Investigating Novel Virtual Reality and Telehealth Mindfulness-Based Interventions for Training Interoceptive Awareness

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Abstract

Interoception – the ability to sense and integrate internal body signals – plays a critical role in how complex organisms survive and function. It is essential for maintaining stable conditions within the body (e.g., keeping warm), for meeting daily needs within a changing world (e.g., quenching thirst), and for adapting to future needs (e.g., remembering seasonal changes in foraging spots). While research into interoception started more than a hundred years ago, it is not well understood today. Researchers are still mapping out all of the brain and body pathways through which interoception operates. Additionally, research into the most optimal methods for manipulating and measuring interoception is at an early stage. Despite these uncertainties, prior research suggests that a person's conscious awareness of internal body signals, known as interoceptive awareness, is not a fixed capacity, rather it can be altered through training.

This dissertation investigates how mindfulness practices can be combined with emerging technology to train interoceptive awareness. First, we introduce a novel virtual reality (VR) mindfulness-based intervention that is designed for cultivating greater interoceptive awareness. As part of this work, we also introduce a new qualitative methodology to understand users' experiences of interoceptive awareness in VR. We found that the methodology elicited valuable responses from participants regarding their interoceptive awareness experiences within the novel VR mindfulness-based intervention. Most significantly, our work represents the first attempts to qualitatively investigate a multi-dimensional model of interoceptive awareness in VR. It also establishes a critical foundation for conducting future follow-on comparative studies that can provide more complete design guidelines for how best to train interoceptive awareness in VR.

Next, we assessed the efficacy of a novel group telehealth mindfulness intervention, compared to an active control, for enhancing interoceptive awareness. While this second intervention is distinct from the prior VR mindfulness-based intervention, it answers the critical question of whether interoceptive awareness can be trained via a group intervention delivered remotely versus alone in a lab. We found that the remote, group mindfulness intervention can improve interoceptive awareness and that these gains are relatively stable at six and twelve month follow-up time points. Lastly, we confirmed

that the telehealth intervention can be delivered by non-mindfulness experts, which points to the promise of scalable, group telehealth mindfulness interventions.

Finally, we examine potential predictive factors related to interoceptive awareness outcomes by conducting a hierarchical regression analysis. Knowledge of potential predictive factors is useful for optimizing interventions to enhance interoceptive awareness outcomes for various populations. We found that several factors influence post-intervention interoceptive awareness outcomes. Specifically, the factors of age, baseline mindfulness, and change in mindfulness from baseline to intervention completion significantly influence interoceptive awareness. In terms of baseline mindfulness, current literature has under-investigated this factor even though there is evidence that prior experience with mindfulness is very widespread in the United States.

In summary, our work is a first step in the longer journey of weaving together emerging technologies with evidence-based interventions to positively impact public health. By studying two novel interventions individually before pursuing their combination, we hope to establish a solid foundation from which to pursue our larger, long-term vision. This larger vision includes the potential of VR as a powerful *computing medium for embodied simulations* to leverage telehealth as a *critical mode of healthcare delivery* to bring evidence-based health interventions outside the confines of traditional healthcare settings. We envision a future where clinicians, computer scientists, artists, and community members co-create immersive, social VR applications that connect geographically distant users to cultivate greater health and wellbeing around the world.

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Chapter 1

Introduction

1.1 Interoception

Interoception refers to a nervous system's ability to sense and integrate internal body signals at conscious and unconscious levels [74]. While many interoceptive signals happen below the conscious level (e.g., liver functioning), human beings can become aware of certain interoceptive signals that facilitate adaptive regulatory behaviors (e.g., sensing an elevated heart rate and then taking deeper, slower breaths in order to relax) [7]. A person's conscious awareness of internal body signals, known as interoceptive awareness, is not a fixed capacity, rather studies suggest it can be altered through training [158].

Beyond an awareness of one's internal bodily experience that can be practiced and improved, interoception also plays a critical role in an organism's survival and functioning. Interoception is central to maintaining stable body conditions by meeting current needs amidst a constantly changing world (i.e., homeostasis) and the process of adapting to new circumstances and anticipating future needs (i.e., allostasis) [123]. Additionally, interoception is critical for alerting an organism to injury and sickness [7]. Beyond moment-to-moment survival, interoception is also involved in the overall lifespan of an organism through its sense of self [123]. Beginning in infancy with body ownership [113] and developing into adulthood with emotion regulation and decision-making capacities [30, 44, 77], interoception is involved in a host of self-related processes critical to a human being's day-to-day functioning.

While the term interoception was first coined more than 100 years ago [139], it is still not well understood. Specifically, methods for measuring and manipulating interoception are still in their infancy [74]. From a measurement perspective, an array of various performance and self-report measures exist that purport to measure the common construct of *interoception* [24, 112]. Unfortunately, recent research has found that many of these measures actually evaluate distinct domains and there is little to no empirical convergence among these different measures [24]. This current measurement gap highlights that "researchers should select questionnaires according to the specific construct they intend to measure" [24]. In short, a tighter mapping of intervention targets to specific outcomes of interest is needed. From an intervention perspective, current approaches that target and manipulate interoception are typically classified as pharmacological (e.g., blockade of ghrelin receptor), neurological (e.g., direct vagal nerve stimulation) and psychological (e.g., mindfulness) [158]. While these broad classifications are helpful in thinking about intervention type, they do not provide guidance about how a particular intervention might be optimized. In addition, there is almost no guidance about how an intervention combined with the types of technology increasingly used by health care providers (e.g., videoconferencing and virtual reality) might work to enhance the training of interoceptive awareness and provide greater access to such training outside a laboratory environment [135].

1.2 Emerging Technology and Interoception

Virtual reality (VR) has emerged as a novel multimodal technology that mirrors much of how interoception works in the human body via the process of embodied simulations [127]. Specifically, VR maintains a model of the virtual body and the virtual world that is continuously updated from the perspective of the VR user. By utilizing visual, auditory and haptic signals with sufficient fidelity, computer scientists can create a sense of presence and embodiment for VR users within virtual worlds [142]. Similar to VR, the human brain is believed to utilize simulated maps of the body and the external environment that are continuously updated through Bayesian inference [34, 74]. Given that VR and interoception both involve simulations, it is plausible that VR may be able to alter interoceptive experiences through custom training environments [127]. For example, VR researchers have shown that when participants see a virtual body in a mirror and learn that it moves in correspondence with their own, they respond as if it were their own [54]. This virtual body-ownership illusion has been used as a strategy for fostering empathy for people of a different gender [144], race [90], age [6], and ability [116].

Although motivated, in part, by the power of VR to transport a person to a different place or body, this dissertation's use of VR has an "inverse" goal, summed up by the phrase, *Inward VR*. The work presented in this dissertation investigates the potential for VR to facilitate looking inward to develop a deeper awareness of one's own, real body (i.e, interoceptive awareness). VR has shown early promise for this purpose [5]. VR has been successfully incorporated into a variety of mindfulness-based health interventions (e.g., [56]). Similarly, VR has been shown to be a powerful multi-sensory medium for delivering biofeedback (e.g., [88]). However, in contrast to the host of methodologies and metrics that have been developed for evaluating the technology's success at delivering exteroceptive and proprioceptive signals that transport us to new places and bodies, the literature includes little guidance on how we might understand VR's ability to promote interoceptive awareness. If we could reliably measure the various dimensions of interoceptive awareness produced during VR experiences, such measures could provide invaluable design guidance, similar to existing measures of presence or body ownership.

Even though VR represents a special *computing medium for embodied simulations* that could train interoceptive awareness, it is still figuring out how best to create remotely delivered social experiences, such as are typical in group telehealth interventions. In fact, the potential of using VR for a group telehealth intervention is only now becoming a viable possibility with the widespread roll out of stable, next generation network systems (e.g., 5G with a theoretical throughput of 10-20 Gbps) [16] combined with lower-cost virtual reality hardware. Nevertheless, significant barriers still remain for connecting geographically distant VR users in a shared, immersive health intervention. For example, one recent study found that the newly released social VR application Workrooms, created by Meta (formerly known as Facebook), had significant usability issues due to latency problems and high bandwidth requirements [16]. Given these existing technical barriers (albeit likely to be solved by network providers), the scope of this dissertation is limited to exploring a proof of concept VR environment for training interoceptive awareness without the complexities of remote delivery and then separately exploring the efficacy of a telehealth mindfulness intervention for improving interoceptive awareness.

1.3 Mindfulness Research Without a Body

While VR as a *computing medium* and telehealth as *a mode of delivery* represent promising new research directions for interoceptive awareness, mindfulness is a more than 2500 year old, evidence-based contemplative practice for training attention to notice interoceptive cues (e.g., breathing). Mindfulness practices typically involve formal exercises, such as knowing whether a breath is long or short in sitting meditation, and applied practices, such as knowing the activities of the body (e.g., while walking, know that you are walking) [52]. The goal of these formal exercises and applied practices is to increase the duration and frequency to which a practitioner is aware of their body. Awareness of the body is often considered a foundational skill for developing calm and insight [2].

Most contemporary mindfulness-based interventions (MBIs), like traditional contemplative practices, emphasize cultivating greater attention to interoceptive cues. For instance, the Mindfulness-Based Stress Reduction program (MBSR), which is the most implemented mindfulness program in U.S. healthcare settings [130], introduces participants to meditation through the practice of a body scan, which involves systematically sweeping one's attention through the body starting with the feet and progressing to the head [72]. The point of the body scan is to "actually feel and inhabit each region [of the body] you focus on and linger in it in the timeless present as best as you can" [72].

Despite MBIs emphasis on practices that train awareness to interoceptive cues, most measures used in MBI research neglect interoceptive awareness. For example, the Mindfulness Attention Awareness Scale (MAAS), which is one of the most widely used mindfulness measures [132], does not explicitly include interoceptive awareness, rather it focuses solely on investigating attention in daily life activities [75]. The unidimensional construct and short-form structure of the MAAS likely accounts for its widespread appeal[1] within mindfulness research [124]. The fact that interoceptive awareness is understudied in existing mindfulness research is problematic given contemplative theories that highlight its importance to mental health and well-being [3, 108].

1.4 A New Direction for Interoception Research

Considering the aforementioned gaps, there is an opportunity to combine mindfulness practices with emerging technology to better train and measure interoceptive awareness. In fact, bringing together ancient contemplative practices with emerging technology may be the key to optimizing the training of interoceptive awareness while also increasing access to such training outside of traditional settings (e.g., clinic or lab). This bigger vision includes VR as a unique *computing medium for embodied simulations* that could leverage telehealth as a *critical mode of healthcare delivery* in order to provide evidence-based interventions. Some promising prior work has taken initial steps in this new direction, however, it has not explicitly focused on training interoceptive awareness. For example, ReCoVR adapted the entire MBSR program to a remotely-delivered VR environment, but hardware overheating issues led to sessions lasting only 30 minutes at a time versus the standard two and a half hours of MBSR class time [18]. Similarly, a recent review of VR and mindfulness found that most of the VR environments studied did not include interactivity (beyond basic head tracking) or a virtual avatar [28], features that the VR research community has established as being closely tied to presence and embodiment (see e.g., [144, 54]). When training awareness of interoceptive cues, the lack of a virtual body and limited interactivity are likely to pose significant barriers.

Combining mindfulness practices and emerging technology to train interoceptive awareness may also lead to numerous new benefits. First, it could radically alter how current interventions are implemented and deployed. For instance, current programs require travel time and in-person attendance at set times and locations, making them inaccessible or unsustainable for many participants [17, 93]. By implementing remote and on-demand opportunities, these participant-level barriers could be significantly reduced, which would support the widespread use and uptake of training. Second, most

[1] A 2017 systematic review by Tomlinson et al. found that in 93 studies, the MAAS was the most widely used mindfulness measure [148].

existing programs are limited by a very small pool of trained and qualified teachers. By leveraging the affordances of emerging technology, it would be possible to scale the efforts of existing qualified teachers without drastically reducing the fidelity of instruction. For instance, instruction delivered via mobile apps has been found to be as effective as in-person live instruction as measured on several general instruments of wellbeing [106]. By leveraging the embodied simulations of VR and the ubiquity of telehealth, it should be possible to extend these promising findings from mobile apps and further enhance training.

1.5 Thesis Statement

This dissertation is a first step in the longer journey of weaving together emerging technologies with evidence-based interventions to positively impact public health. The scope of this dissertation is limited to taking the logical first steps toward this bigger vision by studying several components individually before pursuing their combination. Namely, this dissertation begins by investigating the potential of a novel mindfulness VR environment to cultivate interoceptive awareness and then explores the efficacy of a larger novel telehealth mindfulness intervention to improve interoceptive awareness. If both of these research directions show promise, then they provide the essential foundation for pursuing a larger, long-term vision: creating immersive, social VR applications that connect geographically distant users through evidence-based health interventions.

Towards this end, the central thesis of this dissertation is:

Interoceptive awareness can be effectively taught and measured in novel training environments that weave together evidence-based psychological interventions (e.g., MBIs) and emerging computer science technologies (e.g. VR and telehealth)

1.6 Specific Aims

The following three specific aims are designed to evaluate my aforementioned thesis statement. All three aims, leverage de-identified data from two sources: (1)

an exploratory lab-based user study investigating interoceptive awareness in virtual reality and (2) a randomized hybrid type 2 effectiveness-implementation trial investigating a community-based mindfulness intervention for increasing physical activity in older adults. I was a co-investigator on both studies and extensively involved in the intervention design and study implementation.

1. **Aim 1:** Investigate participants' experiences of interoceptive awareness when using a novel mindfulness VR environment. I hypothesize that a qualitative methodology can be developed to elicit valuable feedback about interoceptive awareness experiences in VR and that this method can be applied in an exploratory user study to understand experiences of interoceptive awareness within a custom-designed immersive, stereoscopic, perspective-tracked VR environment that implements a guided body scan exercise with an interactive visualization of a biometric signal detected via a heartbeat sensor.

2. **Aim 2:** Determine the relative effectiveness of eight weeks of an experimental mindfulness intervention versus an active control intervention in a full scale randomized controlled trial as measured by changes in four subscales from the Multidimensional Assessment of Interoceptive Awareness, Version 2 (MAIA). I hypothesize that participants receiving the mindfulness intervention will experience a greater improvement in all four subscales of interoceptive awareness at months 2 (i.e., post-intervention), 6 and 12 compared with participants in the active control.

3. **Aim 3:** Examine whether specific baseline characteristics (e.g., age, gender, pain, mindfulness) and intervention-related characteristics (e.g., intervention type, attendance, home practice, and change in mindfulness from baseline) explain a statistically significant amount of variance in the four subscales of the MAIA post-intervention in a randomized controlled trial. I hypothesize that age, gender, baseline pain, baseline mindfulness, intervention type, attendance, home practice and change in mindfulness from baseline would explain a statistically significant amount of variance post-intervention.

1.7 Key Contributions

The key contributions of this dissertation are:

- A novel, custom-designed immersive, stereoscopic, perspective-tracked VR environment to explore interoceptive awareness that implements a guided body scan exercise with an interactive visualization of a biometric signal detected via a heartbeat sensor [60].

- A qualitative methodology, including a reusable codebook, for applying the five dimensions of the MAIA's *underlying conceptual framework* to understand VR users' experiences of interoceptive awareness [60].

- Results from an exploratory quantitative analysis of the relative effectiveness of a novel telehealth mindfulness intervention compared to a structurally and contextually matched control intervention in enhancing interoceptive awareness.

- Identification and articulation of predictive factors that can affect post-intervention interoceptive awareness outcomes, which can aid in the optimization of future interventions targeting interoception.

1.8 Cognitive Science and Collaboration

Cognitive science aspires to a worthy goal – namely, the scientific study of the mind and its underlying processes in the brain. At its inception, cognitive science beckoned scientists from various backgrounds to look beyond the confines of their familiar discipline and imagine new possibilities within an uncertain interdisciplinary endeavor. The courage to step into an unknown space, akin to an ancient mariner who willingly enters uncharted waters marked by a monster on the edge of a map, is no small feat. As George A. Miller, one of the founders of cognitive science, once opined about its origins: "at the time it was happening I did not realize that I was, in fact, a revolutionary" [105]. The courage to imagine is, for me, the very beating heart of cognitive science because without it, the long hard work of collaboration is not sustainable. My own experience of writing this dissertation involved traversing the disciplines of computer science, psychology, neuroscience and philosophy. In this journey, I would, at times, feel lost as though I were in an endless labyrinth without a way forward. Fortunately, it was always the collaborative voice of a colleague or mentor that would reignite the spark of possibility and reveal a hidden passageway that I had overlooked. In the end, this dissertation, like the discipline of cognitive science, is about collaboration and the ability, as Miller states, "to recognize that the solution to some of ... [a discipline's] problems depended crucially on the solution of problems traditionally allocated to other disciplines" [105]. This is what truly makes the work meaningful and can accommodate a dissertation connecting research in interoception (neuroscience) with novel VR and telehealth technologies (computer science) to implement therapeutic interventions (psychology) that have their roots in ancient contemplative theories of mind (philosophy).

1.9 Overview of this Dissertation

Each chapter of this dissertation helps to advance the central thesis statement presented above in Section 1.5. This section briefly introduces each chapter and its contribution to the central thesis.

- **Chapter 2** provides important related work that contextualizes the thesis statement within the major themes and findings of prior research and sets the stage for investigating the three specific aims described in Section 1.6.
- **Chapter 3** introduces a novel VR environment for investigating interoceptive awareness. Specifically, an interactive VR environment that re-maps a user's heart beat (i.e., an interoceptive body signal) to a visualization on a virtual avatar in order to test out a new qualitative methodology for exploring the interoceptive awareness experiences of VR users (Aim 1). This chapter represents an important proof-of-concept that interoceptive awareness can be taught and qualitatively assessed in a custom-designed immersive, stereoscopic, perspective-tracked VR environment. The findings from

this chapter provide new insights about interoceptive awareness in VR and set the foundation for its continued future development.

- **Chapter 4** introduces a novel telehealth mindfulness intervention and assesses its comparative effectiveness at enhancing interoceptive awareness. Specifically, the mindfulness intervention is compared to a structurally and contextually matched active control telehealth intervention through an exploratory secondary analysis of a randomized type 2 hybrid effectiveness-implementation trial (Aim 2). This chapter provides important quantitative findings about the connection between mindfulness and interoceptive awareness and the extent that this can be accomplished in a unique telehealth intervention delivered by non-mindfulness facilitators. The findings from this chapter answer important questions about efficacy, intervention implementation and the long-term effects of training to enhance interoceptive awareness – areas which are still not well understood within interoception research.

- **Chapter 5** extends the prior chapter by exploring potential predictive factors that matter to the development of interoceptive awareness. Specifically, factors of age, gender, self-reported pain, baseline mindfulness, treatment group, intervention attendance and home practice are investigated as predictors of variance in post-intervention interoceptive awareness (Aim 3). The findings from this chapter challenge some of the prior literature on interoceptive awareness and highlights a new area that is largely unexamined in current interoception research.

- **Chapter 6** revisits the thesis statement of this dissertation in light of the findings from proceeding chapters. Future research directions for interoceptive awareness are discussed and a final synthesis of key findings, including related implications for future work, are presented.

Chapter 2

Related Work

This chapter provides an overview of related work that situates the thesis statement within the existent literature related to interoception, VR, telehealth and mindfulness. Importantly, it lays out the major themes and findings from this prior research as a basis for investigating the three specific aims of this dissertation. The related work is discussed in the same order as the specific aims: (1) the relationship of telehealth, VR, mindfulness and interoceptive awareness, (2) mindfulness interventions and their effects on interoceptive awareness, (3) predictive factors relevant to mindfulness interventions targeting interoceptive awareness.

2.1 Leveraging Emerging Technologies for Training Interoceptive Awareness

While telehealth (using telecommunication technology) and VR have existed separately since the 1870s and the 1960s, respectively [50, 138], this dissertation focuses on VR, first and foremost, as a special *computing medium for embodied simulations* and telehealth as a supporting and effective *mode of healthcare delivery* that could connect geographically distant VR users in a shared, immersive health intervention. As stated in Chapter 1, there currently exist a number of network system issues (e.g., bandwidth, latency) [16] that inhibit the full realization of this vision. Nevertheless, there is early promising evidence that VR can be used to connect geographically distant users in shared immersive experiences for health education [125]. The subsections below present prior work that illustrate both the potential and prior use of VR and telehealth technology for studying interoception and mindfulness interventions.

2.1.1 Immersion, Presence, Embodiment and Body Ownership in VR

Immersive computing researchers carefully define the following terms, which lay the foundation for theories of immersive, embodied computing. **Immersion** is the objective fidelity of the technology (e.g., displays, tracking) relative to real-world counterparts [141]. If the technologies support a sufficient level of immersion, then it is possible to experience presence, also known as **Place Illusion**: the strong illusion of being in a place in spite of knowing that you surely are not there [142]. **Plausibility Illusion** is a related but distinct concept—the illusion that a virtual experience is really happening even though you know it is not happening [142] (e.g., getting nervous while delivering a speech to a virtual audience [143], experiencing fear while walking along a virtual ledge [95]). These concepts deeply influence the design of many of today's VR environments. They are certainly relevant to dimensions of interoceptive awareness, but it is fair to say that it is not yet clear how to apply such theories to foster interoceptive awareness. In a sense, they are divergent since they relate to being somewhere else; yet, it is also possible that "somewhere else" could be a deeper look inside oneself (i.e., Inward VR).

Similar questions emerge when considering theories of embodiment, body ownership and body transfer [163]. Early research showed that VR users can develop ownership of a virtual body even without synchronous visuotactile stimulation, which is the key to the real-world body transfer technique known as the rubber hand illusion (RHI) [9]. When participants see a virtual body in the mirror and learn that it moves in a way that corresponds to their own, they respond as if it were their own [54]. This applies to low-level effects (e.g., heart rate changes in response to a threat to the virtual body [144]) as well as higher-level behaviors (e.g., users play a conga drum differently when dressed in casual vs. formal attire [76]).

Extending these results, Bailenson and colleagues found that "perspective-taking" experiences in VR can increase prosocial behavior [129] and present early evidence that such experiences can translate into long-term empathy [68, 153]. Certainly, the aforementioned work should influence the design of successful Inward VR experiences, but precisely how, given numerous resource and design tradeoffs, remains unclear. Can ownership of a virtual body be a powerful technique for fostering awareness of one's own body and to what extent might this awareness continue when the VR glasses are removed? Or, does virtual body ownership lead to the opposite outcome, guiding us toward an outward rather than inward orientation?

Some recent research has specifically investigated the possible connection between the sense of embodiment and interoceptive awareness. A 2022 study by Döllinger et al. found a significant relationship between a sense of embodiment and self-reported body awareness when participants performed a movement task in front of a virtual mirror with a photorealistic, personalized avatar [29]. A well-calibrated, possibly personalized avatar may be critical to such effects, as noticeable viso-proprioceptive mismatches between an avatar's pose appearance and a user's self-contacts (e.g., feeling a hand controller pressing on one's leg while seeing a gap between the avatar's hand and leg) are known to reduce the sense of embodiment [10]. In a non-VR context, several studies have shown an increased susceptibility to the RHI for individuals with lower levels of interoceptive sensitivity, suggesting an inverse relationship between the sense of embodiment and interoceptive awareness [150, 134, 37]. However, other studies (two of which involved VR [25, 107]) suggest that a sense of embodiment is not purely reliant on interoceptive awareness; rather the relationship displays a more multifaceted interplay of cognitive and trait factors including allocation of attentional resources, visual context, and conflict processing [21, 107, 25].

2.1.2 VR for Bodily Pain and Mindfulness Skills

One area of prior research where interoception may have been implicitly considered in VR environments is that of coping with bodily pain. Early research showed that burn victims report significantly less pain during wound care [69] and physical therapy [70] when immersed in VR. Though related in that these VR experiences were designed with close attention to our own, real bodies, the underlying theory in much of the work applying VR to pain management is not to look inward, but instead to create a distraction. The theory is that the multi-sensory, immersive display occupies the user's attention, leaving few attentional resources to process pain signals [69].

