from participating in the study with research staff could also be an explanation for the decreased feeling of loneliness participants reported within both groups. Finally, the effect the MM group had on mental health outcomes highlights its potential as a mental health resources for older adults, specifically when trying to manage depression and depressive symptoms. Suggesting that mindfulness mediation may be useful as a alternative means of reducing depressive symptoms and possibly preventing development of depression and later in life cognitive decline The analysis of outcome measures should be interpreted with caution, as the small sample size of this pilot study limits the conclusiveness of the results and these findings should be considered preliminary.

Social Interaction and Satisfaction

The DSSI results showed no significant effects of effects of group or time, which suggests that the mindfulness meditation intervention did not significantly change n the number of social interactions or satisfaction levels. Previous studies have found positive correlations between mindfulness, prosocial behaviors and empathy (Feruglio et al., 2022) (Ek et al.,2019), and some participants in their exit surveys expressed improved social connectedness. This suggests that some participants may have experienced a subjective change in connectedness that was not detected by the DSSI. The decrease in loneliness observed in the mindfulness group accompanied by no change in social interactions indicate that a decrease in loneliness with mindfulness may not necessarily be accompanied by increased social interactions and attitudes. Future research with larger sample sizes could examine this trend further.

QOL

The WHOQOL results found significant improvements in physical and psychological quality of life in the MM group. The improvements in physical quality of life suggest the mindfulness intervention had positive effects on participants energy levels and ability to perform daily tasks, which is consistent with previous claims of improved well being and research claims of improved physical health (Cramer et al., 2016, Wong, 2021). A possible explanation for these findings is that mindfulness helps reduce stress and emotional regulation which in turn promotes healthier lifestyle choices. The improvements in psychological quality of life suggests that mindfulness intervention increased emotional well-being, self-esteem, and positive affect, consistent with the observed reductions in depression and stress in the MM group. Mindfulness practices are thought to enhance psychological health by fostering present-moment awareness, non-judgmental acceptance, and emotional regulation, but we found that present moment awareness (based on TMS measures) and non-judgmental attitude (based on the FFMQ measures) were not affected by mindfulness meditation. A possible explanation for our failure to see these effects is that psychological health measures like depression and stress could be more directly tied to symptoms participants can feel improving more clearly. The mindfulness facets are more abstract, so participants might not perceive changes even if they're benefiting or these improvements in psychological quality of life yet not mindfulness may reflect behavioral changes, reinforced routines, induced relaxation, and instilled sense of accomplishment, indirectly impacting mood and self-efficacy.

Mindfulness

The FFMQ results revealed a significant improvement of non reactivity but not any of the other facets. The combination of a significant group and group x time interaction effect coupled with a significant simple main effect suggest that Mindfulness intervention improved participants ability to respond to stressors with greater self-control. This result aligns with fundamental concepts of mindfulness, based on FFMQ questionnaire (Ra et al., 2008), that emphasize reducing automatic, stress-driven responses.

Results from non-reactivity could imply that this facet can be influenced by short-term interventions more then the other facets and that other facets may require prolonged engagement for significant changes.

Interpretation

When examining the results holistically, mindfulness meditation practice with the Muse app and headband seem highly feasible. Evidence from the study shows a good retention rate in the MM group although half participants chose not to continue to use the app during the follow up period and from that half that chose to continue engagement was low. This result emphasises the importance of structured guidance and external accountability in maintaining practice. Qualitative feedback revealed that participants appreciated the routine and reminders provided during the main intervention, which helped them stay on track. Looking more holistically at the self reported data from the MM group several factors emerged as possible influences to continued practice in older adults that include perceived benefit, ease of use, personal motivation and commitment and social and emotional support.

There are several possible explanations for the observed differences between the effects of mindfulness practice and brain training. The difference between groups could be attributed to the intervention design being designed to target depressive symptoms particularly. Meditation could have a more specific effect on neurotransmitters involved in depression while not affecting social or environmental factors connected to stress, loneliness and other mental health indicators.