An alternative to distraction is to specifically teach and train mindfulness for enhancing attention regulation, body awareness, emotional regulation and shifts in self-perception [72]. For supporting mindfulness in VR, early work by Shaw et al. [137] introduced The Meditation Chamber, a VR environment designed to train stress reduction via mindfulness meditation and muscle relaxation. Additional work includes adaptations of specific mindfulness practices from Dialectical Behavior Therapy to VR [53] and even a VR adaptation of the entire Mindfulness-Based Stress Reduction program [18], which is the most widely researched mindfulness program [130]. Innovative approaches to immersive biofeedback are possible in these environments. For example, in Sonic Cradle, users are suspended in a hammock and immersed in a dark chamber (similar to a sensory deprivation tank); biofeedback sensors measure respiration, and the soundscape changes in response [155]. RelaWorld combines an Oculus Rift headset and an electroencephalography (EEG) cap to assist in achieving deeper meditative experiences via real-time neurofeedback [79]. Our work shares a similar motivation with all of these examples, which fit perfectly within our conception of Inward VR. A recent narrative review in the journal, *Mindfulness*, highlighted that interoceptive awareness has been overlooked in the mindfulness-and-VR literature and calls for more randomized controlled studies in the future [5]. However, the underlying VR technologies should be systematically explored and optimized prior to large-scale evaluations of therapeutic efficacy. In addressing this gap, a recent review in the journal, *Frontiers in Virtual Reality*, notes that the current VR environments for mindfulness instruction can hardly be considered to be optimally designed and presents a detailed design space to guide future research in creating such environments [28]. For example, one criticism of many existing VR environments for mindfulness instruction is that they do not include interactivity (beyond head tracking) or a representation of the body [28].

2.1.3 VR, Biofeedback and Interoceptive Awareness

Interoceptive awareness is defined "as the conscious level of interoception with its multiple dimensions potentially accessible to self-report" [100]. This emphasis on a multidimensional experience is significant in that interoceptive awareness is not about unidimensional task performance. For example, while accurate counting of one's heartbeat would demonstrate interoceptive accuracy (i.e., correct and precise monitoring of an internal bodily experience [74]), interoceptive awareness refers to a broader understanding of inner body sensations accessible to conscious self-report that includes noticing, feeling, and regulating (vs. just precision) [98]. This distinction is relevant when considering prior work on biofeedback in VR, which is discussed in a recent summary article [88]. In biofeedback, instruments measure some of the body's functions (e.g., heart rate) and provide this information back to an individual via a visual, auditory, or other signal, often with the intent for this feedback to aid in learning to control that function [88]. Biofeedback, therefore, deals directly with interoceptive signals. Biofeedback could potentially play a role in increasing interoceptive awareness, but VR applications designed for biofeedback tend to focus on objective outcome measures of task performance, such as slowing the heart rate or lowering respiration rate (e.g., [8]).

In contrast, our work targets a multifaceted awareness of the body's internal state that aligns more closely with Heeter et al.'s theories of "embodied presence " [64, 63, 62]. These define presence within virtual worlds in a more holistic way than commonly seen in the VR literature so as to better reflect the construct of presence in our everyday lives and in neuroscience, i.e., "we feel present when we are aware of 'how I feel now' " [65]. Heeter et al. have linked embodied presence to interoceptive awareness and were one of the first to employ the Multidimensional Assessment of Interoceptive Awareness (MAIA) instrument within a VR study to investigate interoceptive awareness [65]. However, findings from Heeter et al.'s work are at odds with some of the findings from our work, which is discussed in greater detail in Chapter 3. These divergent findings, including the limited prior work in this area, highlight that research into interoceptive awareness within VR is at a very early, exploratory stage.

2.1.4 Telehealth, Mindfulness and Interoceptive Awareness

As defined by the World Health Organization, telehealth is the delivery of health care services using information and communication technologies, such as videoconferencing, where distance is a major factor [80]. The adoption and utilization of telehealth by providers and patients has accelerated rapidly due to the circumstances of the COVID-19 pandemic when many in-person visits were shutdown [82, 154]. Health providers generally express favorable views about the use of telehealth [160] and recognize its ability to reduce patient-level barriers to accessing healthcare (e.g., cost, ease of access, travel) [80]. Research regarding the effectiveness of videoconferencing-based telehealth has found treatment outcomes to be largely equivalent to in-person sessions [67, 57, 94]. In terms of mindfulness, videoconferencing-based mindfulness interventions have also been found to have similar outcomes to in-person programs, however, there are still relatively few studies on this topic [109].

In the area of videoconferencing-based telehealth and interoceptive awareness, a majority of prior work has focused on exposure-based therapies that involve bringing attention to interoceptive cues (e.g., noticing bodily reactions while recalling an unpleasant situation) [57]. Results from these videoconferencing-based sessions found statistically significant positive treatment outcomes on numerous measures (e.g., panic frequency and agoraphobia scores) as well as high working alliance scores [57]. One telehealth paper from 2003 even describes the technical details of a system to treat agoraphobia in a one-on-one session using telehealth and virtual environments meant to provide exposure to challenging situations [1], however, the results of using the system with an actual patient were not discussed.

In summary, telehealth has become a widely adopted healthcare delivery modality and will continue to grow in the future. Large healthcare systems, such as the

U.S. Veterans Health Administration (VA), are committed to the use of telehealth going forward [32]. This is significant because the VA is a recognized national leader in virtual care and also delivers more complementary and integrative health therapies, including mindfulness interventions, than any other healthcare system [23]. Finally, the continued deployment of advanced fifth generation (5G) technologies and networks will help to accelerate the adoption of telehealth [85].

2.2 Prior Clinical Trials on Interoceptive Awareness and Mindfulness

There have been few clinical trials investigating the effect of mindfulness interventions on interoceptive awareness. A 2021 honors thesis that conducted a systematic meta-analysis of existing literature identified only six full-scale randomized controlled trials (RCTs)[1] [92]. In brief, the findings of this analysis revealed that only two of these six RCTs included follow-up data collection and most studies had small sample sizes (n $<$ 75) [92]. Additionally, the predictive factors of gender and home practice were flagged as needing future research into their effects on interoception outcomes [92]. As relates to interoceptive awareness, the meta-analysis found evidence that suggests mindfulness training produces medium to large improvements in interoceptive awareness post-intervention [92].

For this dissertation, an updated search from 2021 to present was conducted using the same terms and databases as the 2021 thesis (see Appendix B). Recent RCTs were identified in consultation with a research librarian who ensured that search terms were properly entered for each database. Additionally, the same study inclusion and exclusion criteria were used as well as employing a similar screening process (i.e., screening abstracts and then conducting a full-text review). An extensive description of this updated literature search is beyond the scope of this dissertation, however Appendix B provides additional detail.

The results of the updated literature search identified ten additional RCTs. All

[1] The meta-analysis identified 12 studies in total, however, six were pilot and feasibility studies and thus not suitable for testing effects [78].

of these RCTs used the Multidimensional Assessment of Interoceptive Awareness (MAIA) instrument [98], which measures eight subscales of interoceptive awareness – (1) Noticing: awareness of uncomfortable, comfortable, and neutral body sensations, (2) Not Distracting: tendency to ignore or distract oneself from sensations of pain or discomfort (reverse scored), (3) Not Worrying: emotional distress or worry with sensations of pain or discomfort (reverse scored), (4) Attention Regulation: ability to sustain and control attention to body sensations, (5) Emotional Awareness: awareness of the connection between body sensations and emotional states, (6) Self-Regulation: ability to regulate psychological distress by attention to body sensations, (7) Body Listening: actively listening to the body for insight, and (8) Trusting: experiencing one's body as safe and trustworthy. Four of the ten RCTs reported only a single global mean score for the MAIA (even though the MAIA is intended to be scored by each subscale [97]) and found increases in within-group differences for the mindfulness intervention group post-intervention [14, 49, 87, 152]. Only two of these four RCTs included follow up data collection (i.e., one with six month follow up [49] and the other with six and 12 month follow up [14]). The global mean MAIA scores at follow up for these two RCTs were fairly stable with slight increases from post-intervention to final data collection time points [49, 14]. Of the remaining six RCTs, one RCT involved a brief mindfulness intervention (i.e., 10 - 15 minute doses per day over two weeks) and found no significant changes between the mindfulness group and active control on any of the MAIA subscales [59]. The remaining five RCTs all reported significant within mindfulness group changes post-intervention (with medium to large effect sizes) on specific MAIA subscales: attention regulation subscale [4, 38], emotional awareness subscale [84, 35, 38, 86], and self-regulation subscale [4, 84, 35, 38]. Finally, only two of the ten RCTs identified from the literature search had sample sizes greater than 100 participants [14, 38].

The overall pattern from the results of the aforementioned RCTs suggests that mindfulness improves interoceptive awareness. This pattern applies (in general) with studies reporting increased global MAIA mean scores post-intervention, but also on specific MAIA subscales (i.e., attention regulation, emotional awareness, and self-regulation) post-intervention. Additionally, demographic and intervention factors, such as gender, home practice, intervention intensity (e.g., brief MBI versus longer MBI) and prior belief about mindfulness, have been identified as being important predictive factors for post-intervention interoceptive awareness outcomes. Finally, the long-term temporal stability of mindfulness-induced improvements post-intervention is still largely understudied within existing RCTs. A more detailed discussion of the literature related to predictive factors is discussed in the next section.

2.3 Exploring Predictive Factors Affecting Mindfulness Training for Interoceptive Awareness

Current evidence regarding participant-level predictive factors of interoception outcomes is limited. Within the existing literature, the main identified predictive factors are: age, gender, pain, home practice, and intervention intensity. Age is negatively correlated with interoception [111, 73]. With respect to gender, women have been found to report higher scores on some subscales of the MAIA as compared to men [55]. People with pain were found to report lower scores on some subscales of the MAIA as compared to mindfulness practitioners [99]. In terms of home practice, current literature suggests that there is a small to moderate positive correlation between home practice and treatment outcomes in general [117] and specifically as relates to interoceptive awareness outcomes [4]. For intervention intensity, some studies that have used brief mindfulness interventions have found no effect on interoceptive awareness (see e.g., [59] and discussion of brief mindfulness intervention) while other studies using more intensive mindfulness interventions have found positive effects across multiple MAIA subscales (see e.g., [4]). The aforementioned findings suggest that further investigation of predictive factors would be helpful to understanding differences in post-intervention interoceptive awareness outcomes within various populations.

Chapter 3

Inward Virtual Reality

Toward a Qualitative Method for Investigating Interoceptive Awareness in VR

3.1 Introduction

This chapter focuses on the potential of virtual reality (VR) as a powerful *computing medium for embodied simulations*. It investigates a novel VR mindfulness-based intervention that is designed for cultivating greater interoceptive awareness. While this VR application currently runs only within a lab, it is the necessary first step before extending to a remote delivery format.

3.2 Background

VR is a powerful computing platform for creating multi-sensory and embodied user experiences [126]. Immersive technologies with sufficient fidelity can produce signals through visual, auditory, haptic, and other channels that create a sense of presence, i.e., "the strong illusion of being in a place in spite of the sure knowledge that you are not there" [142]. Similarly, VR can produce illusions of inhabiting a different, virtual body. When participants see a virtual body in a mirror and learn that it moves in correspondence with their own, they respond as if it were their own [54]. The powerful body-ownership illusion has even been explored as a strategy for fostering empathy for people of a different gender [144], race [90], age [6], or ability [116]. Such illusions are widely utilized. In fact, the degree to which they succeed is often utilized as an important overall metric of success for VR experiences.

By contrast, our motivation is to explore the potential for VR to facilitate looking inward to develop a deeper awareness of our own, real bodies – captured by the phrase, *Inward VR*. In this respect, investigating how VR can cultivate awareness of the condition's inside the body as opposed to evaluating how well it can transport us to new places and different bodies becomes an important metric. This is where interoception research intersects with VR applications. Interoception refers to "the process by which the nervous system senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the body's internal landscape across conscious and unconscious levels" [74]. The term, interoceptive awareness, describes the different aspects of interoception that a person can consciously self-report, an important skill that can, for example, help us process feelings in real-time [119], enhance our ability to self-regulate [121], reduce depressive symptoms [39] and modify behavior [120]. Interoceptive awareness serves as a basis for mind-body interventions for multiple clinical conditions, including pain, PTSD, depression, and eating disorders (see [96] for an overview) and is, therefore, relevant to many VR applications. If we could reliably measure the various dimensions of interoceptive awareness produced during VR experiences, such measures could provide invaluable design guidance, similar to measures of presence or body ownership, but specific to Inward VR.

One of the most widely used self-report measures of interoceptive awareness outside of VR research is the Multidimensional Assessment of Interoceptive Awareness (MAIA) [98, 100]. The MAIA self-report measure has, to date, been translated into more than 25 different languages and been subjected to a multitude of studies investigating both criterion and construct validity in varied populations (e.g., community, clinical, higher education settings) around the world [147]. Despite the wide application, we have been able to identify only three prior uses of the MAIA within a VR context [65, 114, 29]. Our approach builds upon this early work, which concluded, in one of the studies [65], that interoceptive awareness improves VR experiences. Unlike the prior work, we designed the environment to include an avatar, virtual mirror, and inverse kinematics to drive the avatar's torso and limbs in a physically plausible manner based on the head and hand tracking data available via today's typical VR devices, and as part of the orientation to the environment, the participants are guided to move in ways that reveal how the avatar responds in correspondence with their own body movements. We believe these differing design decisions will be significant in terms of their impact on interoceptive awareness, but the research is at such an early, exploratory stage that we hesitate to suggest how. With so few precedents, we reason that a theory-driven qualitative methodology that aligns with the underlying conceptual model of the MAIA but departs from the specific questionnaire and subscales, some of which were found to not factor significantly into understanding the VR experience [65], is a valuable next step for this emerging research area.

To this end, this chapter makes two main contributions:

- A qualitative methodology, including a reusable codebook, for applying the five dimensions of the MAIA's *underlying conceptual framework* to understand users' experiences of interoceptive awareness in VR.
- The design, results, analysis, and discussion of an exploratory study (n=21) that applied this qualitative method to understand participants' experiences of interoceptive awareness within a custom-designed immersive, stereoscopic, perspective-tracked VR environment that implements a guided body scan exercise with an interactive visualization of a biometric signal detected via a heartbeat sensor.

We believe this methodology and study represent the first attempts to qualitatively investigate a multi-dimensional model of interoceptive awareness in VR.

3.3 Developing a Qualitative Method for Investigating Interoceptive Awareness in VR

This section describes the process of developing a codebook to assess users' experiences of interoceptive awareness in VR. The rationale is that we do not yet have a strong scientific basis for understanding what makes immersive computing work for interoception specifically and, hence, no way to optimize the VR technologies for success. Developing this codebook is a first step towards establishing additional methods and tools to assist in this emerging research area within VR.

3.3.1 Codebook Development

The codebook for this study was developed using a multi-step process consistent with typical codebook development [22]. We utilized a theory-driven (deductive) methodology with a phenomenological orientation. This subsection explicates each step of the process so that others could replicate this process in devising their own codebook or refining our existing codebook. The first step began with understanding the research question and the target population. Given our topic of interoceptive awareness, we devised our research question as broadly as possible since there was little prior VR research in this topic area. We formulated our question as: "What are users' experiences related to interoceptive awareness when using a novel mindfulness VR environment?" Our target population was conceived of in terms of casting a wide net, within our time and resource constraints, to ideally include individuals with a range of demographics and prior experience with VR and meditation. The next step involved a series of discussions with a multi-disciplinary group regarding the theoretical frameworks relevant to interoceptive awareness. The discussions involved examining the existing literature and theories, surfacing questions and providing recommendations and rationale for a proposed approach to our exploratory user study. Through discussions, we arrived at utilizing the conceptual framework underpinning one of the most widely used self-report measures of interoceptive awareness (i.e., the MAIA) [100] because from the conceptual framework we could explore nuance through interviews to uncover new associations between concepts, raise novel questions and re-examine assumptions that would otherwise remain hidden by simply administering standardized items to our sample. Our third step was to develop deductive code groups (parent nodes) for each of the five dimensions of the MAIA conceptual framework. This step took considerable time as we revisited the original literature about the MAIA [98] and then proposed possible operational definitions for each code that would be meaningfully relevant to exploration of interoceptive awareness in VR - see the additional material in Appendix C for the original definitions and our operational definitions. Our fourth step involved application of the codes to actual interview transcripts in order to ensure there was a shared understanding of scope, applicability and meaning. This step pushed us to refine some of our operational definitions to ensure consistent coding within a team. For example, we refined the definition for the concept of “capacity to regulate attention” to emphasize that it was a skill (i.e., requiring intention and effort) and not a response (i.e., an outcome or effect of something that was noticed), which helped us to make meaningful distinctions among an adjacent dimension of the MAIA. Next, we developed positive and negative examples to aid our team in applying codes to the interview transcripts. Finally, we undertook a process of coding individually and then checking in to uncover and resolve inconsistencies in coding and to enhance reliability. Figure 3.1 depicts our coding tree that is derived from the codebook. The more detailed codebook used in this study is included as additional material in Appendix C for other researchers to reuse or further refine for future studies investigating interoceptive awareness.

3.3.2 Interview Schedule

The interview schedule (Table 3.1) consists of three parts, each covering an aspect of interest related to a participant’s interoceptive awareness experience: starting with open-ended questions related to overall impressions, progressing to more focused open-ended questions related to typical characterizations of embodiment in VR, then exploring technical features of the virtual environment in relation to body awareness, and concluding with an open-ended catch-all inquiry. This

Question	Probe Questions
What was your experience like in the VR session?	What did you think of it? What did it feel like?
To what extent did you feel like you were really the person on the bench in the VR session?	What are the things that made you feel this way? Are there specific things that you experienced that contributed to feeling like you really were the person on the bench? Are there specific things that you experienced that detracted from feeling like you really were the person on the bench?
Let's talk a little bit about what you experienced or felt in your body during the VR session... To what extent were you able to focus your attention on body regions that were illuminated during the session? What did you think of seeing your reflection in the mirror? To what extent did you feel like it connected you to your body or didn't? What did you think of the glowing of each body part? To what extent did you feel like it connected you to your body or didn't? What did you think of the pulsing of each body part? To what extent did you feel like it connected you to your body or didn't?	Can you tell me more?
Is there anything else that you think is important for me to know about your experience?	

Table 3.1: Interview Schedule

interview schedule was pilot tested prior to conducting actual interviews.

3.4 Applying the Methodology in a First Experiment

This section describes the virtual environment, hardware and procedures used to apply the methodology described in Section 3.3. The study was conducted from August 2022 to September 2022 and is reported following the COREQ (Consolidated Criteria for Reporting Qualitative Research) checklist [149] - see the additional material in Appendix C. The University of Minnesota's Institutional Review Board approved this study.

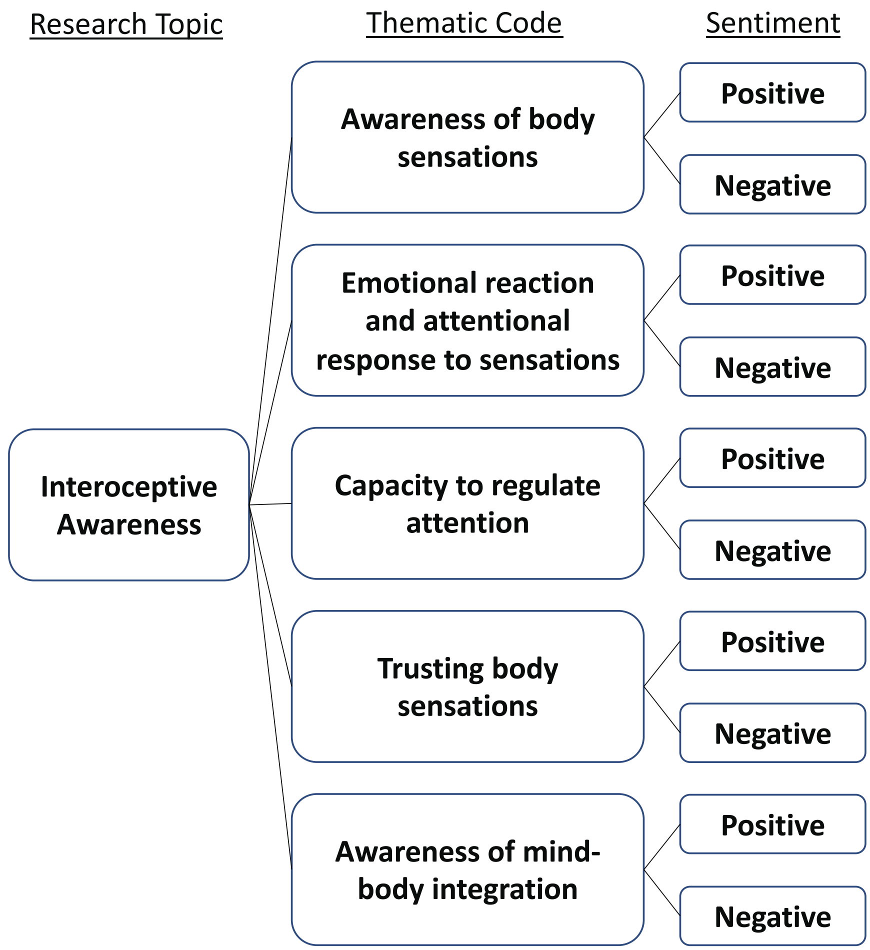

Figure 3.1: Code tree

While mindfulness-based interventions that include a body scan exercise similar to the one used in this study have been found to be relatively safe [161], this study incorporated several intentional safety measures. First, I discussed with each participant the risk of feeling uncomfortable (i.e., physically or emotionally) and provided instructions on what to do in such an event. Second, my colleague Alex Pelletier and I monitored all participants during the VR session for signs of distress. I have extensive formal training in safety protocols and procedures for mindfulness-based interventions. Third, the virtual environment was intentionally designed to incorporate safety practices, including an orientation phase involving

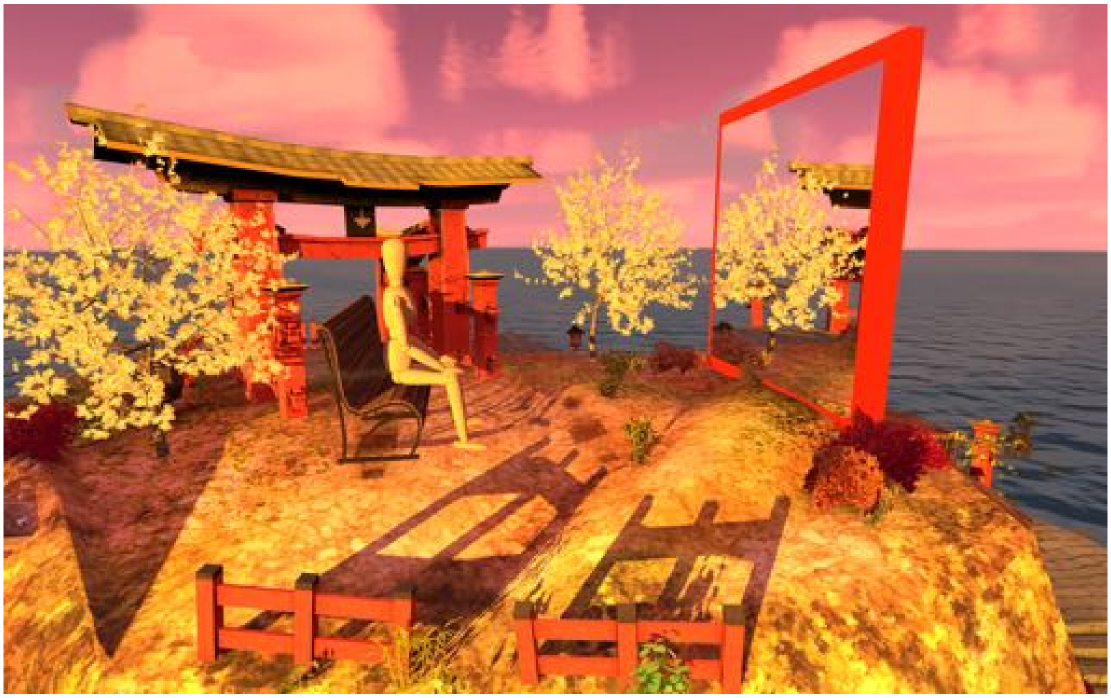

Figure 3.2: Virtual environment selected and modified for the mindfulness exercise.

movement, guided instruction on what to do in the event of distress, and use of a shorter duration body scan exercise.