Although engagement in the MM groups stayed above that of the BT group throughout the study, engagement with both interventions dropped significantly during the follow up phase. Most participants did very little to no practice with the Mindfulness intervention. Half of the MM group chose to continue using the app during the follow up period and from those participants engagement was sporadic with only about two participants exhibiting any sort of consistent practice. These results suggests that structured layout with added reminders could have played a role in sustaining adherence because a key difference between these two periods was that participants did not receive emails to continue practice. The lack of study contact may have caused participants to reduce engagement in the follow up period.

Results found align with meta-analysis research that reviewed 136 trials of 11,605 participants from 29 different countries and that found that mindfulness-based programs generally improved anxiety, distress, and well-being only when compared to no other interventions. Excluding high risk populations removed this effect of mindfulness on mental health entirely with only reduction in distress being found. In comparison to non-specific active controls groups, mindfulness practices reduced depression, but did not significantly reduce anxiety, or improve well-being (Galante et al., 2021), which was similar to the results found in this study. Studies using active control groups found no evidence of mindfulness practices being better than its control group. Galante et al. concluded that mindfulness-based practices seem to only improve high-risk populations who are stressed and not taking actions to remedy the problem.

The meditation's duration, intensity or very nature may have been sufficient to influence depression, but not enough to affect stress, loneliness or mindfulness. The surveys used to measure depression may be more sensitive to change than those used to measure other factors tested, or the setting and context of mindfulness meditation as an intervention may provide immediate relief from depressive symptoms through supportive interactions or structured activities while failing to address the underlying causes of participants mental health issues. There is also the strength of the effect to take into account, while mindfulness meditation effect on depression is medium to large, based on meta-analysis, but small medium and small for loneliness so with a small sample size, we had a high chance of not finding an effect on stress and loneliness due to the effects being small.

Limitations and Future Direction

This study has some limitations that are important to note. First, the participants all spoke fluent English, were comfortable using mobile devices, and had access to one. Most were of European descent, and a majority were women. They also knew the study would take eight weeks and require a significant time commitment, something not all older adults can do. Because of this, the results may not apply to everyone outside this specific group.

There are also technological limitations to recognize within the study. If the muse headband and app functioned as predicted by boosting adherence to the practice by providing real time feedback to its users, then the headband and app may be required to promote continuous practice. Possibly limiting success in mindfulness to those who are technologically proficient enough to use the device and those who have the resources to acquire a phone and muse headband. Another technological limitation has to do with the design of the Muse headband. Participants and users with more textured hair found that the muse headband struggled to pick up their brainwaves. While this did not affect the study to a considerable degree it is important that the device can be used in all demographics especially if the Muse device is responsible for sustained practice of mindfulness.

The remote nature also brings into question whether lack of in-person monitoring influenced the study's findings. Other than the direction and guidance from the Muse app no other input could be given from study staff on participants' meditation practices. This lack of in-person supervision could introduce variability in adherence to, and engagement with. Although the monitoring tools used in this study and within the Muse app do aid in mitigating this problem they are not as nuanced as the oversight from in-person studies and can not control for distractors or stressors a participant may face while not in a controlled environment. The remote nature of this study also raises concerns with the ability to retain participants. The mindfulness meditation group retained all participants throughout the study, but the BT control group had a high dropout rate with more than half of participants dropping out before the completion of the study. This disparity in retention can introduce biases and reduce the generalizability of the findings, obfuscating any conclusions that can be drawn from this study.

Outcome measures used in this study were also greatly reliant on self reported data, which can be influenced by response bias, recall biases and social acceptability biases. Using validated questionnaires does reduce the risk of these biases but not completely. Collecting these outcome measures while keeping the nature of them anonymous may aid in reducing any social acceptability biases involved in the results. Modifications of the DSSI survey due to the pandemic may also limit comparability with studies pre-pandemic.

The sample size of 26 participants, with only half being in the mindfulness group and an even smaller proportion engaging with the Muse device into the follow-up phase, warrant cautious interpretation of the results found. Any number of external factors could skew the results due to the low statistical power. To reach meaningful conclusions, a larger participant cohort is key in discovering significant differences or genuine trends within the data collected.