3.4.1 Virtual Environment, Hardware and Task

The virtual environment is built upon the Unity Game Engine to run on head-worn commodity VR displays that support perspective-tracked, stereoscopic vision, such as Meta's Quest 2. While immersed in the environment (See Figure 3.2), users wear the headset, including headphones for spatial audio, and hold a controller in each hand. One input device is added to this standard configuration, a heartbeat sensor secured via an elastic strap and worn on the right thumb. The sensor is an ICube-X Biobeat v2.1 attached to an ICube-X WiDig v8.02 running firmware v8.11 that uses ICube-X's iConnect to send the heart rate data in the form of MIDI values via USB directly to the Unity application running via Oculus Link (wired mode) on a VR-capable laptop (Gigabyte G5 KD: Nvidia GeForce

Figure 3.3: Blue tint depicting the pulsing of the user's heartbeat. Currently, the user is being asked to focus on their chest.

RTX 3060, 16GB DDR4 RAM, Intel Core i5-11400H), which exceeds Meta's recommended specifications for its Link compatibility. The Link mode is utilized, as opposed to deploying a standalone app to the device, because we found during pilot testing that having an on-laptop display that mirrors the viewpoint of the participant was useful for research staff to be able to visually confirm participants are oriented correctly in front of the virtual mirror within the environment prior to beginning the VR exercise.

The virtual environment conveys a peaceful garden (modified "Japan Environment Pack – Zen Garden" by Level One Games, Unity Asset Store), where a sitting meditation might be practiced in proximity to a body of water, as blue spaces, albeit virtual in this case, have been shown to have a positive impact on emotion [11]. The user is represented within the scene via an avatar. Researchers have identified a link between virtual embodiment and interoceptive awareness [29];

thus, the design of the avatar and its movement are likely to be important considerations. Avatars could be highly personalized and photorealistic, potentially even created “just-in-time” (e.g., from 3D scans of users [36]), or they could be abstracted to varying degrees. Our design samples one point in this design space. Our requirements were that the avatar should: (a) have recognizable human body parts (to facilitate feedback during a body scan exercise), (b) be sufficiently abstracted to avoid uncanny valley effects [136], (c) be androgynous, (d) have a natural aesthetic (e.g., non-metallic, non-robotic), (e) be textured (to facilitate depth perception) but subtly so, such that patterns and colors of clothing would not be viewed as in conflict with participants’ own clothes, and (f) avoid cultural references to popular games or movies (e.g., in testing, we found abstract blue avatars elicited comparisons to movies). We reasoned that an artist’s drawing mannequin made of jointed wooden body parts (modified “Realistic Mannequin Doll Character” by Bevans Media, Unity Asset Store) meets these criteria. Within the environment, the avatar is seated on a bench (modified “Bench” by IL.ranch, Unity Asset Store), facing a mirror. Each participant has an identical avatar and the height of the virtual bench is adjusted for each participant during orientation so that the avatar appears seated comfortably on the bench. The avatar’s head, hands, arms, and torso are controlled via inverse kinematics (“Final IK” plugin by RootMotion, Unity Asset Store) to move in a physically plausible manner given the six degree-of-freedom tracking data reported by the device, which is available only at the location of the head and the hand-held controllers. From the user’s seated position, they may comfortably observe their movements in the virtual mirror.

With regard to the avatar’s movement, there is a clear design tradeoff with respect to the realism of the motion and the customization or sophistication of the tracking systems required. Our design is motivated by a desire to leverage the newfound availability of low-cost, commodity devices, which limits the available six degree-of-freedom tracking data to the head and two hands. We have added one sensor (heartbeat) to this standard – we justify this because some form of interactive biofeedback seems essential to exploring an interesting point in the design space. However, we stopped short of additional customization that may well impact users interoceptive awareness. For example, additional commodity-grade six degree-of-freedom sensors could be added to the feet or more sophisticated full-body tracking solutions could be incorporated. Likewise, additional biometric sensors (e.g., respiration, neural activity) could also be incorporated. A systematic exploration of the design space of possibilities is needed.

Similar to reports from related work [63], early pilot testing confirmed the importance of providing users with a gradual introduction to the environment and a moment to orient themselves. Without this initial orientation, users reported feeling some base level of anxiety going into the meditation, stemming from the lack of knowledge and familiarity of their new environment and avatar. Thus, upon entering the environment, users are invited to look around at the scenery, recognize that they are safely seated on an island and invited to wave their arms in front of the virtual mirror. After this, they engage in a pre-recorded guided body scan exercise that includes safety reminders and follows a standard progression [72] – from the feet, to the lower legs, and so on, moving up through the body. The goal of a body scan is to feel the body instead of think about it [72], which is associated with enhanced interoceptive awareness [158], and the script utilizes best practices to promote this.

The most critical design decision within the environment is to visualize the interoceptive signal from the heartbeat sensor as an exteroceptive visual change in the avatar. Specifically, the heartbeat signal, with a subtle smoothing applied via a weighted average over a sliding time window of ten seconds is mapped to the intensity of a blue tint applied to the body part(s) where the user is instructed to focus. The technique results in a blue pulse with a frequency that matches the user's current heartbeat.

3.4.2 Participants

Participants were recruited via convenience sampling through personal and professional networks using email and Slack. Convenience sampling was selected given the exploratory nature of the study and time and resource constraints, which is consistent with rationale for using a convenience sampling method [33]. The inclusion criteria for eligibility in the study were: (1) 18 years of age or older, (2) able to communicate in written and spoken English, and (3) normal or corrected vision using glasses or contact lenses. The exclusion criteria were: (1) pregnancy or (2) a history of epilepsy, seizures or severe motion sickness. 25 people expressed interest in the study based upon recruitment efforts, of whom one (4%) did not respond to a study staff scheduling email, and three (12%) subsequently canceled after expressing that they were no longer interested in the study, leaving 21 individuals who volunteered for participation and satisfied the eligibility criteria. Recruitment was stopped when a priori thematic saturation [133] was reached as all interoceptive awareness themes were exemplified in the data gathered from interviews. 20 participants received an e-gift card worth $15, while one participant received two e-gift cards worth $10 each.

3.4.3 Procedure

The 21 participants who were interested in the study and met the eligibility criteria (see above) were invited to the laboratory where informed consent, including permission to record the interview, was obtained by research staff. Participants were given a brief overview of the VR hardware (Meta Quest 2), the headphones (Anker Life Q30), the heart rate monitor (I-CubeX BioBeat v2.1) and the roller chair (Herman Miller Aeron) used during the VR session (See Figure 3.4). The 12-minute VR session was then started for each participant while research staff monitored for any technical or safety issues. Immediately upon conclusion of the VR session, research staff assisted the participant in removing the study equipment. The participant was then invited to complete a brief questionnaire to collect information on demographics and prior experiences with VR and meditation. After turning in a completed questionnaire, research staff confirmed the participant's email address for receipt of an Amazon.com e-gift card. The last step of the study was to conduct the interview with research staff.

All interviews were recorded and conducted face-to-face by me (a man) between

Figure 3.4: Seated posture with VR and heart rate hardware. Inset: A closer view of the heart rate sensor worn while holding a standard VR controller/tracker.

August 2022 and September 2022 and took place in the University of Minnesota's Interactive Visualization Lab in Minneapolis, MN (IV Lab). I work as a researcher on a clinical research team and am a PhD candidate in Cognitive Science, currently hold an MS in Cognitive Science, and have received training in qualitative research methodology from senior qualitative researchers with extensive experience in large-scale, mixed methods studies. Besides the participant and me, the only other person present in the IV Lab was my colleague Alex Pelletier, who was responsible for the technical implementation of the VR session immediately prior to the interview. The interviews lasted between 4 and 15 minutes. All interviews used a semi-structured technique to explore participants' experiences relevant to interoceptive awareness during the VR session. No field notes were taken. Most participants (12/21, 57%) knew me prior to the study from a professional or personal context and that the study involved VR, which was known to be an aspect of my PhD work. Nothing was known by or communicated to participants about the use of the MAIA conceptual framework or interoceptive awareness.

3.4.4 Data Analysis

We used descriptive statistics to summarize the demographic characteristics as well as prior experience with VR and meditation. Interviews were audio recorded and transcribed. We used a modified framework method [45] to analyze the interviews. Two members of the research team (my colleague Don Thorpe and I) independently coded all 21 transcripts using the codebook developed prior to analysis – see the additional material in Appendix C for the codebook. After independent coding, Don and I met to compare, discuss and resolve any discrepancies in coding through a detailed discussion of seven selected transcripts (representing 33.3% of the transcripts). All coding was conducted in QSR NVivo (Release 1.7) and participants were not given an opportunity to check their transcripts or provide feedback on findings. Theme frequency across all interviews reported by case was calculated and described. NVivo software also allows researcher-assigned sentiment scoring, which Don and I conducted through textual analysis and classifying positive or negative sentiments to the MAIA themes that had been coded. Sentiment frequency by theme across all interviews was calculated and described.

3.5 Results

A total of 21 participants consented to participate in the study and successfully completed the VR Session. Demographics and prior experience with VR and meditation are presented in Table 3.2.

Parameter	Enrolled Participants
Participants, n	21
Age, mean (SD)	41.8 (18.7)
Gender, n/d (%)*	
Men	10 (47.6%)
Women	11 (52.4%)
Non-binary	1 (4.8%)
Race, n/d (%)*	
White	14 (66.7%)
Black or African American	3 (14.3%)
American Indian or Alaska Native	2 (9.5%)
Chinese	1 (4.8%)
Asian Indian	1 (4.8%)
Vietnamese	1 (4.8%)
Hispanic ethnicity, n/d (%)	
None	20 (95.2%)
Mexican, Mexican American, Chicano	1 (4.8%)
Prior experience with VR, n/d (%)	
Never	7 (33.3%)
Some (1 to 20 times)	10 (47.6%)
Lots (more than 20 times)	4 (19.0%)
Prior experience meditating, n/d (%)	
Never	2 (9.5%)
Less than 5 hours total	3 (14.3%)
Between 5 and 20 hours total	8 (38.1%)
More than 20 hours total	8 (38.1%)

* Participants indicated multiple choices

Table 3.2: Demographics and characteristics.

3.5.1 Interoceptive Awareness Themes

All interviews were interpretable and able to be analyzed in NVivo. No repeat interviews were needed. Results of the interview analysis are described below and organized under each of the five dimensions of the MAIA conceptual framework in order of most frequent to least frequent by case to facilitate a more nuanced discussion of each interoceptive awareness theme. Table 3.3 presents the frequency of themes across all interviews reported by case.

Theme	Frequency
Capacity to regulate attention	21 (100%)
Awareness of mind-body integration	20 (95.2%)
Emotional reaction and attentional response to sensations	20 (95.2%)
Trusting body sensations	17 (80.9%)
Awareness of body sensations	16 (76.1%)

Table 3.3: Theme frequency by case.

3.5.2 Capacity to Regulate Attention

From the codebook that was developed, capacity to regulate attention refers to controlling attention (i.e., a skill) by sustaining awareness of, directing attention to, narrowing or widening attention of, or allowing attention of body sensations in connection with the VR session. Although differences were reported among participants regarding the degree of their capacity to regulate attention, some common categories of experience emerged that shed light on aspects of the VR session that impacted this dimension of the MAIA conceptual framework. Specifically, participants reported attentional conflict between interoceptive and exteroceptive signals during the early parts of the VR session. The gradual use of a wider attention to simultaneously feel body sensations while receiving the visual attention cues in the VR environment was helpful for preventing a wandering mind during the VR session.

The most common participant report for this theme was feeling conflicted about noticing the main exteroceptive signal in the VR session (i.e., the body part of the avatar that pulsed in response to the participant's heartbeat and the guided audio of the meditation) and sustaining attention on the felt-sense of their body during the initial portions of the VR session.

"I felt some conflict between, you know, trying to notice body sensations versus kind of watching what was happening in the mirror." – Participant 8

Part of the challenge of sustaining attention to the multisensory experience (i.e., combination of exteroceptive and interoceptive modalities) was the novelty of the experience and the tendency to want to close the eyes to listen to the audio guidance.

"It was sort of interesting, like, meditating with my eyes open, but it was new to me" – Participant 5

"My mind wandered a fair bit mostly, I think, because of the novelty of the environment. If I'd only been able to close my eyes after seeing a part of my body light up and stick with that." – Participant 13

After struggling with the attentional conflict for a while in the VR session, many participants described using the strategy of widening attention to feel less conflicted and reported an ability to sustain awareness of the multisensory experience.

"But eventually I was like, 'oh, I should just soften my gaze' because when I do meditate with my eyes open it's a pretty soft gaze at what's in front of me. So when I softened my gaze I was like, 'oh, I can still see the body lighting up there but I can much better feel what's going on internally.'" – Participant 16

"And then at the end when you did the whole body, I also noticed my body was also lit up and that congruence, I think, was also easier to with my eyes open, to go, 'oh yeah, this is kind of okay,' so that was a nice visual prompt." – Participant 20

Many participants reported that the pulsing of the avatar (i.e., the interoceptive heartbeat signal remapped to an exteroceptive visual signal) was helpful in preventing their attention from wandering away from noticing their body.

"Because there is flashing light, I think that's the only thing going on inside the environment, my attention got attracted by that very naturally, otherwise I would, I might get distracted more like by the smoke or the sea water that is fluctuating, or like the, that tree that is moving and leaves dropping down to the ground, but with the flashing body part I felt like I'm, my attention got attracted more." – Participant 3

Across all participants, 57 sentiments were coded as relating to the capacity to regulate attention theme. The sentiment analysis for this MAIA theme revealed that participants overall had positive experiences (41/57, 71.9%) related to controlling attention within the VR session versus negative experiences (16/57, 28.1%).

3.5.3 Awareness of Mind-Body Integration

Awareness of mind-body integration refers to body sensations related to awareness of an emotion, using a self-regulating skill or feeling embodied in connection with the VR session. The key aspect of this thematic domain is that a participant reports something that indicates greater access to more developed levels of body awareness (e.g., the participant reports a nuanced understanding of the mind-body interaction such as being aware of how tightness in the chest is connected to feeling anxious or how slowing down respiration can lead to feeling relaxed through the whole body). This thematic domain also encompasses the feeling of being embodied versus feeling disconnected, dissociated or distant. While the specific details of a participant's mind-body experience showed variation, there was considerable convergence on two key areas: the responsiveness of the avatar's tracking being representative of feeling embodied, often in relationship to the virtual mirror, and a mismatch between the avatar's pose and a participant's self-contacts leading to feelings of disconnection.

In terms of the avatar's responsiveness, participants reported feeling more connected to their body (and at times even surprise) when the inverse kinematics was highly tuned to the participant's movement. Conversely, if there was a lack of attunement to physical movements, then the participant reported disconnection.

"Being able to see like my arms moving in relation to my actual body and my head, like cracking my neck to the avatar cracking its neck, that was like, 'OK, that's cool!' " – Participant 1

"At first when you're just sort of there and you're not really sure what's going on, but then to kind of see yourself move in the mirror, it's a little bit easier to kind of connect with your body." – Participant 11

"It definitely felt like I was in a mirror just like a mirror. I was paying attention to my body. I was actually the character in the mirror. What took away from it

was not having my feet move when I was focusing on them. I moved my foot and it didn't move." – Participant 13

"It would be good if you guys had foot monitors too so that you could move everything, you know, beyond your, you know, beyond your arms and and your head. Because I kind of knew that I was half of the person on the bench, so to speak, you know." – Participant 19

Participants strongly expressed how if an aspect of the avatar was in conflict with their own proprioceptive sense, then they felt disconnected (i.e., disrupting awareness of the mind-body integration)

"The only other thing is immediately when I got in, when I was prompted to look down, I did feel a little off because it didn't feel like my body. I felt like my, uh, like it didn't, not that it didn't feel like my body, it just felt like that's not where my butt would be if I was sitting, so it didn't feel proportional and that kind of threw me, so I didn't bother looking down much after that." – Participant 4

"Actually, looking at the mirror makes me feel like I'm more connected to the virtual character because whenever I look down at the bench, I can notice like the height difference, like I notice that the bench is not on the same level, the virtual bench is not on the same level as the actual chair I'm sitting on, so the mirror is quite helpful." – Participant 2

"Yeah, so I did notice at one point where I'm watching it and I, you know, my hands are resting here, but the person there, their hands are up like that and that distressed me." – Participant 12

"I was aware in the visual of minor things about the avatar that were not descriptive of my experience. The biggest one that I was noticing being that my hands are resting on my legs and in the avatar's image they were floating above the leg." – Participant 8

Across all participants, 63 sentiments were coded as relating to the awareness of mind-body integration theme. The sentiment analysis for this MAIA theme revealed that participants reported approximately balanced positive (28/63, 44.4%) and negative experiences (35/63, 55.6%), with slightly more negative sentiments, related to awareness of mind-body integration during the VR session.

3.5.4 Emotional Reaction and Attentional Response to Sensations

Emotional reaction and attention response to sensations is defined as an affective response (e.g., bothersomeness or pleasantness) or attentional response (e.g., suppressing, ignoring, avoiding, distracting, narrating, judging, analyzing / proliferating, or mindfully noticing) to body sensations in connection with the VR session. The key element of this dimension is the response to body sensations, which refers to an effect or outcome related to what was being noticed in the body. Within this thematic domain of the MAIA conceptual framework, participants mostly reported feeling calm and comfortable, however, there were two deviant reports (i.e., atypical, contradictory to other reports) that highlight significant amounts of anxiety about the VR session and that felt similar to the participant's past experience.

The most common condition for a feeling of comfort arose when a participant noticed something representative of their internal felt-sense experience that was reflected in the environment. This elicited an affective response. This process represents a complex interaction of an interoceptive signal being remapped to an exteroceptive signal, which then elicited an embodied emotional response.

"But when you see the entire body, as a pulsing, radiating light, that makes more sense to the way that I view who we are as spirits. And so, like, that was comforting." – Participant 4

"Like the blue light going up and pulsing, and I thought, 'I think that's my pulse' and that was very comforting. I just thought maybe I could slow down my pulse during this." – Participant 10

Although most participants reported feeling calm or comfortable during the VR session, there were two reports of feeling anxious.

"I got a little stressed out personally, but I always get stressed out in VR just 'cause I'm like, 'I feel like there is something going to pop up at, like, out of the corner, like a jumpscare.' I always feel like that, but other than that it was nice."

– Participant 7

"I'm a generally claustrophobic person and I was like, 'huh, this is kind of anxiety inducing' and then I felt like I was supposed to sit still and I did, but when the parts of the body started blinking, they blinked really quickly and it made me on edge, like I felt when it was on the neck, 'is my head going to explode?' Is that, and I kind of just got pretty distracted. I've always been really bad at meditation apps and I've spent a lot of time and I just wanted to make it work for me with meditation apps, but they never did, they always increase my heart rate and always make me pretty anxious and this was no exception, except that I kind of felt like I couldn't close my eyes because I was supposed have them open." – Participant 13

Across all participants, 50 sentiments were coded as relating to the emotional reaction and attentional response to sensations theme. Similar to the prior theme, sentiment analysis for this MAIA theme revealed that participants reported approximately balanced positive (29/50, 58%) and negative experiences (21/50, 42%), with slightly more positive sentiments, related to emotional reactions and attentional responses to sensations during the VR session.

3.5.5 Trusting Body Sensations

Trusting body sensations encompasses the importance of body sensations as helpful in making a decision or in considering an aspect of health in connection with the VR session. This dimension includes feelings of trustworthiness and safety related to bodily experiences. Within this thematic domain, participants commented on either aspects of their bodily experience that led them to decide the VR session was not plausible because it was incongruent with what they knew of themselves or it prompted them to want to act to correct something health-related.

With respect to incongruence, some participants noted the abstract, non-representativeness of the avatar (e.g., gender, morphology) as being important regarding decisions about the avatar and its trustworthiness of experience.

"I was not the person on the bench. Uh, but I did feel like, especially because I don't look anything like that, absolutely not, but it felt more like a reflection

of where I needed to be rather than being me. You know, I kind of, like I said, would've liked it to look like me, but no it was just somebody meditating and encouraging me to meditate or to sit." – Participant 15

"I mean in terms of the person on the bench, I did kind of notice a sort of gender neutral thing. I felt like I fit in as a woman, you know, it just, you know, not that that mattered that much but I noticed it." – Participant 21

"The pelvis was a little too tall and the abdomen was a little too high, too small and that slightly jolted me out of it, especially when it was blinking and I was like, 'this is supposed to be the big like breathing portion and it feels like just like the bottom rib' and I could feel my stomach coming in now and the avatar was not reflecting that, that was a thing." – Participant 13

When participants noted something that was physically difficult, they would trust the assessment of their bodily experience and then act to try and mitigate the impact.

"I think the headset is heavy and I think, like you know, like we tried to adjust it a little bit, it didn't quite fit, kind of slid around so I think, that like, that's one element that takes you out of it a little bit, like you're, you're kind of thinking about like 'is this right?' Or do I need to adjust it?" – Participant 9

"When we were concentrating on what part of the body, that like there was flashing on it and then at one point I had to close my eyes because the flashing was intense and that kind of bothered my eyes." – Participant 18

Across all participants, 27 sentiments were coded as relating to the trusting body sensations theme. The sentiment analysis for this MAIA theme revealed that participants had more negative experiences (19/27, 70.4%) than positive experiences (8/27, 29.6%) in the VR session related to trusting body sensations.

3.5.6 Awareness of Body Sensations

Awareness of body sensations is defined as awareness of negative, positive or neutral body sensations in connection with the VR session. This dimension taps into more of the bare noticing of bodily experience (e.g., I notice tension, changes in my breathing, or feeling easeful). Participants reported many different dimensions of bodily sensations that they noticed during the VR session. The most common experience related to a more refined noticing of an internal bodily experience, whether it was positive, neutral or negative.

"If I were to kind of replay my experiences from the feet was just like, 'oh yeah, I'm checking in. Oh yeah, right, how do the feet actually feel?' And then when I got to my calves, or my lower legs, I realized I have pent up energy I want to expend." – Participant 4

"I felt like when I would start focusing on that body part I could feel like my heart beating through that body part and sometimes the pulsing in the VR would match up with it." – Participant 17

"My biggest challenge was I had a little bit of trouble staying awake. My eyelids were getting really heavy." – Participant 6

One often reported bodily sensation was the challenge of comfortably breathing during the VR session while wearing a mask and feeling the weight of the headset against the nostrils. This was a unique experience given that it relates to the temporary procedures used to mitigate the risk of COVID-19 exposure.

"The only problem that I had was wearing this mask and then the breathing. It was, and because the headset was kind of pushing down on my nose, it was a little difficult sometimes to concentrate." – Participant 18

"You know, COVID makes it difficult because I'm wearing a mask and I have the headset on and towards the end I was, you know, I felt my breathing a little bit labored just because of wearing the mask and having this thing on my head." – Participant 19

Across all participants, 28 sentiments were coded as relating to the awareness of body theme. The sentiment analysis for this MAIA theme revealed that participants had more negative experiences (17/28, 60.7%) than positive experiences (11/28, 39.3%) in the VR session related to awareness of body sensations.

3.6 Discussion

In response to the noted attentional demand (section 3.5.2 above), research focused on interoceptive awareness within VR would benefit from reducing the exteroceptive cognitive load, primarily visual demand. For example, multiple participants noted that the animated fog was distracting when in the VR session, and by minimizing these features, especially in the acclimation period, the interoceptive sensations can be situated more in the forefront of the participant's awareness. Importantly, despite the visual stimuli being the primary source of distraction, it also played a significant role in promoting a positive affective response (e.g., a sense of calm due to pleasant scenery). Finding a balance of including pleasant surroundings to increase positive affect without the element of distraction will be key moving forward. A potential solution to decreasing visual attentional demand and cognitive load while promoting positive affect is to incorporate non-distracting stimuli from other senses such as audio of the waves and surrounding environment to rely on a different sensory channel. Alternatively, Shroeder et al. clear the virtual scene to show only a black background and then slowly reveal portions of the virtual environment, one by one [135]. Minimizing the visual burden could also function in another capacity to lessen the perceived desire of individuals to close their eyes to facilitate concentration, although Heeter suggests to simply embrace directing users to close their eyes during strategic portions of a VR exercise [62]. A more intentional design to an environment may prove beneficial for an individual's ability to feel immersed and stay focused.

The ability to feel completely immersed in the VR environment and embodied as the avatar relied heavily on three aspects: how well the avatar's movement reflected their own, how well the avatar was calibrated (e.g., viso-proprioceptive matching), and whether the avatar was scaled appropriately, all findings that agree with prior research on VR embodiment [54, 10, 29]. Maintaining embodiment could be achieved by ensuring the activity is designed with the available technology in mind (only focus on upper extremity if lower extremity does not reflect movement), or adapt technology to this need (include more motion sensors, better calibration and appropriate scaling to increase the embodied feeling). Either way, the movement, pose and size of the avatar must reflect the movement, pose and size of the individual in order to achieve greater embodiment. Participants relied heavily on their own experience, and trusting their felt sense of their body, and there seemed to be only a small window of error that was acceptable before an individual would feel less immersed.

Results also indicated that individuals may benefit from an initial screening that would help identify those that have a proclivity for anxiety or traumatic responses that could be triggered through the VR experience. Research tailored to the needs of these individuals, as well as those suffering from other mental health conditions, could be an avenue for future research. Furthermore this screening would ensure that the technological hardware (e.g., headset, heart rate monitor) is appropriate for the individual. Some users found the equipment did not fit correctly, and it decreased their ability to hold attention or feel immersed in the experience.

Methodological considerations were also evident. The five themes adapted from Mehling's MAIA lacked a robust quality when applied to VR experience. There was substantial overlap between some codes, namely Awareness of Mind-Body Integration/Trusting Body Sensations and Awareness of Mind-Body Integration/Capacity to Regulate Attention. Future research could benefit from further refinement of these concepts in VR via an inductive (data-driven) approach, which would increase the ability to differentiate themes of interoception. Additionally, future studies could consider cross-walking Mehling's work with more recent work focused on developing a more precise taxonomy of interoception that teases out clearer distinctions (e.g., attention, detection, magnitude) [74] while simultaneously keeping the flexibility of allowing for emergent themes via analyzing raw qualitative data (i.e., a data-driven approach to code development).

By reporting our process and findings according to the COREQ checklist, we hope that we have made aspects of our team, methods, and findings more transparent.

3.7 Limitations and Future Work

Artists and designers can make valuable contributions to VR research, and our preference when creating VR experiences, like the one used for the experiment, is to custom design each visual and interactive aspect of the environment. For the experiment described here, it is true that the VR experience was designed specifically to include an avatar, inverse kinematics, and a virtual mirror effect, which matches many of the suggestions from Döllinger et al. [28] about how VR can support the cultivation of mindfulness. However, due to expediency and resource constraints as well as our primary focus on testing a novel qualitative methodology, a number of tradeoffs were made, including (a) not scaling the avatar to a participant's height, (b) not using full-body tracking or motion capture to address viso-proprioceptive mismatches between the avatar and the participant, and (c) incorporating 3D models and visual effects from Unity's Asset Store. We can trace each comment by participants that relates to being distracted by an aspect of the environment back to this tradeoff between creating a custom-designed versus a more rapidly designed environment. In other words, we are confident that a process of iterative design and critique with, for example, an interdisciplinary team of artists, game designers, technologists, and clinicians, would catch and resolve the type of distractions noted in these comments. Such careful design requires a level of effort and resources that is not always possible or appropriate for certain VR applications. Our insight from the experiment is, thus, that this effort is especially important in Inward VR contexts.

While mindfulness-based interventions are generally considered safe [161], researchers that incorporate mindfulness exercises into VR should ensure adequate safety measures are considered and implemented. Even with the intentional safety measures included in our study (e.g., discussion, observation, researcher training, and safety instructions in the VR environment), two participants reported feeling anxious during the 12-minute VR session. More research is needed to address potential negative emotional experiences while in VR as well as the potential for hardware and software solutions that can automatically adjust the VR environment depending on distress cues (e.g., dilated pupils, rapid heartbeats).

We expect alternative techniques for mapping an interoceptive signal (e.g., heartbeat) to an exteroceptive signal (e.g., visual pulsing of body region) to influence users' experiences of interoceptive awareness. We cannot be certain that the straightforward mapping utilized in the experiment is a good one, as we do not know how it compares to alternatives that sense other or additional signals or that utilize other channels (e.g., haptic, auditory) to convey the signal(s) back to the user. The question of how representational versus abstract (or even ambient) such feedback should be is also likely to be important. The clear direction for future work is to utilize the methodology to conduct follow-on comparative studies to better understand these key design decisions.

Our codebook can be further refined by adopting an inductive (data-driven) approach in addition to the deductive (theory-driven) approach used in this chapter. Such a dual approach may facilitate further differentiation between existing MAIA dimensions.

3.8 Conclusion

This research contributes a new qualitative methodology, including a reusable codebook, for applying the five dimensions of the MAIA conceptual framework to understand users' experiences of interoceptive awareness in VR. In a first exploratory study applying the methodology, we found that the methodology is successful at eliciting valuable responses from participants across all five dimensions. In some cases (e.g., the question of eyes open or closed), responses differed from those gathered in the prior MAIA study from Heeter et al. [65], and due to the qualitative nature of the responses, we can begin to understand some of the nuances that underlie this and other questions. We believe the methodology can be successfully employed by other researchers to contribute to a growing understanding of interoceptive awareness in VR. A key next step is to conduct comparative studies needed to provide more complete design guidelines for Inward

VR application developers about the most effective VR tasks and representations of the body and body signals in order to facilitate interoceptive awareness.

While this chapter demonstrates the potential of using VR to train interoceptive awareness in a lab, it does not address the question of whether a group intervention delivered remotely could do the same. The next chapter addresses this question by assessing the effectiveness of a novel group telehealth mindfulness intervention.

3.9 Relevant Publications and Presentations

- Haley, A. C., Thorpe, D., Pelletier, A., Yarosh, S., & Keefe, D. F. (2023). Inward VR: Toward a Qualitative Method for Investigating Interoceptive Awareness in VR. *IEEE Transactions on Visualization and Computer Graphics*, 29(5), 2557-2566.

- Haley, A. (2023, March 25-29). Inward VR: Toward a Qualitative Method for Investigating Interoceptive Awareness in VR [Conference Presentation]. IEEE VR 2023, Shanghai, China.

Chapter 4

Mindfulness Training for Enhancing Interoceptive Awareness

A Secondary Analysis of a Type 2 Randomized Controlled Trial of a Community-Based Mindfulness Intervention for Increasing Physical Activity in Older Adults

4.1 Introduction

This chapter focuses on the potential of telehealth as a *critical mode of healthcare delivery*. It assesses the relative effectiveness of eight weeks of an experimental telehealth mindfulness intervention versus an active control intervention in improving interoceptive awareness outcomes. This work is the second necessary step before attempting to combine VR with telehealth in a single application for the purposes of training interoceptive awareness.

4.2 Background

Prior research has found that interoception declines with age, similar to proprioception and exteroception [73, 111]. This decline of interoceptive abilities is of particular importance given the prior research linking interoception to various aspects of cognition, such as decision-making [58, 146, 145, 19], emotional processing [146, 89, 110] and memory [47, 61, 102]. While mindfulness-based interventions (MBIs) have been shown to be helpful to multiple aspects of cognition across the lifespan [31, 159, 46], there is relatively little work investigating the efficacy of MBIs for cultivating interoceptive awareness in different populations.

There is some existing evidence for the ability of MBIs to enhance interoception in specific populations. For example, Gawande et al. studied the impact of mindfulness on interoceptive awareness in a primary care population with at least one DSM-V diagnosis (RCT, n = 136, mean age = 41.52 [SD = 12.30]) [48]. Gawande et al. found that an eight-week mindfulness intervention, compared to a low-dose comparator of mindfulness and usual care, led to a statistically significant improvement in interoceptive awareness as measured by the Multidimensional Assessment of Interoceptive Awareness (MAIA) [48]. In another study, Price et al. studied the longitudinal effects of mindfulness training on interoceptive awareness for women in treatment for substance use disorder (RCT, n = 187, median age = 35 [range 20-61]) [122]. Price et al., found that mindfulness training, as compared to a treatment-as-usual group and a health education control group, resulted in statistically significant improvements in interoceptive awareness, as measured by the MAIA, following the intervention and at month six, but not at month 12 relative to treatment-as-usual [122]. Taken together, the above studies highlight the potential of mindfulness training to enhance interoceptive awareness, however, this potential is understudied in older populations.

To address this gap, this chapter presents findings from a secondary analysis of a recently completed RCT investigating a community-based mindfulness intervention for increasing physical activity in adults ≥ 50 years of age. The aim of this analysis was to assess the relative effectiveness of mindfulness training, versus an active control, in improving interoceptive awareness in older adults. Importantly, this analysis also includes investigation of longitudinal effects at six and 12 months post-intervention. The central hypothesis is that participants receiving the mindfulness intervention would experience a greater improvement in the four MAIA subscales of interoceptive awareness, included as secondary outcomes in the RCT, at nine, 26 and 52 weeks compared with participants in the active control.

4.3 Methods

4.3.1 Study Design

This was a randomized type 2 hybrid effectiveness-implementation trial. 176 adults $\geq$ 50 years of age were randomized to either an eight-week experimental intervention (Mindful Movement) or an active control intervention (Keys to Health & Wellbeing). Data collection occurred at baseline and weeks nine, 26 and 52. The primary outcome measures of the trial related to objective and self-reported measurement of moderate-to-vigorous physical activity (MVPA). Secondary self-report measures included, among many other things, interoceptive awareness as measured at baseline and nine, 26, and 52 weeks. The University of Minnesota's Institutional Review Board approved this study (1611S99323). Additionally, the protocol for this randomized type 2 hybrid effectiveness-implementation trial was prospectively registered at ClinicalTrials.gov (NCT03929393). All participants provided written informed consent prior to enrollment in the study.

4.3.2 Population

Enrollment occurred in Minneapolis/Saint Paul, Minnesota between September 2019 and March 2022 with multiple screening visits. Enrollment was originally designed to be conducted at various YMCA locations, however, this changed with the formal declaration of the COVID-19 pandemic (see below). The inclusion criteria for eligibility in the study were: $\geq$ 50 years of age (as of date of initial screen, confirmed with date of birth); accelerometer wear time $\leq$10 hours on at least four days in a seven consecutive day period between the two baseline evaluations; self-report of <140 minutes of MVPA per week (in 10 minute bouts, in the past 3 months at initial screen and first baseline evaluation) and accelerometer recorded <100 minutes of MVPA (in 10 minute bouts, between the two baseline evaluations); independent self-ambulation (without assistance of another individual; can use mobility aid such as a cane, walker, scooter or wheelchair); provides informed consent (signed consent form and demonstrated understanding using Modified Deaconess Questionnaire); Folstein Mini Mental Status Exam (MMSE) $\geq$ 24 for those with suspected cognitive decline. The exclusion criteria were: pregnancy (self-report of current pregnancy or trying to get pregnant); unwillingness or inability to participate in study activities (not able and willing to attend baseline study visits; not able and willing to wear the accelerometer daily for at least 10 hours per day on 7 days; not able and willing to complete self-report questionnaires unassisted, using electronic or paper formats, in English; current or upcoming participation in educational programs similar to those under study; terminal illness; medical restrictions to increasing MVPA (Participant self-report and health care provider does not provide clearance to participate). Other exclusions were contraindications to mindfulness practices including: serious mental health or brain conditions (bipolar disorder, schizophrenia, psychotic disorder or problems, Alzheimer's, dementia, major depressive disorder, major anxiety disorders); self-report of diagnosis of the following by a health provider and health care provider does not provide clearance to participate: suicidality (score of >2 on the suicidal ideation screen from the Quick Inventory of Depressive Symptomatology-Self Report (QIDS-SR); substance abuse (self-report of substance abuse at time of screening as measured by affirmative responses to screening questions of drinking more alcohol or using more drugs than intended in the past 6 months AND feeling the need to cut down on alcohol use or drugs); Post-Traumatic Stress Disorder (self-report of diagnosis of PTSD and health care provider does not provide clearance to participate); seizure disorder (self-report of diagnosis by a health provider and health care provider does not provide clearance to participate).

4.3.3 Impact of COVID-19

In March 2020, the formal declaration of the COVID-19 pandemic shut down the in-person delivery of the program. This occurred between the second and third week of the intervention within the Wave 2 cohort (see the dates and participant numbers for each wave below in Section 4.4.1). The full impacts of this transition from in-person to telehealth are described in a forthcoming publication about the entire trial. As relates to this chapter, the impact of COVID-19 resulted in both the experimental and active control interventions converting from in-person group interventions at various YMCA locations to being remotely delivered via the Zoom videoconferencing application. While this intervention was not originally offered in a telehealth mode, its conversion to telehealth occurred before a majority of participants had gone through the intervention.

4.3.4 Interventions

The study included two interventions: Mindful Movement (experimental intervention) and Keys to Health & Wellbeing (active control intervention). Both interventions were comprised of eight weekly, 90-minute group sessions. The two interventions were designed to be as equivalent as possible, controlling for time, attention, and social interaction. Each session included a facilitator-led orientation, workbook reflections and facilitator-moderated group discussions, viewing of expert narrated videos, and facilitator-led goal setting and action planning for home practice. The main distinction between the interventions was related to the goals and content. The experimental intervention focused on mindfulness and physical activity, whereas the control intervention focused on general health and wellbeing.

4.3.5 Mindful Movement

Mindful Movement incorporates elements from Mindfulness-Based Stress Reduction (MBSR), the most implemented mindfulness program in U.S. healthcare settings [130], and the Behavior Change Wheel (BCW), a comprehensive framework for designing behavior-changing interventions that is based upon the synthesis of 19 evidence-based behavior change theories [103]. Mindful Movement was designed with an explicit focus on the mind-body connection and places a strong emphasis on training interoceptive awareness (e.g., body sensations, breathing, etc.). Mindful Movement encompasses eight weekly 90-minute sessions that include written reflection with group discussion (25-30 mins), an educational video (<15 mins), a guided meditation (< 15 mins) and a guided mindful movement practice (<15 mins). The weekly education content covers the topics of mindfulness and physical activity, the mind-body connection, kindness and self-compassion, working with thoughts and feelings, shifting perspectives, awareness of daily positive moments, connecting with others, and personalizing mindfulness practice for your life. In addition to emphasizing interoceptive awareness, the Mindful Movement curricula is informed by the COM-B model from the BCW framework [103]. The COM-B model posits that to change behaviors (e.g., increase physical activity), participants must gain the capabilities (**C**) required for the behavior (e.g., knowledge about how to practice mindfulness) with opportunities (**O**) to develop these capabilities (e.g., practice at home and in the remote sessions) all supported by the necessary (**M**) motivations (e.g., intention to practice and belief in potential outcomes) [104]. Each session was mapped out so that learning objectives were aligned with the COM-B model as well as specific intervention elements from the BCW framework.

4.3.6 Keys to Health & Wellbeing

Keys to Health & Wellbeing includes exercise and physical activity information from a booklet written by the NIH's National Institute on Aging [115], and elements from the BCW [104]. The Keys to Health & Wellbeing program was designed to include evidence-based habits known to positively affect health and wellbeing in older adults. Similar to the Mindful Movement program, the Keys to Health & Wellbeing program encompasses eight weekly 90-minute sessions that include written reflection with group discussion (25-30 mins), an educational video

(< 15 mins), a guided physical activity (< 15 mins) and a workbook activity related to the educational topic (< 15 mins). The main difference between this program and Mindful Movement is the absence of mindfulness training or any explicit focus on interoceptive awareness. The weekly education content covers the topics of understanding wellbeing and how to cultivate it, keeping fit through physical activity, finding meaning and purpose by exploring values and passions, sorting fact from fiction about health information, recharging through rest and relaxation, connecting to others and the world around you, nourishing yourself through healthy eating, and managing pain so it doesn't manage you. Similar to the Mindful Movement program, the Keys to Health & Wellbeing program was mapped out so that learning objectives were aligned with the COM-B model as well as specific intervention elements from the BCW framework.

4.3.7 Randomization

Eligible individuals were randomized using the web-based Randomizing Module in REDCap, a data capture software for research studies, by trained study staff masked to upcoming treatment assignments. Randomization was stratified by site (including a "online sites/group" for participants enrolled during specific time-intervals corresponding to treatment cohorts/classes after the transition to remote intervention delivery) and age (50-69 and 70+). Block randomization was used with random sized blocks, varying between four and six, and a 1:1 allocation ratio, to ensure group balance.

4.3.8 Assessment of Interoceptive Awareness

Interoceptive Awareness was measured with the Multidimensional Assessment of Interoceptive Awareness (Version 2) [100], which is a widely used self-report measure of interoception [24] and has undergone both criterion and construct validity testing in varied populations around the world [147]. The MAIA is a 37-item questionnaire comprised of eight subscales, where participants answer how often a statement applies to them in daily life (e.g., "I notice when I am uncomfortable in my body") based on scores range from 0 (never) to 5 (always). The eight subscales are: (1) Noticing (four items): awareness of uncomfortable, comfortable, and neutral body sensations, (2) Not Distracting (six items): tendency to ignore or distract oneself from sensations of pain or discomfort (reverse scored), (3) Not Worrying (five items): emotional distress or worry with sensations of pain or discomfort (reverse scored), (4) Attention Regulation (seven items): ability to sustain and control attention to body sensations, (5) Emotional Awareness (five items): awareness of the connection between body sensations and emotional states, (6) Self-Regulation (four items): ability to regulate psychological distress by attention to body sensations, (7) Body Listening (three items): actively listening to the body for insight, and (8) Trusting (three items): experiencing one's body as safe and trustworthy. Higher scores on each subscale indicate higher interoceptive awareness in that domain. Scores on each subscale are calculated by taking the average of all items within each subscale (score range of 0-5) and reported by subscale. There is not an overall score for the entire instrument.

For the RCT, only the four subscales of noticing, attention regulation, emotional awareness, and self-regulation were used because these subscales align specifically with content covered in the experimental intervention (i.e., Mindful Movement) and also to reduce participant data collection burden. Change scores for the four subscales of the MAIA were calculated by subtracting baseline subscale scores from the 9-, 26-, and 52-week scores. Positive MAIA subscale change-scores indicate improvements in interoceptive awareness in that domain (e.g., positive score indicating increased emotional awareness).

4.3.9 Analysis

An intention-to-treat approach was used for the statistical analysis in which participants were analyzed according to their original group assignment. Mean differences and 95% CIs between groups at weeks 9, 26 and 52 were calculated using a mixed model longitudinal regression. The primary outcome variable of interoceptive awareness, measured by each of the four subscales of the MAIA included in the RCT, was modeled with a linear mixed effect model including fixed effects for time, treatment, and a time-by-treatment interaction in addition to the stratification variable of age that was used in the randomization scheme as well as random effects to account for within-subject correlation due to repeated measures and clustering effects due to the group interventions. An AR(1) variance-covariance structure was used to model the repeated outcome measures. The primary end point of interest was at nine weeks, which reflects the change in interoceptive awareness immediately following the completion of the intervention. Weeks 26 and 52 provide the follow-up data regarding the temporal stability of any observed intervention effects at nine weeks. All analyses were performed using the statistical software R (4.2.2).

4.4 Results

4.4.1 Enrollment

Enrollment occurred in three waves (September 2019, Wave 1: n=31; February 2020, Wave 2: n=53; February 2021, Wave 3: n=92) in Minneapolis/Saint Paul, Minnesota. A total of 1,480 people expressed interest in the study by completing an online screener. Fig. 4.1 presents a CONSORT flow diagram of the study.

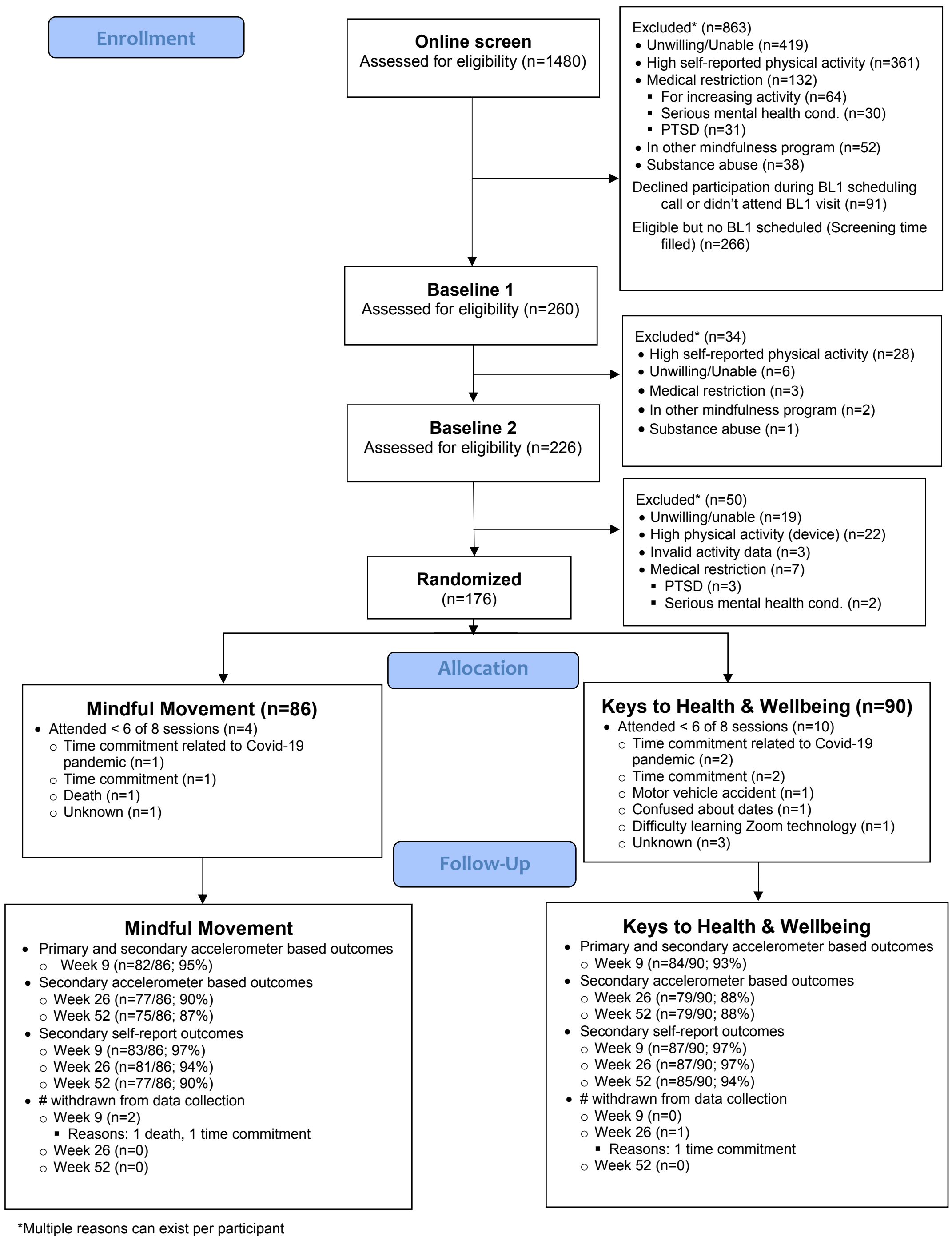

Figure 4.1: CONSORT flow diagram for mindfulness and physical activity trial

4.4.2 Baseline Characteristics

A total of 176 participants consented to participate in the study and were successfully enrolled and randomly assigned to either the experimental intervention (Mindful Movement) or the contextually matched control intervention (Keys to Health & Wellbeing). Baseline characteristics are reported in Table 4.1. Within the 176 participants in the study, the majority were women (86%), white (88%), older (mean age = 66 [SD = 7.86]), and retired (53%). Appendix A contains a more detailed demographic table that includes baseline characteristics beyond the scope of this secondary analysis.

Table 4.1: Baseline Characteristics of the RCT

Parameter	**Mindful Movement**	**Keys**
Participants, n	86	90
Gender, n (%)		
Women	78 (90.7)	74 (82.2)
Men	8 (9.3)	16 (17.8)
Age, mean (SD)	65.55 (7.24)	66.83 (8.41)
Ethnicity, n (%)		
Not Hispanic or Latino	82 (95.3)	85 (94.4)
Hispanic or Latino	2 (2.3)	3 (3.3)
Prefer not to answer	2 (2.3)	2 (2.2)
Race, n (%)		
American Indian or Alaska Native	1 (1.2)	0 (0)
Black or African American	5 (5.8)	8 (8.9)
Asian	1 (1.2)	0 (0)
White	75 (87.2)	80 (88.9)
Multiracial	4 (4.7)	2 (2.2)
Employment, n (%)		
Currently working full-time	21 (24.4)	18 (20.0)
Currently working part-time	19 (22.1)	12 (13.3)

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Table 4.1, cont'd.