The potential influence of participants' desire for increased social interactions rather than genuine interest in continuing mindfulness meditation is a possible reasoning for the findings and the MM group low dropout rate and high engagement during the main intervention could be a reflection of participants desire for more social interaction rather than their commitment to meditation creating conflict between social motivation being a factor in mindfulness retention or therapeutic motivation as many of the participants who dropped out during the follow up period or displayed reduced engagement mentioned lessened contact and check ins as a result. To maintain participant attrition, regular communication during the intervention and follow-up periods may be necessary. Sending reminder emails, giving ongoing technical support, and scheduling regular and more personal check-ins can all help to sustain commitment and encourage continuous practice. It is possible that novelty played a role in keeping attrition rates within the meditation group compared to the active control group where participants used an app to play games and listen to podcasts. Although the length of assessment visits could be altered due to some participants displeasure with the time commitment required in order to improve adherence and drop out rate for future studies.

The findings also suggest various practical implications and recommendations for improving mindfulness meditation therapies. The considerable reduction in depression scores within the meditation group demonstrates mindfulness meditation's potential as an effective treatment for depressive symptoms. Implying that mindfulness training could be tailored as a possible therapeutic treatment for depression. The observed decrease in loneliness and stress across both intervention groups also emphasizes the importance of social components in therapies, even when not expressly stated. Integrating structured social interactions, such as virtual group meditation sessions or peer support groups in addition with practice, may enhance the advantages of mindfulness programs.

The results also show that consistency and stability in individuals' lives may lead to better outcomes. Mindfulness programs should encourage frequent practice and take into account participants' life stability in order to be more effective. Furthermore, the lack of substantial decrease in stress and loneliness compared to the control group and increase in some aspects of mindfulness suggests the necessity for longer or more intensive therapies to obtain meaningful results. To see meaningful gains in these areas, mindfulness training may need to be extended or have the frequency and intensity of sessions be increased.

Finally, collecting and analyzing participant feedback on a regular basis is critical for identifying engagement barriers and opportunities for growth. Adjusting the program based on participant feedback ensures that it remains relevant to their needs and interests. Training facilitators to spot symptoms of disengagement and apply re-engagement tactics would also help to maintain participant involvement. By applying these recommendations, mindfulness meditation programs can be adapted to increase participation and therapeutic outcomes, resulting in more successful and effective therapies. Future studies with more extensive and diverse participant pools and deeper investigations into the environment and routine of the participant are essential to provide a better understanding of the factors at play in mindfulness practice and its long-term retention.

Conclusions

The findings provide preliminary support for the feasibility and acceptability of an app-based mindfulness meditation program for older people but further integration of the practice or as well as evidence of potential benefits for reducing depressive symptoms as well as loneliness and stress in lesser effect. Given our rapidly aging population and increased digital usage among older people, these findings underscore the importance of conducting larger randomized controlled trials to investigate the efficacy of digital mindfulness meditation therapies for older adults.

The study's limitations, included a small sample size and the potential underlying influence of participants' desire for social interactions, highlight the need for larger and more diverse participant cohorts to establish definitive correlations and causative factors as well as issues with generalizability of the findings to a wider group of older adults.

This study aimed to evaluate the effectiveness of mindfulness meditation as an intervention for loneliness and stress, as well as to identify factors that retain people in the practice. The findings suggest that mindfulness meditation can significantly reduce depression and improve physical and psychological quality of life. It's impact on stress; loneliness were less pronounced but still present and other aspects of mindfulness was less clear or non-existent within the study findings. The reductions in depression, stress and loneliness and the improvements in some aspect of quality of life highlight the potential benefits of mindfulness meditation for mental health and mitigating age-related cognitive decline. The variability in adherence indicates that the individual differences could play a significant role in engagement with mindfulness practices, and future interventions might need to consider personalized approaches to enhance adherence and effectiveness.

This research also underscores the complex interplay of various factors influencing mindfulness meditation engagement. Social support, life stability, and individual motivations, are crucial considerations in designing future effective mindfulness interventions. Future studies should include larger participant pools and deeper investigations into the participants' environments and routines to better understand these factors and their impact on long-term mindfulness practice retention and its effects.

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