Parameter	**Mindful Movement**	**Keys**
Not currently employed	3 (3.5)	4 (4.4)
Retired	42 (48.8)	52 (57.8)
Other	1 (1.2)	4 (4.4)
Household Income, n (%)		
Less than \$9,999	1 (1.2)	1 (1.1)
\$10,000 to \$14,999	3 (3.5)	2 (2.2)
\$15,000 to \$24,999	4 (4.7)	5 (5.6)
\$25,000 to \$34,999	11 (12.8)	8 (8.9)
\$35,000 to \$49,999	7 (8.1)	13 (14.4)
\$50,000 to \$74,999	19 (22.1)	19 (21.1)
\$75,000 to \$99,999	14 (16.3)	14 (15.6)
\$100,000 or more	17 (19.8)	13 (14.4)
Prefer not to answer	10 (11.6)	15 (16.7)
Education, n (%)		
High school graduate, or equivalent	1 (1.2)	6 (6.7)
Vocational/technical/trade school	4 (4.7)	7 (7.8)
Associate's Degree	5 (5.8)	2 (2.2)
Bachelor Degree	37 (43.0)	28 (31.1)
Master's Degree	22 (25.6)	26 (28.9)
Doctoral Degree	2 (2.3)	6 (6.7)
Professional Degree (e.g., JD, MD)	6 (7.0)	4 (4.4)
Self-reported pain* > 0 in past week, n (%)	77 (89.5)	84 (93.3)
Arm, mean (SD)	1.49 (1.85)	1.41 (1.71)
Leg, mean (SD)	2.28 (2.22)	2.41 (2.26)
Back, mean (SD)	2.0 (2.24)	2.24 (2.51)
Other bodily pain, mean (SD)	1.17 (1.70)	1.13 (1.64)
MAIA		
Noticing Subscale, mean (SD)	2.87 (1.02)	2.78 (0.93)

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Table 4.1, cont'd.

Parameter	Mindful Movement	Keys
Attention Regulation Subscale, mean (SD)	2.40 (1.05)	2.60 (1.05)
Emotional Awareness Subscale, mean (SD)	3.03 (1.06)	3.05 (0.99)
Self-Regulation Subscale, mean (SD)	2.65 (1.12)	2.74 (1.05)

SD, standard deviation; *Self-reported pain on 0–10 numerical rating scale; MAIA, Multidimensional Assessment of Interoceptive Awareness, version 2

4.4.3 Missing and Incomplete Data

An assessment of missing and incomplete data for all MAIA subscales across the different time points of the study is presented in Table 4.2. The percentage of missing data across time points is small (i.e., 10% or less at all time points) and similar between groups. Additionally, there was no missing baseline data, which means all participants (n=176) were included in the linear mixed effect model to generate estimates at each time point. In terms of incomplete data, Table 4.3 presents a detailed analysis of the number of participants with their corresponding number of incomplete responses within a given MAIA subscale. The incomplete data for the subscales of the MAIA was due to a programming error in REDCap whereby research staff failed to mark each MAIA subscale question as required, which allowed participants to omit a response to a particular question and proceed without receiving a warning prompt about incomplete responses. Results of this analysis of incomplete MAIA data shows that the vast majority of participants were missing responses to a single question within a specific subscale. To address this incomplete data, a question-level within individual mean imputation method was used in which a participant's missing question response(s) were imputed by calculating the mean of the other completed responses within the subscale. Prior research comparing various imputation methods (e.g., multiple imputation, single regression) for incomplete question-level data in self-report questionnaires has found that straightforward question-level within individual mean imputation demonstrates comparable accuracy (i.e., Kappa statistic and Spearman correlation coefficient) to much more complex approaches such as multiple imputation [140]. Specifically, in cases similar to the pattern of incomplete data presented here (i.e., participants exhibiting three or less missing items within a scale), there is an extremely small difference between using a question-level within individual mean imputation approach versus more complex imputation approaches [140].

Table 4.2: MAIA Missing and Incomplete Data Across Time Points

All MAIA Subscales	**Mindful Movement**	**Keys**	**Total**
Participants, n	86	90	176
Baseline			
Complete	78 (91%)	87 (97%)	165 (94%)
Incomplete	8 (9%)	3 (3%)	11 (6%)
Missing	0	0	0
9 weeks			
Complete	78 (91%)	74 (82%)	152 (86%)
Incomplete	5 (6%)	13 (14%)	18 (10%)
Missing	3 (3%)	3 (3%)	6 (3%)
26 weeks			
Complete	76 (88%)	80 (89%)	156 (89%)
Incomplete	5 (6%)	7 (8%)	12 (7%)
Missing	5 (6%)	3 (3%)	8 (5%)
52 weeks			
Complete	72 (84%)	82 (91%)	154 (88%)
Incomplete	5 (6%)	3 (3%)	8 (5%)
Missing	9 (10%)	5 (6%)	14 (8%)

Rounding accounts for slight 1% differences in the above table

Table 4.3: Amount of Incomplete Data by MAIA Subscale by Participant

MAIA Subscale	**Mindful Movement**	**Keys**	**Total**
Participants, n	86	90	176
Noticing (4 items)			
1 item incomplete	5	5	10
2 items incomplete	0	0	0
3 items incomplete	0	0	0
Attention Regulation (7 items)			
1 item incomplete	6	4	10
2 items incomplete	1	2	3
3 items incomplete	0	1	1
Emotional Awareness (5 items)			
1 item incomplete	5	7	12
2 items incomplete	0	1	1
3 items incomplete	0	0	0
Self-Regulation (4 items)			
1 item incomplete	6	6	12
2 items incomplete	0	0	0
3 items incomplete	0	0	0

4.4.4 Change in Interoceptive Awareness Subscales at 9, 26 and 52 Weeks

Table 4.4 presents the within- and between-group treatment differences in change-scores for the four subscales of the MAIA. Given that the results presented in this chapter are part of a secondary analysis, they should be interpreted as exploratory and not confirmatory. Multiplicity concerns arise from the potential increase of a type I error due to the analysis of multiple outcomes in a single trial (See [83] for a detailed discussion). In this case, the primary outcome of the trial was specified as a measurement of moderate to vigorous physical activity (MVPA) while all other measures were consider secondary and thus exploratory.

Both the Mindful Movement and Keys group showed improvements over baseline across all MAIA subscales. Notably, the Mindful Movement group improved more than the Keys group post-intervention at week 9 (Noticing: MD = 0.26, 95% CI -0.02, 0.55; Attention Regulation: MD = 0.43, 95% CI -0.18, 0.68; Emotional Awareness: MD = 0.47, 95% CI 0.21, 0.73; Self-Regulation: MD = 0.61, 95% CI 0.34, 0.88). Moreover, this between-group improvement in interoceptive awareness (as measured by these four subscales) exhibited some temporal stability even at 52 weeks (Noticing: MD = 0.16, 95% CI -0.15, 0.46; Attention Regulation: MD = 0.57, 95% CI 0.25, 0.89; Emotional Awareness: MD = 0.40, 95% CI 0.09, 0.71; Self-Regulation: MD = 0.48, 95% CI 0.17, 0.78). Within-group differences for Mindful Movement showed considerable improvements across all time points and all subscales. Additionally, gains in each subscale indicated at week 9 for the Mindful Movement group remained relatively stable at weeks 26 and 52. Changes in each subscale over the 52 weeks were plotted and are presented below as part of detailed presentation of each subscale result.

Table 4.4: Mean within-group and between-group differences (95% confidence interval)

Parameter	**Mindful Movement**	**Keys**	**Mindful M. vs. Keys**
Baseline MAIA Scores [0-5], mean (SD)			
Noticing	2.87 (1.02)	2.78 (0.93)	-
Attention Regulation	2.40 (1.05)	2.60 (1.05)	-
Emotional Awareness	3.03 (1.06)	3.05 (0.99)	-
Self-Regulation	2.65 (1.12)	2.74 (1.05)	-
Change Scores from Baseline			
Noticing			
Δ at 9 weeks (95% CI)	**0.46*** (0.26, 0.66)**	0.20 (-0.001, 0.40)	0.26 (-0.02, 0.55)
Δ at 26 weeks (95% CI)	**0.44*** (0.22, 0.66)**	**0.34** (0.13, 0.55)**	0.10 (-0.20, 0.40)

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Table 4.4, cont'd.

Parameter	Mindful Movement	Keys	Mindful M. vs. Keys
Δ at 52 weeks (95% CI)	**0.51*** (0.29, 0.73)**	**0.35** (0.14, 0.57)**	0.16 (-0.15, 0.46)
Attention Regulation			
Δ at 9 weeks (95% CI)	**0.59*** (0.41, 0.76)**	0.16 (-0.01, 0.33)	**0.43** (0.18, 0.68)**
Δ at 26 weeks (95% CI)	**0.58*** (0.36, 0.79)**	0.19 (-0.02, 0.39)	**0.39* (0.09, 0.68)**
Δ at 52 weeks (95% CI)	**0.64*** (0.41, 0.87)**	0.06 (-0.16, 0.28)	**0.57** (0.25, 0.89)**
Emotional Awareness			
Δ at 9 weeks (95% CI)	**0.60*** (0.41, 0.79)**	0.13 (-0.05, 0.31)	**0.47** (0.21, 0.73)**
Δ at 26 weeks (95% CI)	**0.55*** (0.34, 0.76)**	**0.26* (0.05, 0.46)**	0.29 (-0.001, 0.59)
Δ at 52 weeks (95% CI)	**0.55*** (0.33, 0.78)**	0.15 (-0.06, 0.37)	**0.40* (0.09, 0.71)**
Self-Regulation			
Δ at 9 weeks (95% CI)	**0.75*** (0.56, 0.94)**	0.13 (-0.05, 0.32)	**0.61*** (0.34, 0.88)**
Δ at 26 weeks (95% CI)	**0.63*** (0.42, 0.85)**	**0.26* (0.05, 0.46)**	**0.38* (0.08, 0.68)**
Δ at 52 weeks (95% CI)	**0.70*** (0.48, 0.92)**	0.22 (0.01, 0.44)	**0.48** (0.17, 0.78)**

* $p < .05$; ** $p < .01$; *** $p < .001$

Changes in the MAIA Noticing Subscale

The MAIA Noticing subscale measures the basic human ability to sense uncomfortable, comfortable or neutral body sensations [98]. Figure 4.2 presents a plot of changes in the mean MAIA Noticing subscale scores over 52 weeks. As indicated by the plot, both the Mindful Movement group and the Keys group exhibited increases in noticing relative to baseline. The Mindful Movement group exhibited a greater increase in this noticing ability relative to the Keys group. Both groups experienced stability in these noticing gains at the follow up times points of week 26 and 52.

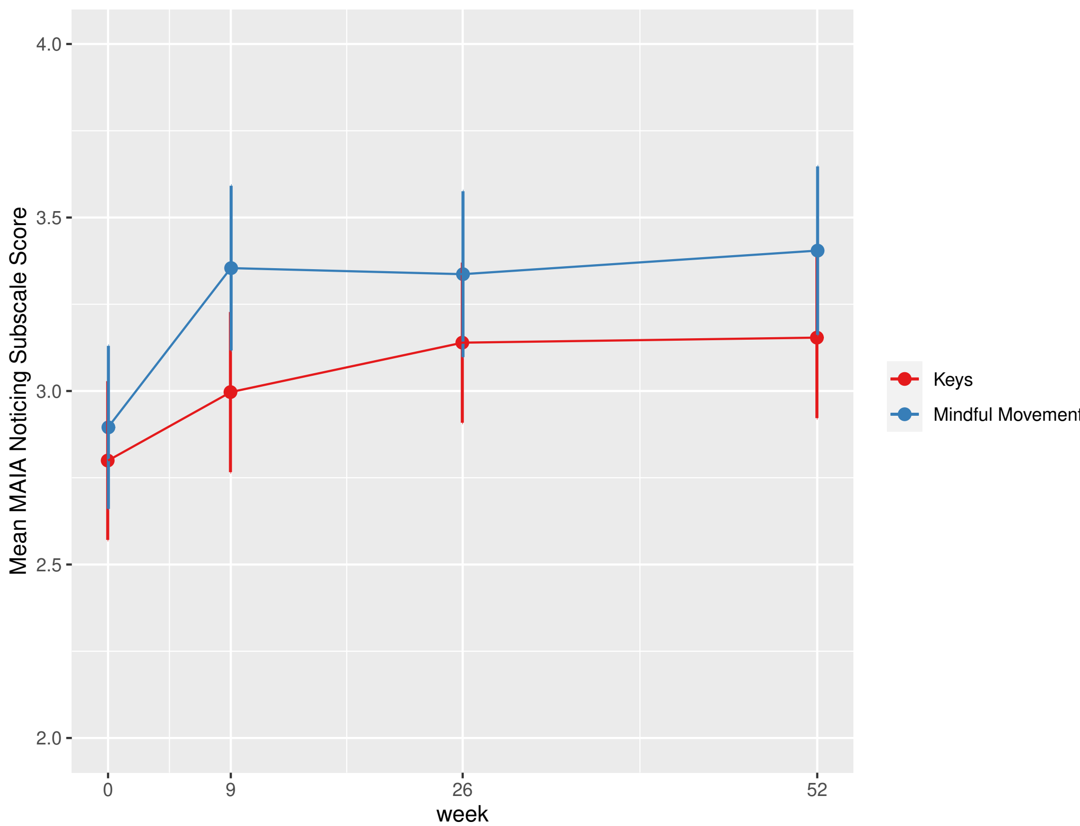

Figure 4.2: Change in Mean MAIA Noticing Subscale score at 9, 26 and 52 weeks

Changes in the MAIA Noticing Subscale

The MAIA Attention Regulation subscale measures a person's ability to sustain and control attention to bodily sensations (e.g., maintaining awareness of one's entire body even in the midst of painful sensations within a specific body region), which includes the capacity for a non-reactive observation of the body [98]. Figure 4.3 shows the changes in the mean MAIA Attention Regulation subscale scores across 9, 26 and 52 weeks. The Mindful Movement group experienced a considerable increase in attention regulation capacities post-intervention. These post-intervention improvements were sustained at weeks 26 and 52. In contrast, the Keys group experienced more modest gains in attention regulation capabilities post-intervention. By week 52, these gains for the Keys group had decreased relative to Week 9.

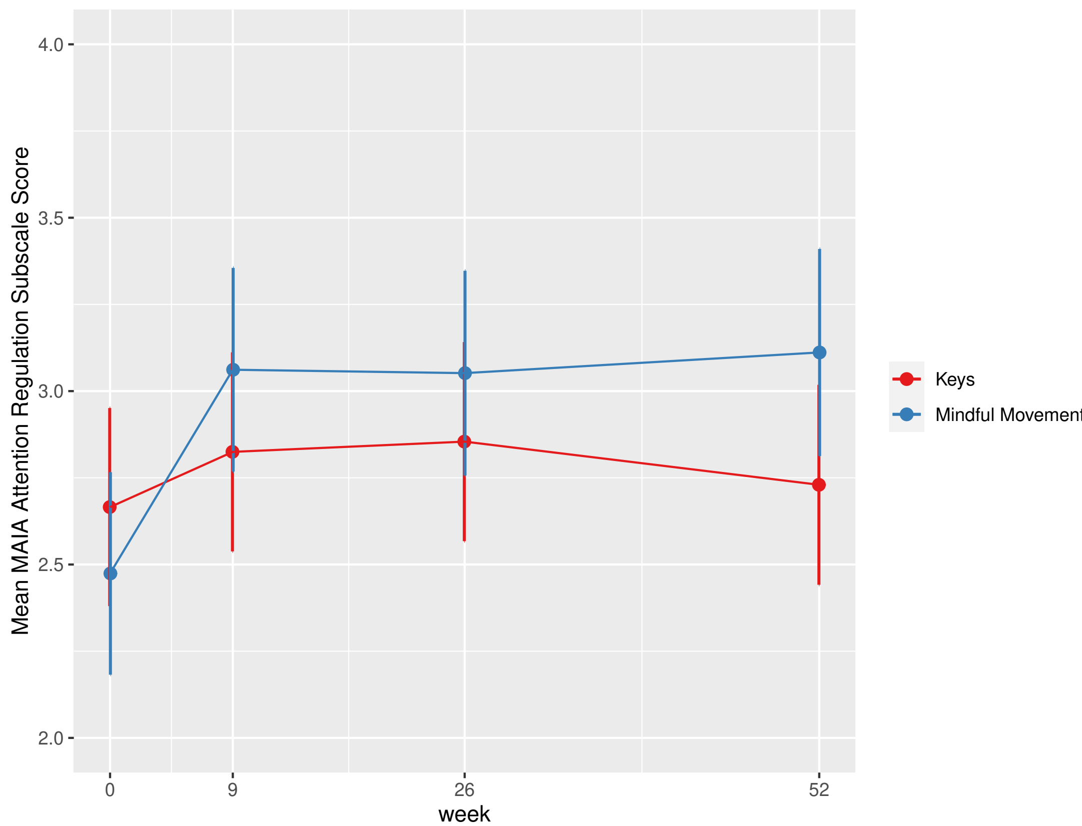

Figure 4.3: Change in Mean MAIA Attention Regulation Subscale score at 9, 26 and 52 weeks

Changes in the MAIA Emotional Awareness Subscale

The MAIA Emotional Awareness subscale assesses a person's ability to attribute sensations to physical manifestations of emotion (e.g., knowing the sensations of 'butterflies' in one's stomach as a physical experience of worry) [98]. Figure 4.4 illustrates the changes in mean MAIA Emotional Awareness subscale scores over 52 weeks. Within this subscale, the Mindful Movement group experienced a noticeable increase in emotional awareness capabilities at week 9. The gains in this subscale for the Mindful Movement group were sustained at the follow up data collection points of 26 and 52 weeks. The Keys group experienced modest gains within this subscale at week 9. These modest gains were sustained at the follow up data collection point of week 52.

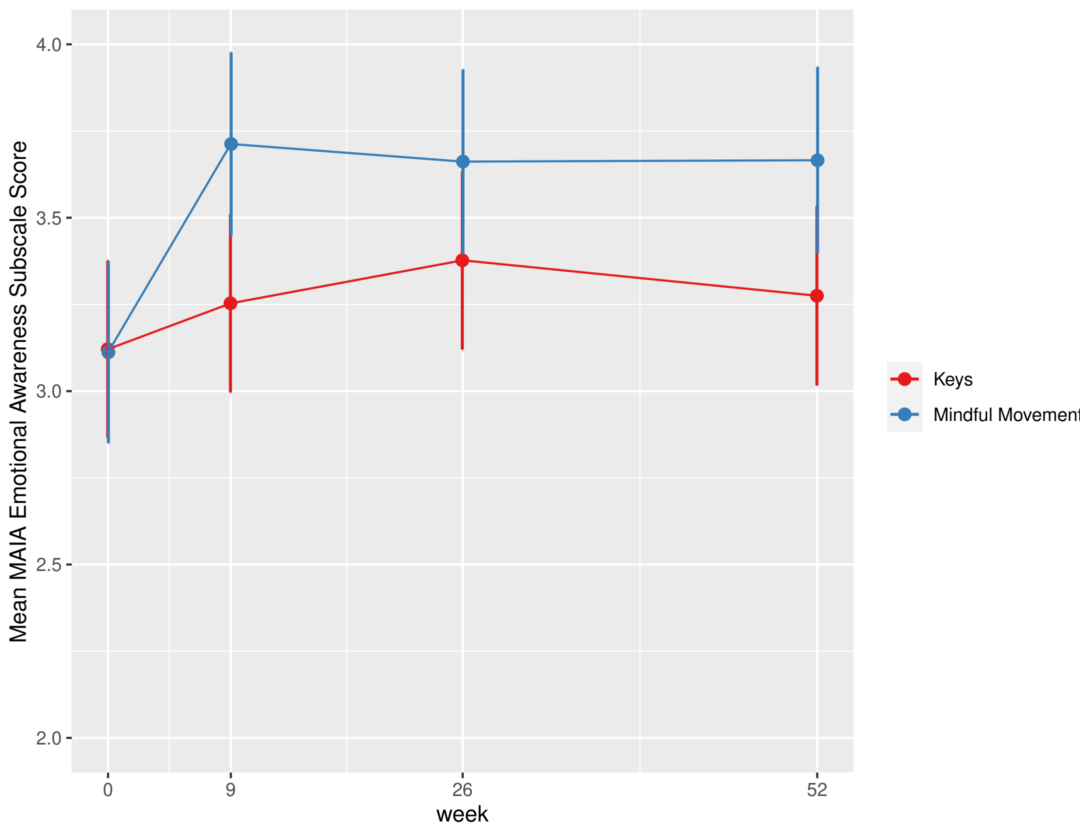

Figure 4.4: Change in Mean MAIA Emotional Awareness Subscale score at 9, 26 and 52 weeks

Changes in the MAIA Self-Regulation Subscale

The MAIA Self-Regulation subscale measures a person's capacity to regulate distress by attention to bodily sensations (e.g., paying attention to one's breathing to reduce a feeling of worry) [98]. Figure 4.5 illustrates the changes in mean MAIA Self-Regulation subscale scores across 9, 26 and 52 weeks. The Mindful Movement group exhibited a considerable post-intervention increase in self-regulation capacity at week 9. This increased capacity was stable at weeks 26 and 52. The Keys group experienced much more modest gains in self-regulation capacity with a peak at week 26 that was largely maintained at week 52.

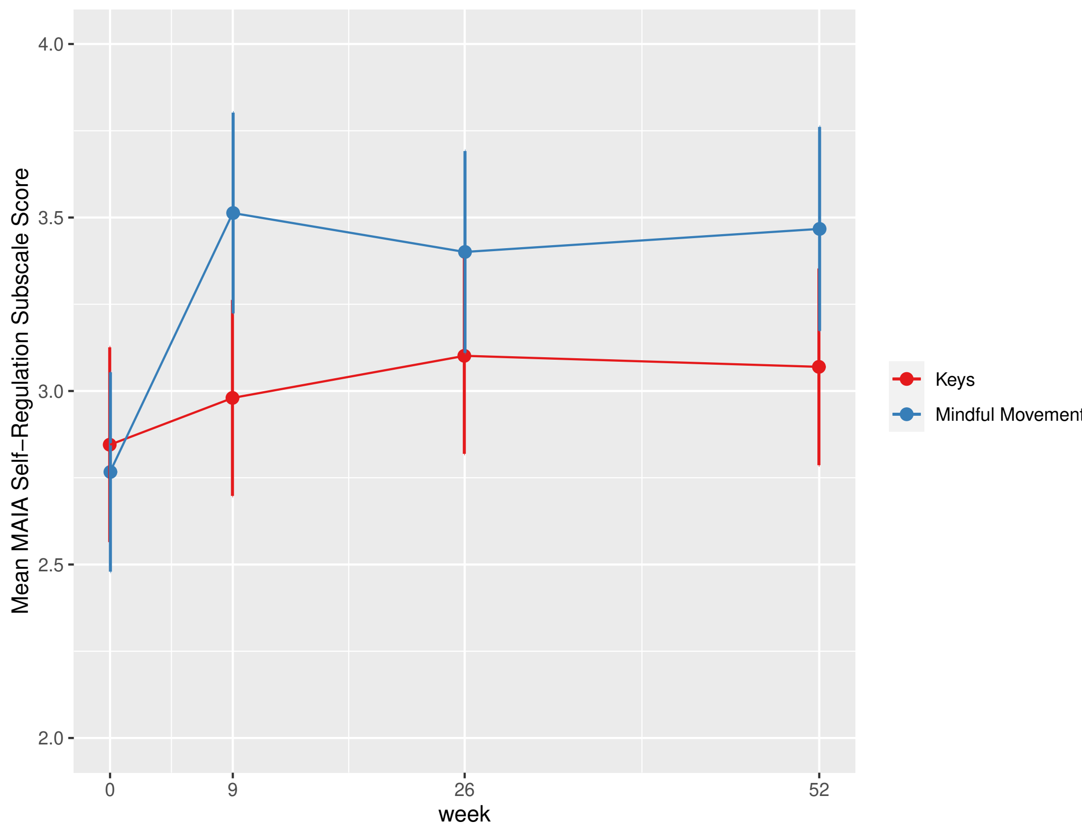

Figure 4.5: Change in Mean MAIA Self-Regulation Subscale score at 9, 26 and 52 weeks

4.5 Discussion

4.5.1 Summary of Main Findings

This secondary analysis of interoceptive awareness found important differences between the Mindful Movement group (experimental intervention) and the Keys to Health & Wellbeing group (active control intervention) in a population of adults $\geq$ 50 years of age. Specifically, immediately following the completion of the intervention (week 9), the Mindful Movement group, as compared to the Keys group, experienced statistically significant differences in interoceptive awareness (Attention Regulation: 0.43 (95% CI 0.18, 0.68); Emotional Awareness: 0.47 (95% CI 0.21, 0.73); Self-Regulation: 0.61 (95% CI 0.34, 0.88)). With respect to prior studies that have reported between-group differences, the differences found here are comparable – Gawande et al. reported a global MAIA between-group difference for all subscales of 0.58 for a mindfulness intervention compared to a low-dose comparator [49] – however, there is a general lack of detail in existent literature related to between-group differences for MAIA subscales. At follow-up time points, the considerable within-group gains for the Mindful Movement group were fairly stable across the one year study period. This may be partially explained by the Mindful Movement group's strong emphasis on the skills of curiosity (i.e., repeatedly noticing what's happening moment-to-moment in the body and mind) and steadying attention while being physically active (e.g., the ability to control and sustain attention on the entire body during exercise even when an uncomfortable or painful body region is pulling one's attention). By contrast, the skills related to emotional awareness and self-regulation are higher order skills that require frequent and repeated practice to master. This may partially explain why improvements at week 9 in these two subscales were not as easily maintained by week 52 when there was no group accountability for routine practice.

The pattern of gains exhibited by the Keys group was distinctly different from the Mindful Movement group in that peak gains in interoceptive awareness were not experienced post-intervention, rather at week 26 (with the one exception being the Noticing subscale peak at week 52). Additionally, gains within the Keys group diminished by week 52 (with the exception of the Noticing subscale). The gains in the Noticing subscale for the Keys group might be due to the inclusion of a physical activity routine within the intervention (see the following paragraph for a full discussion). It is less clear why the other subscales exhibit a week 26 peak, other than the possible influence of contextual effects, such as measurement reactivity [42] due to repeated measurement. Even so, the differences between the Mindful Movement group and the Keys group for Attention Regulation, Emotional Awareness and Self-Regulation were significant post-intervention and at the one year follow up. This suggests that important between-group differences remain even with the potential influence of contextual effects.

There are several factors that likely account for the variation of between-group results observed in the four MAIA subscales. In terms of the Noticing subscale, the fact that the between-group difference was smaller for this subscale is likely explained by the inclusion of physical exercise routines in both groups. The Noticing subscale assesses a person's ability to sense uncomfortable, comfortable or neutral body sensations, something which is a regular component of engaging in physical exercise (e.g., feeling the discomfort of physical exertion). The between-group difference for the Self-Regulation subscale, which exhibited the largest between-group difference of all the subscales, is likely explained by the content within the Mindful Movement group that focused on applying mindfulness in challenging situations. In particular, the Mindful Movement group included training on working with challenging thoughts and feelings and how to shift perspectives. Moreover, the explicit mapping of mindfulness to the COM-B behavior change model makes the application of mindfulness to managing distress a behavioral skill. For the Attention Regulation and Emotional Awareness subscales, the important between-group differences are likely explained by the nature of the mindfulness training within the Mindful Movement group. The mindfulness training included guided meditation and educational videos related to focused attention and open monitoring. Focused attention refers to the practice of narrowing one's attentional scope to sustain awareness of a particular object (e.g., a specific region of the body) [20]. Open monitoring involves maintaining a wider attentional scope to sustain awareness of changing experiences, such as the flux of thoughts, emotions and body sensations [20]. The Keys group did not include explicit training in these practices that develop attentional control and somatic awareness of emotion. It is thus not entirely surprising that the Mindful Movement group experienced greater gains in these two scales compared to the Keys group.

4.5.2 Strengths and Limitations

This secondary analysis has important strengths that contribute to the field of existing interoception research. First, this study used a structurally and contextually matched active control, which addresses a central criticism directed at other mindfulness studies [51]. Specifically, this study controlled for time and attention as well as non-specific factors, such as social support through group interactions. Second, this study's inclusion of follow-up data collection at weeks 26 and 52 is a considerable strength. Only a few other studies have included follow-up data collection to investigate longer-term intervention effects. Some of these prior studies have found that improvements in interoceptive awareness were not sustained at a one year follow-up time point (see e.g., [122]), a finding that differs from what is reported here for the Noticing and Attention Regulation subscales. Third, this study resulted in two innovative telehealth interventions that mapped a comprehensive, evidence-based behavior change framework, the Behavior Change Wheel, with physical activity. While both interventions were converted from in-person to telehealth as a result of the COVID-19 pandemic, the findings presented here support the possibility of leveraging emerging technology to reduce participant-level barriers and increase access to training that positively impacts interoceptive awareness.

While this study exhibits a number of strengths, it also includes several important limitations. The first limitation is the nature of this secondary analysis, which means the results presented here are exploratory. Future work (discussed below) would be needed to confirm what these exploratory findings suggest. Another limitation relates to the use of only four subscales from the MAIA instead using all eight subscales from the MAIA instrument. Additionally, the issue of incomplete data presents another point of caution when interpreting the findings presented here. Yet another limitation relates to the conversion of the in-person programs to telehealth interventions as a result of the COVID-19 pandemic. While a post hoc analysis using a stratified variable accounting for the different formats of delivery (e.g., in-person for Wave 1, some in-person and mostly telehealth for Wave 2, all telehealth for Wave 3) found no significant impact on interoceptive awareness outcomes, future studies should use a telehealth intervention for the entirety of the trial. The final major limitation relates to generalizability. Beyond just older adults, which was a part of this trial's design, the demographics of this study (e.g., predominately white, mostly women, highly educated, above average income) are not representative of the US population as a whole, which can limit the ability to generalize the findings presented here. This is a known problem with most mindfulness research [157], however, it highlights a need for greater efforts to correct this known issue.

4.6 Future Work

Future studies should endeavor to address the limitations of the present study. With respect to the study population that is non-representative, a number of multi-tiered community-based approaches are needed [66], such as involvement of a community advisory board, community sessions to address historical legacies of research harm and mistrust, researcher training regarding potential sources of conscious and unconscious bias, adoption of flexible options from enrollment through intervention to reduce participant-level barriers, and frequent testing and review of recruitment strategies and enrollment locations. In regards to areas of further development, future studies could incorporate experience-sampling procedures as a means of obtaining a more objective measure of interoceptive awareness beyond just the MAIA. Murphy et al. have suggested such an approach: "Note that an objective measure of interoceptive attention may rely on self-report (e.g., in an experience-sampling procedure, the participant might be repeatedly asked what is the object of their attention), but the proportion of time that interoceptive signals are the object of attention can then be objectively determined" [112]. Finally, future work should seek to replicate the findings suggested here, albeit with the use of all eight subscales from the MAIA instrument.

4.7 Conclusion

The findings from this secondary analysis of a randomized trial suggest that mindfulness training, delivered as a telehealth intervention, can significantly improve interoceptive awareness as detected through a well-validated measure in a population of adults ≥ 50 years of age. Additionally, the longer-term effects of these gains in interoceptive awareness appear fairly stable. Taken together, these findings point to the opportunity of new interventions that combine emerging technologies with mindfulness practices in order to enhance interoceptive awareness. These novel interventions also have the potential to provide greater access to such training through a remote delivery format.

Even though the findings from this chapter suggest that interoceptive awareness can be measured and cultivated through telehealth mindfulness training, they do not provide insight into other factors (e.g., gender) that might predict differences in interoceptive awareness outcomes. Knowledge of potential predictive factors would be extremely useful in refining existing interventions to potentially optimize outcomes. Additionally, analyzing potential predictive factors and determining if they are consistent with prior studies would help to support the wider interoception research field. To this end, the next chapter takes a deeper dive into examining potential factors that might affect interoceptive awareness outcomes.

Chapter 5

Predictors of Interoceptive Awareness

A Secondary Analysis of a Type 2 Randomized Controlled Trial of a Community Based Mindfulness Intervention for Increasing Physical Activity in Older Adults

5.1 Introduction

This chapter focuses on examining potential predictive factors, such as age and home practice, that may explain differences in interoceptive awareness outcomes. Knowledge of potential predictive factors is useful for optimizing interventions to enhance interoceptive awareness outcomes for various populations. This work is a step towards tailoring interventions to account for these predictive factors to ensure *the right message is given to the right participant.*

5.2 Background

Interoception refers to the ability to sense and integrate internal body signals at conscious and unconscious levels [74]. Interoception is an important human capacity because it allows human beings to satisfy basic needs (e.g., hunger) [123] and is also involved in high-order cognitive processes, such as emotional processing [89], decision-making [146] and self-regulation [44]. At the conscious level, awareness of interoceptive cues, known as interoceptive awareness, is a trainable skill [158]. The findings from Chapter 4 of this dissertation suggest that mindfulness training can significantly improve interoceptive awareness in older adults.

While the findings from Chapter 4 are consistent with prior studies that showed mindfulness can enhance interoceptive awareness for specific populations, such as veterans [101] and women in a substance use treatment program [122], it does not provide insight into specific predictive factors. Investigating participant-level predictive factors could help with refining future interventions and understanding potential outcome differences within various populations. At present, there is limited literature on potential predictive factors that affect interoceptive awareness outcomes. Of the limited existent literature, prior studies have identified five potential predictive factors: gender, age, pain, home practice, and intervention intensity. In terms of gender, women have been found to report higher scores on some subscales of the MAIA as compared to men [55]. In regards to age, increased age is associated with lower interoception as measured via self-report measures [111]. In terms of pain, persons with pain have been found to report lower scores on some subscales of the MAIA as compared to mindfulness practitioners [99]. For home practice, a positive correlation between home practice and treatment outcomes has been found in several studies [117, 4]. Finally, the use of a more intense mindfulness intervention (e.g., two hour classes versus 20 minute sessions) has been found to produce positive gains across multiple MAIA subscales post-intervention (e.g., compare [4] to [59]). These prior studies suggest that important predictive factors exist and warrant further study in terms of their potential impact on post-intervention interoceptive awareness outcomes.

In order to explore the aforementioned topic, this chapter presents findings from a secondary analysis of potential predictive factors from a randomized type 2 hybrid effectiveness-implementation trial. The aim of this analysis was to examine whether specific baseline characteristics (e.g., self-reported pain, dispositional mindfulness) and intervention-related characteristics (e.g., attendance and home practice) explain a statistically significant amount of variance post-intervention in the four subscales of the MAIA in a randomized controlled trial. Importantly, this analysis also includes analysis of gender, age and intervention type (e.g., mindfulness group or active control) in order to evaluate findings from prior studies suggesting that these predictors matter to interoceptive awareness outcomes. The central hypothesis is that age, gender, self-reported pain, dispositional mindfulness, intervention type, attendance, home practice and change in mindfulness from baseline to intervention completion all explain a statistically significant amount of variance in interoceptive awareness post-intervention.

5.3 Methods

5.3.1 Study Design

A full description of the randomized type 2 hybrid effectiveness-implementation trial is described in Chapter 4. In brief, 176 adults $\geq$ 50 years of age were randomized to one of two different eight-week interventions (Mindful Movement or Keys to Health & Wellbeing). At the beginning of the trial, baseline information was collected, which included, among other things, age, gender, prior experience with mind-body practices, pain, mindfulness, and interoceptive awareness. Additional data was collected during the intervention as well as post-intervention and at weeks 26 and 52. This additional data included, but was not limited to, attendance, home practice, mindfulness and interoceptive awareness. The University of Minnesota's Institutional Review Board approved this study and all participants provided written informed consent to participate in the trial.

5.3.2 Population

Adults ages ≥ 50 years of age who satisfied the pre-specified inclusion / exclusion criteria were enrolled in three waves. The detailed list of inclusion and exclusion criteria are provided in Chapter 4. A total of 1,480 people completed the initial online screener to assess their eligibilty for the trial – see Figure 4.1 in Chapter 4 for a CONSORT flow diagram of the trial.

5.3.3 Interventions

The study included two interventions: Mindful Movement (experimental intervention) and Keys to Health & Wellbeing (active control intervention). Both interventions were comprised of eight weekly 90-minute group sessions. The two interventions were designed to be as contextually and structurally equivalent as possible. Each session included a facilitator-led orientation, workbook reflections and facilitator-moderated group discussions, viewing of expert narrated videos, and facilitator-led goal setting and action planning for home practice. The main distinction between the interventions was related to the goals and content. The experimental intervention focused on mindfulness and physical activity, whereas the control intervention focused on general health and wellbeing.

5.3.4 Measures

Self-Reported Pain

Participants were asked to self-rate their pain in the past seven days in four bodily areas (legs including foot, ankle, knee and hip; arm including hand, wrist, elbow and shoulder; back including neck, mid and low back; and other such as head or jaw) on a numerical rating scale with anchors at the ends (0=no pain, 10=the worst pain possible). Questions were phrased as "What was the typical level of your << pain type (e.g, back pain) >> during the past week (choose only one number)?" For this analysis, the maximum pain rating from across the four different regions was used as a participant's pain score [151].

Prior Experience with Mind-Body Practices

Participants were asked about prior exposure to mind-body practices by their self-reported use of meditation, mindfulness, breathing practices, prayer, progressive relaxation, cognitive behavioral therapy, guided imagery, biofeedback, yoga, and qigong. The first question consisted of a simple "yes," "no," or "prefer not to answer" in regards to having previously engaged in mind-body practices. Participants were then asked to select each of the specific mind-body practices they had engaged in.

Mindfulness

The short-form Freiburg Mindfulness Inventory (FMI) consisting of 14 items was used in this study. It was developed for use in the general population with people who had no prior experience with mindfulness [156]. Items are scored on a four-point Likert scale from 1 (rarely) to 4 (almost always). A total score is calculated by taking the sum of all items, with higher scores indicating more mindfulness. The minimum score is 14 and the maximum score is 56.

Interoceptive Awareness

Interoceptive Awareness was measured with the Multidimensional Assessment of Interoceptive Awareness (Version 2) [100], which is a widely used self-report measure of interoception [24] and has undergone both criterion and construct validity testing in varied populations around the world [147]. The MAIA is a 37-item questionnaire comprised of eight subscales, where participants answer how often a statement applies to them in daily life (e.g., "I notice when I am uncomfortable in my body") based on scores range from 0 (never) to 5 (always). The eight subscales are: (1) Noticing (four items): awareness of uncomfortable, comfortable, and neutral body sensations, (2) Not Distracting (six items): tendency to ignore or distract oneself from sensations of pain or discomfort (reverse scored), (3) Not Worrying (five items): emotional distress or worry with sensations of pain or discomfort (reverse scored), (4) Attention Regulation (seven items): ability to sustain and control attention to body sensations, (5) Emotional Awareness (five items): awareness of the connection between body sensations and emotional states, (6) Self-Regulation (four items): ability to regulate psychological distress by attention to body sensations, (7) Body Listening (three items): actively listening to the body for insight, and (8) Trusting (three items): experiencing one's body as safe and trustworthy. Higher scores on each subscale indicate higher interoceptive awareness in that domain. Scores on each subscale are calculated by taking the average of all items within each subscale (score range of 0-5) and reported by subscale. There is not an overall score for the entire instrument. As more fully described in the previous chapter, only the four subscales of noticing, attention regulation, emotional awareness, and self-regulation were used in the trial.

Self-Reported Home Practice

Self-reported home practice was assessed through a single question asking "On average, how many days per week were you able to try things recommended to you in the program?" Participants then selected from a scale ranging from zero days to seven days.

Analysis

To identify the potential predictor variables of interoceptive awareness post-intervention (i.e., week 9), a hierarchical linear regression analysis was conducted. Nested regression models were built based upon the independent variables of interest to test whether they contributed incrementally to predicting a statistically significant amount of variance in week 9 interoceptive awareness scores from the four subscales of the MAIA. Coefficients, 95% confidence intervals, R^2 and change in R^2 were reported based upon the aforementioned analysis. All analyses were performed using the statistical software R (4.2.2)

Nested models were built with a specific ordering of potential predictor variables. Model 1 consisted of the demographic variables of gender and age as prior literature has indicated these demographic characteristics are important predictors of interoceptive awareness (see Section 5.2 above for a discussion of relevant literature). Model 2 added in baseline self-reported pain because this is another independent variable that has been previously found to impact interoceptive awareness (again, see Section 5.2 above). Model 3 introduced the potential predictor of baseline mindfulness scores since a large percentage of participants reported prior engagement with mindfulness and meditation and the results from Chapter 4 have shown that mindfulness positively impacts interoceptive awareness. Model 4 adds in randomization to the mindfulness group as an important potential predictor variable since the results from Chapter 4 indicated that the mindfulness group had greater gains in interoceptive awareness outcomes compared to the active control group. Models 5 and 6 added in the two adherence measures of attendance and practice outside of the program, respectively, which would both be predicted to positively impact the outcome. Model 7 included the change in mindfulness between week 9 and baseline as a potential proposed mechanism to explain the way in which being randomized to the mindfulness group matters (i.e., if you were assigned to the mindfulness group then the change in mindfulness is what explains the impact on the outcome of interoceptive awareness).

5.4 Results

5.4.1 Participant Characteristics

The baseline data presented below includes only participants who had a response to at least one question for each MAIA subscale at week 9 of the trial (n = 170). Additional participant demographic information and baseline characteristics are provided in Chapter 4 and in Appendix A. Table 5.1 provides baseline measures for all predictor variables included in the models used in the hierarchical linear regression analysis. Ethnicity and race are included given the historical and ongoing under-reporting of ethnic and racial information in RCTs [128].

Table 5.1: Baseline Characteristics for the Linear Hierarchical Regression Analysis

Parameter	Mindful Movement	Keys
Participants, n	83	87
Gender, n (%)		
Women	76 (91.6)	71 (81.6)
Men	7 (8.4)	16 (18.4)
Age, mean (SD)	65.77 (7.03)	66.79 (8.50)
Ethnicity, n (%)		
Not Hispanic or Latino	79 (95.2)	82 (94.3)
Hispanic or Latino	2 (2.4)	3 (3.4)
Prefer not to answer	2 (2.4)	2 (2.3)
Race, n (%)		
American Indian or Alaska Native	1 (1.2)	0 (0)
Black or African American	5 (6.0)	8 (9.2)
Asian	1 (1.2)	0 (0)
White	72 (86.7)	77 (88.5)
Multiracial	4 (4.8)	2 (2.3)
Self-reported pain* > 0 in past week, n (%)	74 (89.2)	78 (89.7)
Max pain across four body regions, mean (SD)	3.39 (2.31)	3.38 (2.38)
FMI, mean (SD)	37.33 (7.92)	38.49 (7.02)

SD, standard deviation; FMI, Freiburg Mindfulness Inventory; *Self-reported pain on 0–10 numerical rating scale

5.4.2 Prior Experience with Mind-Body Practices

There were a large number of participants in both groups that had prior experience with either meditation or mindfulness. Within the Mindful Movement group, a majority of participants had prior experience with meditation (54.2%, 45/83) and almost half had prior experience with mindfulness (44.6%, 37/83). By contrast, more than a third of the participants in the Keys group had prior experience with meditation (40.2%, 35/87) and with mindfulness (37.9%, 33/87).

5.4.3 Attendance

Attendance for Mindful Movement and the Keys group varied slightly; however, intervention adherence overall was very high. Figure 5.1 and Figure 5.2 show attendance over the duration of the eight-week interventions for the Mindful Movement group and the Keys group, respectively. The attendance for the Mindful Movement group (mean attendance in weeks = 7.31 [SD = 0.88]) was higher with less variation than for the the Keys group (mean attendance in weeks = 6.71 [SD = 2.14]).

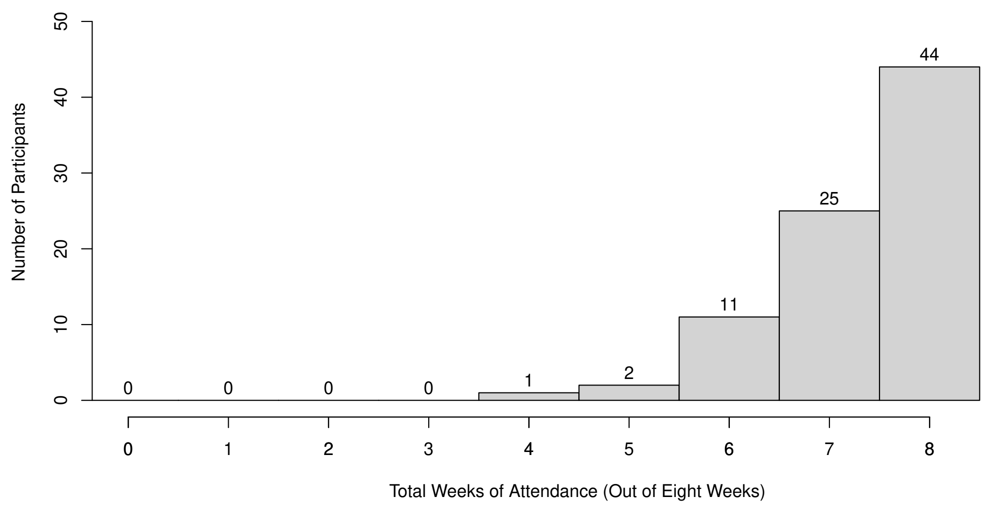

Figure 5.1: Histogram of Participant Attendance for Mindful Movement

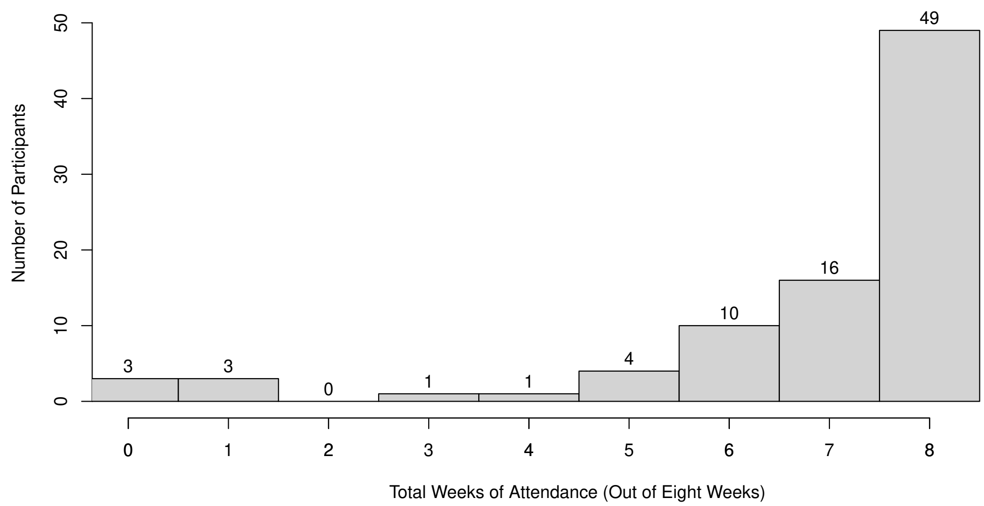

Figure 5.2: Histogram of Participant Attendance for Keys

5.4.4 Home Practice

Home practice for the Mindful Movement and the Keys group exhibited some important differences. Figure 5.3 shows the average number of days of home practice for the Mindful Movement group. By contrast, Figure 5.4 presents the average number of days of home practice for the Keys group. The home practice for the Mindful Group (mean average days of home practice = 4.31 [SD = 1.64]) was greater and exhibited less variation than the Keys Group (mean average days of home practice = 3.31 [SD = 2.01]).

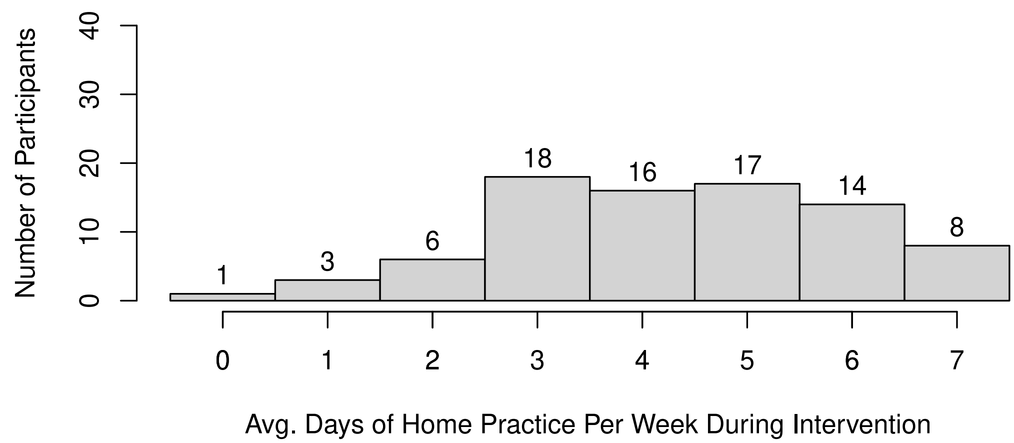

Figure 5.3: Histogram of Participant Home Practice for Mindful Movement

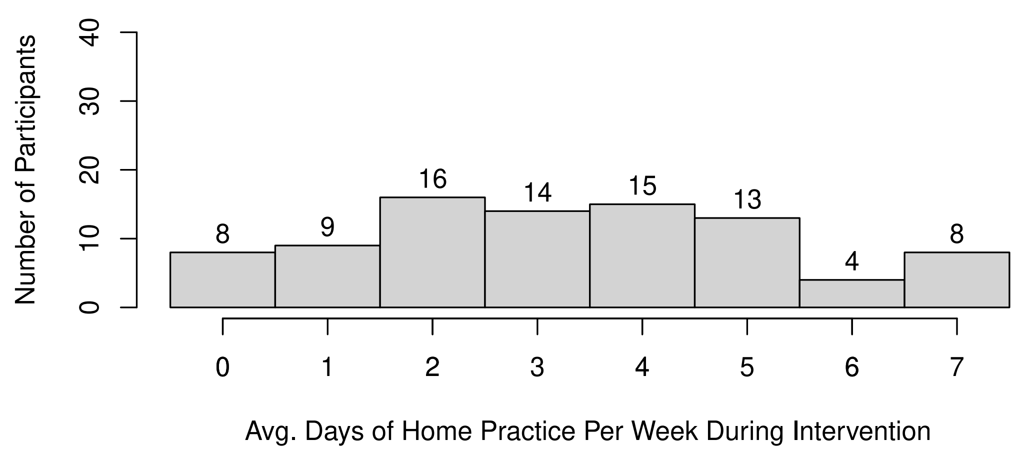

Figure 5.4: Histogram of Participant Home Practice for Keys

5.4.5 Predicting Post-Intervention Interoceptive Awareness Variance

Results from the hierarchical linear regression analysis using the predictor variables discussed earlier are presented below as part of a detailed presentation of each MAIA subscale. The tables below provide the coefficients, 95% confidence intervals, R^2 and change in R^2 for each model within the particular MAIA subscale. Models that were found to account significantly for additional variation in the post-intervention MAIA subscale mean score (i.e., noticing , attention regulation, emotional awareness, and self-regulation) are identified in the column headings with an underline.

Predictors for the MAIA Noticing Subscale

A comparison of the seven models included in the hierarchical regression analysis of the MAIA noticing subscale found that Models 3, 4, and 7, explained a statistically significant amount of variance in the outcome (i.e., mean noticing scores post-intervention) above and beyond the prior nested model. Model 3 explained an additional 8.2% of variance in mean noticing scores beyond Model 2 (Model 3 vs. Model 2 comparison: $F(4{,}165) = 17.98$, $p<0.001$). Model 4 accounted for an additional 3.1% of variance in the outcome over Model 3 (Model 4 vs. Model 3 comparison: $F(5{,}164) = 6.84$, $p=0.009$) Finally, Model 7 explained another 9.2% of variance in mean noticing scores beyond Model 6 (Model 7 vs. Model 6 comparison: $F(8{,}161) = 20.21$, $p<0.001$).

Within Model 3, the variables of age, baseline pain and baseline mindfulness had a significant influence on the outcome of mean noticing scores. A one year increase in a participant's age was associated with a 0.02 decrease in their mean noticing score at the end of the intervention (age: b = -0.02 (95% CI -0.04, -0.001), t(165) = -2.05, $p=0.042$). For pain, a one-point increase in a participant's self-reported pain at baseline was associated with a 0.07 increase in their week 9 mean noticing score (baseline pain: b = 0.07 (95% CI 0.01, 0.13), t(165) = 2.30, $p=0.023$). Finally, a one point increase in a participant's mindfulness score, as measured by the FMI, was associated with a 0.04 increase in their mean noticing score outcome (baseline FMI: *b* = 0.04 (95% CI 0.02, 0.06), t(165) = 3.94, $p<0.001$).

In Model 4, the addition of a variable for the mindfulness group, did significantly account for additional variation in the outcome of mean noticing scores post-intervention. Being randomized to the mindful movement group was associated with a 0.35 point increase in a participant's mean noticing score at week 9 (*b* = 0.35 (95% CI 0.07, 0.62), t(164) = 2.47, p=0.015). The effects of age, baseline pain and baseline mindfulness remained the same as in Model 3.

Model 7 added a variable for a participant's change in mindfulness from baseline to week 9, which did result in the model explaining a significant additional amount of variance in mean noticing scores (see above). Specifically, a one point increase in mindfulness from baseline to week 9, as measured by the FMI, was associated with a 0.05 increase in the mean noticing score immediately post-intervention (FMI change score: *b* = 0.05 (95% CI 0.03, 0.08), t(161) = 4.50, $p<0.001$). The influence of age and baseline mindfulness on the noticing outcome remained largely the same as in Model 4 (age: *b* = -0.02 (95% CI -0.04,-0.001), t(161) = -2.12, p=0.036; baseline FMI: *b* = 0.05 (95% CI 0.03, 0.07), t(161) = 5.47, $p<0.001$). Unlike Model 4, however, baseline pain and the mindfulness group no longer significantly influenced a participant's mean noticing outcome within Model 7.

Table 5.2: Hierarchical Regression Analysis of Predictors of Week 9 MAIA Noticing Subscale Mean Scores

Predictor Variables	**Model 1** *b* (95% CI)	**Model 2** *b* (95% CI)	**Model 3** *b* (95% CI)	**Model 4** *b* (95% CI)	**Model 5** *b* (95% CI)	**Model 6** *b* (95% CI)	**Model 7** *b* (95% CI)
Age	-0.01 (-0.03, 0.01)	-0.01 (-0.03, 0.01)	-0.02* (-0.04,-0.001)	-0.02* (-0.04, 0.000)	-0.02 (-0.04, 0.000)	-0.02 (-0.04, 0.001)	-0.02* (-0.04, -0.001)
Gender	-0.39 (-0.81, 0.04)	-0.39 (-0.82, 0.04)	-0.40 (-0.81, 0.01)	-0.33 (-0.74, 0.08)	-0.34 (-0.75, 0.07)	-0.31 (-0.72, 0.11)	-0.21 (-0.60, 0.18)
Baseline Pain		0.05 (-0.01, 0.11)	0.07* (0.01, 0.13)	0.07* (0.01, 0.13)	0.07* (0.01, 0.13)	0.08* (0.02, 0.14)	0.06 (0.000, 0.11)
Baseline FMI			0.04*** (0.02, 0.06)	0.04*** (0.02, 0.06)	0.04*** (0.02, 0.06)	0.04*** (0.02, 0.06)	0.05*** (0.03, 0.07)

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Table 5.2, cont'd.

Predictor Variables	Model 1 *b* (95% CI)	Model 2 *b* (95% CI)	Model 3 *b* (95% CI)	Model 4 *b* (95% CI)	Model 5 *b* (95% CI)	Model 6 *b* (95% CI)	Model 7 *b* (95% CI)
Mindful Group				0.35* (0.07, 0.62)	0.32* (0.04, 0.60)	0.28 (-0.003, 0.57)	0.18 (-0.10, 0.45)
Attendance					0.05 (-0.04, 0.14)	0.04 (-0.06, 0.13)	0.04 (-0.05, 0.13)
Home Practice						0.05 (-0.03, 0.12)	0.01 (-0.06, 0.09)
FMI Change Score							0.05*** (0.03, 0.08)
R^2	0.036	0.050	0.132	0.163	0.170	0.176	0.268
ΔR^2		0.014	0.082	0.031	0.007	0.006	0.092

* p<.05; ** p<.01; *** p<.001; FMI, Freiburg Mindfulness Inventory

Predictors for the MAIA Attention Regulation Subscale

In comparing the seven models that were part of the hierarchical regression analysis of the MAIA attention regulation subscale, Models 3, 4, 6 and 7 accounted for significant additional variation in post-intervention mean attention regulation scores compared to preceding models. Model 3 accounted for a further 17.9% of variance in the post-intervention attention regulation outcome measure beyond what Model 2 explained (Model 3 vs. Model 2 comparison: $F(4{,}165) = 51.00$, $p<0.001$). Model 4 accounted for an additional 1.5% of variance in mean attention scores (Model 4 vs. Model 3 comparison: $F(5{,}164) = 4.40$, $p=0.038$). Model 6 was able to account for a further 3.7% of variance above Model 5 (Model 6 vs. Model 5 comparison: $F(7{,}162) = 10.68$, $p=0.001$). Finally, Model 7 explained an additional 18.5% of variance in mean attention regulation scores over what Model 6 explained (Model 7 vs. Model 6 comparison: $F(8{,}161) = 52.68$, $p<0.001$).

For Model 3, baseline mindfulness was the only variable with a significant influence on the mean attention regulation scores following the intervention. A one-point increase in a participant's mindfulness score, as measured by the FMI, was associated with a 0.06 increase in their mean attention regulation score (baseline FMI: b = 0.06 (95% CI 0.04, 0.08), t(165) = 6.03, $p<0.001$). All other variables did not significantly influence the outcome.

For Model 4, the addition of the mindfulness group as a variable accounted for the model explaining significant additional variation above Model 3 (see above); however, the mindfulness group variable itself was not a significant influence, at a p-value of 0.05 or below, on the attention regulation outcome (b = 0.25 (95% CI -0.03, 0.52), t(164) = 1.78, p=0.077). The variables of age, gender, and baseline pain did not have a significant effect on attention regulation. The effect of baseline mindfulness remained the same as in Model 3.

Model 6 included the variables of attendance and home practice, both of which were found to have a significant impact on post-intervention mean attention regulation scores. For attendance, a participant who attended an additional week of either program was associated with -0.09 point decrease in their mean attention regulation score at week 9 (b = -0.09 (95% CI -0.18, -0.003), t(162) = -2.05), p=0.043). In terms of home practice, a day per week increase, on average over the intervention, of practicing program activities was associated with a 0.11 increase in the mean attention regulation outcome (b = 0.11 (95% CI 0.03, 0.18), t(162) = 2.84), p=0.005). The effect of baseline mindfulness remained the same as in Model 4.

Within Model 7, the addition of the variable measuring a participant's change in mindfulness from baseline to week 9 resulted in the model explaining a significant additional amount of variance in mean attention regulation scores beyond Model 6 (see above). In particular, a one-point increase in mindfulness from baseline to week 9, as measured by the FMI, was associated with a 0.08 increase in the mean attention regulation score immediately post-intervention (FMI change score: b = 0.08 (95% CI 0.06, 0.10), t(161) = 7.26, p<0.001). The influence of baseline mindfulness and attendance on the mean attention regulation outcome remained largely the same as in Model 6 (baseline FMI: b = 0.09 (95% CI 0.07, 0.10), t(161) = 9.64, p<0.001; attendance: b = -0.09 (95% CI -0.17, -0.01), t(161) = -2.23, p=0.027;).

Table 5.3: Hierarchical Regression Analysis of Predictors of Week 9 MAIA Attention Regulation Subscale Mean Scores

Predictor Variables	Model 1 *b* (95% CI)	Model 2 *b* (95% CI)	Model 3 *b* (95% CI)	Model 4 *b* (95% CI)	Model 5 *b* (95% CI)	Model 6 *b* (95% CI)	Model 7 *b* (95% CI)
Age	-0.005 (-0.02, 0.01)	-0.005 (-0.02, 0.01)	-0.01 (-0.03, 0.003)	-0.01 (-0.03, 0.004)	-0.01 (-0.03, 0.003)	-0.01 (-0.03, 0.004)	-0.02 (-0.03, 0.000)
Gender	-0.23 (-0.67, 0.21)	-0.23 (-0.68, 0.21)	-0.25 (-0.65, 0.15)	-0.20 (-0.61, 0.20)	-0.19 (-0.60, 0.21)	-0.12 (-0.52, 0.28)	0.02 (-0.33, 0.36)
Baseline Pain		-0.02 (-0.08, 0.05)	0.01 (-0.05, 0.07)	0.01 (-0.05, 0.07)	0.01 (-0.05, 0.07)	0.01 (-0.05, 0.07)	-0.02 (-0.07, 0.04)
Baseline FMI			0.06*** (0.04, 0.08)	0.06*** (0.04, 0.08)	0.06*** (0.04, 0.08)	0.06*** (0.04, 0.08)	0.09*** (0.07, 0.10)
Mindful Group				0.25 (-0.03, 0.52)	0.28* (0.002, 0.56)	0.19 (-0.08, 0.47)	0.04 (-0.20, 0.29)
Attendance					-0.06 (-0.15, 0.03)	-0.09* (-0.18, -0.003)	-0.09* (-0.17, -0.01)
Home Practice						0.11** (0.03, 0.18)	0.06 (-0.01, 0.13)
FMI Change Score							0.08*** (0.06, 0.10)
R^2	0.009	0.011	0.190	0.205	0.214	0.251	0.436
ΔR^2		0.002	0.179	0.015	0.009	0.037	0.185

* p<.05; ** p<.01; *** p<.001; FMI, Freiburg Mindfulness Inventory

Predictors for the MAIA Emotional Awareness Subscale

In comparing the seven models included in the hierarchical regression analysis of the MAIA emotional subscale, three models (Models 3, 4, and 7) were found to explain a statistically significant amount of variance in the outcome of mean emotional awareness scores post-intervention over the other models. Model 3 explained an additional 9.2% of variance in mean emotional awareness scores beyond Model 2 (Model 3 vs. Model 2 comparison: $F(4,165) = 21.86$, $p<0.001$). Model 4 accounted for a further 5.4% of variance in the outcome over Model 3 (Model 4 vs. Model 3 comparison: $F(5,164) = 12.70$, $p<0.001$) Finally, Model 7 explained another 12.7% of variance in mean emotional awareness scores beyond Model 6 (Model 7 vs. Model 6 comparison: $F(8,161) = 29.98$, $p<0.001$).

For Model 3, the predictor variables of age, baseline pain and baseline mindfulness had a significant impact on the outcome of mean emotional awareness scores. In terms of age, a one year increase in a participant's age was associated with a 0.02 decrease in their mean emotional awareness score at the end of the intervention (age: b = -0.02 (95% CI -0.04, -0.004), t(165) = -2.40, p=0.017). For pain, a one-point increase in a participant's self-reported pain at baseline was associated with a 0.07 increase in their week 9 mean emotional awareness score (baseline pain: b = 0.07 (95% CI 0.01, 0.13), t(165) = 2.13, p=0.035). Lastly, a one-point increase in a participant's FMI mindfulness score was associated with a 0.04 increase in their mean emotional awareness score (baseline FMI: b = 0.04 (95% CI 0.02, 0.06)), t(165) = 4.20, p<0.001)

In Model 4, including a variable for the mindfulness group significantly accounted for additional variation in the outcome of mean emotional awareness scores post-intervention (see above). Being randomized to the Mindful Movement group was associated with a 0.47 point increase in a participant's mean noticing score at week 9 (b = 0.47 (95% CI 0.19, 0.76), t(164) = 3.29, p=0.001). The effects of age, baseline pain and baseline mindfulness remained the same as in Model 3 with only very slight changes in the 95% CIs (see Table 5.4 below).

Within Model 7, adding a variable for a participant's change in mindfulness from baseline to post-intervention resulted in the model explaining a significant additional amount of variance in mean emotional awareness scores beyond Model 6 (see above). Specifically, a one point increase in mindfulness from baseline to week 9 was associated with a 0.07 increase in the mean emotional awareness score immediately post-intervention (FMI change score: b = 0.07 (95% CI 0.04, 0.09), t(161) = 5.48, p<0.001). The influence of age remained largely the same as in Model 4 (age: b = -0.02 (95% CI -0.04,-0.006), t(161) = -2.69, p=0.008). The effects of baseline mindfulness (increased effect from Model 4) and the mindfulness group (decreased effect from Model 4) maintained their significant influence on mean emotional awareness scores (baseline FMI: b = 0.07 (95% CI 0.05, 0.09), t(161) = 6.58, p<0.001; Mindful Group: b = 0.32 (95% CI 0.05, 0.60), t(161) = 2.32, p=0.022). In contrast to Model 4, baseline pain no longer significantly influenced a participant's mean emotional awareness outcome within Model 7.

Table 5.4: Hierarchical Regression Analysis of Predictors of Week 9 MAIA Emotional Awareness Subscale Mean Scores

Predictor Variables	Model 1 *b* (95% CI)	Model 2 *b* (95% CI)	Model 3 *b* (95% CI)	Model 4 *b* (95% CI)	Model 5 *b* (95% CI)	Model 6 *b* (95% CI)	Model 7 *b* (95% CI)
Age	-0.02 (-0.04, 0.003)	-0.02 (-0.04, 0.003)	-0.02* (-0.04, -0.004)	-0.02* (-0.04, -0.004)	-0.02* (-0.04, -0.004)	-0.02* (-0.04, -0.003)	-0.02** (-0.04, -0.006)
Gender	-0.26 (-0.71, 0.19)	-0.26 (-0.71, 0.19)	-0.28 (-0.70, 0.15)	-0.18 (-0.60, 0.24)	-0.18 (-0.60, 0.24)	-0.15 (-0.58, 0.27)	-0.03 (-0.43, 0.36)
Baseline Pain		0.05 (-0.02, 0.11)	0.07* (0.01, 0.13)	0.07* (0.01, 0.13)	0.07* (0.01, 0.13)	0.06* (0.01, 0,13)	0.05 (-0.01, 0.10)
Baseline FMI			0.04*** (0.02, 0.06)	0.04*** (0.03, 0.06)	0.05*** (0.03, 0.07)	0.05*** (0.03, 0.07)	0.07*** (0.05, 0.09)
Mindful Group				0.47** (0.19, 0.76)	0.48** (0.19, 0.77)	0.45** (0.16, 0.75)	0.32* (0.05, 0.60)
Attendance					-0.02 (-0.11, 0.07)	-0.03 (-0.12, 0.07)	-0.03 (-0.11, 0.06)
Home Practice						0.04 (-0.04, 0.12)	-0.004 (-0.08, 0.07)
FMI Change Score							0.07*** (0.04, 0.09)
R^2	0.029	0.041	0.133	0.187	0.188	0.192	0.319
ΔR^2		0.012	0.092	0.054	0.001	0.004	0.127

* p<.05; ** p<.01; *** p<.001; FMI, Freiburg Mindfulness Inventory

Predictors for the MAIA Self-Regulation Subscale

For the self-regulation subscale, a comparison of the seven models included in the hierarchical regression analysis found that Models 3, 4, 6 and 7 accounted for significant additional variation in post-intervention mean self-regulation scores compared to prior nested models. Model 3 accounted for an additional 18.2% of variance in the post-intervention self-regulation outcome measure beyond what Model 2 explained (Model 3 vs. Model 2 comparison: $F(4,165) = 56.77$, $p<0.001$). Model 4 accounted for a further 7.2% of variance in mean self-regulation scores (Model 4 vs. Model 3 comparison: $F(5,164) = 22.41$, $p<0.001$). Model 6 was able to account for an additional 4.0% of variance above Model 5 (Model 6 vs.

Model 5 comparison: F(7,162) = 12.42, p<0.001). Finally, Model 7 explained an additional 15.2% of variance in mean self-regulation scores over what Model 6 explained (Model 7 vs. Model 6 comparison: F(8,161) = 47.56, p<0.001).

For Model 3, age, baseline pain and baseline mindfulness were the three variables with a significant influence on the mean self-regulation scores post-intervention. For age, a one year increase in a participant's age was associated with a 0.02 decrease in their mean emotional awareness score at the end of the intervention (age: b = -0.02 (95% CI -0.04, -0.002), t(165) = -2.26, p=0.025). In terms of baseline pain, a one-point increase in a participant's pain at baseline was associated with a 0.07 increase in their week 9 mean self-regulation score (baseline pain: b = 0.07 (95% CI 0.02, 0.13), t(165) = 2.41, p=0.017). Lastly, a one-point increase in a participant's baseline mindfulness score was associated with a 0.06 increase in their mean self-regulation score (baseline FMI: b = 0.06 (95% CI 0.04, 0.08), t(165) = 6.20, p<0.001) Gender was the only variable in the model that did not significantly influence the outcome.

Within Model 4, adding a variable for the mindfulness group accounted for the model explaining an additional significant amount of variance beyond Model 3 (see above). A participant being randomized to the Mindful Movement group was associated with a 0.55 point increase in a participant's mean self-regulation score post-intervention (b = 0.55 (95% CI 0.28, 0.81), t(164) = 4.08, p<0.001). The effects of age, baseline pain and baseline mindfulness remained the same as in Model 3 with only very slight changes in some 95% confidence intervals (see Table 5.5).

Model 6 added in the variables of attendance and home practice and only home practice had a significant impact on post-intervention mean self-regulation scores. In terms of home practice, a day per week increase, on average over the duration of the intervention, of practicing program activities was associated with a 0.11 increase in the mean self-regulation outcome (b = 0.11 (95% CI 0.04, 0.19), t(162) = 3.11, p=0.002). Compared to Model 4, the effect of baseline pain on mean self-regulation was slightly increased and the effect of the mindfulness group on mean self-regulation was decreased (see Table 5.5 for the specific changes). The effect of age and baseline mindfulness remained the same as in Model 4 with only very minor changes in the 95% confidence intervals.

For Model 7, the addition of the variable measuring a participant's change in mindfulness from baseline to week 9 resulted in the model explaining a significant additional amount of variance in mean self-regulation scores beyond Model 6 (see above). In particular, a one-point increase in mindfulness from baseline to week 9 was associated with a 0.07 increase in the mean self-regulation score immediately post-intervention (FMI change score: b = 0.07 (95% CI 0.05, 0.09), t(161) = 6.90, p<0.001). As compared to Model 6, the influence of baseline pain, the mindfulness group and home practice on mean self-regulation scores decreased within Model 7 (baseline pain: b = 0.05 (95% CI 0.001, 0.10), t(161) = 2.01, p=0.046; mindful group: b = 0.33 (95% CI 0.09, 0.57), t(161) = 2.70, p=0.008; home practice: b = 0.07 (95% CI 0.004, 0.13), t(161) = 2.09, p=0.038). The impact of age on self-regulation outcomes remained unchanged from Model 6, other than a slight change in confidence intervals (see Table 5.5). Finally, baseline mindfulness was associated with a greater increase mean self-regulation post-intervention (baseline FMI: b = 0.09 (95% CI 0.07, 0.010), t(161) = 9.84, p<0.001).

Table 5.5: Hierarchical Regression Analysis of Predictors of Week 9 MAIA Self-Regulation Subscale Mean Scores

Predictor Variables	Model 1 *b* (95% CI)	Model 2 *b* (95% CI)	Model 3 *b* (95% CI)	Model 4 *b* (95% CI)	Model 5 *b* (95% CI)	Model 6 *b* (95% CI)	Model 7 *b* (95% CI)
Age	-0.01 (-0.03, 0.01)	-0.01 (-0.03, 0.01)	-0.02* (-0.04, -0.003)	-0.02* (-0.04, -0.002)	-0.02* (-0.04, -0.003)	-0.02* (-0.04, -0.002)	-0.02** (-0.04, -0.005)
Gender	-0.35 (-0.80, 0.10)	-0.35 (-0.80, 0.10)	-0.37 (-0.80, 0.03)	-0.26 (-0.65, 0.13)	-0.26 (-0.65, 0.13)	-0.18 (-0.56, 0.20)	-0.05 (-0.39, 0.29)
Baseline Pain		0.04 (-0.02, 0.11)	0.07* (0.01, 0.13)	0.07* (0.02, 0.13)	0.07* (0.02, 0.13)	0.08** (0.02, 0.13)	0.05* (0.001, 0.10)
Baseline FMI			0.06*** (0.04, 0.08)	0.06*** (0.04, 0.08)	0.06*** (0.04, 0.08)	0.06*** (0.05, 0.08)	0.09*** (0.07, 0.10)
Mindful Group				0.55*** (0.28, 0.81)	0.56*** (0.29, 0.83)	0.47*** (0.20, 0.74)	0.33** (0.09, 0.57)
Attendance					-0.02 (-0.11, 0.06)	-0.06 (-0.14, 0.03)	-0.05 (-0.13, 0.02)
Home Practice						0.11** (0.04, 0.19)	0.07* (0.004, 0.13)
FMI Change Score							0.07*** (0.05, 0.09)

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Table 5.5, cont'd.

Predictor Variables	Model 1 *b* (95% CI)	Model 2 *b* (95% CI)	Model 3 *b* (95% CI)	Model 4 *b* (95% CI)	Model 5 *b* (95% CI)	Model 6 *b* (95% CI)	Model 7 *b* (95% CI)
R^2	0.026	0.036	0.218	0.290	0.291	0.331	0.483
ΔR^2		0.010	0.182	0.072	0.001	0.040	0.152

* p<.05; ** p<.01; *** p<.001; FMI, Freiburg Mindfulness Inventory

5.5 Discussion

5.5.1 Summary of Main Findings

The primary aim of this secondary analysis of a large type 2 RCT was to examine whether specific baseline characteristics (e.g., self-reported pain, dispositional mindfulness) and intervention-related characteristics (e.g., attendance and home practice) explain a statistically significant amount of variance post-intervention in the four subscales of the MAIA. Additionally, this analysis sought to investigate the findings from prior studies that suggested that age and gender had a significant influence on interoceptive awareness. Given that this is a secondary analysis, the findings presented here indicate potential predictors related to baseline characteristics and intervention-related characteristics and should be interpreted as exploratory.

One of the major findings of this analysis is that change in mindfulness from baseline to post-intervention has a significant positive impact on all MAIA subscale outcomes. This effect was found across each subscale within all models that accounted for statistically significant variance in the interoceptive awareness outcome measure. This finding suggests that learning mindfulness is important for enhancing one's interoceptive awareness, a finding that matches with the results from Chapter 4. Additionally, this finding highlights a potential mechanism to explain one way in which randomization to the mindfulness group matters. That is, if you were assigned to the mindfulness intervention, it is your change in mindfulness over the course of the intervention that helps explain some of your post-intervention interoceptive awareness outcome – although other factors are also captured by group randomization (discussed below). In other words, even when the mindfulness group is included in a model, the change in a participant's mindfulness score over the course of the intervention is significant ($p<0.001$ in Model 7 of each MAIA subscale). One important caveat, however, is the magnitude of the effect. The mindfulness group, when significant, still accounts for a large amount of post-intervention variation in the interoceptive awareness outcome relative to change in mindfulness. Future work (discussed below) would need to further investigate this effect as part of a primary analysis.

Another major finding from this analysis is that baseline mindfulness, as measured by the FMI, has a significant positive influence on all four MAIA subscales. This effect was true across all subscales and all models that accounted for statistically significant variance in the specific MAIA outcome measure. In fact, the effect of baseline mindfulness remained significant even when including a variable for change in mindfulness from baseline to post-intervention. This suggests that prior exposure to mindfulness in and of itself is an important predictor of interoceptive awareness outcomes post-intervention. Both the Mindful Movement group and Keys group contained a large percentage of participants with prior experience with meditation or mindfulness – sometimes as much as half the group but no less than a third in either group (see Section 5.4.2 above for more detail). This finding highlights a critical gap in much of the existing literature regarding individuals' familiarity with mindfulness prior to participation in a mindfulness-based intervention. There are few studies that measure and report participants' prior mindfulness and meditation experience despite the fact that at least one recent study, using population-based sampling methods, found that nearly half of their U.S. sample reported prior meditation experience [81]. Measuring prior experience with mindfulness and meditation could be used to inform the design of future interventions by better tailoring content to match the understanding of participants. For example, more complex mindfulness skills such as shifting perspectives, working with challenging thoughts or emotions and self-regulation could be given greater time and explanation within the intervention curriculum while other skills such as paying attention in the present moment and placing one's attention on a chosen object (e.g., body or breath) could be less emphasized.

In terms of age, findings from this secondary analysis support the existing literature. In particular, age, when significant, has a negative influence on interoceptive awareness. The magnitude of this effect appears to be small, however, it's important to note that this RCT sample is an older population by design, thus magnitude and significance may differ with a population spanning larger age ranges. Interestingly, age did not have a significant effect on mean attention regulation scores. This may suggest that attention regulation, which is the ability to sustain and control attention, is somewhat resistant to the effects of aging, however, this also could be caused by another factor unique to this older population. For example, attention regulation may have already declined (i.e., before age 50) and is simply not declining further due to age as compared to the other aspects of interoceptive awareness (i.e., noticing, emotional awareness and self-regulation). Future work (discussed below) should seek to further investigate these findings related to age and interoceptive awareness.

With respect to gender, the findings in this chapter are at odds with the prior literature. At least one prior study has found that women tend to score higher than men on the MAIA subscales of noticing and emotional awareness [55], which suggests that gender matters. The findings from this study indicated that across all the models and each subscale, gender never had a significant influence on the post-intervention interoceptive awareness outcome. A major caveat of this finding is that the sample for this analysis was overwhelmingly comprised of women (Mindful Movement group: 91.6% women; Keys group: 81.6 % women). By contrast Grabauskaite et al., which is the study where women were found to report higher MAIA subscale scores compared to men, had a sample that was much younger (17-30 years old) and consisted of nearly equal men (51%) and women (49%) [55].

The findings regarding baseline pain suggest that it is important for some aspects of interoceptive awareness. It appears to positively influence the noticing, emotional awareness and self-regulation aspects of interoceptive awareness, but not significantly impact attention regulation. The very limited literature suggests that pain has a negative, not positive effect, on interoceptive awareness, however, the sample of this study is quite different from that of the prior literature (see [99] comparing people with pain to meditators), so direct comparisons should be approached cautiously. At first glance, the finding that baseline pain seems to positively influence interoceptive awareness may appear a curious finding, however, it can likely be explained by the nature of pain. People with pain develop many of the same skills measured by the MAIA (see [98] for a detailed discussion of this intersection). For example, people with pain are quite familiar with noticing painful sensations. They also are aware of the connection between painful sensations and emotion, especially negative emotions. Lastly, people with pain know first-hand how pain can derail daily activities without self-management skills. Thus, the positive effect of pain on interoceptive awareness can likely be explained by these prior abilities of noticing, emotional awareness and self-regulation and that both interventions (Mindful Movement and Keys) likely helped with re-framing these skills away from a hyper-vigilant and reactive mode to a more neutral mode. In terms of attention regulation, which is the ability to sustain and control attention, it is unclear why this subscale did not exhibit a similar pattern as the other subscales. As with gender, a major caveat of the above discussion is that the sample for this analysis was overwhelmingly people who reported pain at baseline (Mindful Movement group: 89.2% people with pain; Keys group: 94.3% people with pain) and also people who exhibited relatively low baseline pain compared to other trials that use higher inclusion criteria for pain ratings (see e.g., [12] for a large multi-site trial of chronic low back pain that requires a pain rating of at least 3 or higher to be eligible to participate). Results would likely vary with a different sample and future work should investigate this question.

For the variables of attendance and home practice, the results suggest that these factors sometimes matter for certain facets of interoceptive awareness. Home practice seems to be positively associated with self-regulation but it does not significantly influence the noticing or emotional awareness facets of interoceptive awareness. Its effect on attention regulation is less clear as it ceased to exert a significant influence once change in mindfulness from baseline to week 9 was included in the model. Since self-regulation is a higher-order skill it would make sense that out-of-class home practice would be associated with an increase in this domain of interoceptive awareness post-intervention. It is less clear why home practice does not significantly influence the other facets of interoceptive awareness. Attendance, other than for negatively influencing the attention regulation subscale, did not significantly impact interoceptive awareness. One likely explanation for this lack of effect of attendance could be the very high rates of intervention adherence (Mindful Movement: 96.4% attended six or more of eight sessions; Keys: 86.3% attended six or more of eight sessions). For the attention regulation subscale, the one place where attendance had a significant influence, it is still not clear why attendance had a negative effect. It may be that this negative effect is due to mindfulness training emphasizing curiosity and non-reactive observation, which as a new skill, could temporarily impede one's prior ability to redirect attention elsewhere.

5.5.2 Strengths and Limitations

This secondary analysis has important strengths that contribute to the field of existing interoception research. First, this study indicates potential predictive factors that matter for the design and implementation of future interventions. Specifically, the finding that baseline mindfulness has a significant effect on numerous aspects of interoceptive awareness means that future mindfulness studies should measure this factor and also potentially alter curriculum to account for prior familiarity with mindfulness. Second, the results presented here support some (e.g., aging) but not all (e.g., gender and pain) of the findings from prior literature related to potential factors that influence interoceptive awareness. Moreover, the findings suggest that in an older population, not all facets of interoceptive awareness are equally impacted by aging, such as attention regulation versus noticing, emotional awareness and self-regulation). Third, this study is one of the first to attempt to disentangle the effects of various predictive factors on interoceptive awareness. As such, it provides useful information for potential future work that seeks to investigate specific mechanisms that underlie differences in interoceptive awareness.

While this secondary analysis includes a number of strengths, it also includes several important limitations. The first limitation is the nature of this secondary analysis, which means the results presented here are exploratory. Additionally, future work is needed to investigate the post hoc interpretation of the potential reasons for differences in outcomes based on the predictive factors analyzed here. Another limitation relates to the generalizability of these findings. The sample for this analysis was older, which was an intentional part of the RCT's design, and predominately white and mostly women. This sample is not representative of the US population as a whole, which can limit the ability to generalize the findings presented here and also account for findings that differ from prior findings with different populations. The lack of a representative sample is a known problem with most mindfulness research [157] and it highlights a need for future studies to address this issue. Moreover, this study did not include baseline questions inclusive of transgender, non-binary or gender-diverse people, which represents a significant limitation in regards to the analysis, discussion and interpretation of gender within this chapter and should be addressed in future work.

5.6 Future Work

Future studies should endeavor to address the limitations of the present study. With respect to the study population that is non-representative, a number of multi-tiered community-based approaches are needed [66] and the full details of specific approaches to address this limitation have been discussed in Chapter 4. As relates specifically to gender identity, future studies should consider the use of certain Common Data Elements (CDEs) that include known social determinants of health (see e.g., www.phenxtoolkit.org). The PhenX toolkit, in particular, provides researchers with multi-tiered questions that are much more inclusive of a diversity of gender identities than the typical binary options presented in many studies (such as the trial described here). These CDEs also help with subsequent meta-analyses seeking to investigate questions related to gender identities within existing research on interoception. In regards to mechanisms, future studies should seek to use additional instruments to directly measure some of the effects indicated here. For example, the questions related to prior exposure to mindfulness were limited to a simple 'yes or no' response followed by a check all that apply question. Future work should seek to delve deeper into understanding prior experiences and lifetime exposure to mindfulness practice pre-intervention. Additionally, the pain scale used in this study could be replaced with other scales and possibly include additional measures of pain interference. Finally, future work should also seek to investigate interoceptive awareness as a primary outcome measure as this will allow for a deeper understanding of correlations beyond the basic associations that are possible with the hierarchical linear regression approach used here.

5.7 Conclusion

The findings from this secondary analysis of a type 2 RCT suggest that several factors influence interoceptive awareness - in particular, age, baseline mindfulness and change in mindfulness post-intervention. These findings extended the work from Chapter 4 and identified certain under-investigated factors in the current literature, such as prior experience with mindfulness pre-intervention. They also highlighted the need for further investigation into other factors, such as pain and gender. A key next step is to replicate the exploratory findings presented here in a more representative population with interoceptive awareness representing the primary outcome measure.

The results from this chapter and the prior chapters provide important support for the central thesis of this dissertation. In the next chapter, the thesis statement of this dissertation will be revisited in light of all of the proceeding findings. A final synthesis of key findings as well as implications for future work are presented.

Chapter 6

Conclusion

This final chapter revisits the thesis statement of this dissertation in light of the findings from the previous three chapters. It also provides a final synopsis and synthesis of key findings. Most importantly, it provides a detailed discussion of potential future work oriented towards the pursuit of a longer-term goal that envisions virtual reality (VR) applications that are deployed in a telehealth mode. Potential implications of such a vision are also explored.

6.1 Central Thesis Revisited

The central thesis of this dissertation is:

Interoceptive awareness can be effectively taught and measured in novel training environments that weave together evidence-based psychological interventions (e.g., MBIs) and emerging computer science technologies (e.g. VR and telehealth).

Chapter 3 introduced a novel VR environment designed for investigating interoceptive awareness. This custom designed environment included a motion-tracked avatar visible in a virtual mirror with an interactive visualization of a biometric signal detected via a heartbeat sensor. Importantly, this virtual environment also addressed several limitations from prior related work (as discussed in Chapter 2) by including biofeedback, an avatar and interactivity beyond just head tracking. In terms of measurement, Chapter 3 introduced a new qualitative methodology, including a reusable codebook, for researchers to understand users' experiences of interoceptive awareness in VR. Results from a first exploratory study applying the methodology showed that the methodology elicited valuable responses from participants regarding their experience of interoceptive awareness in VR. The work from Chapter 3, therefore, supports the central thesis by providing an important proof-of-concept that interoceptive awareness can be taught and qualitatively assessed in a custom-designed immersive, stereoscopic, perspective-tracked VR environment. Most significantly, the methodology and study presented in Chapter 3 represent the first attempts to qualitatively investigate a multi-dimensional model of interoceptive awareness in VR. This work establishes a critical foundation for conducting future follow-on comparative studies that can provide more complete design guidelines for the most effective VR tasks and representations of the body and body signals that can facilitate interoceptive awareness training. While Chapter 3 demonstrates the potential of using VR to train interoceptive awareness in a lab, it leaves unanswered the question of whether interoceptive awareness could be trained via a group intervention delivered remotely.

Chapter 4 addressed this issue by assessing the effectiveness of a novel group telehealth mindfulness intervention, compared to an active control, for enhancing interoceptive awareness. The quantitative results from this secondary analysis of a randomized type 2 hybrid effectiveness-implementation trial support the central thesis that interoceptive awareness can be taught and measured even in a group telehealth environment. In addition, the findings also provide important exploratory data about the temporal stability of gains in interoceptive awareness resulting from the mindfulness intervention. Finally, the intervention itself was delivered by non-mindfulness facilitators, which shows the promise of future scalable group interventions. Taken together, these findings highlight the potential of combining emerging technologies with mindfulness practices to increase interoceptive awareness. Even though Chapter 4 illustrates the potential of a group mindfulness intervention in general, it does not provide insight into potential factors, such as age, pain and prior experience with mindfulness, that might predict differences in interoceptive awareness outcomes. Knowledge of potential predictive factors is useful for designing interventions to be optimized to enhance outcomes for specific populations.

Chapter 5 addressed the question of potential predictive factors by conducting a hierarchical regression analysis. The exploratory findings from this analysis suggested that several factors influence post-intervention interoceptive awareness outcomes. Specifically, the factors of age (negative influence), baseline mindfulness (positive influence), and change in mindfulness from baseline to intervention completion (positive influence) significantly impact interoceptive awareness. With respect to baseline mindfulness, current literature has under-investigated this factor even though there is evidence that prior experience with mindfulness is very widespread in the U.S (see e.g., [81]). The findings from Chapter 5 also highlight the need for further investigation into factors, such as gender, pain, intervention attendance, and home practice. The findings from Chapter 5 support the central thesis by delving deeper into potential predictive factors that may impact the effectiveness of interventions targeting different populations while also suggesting potential reasons for observed outcome differences within a heterogeneous group. These findings provide important information about how teaching and measuring interoceptive awareness might be further refined based on various population characteristics, such as measuring prior experience with mindfulness and changing curriculum to emphasize higher-order skills versus introductory information that is likely to be known by many participants.

In summary, novel VR and telehealth mindfulness-based interventions show considerable promise for training interoceptive awareness and can also support the widespread access and uptake of such training. VR provides a powerful *computing medium for embodied simulations* that can alter interoceptive experiences through custom-designed training environments. Telehealth provides a *critical mode of healthcare delivery* that can improve access to healthcare resources across geographically disparate regions while maintaining quality of care. Finally, tailoring interventions to account for predictive factors helps ensure *the right message* *is given to the right participant*. When a powerful *computing medium* uses an effective *mode of healthcare delivery* to provide *the right message*, then truly transformative opportunities emerge for taking evidence-based behavioral interventions outside the confines of traditional healthcare settings. Investigating these novel interventions is the primary motivation that underlies the entirety of the work presented in this dissertation.

6.2 Future Work

This section describes future directions for pursuing a longer-term goal of combining VR, telehealth and mindfulness-based interventions. Additionally, some of the implications of this vision are explored.

6.2.1 A Driving-Problem Approach to Embodied Simulations

A critical component of further developing immersive embodied simulations for health interventions is to increase interdisciplinary collaboration on larger scale projects that seek to create additional technical prototypes and gather pilot clinical data. The work presented in Chapter 3 is still in its early stages. While the VR user study described in Chapter 3 provided important information about design tradeoffs and technical specifications needed for creating a working prototype, it still needs to be refined before it could be deployed to participants in a clinical pilot study. Additionally, this prototype has not yet realized its full potential where clinicians and patients, supported by computer scientists, could customize the immersive experience with patient-specific scripts, imagery or sound. The building blocks for this next logical step exist within the current prototype as a significant portion of the environment, including the guiding audio and specification of the timing for key events within the exercise (e.g., moving focus to the next body part) was customized by me, a non-programmer, via a simple, textfile scripting interface developed for this purpose. This existing interface means that future environments could be developed and customized directly by practitioners and clinicians using a similar approach.

Beyond taking the next logical steps in development and pilot testing, there exists a need for deeper partnership via an on-going interdisciplinary working group in order to meaningfully advance a bigger vision. This working group should be multi-faceted and include artists and designers, computer scientists, clinicians, and community members. Of utmost importance is linking the technology to a pressing societal need. By linking the technology to a condition of interest, an important force emerges. This force is what the renowned computer scientist and engineer Fred Brooks termed the 'driving-problem approach,' which he defined as "hitching our research to someone else's driving problems, and solving those problems on the owners' terms, leads us to richer computer science research" [13]. In short, the on-going work of designing embodied simulations for health interventions requires the constraints that a clinical pilot study would impose based upon the condition or behavior that is being targeted. The constraints of a pilot clinical study also act as a forcing function for everyone involved to ensure that a clear societal need is addressed and that the technology does not simply become an interesting curio with no real-world impact. In this respect, one of the likeliest conditions to 'hitch' this work to is chronic pain, which is explored below.

6.2.2 Scalable, Immersive Pain Education Programs

Back pain is a leading cause of disability worldwide [162] and represents the most common chronic pain condition for seeking out healthcare [41]. In the U.S. as of 2016, approximately ten percent of healthcare costs were tied up in treating back pain [27]. As a condition, back pain is extremely complex because it involves interconnected physical, psychological and social factors [118, 71]. In terms of treatment, most current approaches focus on physical factors and symptom management through the use of opioids, injections and surgery [40]. Of particular concern is that these invasive treatments have had limited long-term positive impacts on patient outcomes [26]. While more invasive treatment approaches are needed in some cases, a majority of people who suffer from back pain would benefit from less invasive self-management programs that teach adaptive pain behaviors [15, 91]. These self-management programs have an added benefit of being deployable in community settings (i.e., outside the costly and difficult to navigate healthcare system) and can be delivered by lay facilitators out in the community (i.e., an alternative to provider-dependent, clinic-based care such as injections and prescription medication) – see, e.g., [43] for a description of a lay-facilitated program.

With this driving problem of back pain, an exciting new direction emerges for future work when we link the VR work of Chapter 3 with the telehealth findings from Chapter 4. In particular, a longer-term goal of creating virtual worlds with real-time social interactions and patient-centered practices related to pain education becomes possible. This vision leverages the affordances of VR as an embodied technology that can increase patient engagement with current evidence-based self-management programs that have been developed for community-based settings. In fact, recent scholarship on managing another chronic disease, chronic obstructive pulmonary disease (COPD), highlighted the critical need to explore both telehealth and VR as new directions for managing COPD [131]. This new *teleVR* future can also address an under-emphasized dimension of most chronic conditions (in general) and back pain (in particular), namely the social and psychological dimensions as opposed to just physical symptom management. It is this vision of the future that motivates the ongoing work of exploring bold new visions of scalable, immersive pain management programs.

6.3 Final Reflections

This dissertation aims to establish a solid foundation for the potential of novel VR and telehealth mindfulness-based interventions to enhance interoceptive awareness. As such, it represents a first step in a longer journey of weaving together emerging technologies with evidence-based interventions to develop wellbeing behaviors. Cultivating greater body awareness, such as through training interoceptive awareness, is a foundational skill for any self-management practice and equally essential for long-term wellbeing. VR and telehealth offer an opportunity to address many of the patient-level barriers that plague our current healthcare system and disproportionately impact marginalized and low-income communities. My hope is that this dissertation provides some measure of inspiration for clinicians, computer scientists, artists, and community members to actively work together to imagine and realize a future where immersive, personalized VR applications improve public health beyond the confines of traditional healthcare systems.

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Appendix A

Detailed Baseline Characteristics & Demographic Table

This appendix provides a detailed table of baseline characteristics and demographic information for the randomized type 2 hybrid effectiveness-implementation trial described in Chapters 4 and 5.

Table A.1: Baseline Characteristics of the RCT

Parameter	**Mindful Movement**	**Keys**
Participants, n	86	90
Gender, n (%)		
Women	78 (90.7)	74 (82.2)
Men	8 (9.3)	16 (17.8)
Age, mean (SD)	65.55 (7.24)	66.83 (8.41)
10 min. bouts of MVPA in 7-day period, mean (SD)	18.35 (24.97)	15.54 (23.94)
Ethnicity, n (%)		
Not Hispanic or Latino	82 (95.3)	85 (94.4)
Hispanic or Latino	2 (2.3)	3 (3.3)
Prefer not to answer	2 (2.3)	2 (2.2)
Race, n (%)		

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Table A.1, cont'd.

Parameter	**Mindful Movement**	**Keys**
American Indian or Alaska Native	1 (1.2)	0 (0)
Black or African American	5 (5.8)	8 (8.9)
Asian	1 (1.2)	0 (0)
White	75 (87.2)	80 (88.9)
Multiracial	4 (4.7)	2 (2.2)
Employment, n (%)		
Currently working full-time	21 (24.4)	18 (20.0)
Currently working part-time	19 (22.1)	12 (13.3)
Not currently employed	3 (3.5)	4 (4.4)
Retired	42 (48.8)	52 (57.8)
Other	1 (1.2)	4 (4.4)
Marital Status, n (%)		
Married	43 (50.0)	45 (50.0)
Single	17 (19.8)	16 (17.8)
Separated	0 (0)	1 (1.1)
Divorced	14 (16.3)	14 (15.6)
Widowed	9 (10.5)	10 (11.1)
YMCA Member, n (%)		
No (non-members)	36 (41.9)	28 (31.1)
Yes (members)	50 (58.1)	62 (68.9)
Household Income, n (%)		
Less than $9,999	1 (1.2)	1 (1.1)
$10,000 to $14,999	3 (3.5)	2 (2.2)
$15,000 to $24,999	4 (4.7)	5 (5.6)
$25,000 to $34,999	11 (12.8)	8 (8.9)
$35,000 to $49,999	7 (8.1)	13 (14.4)
$50,000 to $74,999	19 (22.1)	19 (21.1)
$75,000 to $99,999	14 (16.3)	14 (15.6)

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Table A.1, cont'd.

Parameter	**Mindful Movement**	**Keys**
$100,000 or more	17 (19.8)	13 (14.4)
Prefer not to answer	10 (11.6)	15 (16.7)
Education, n (%)		
High school graduate, or equivalent	1 (1.2)	6 (6.7)
Vocational/technical/trade school	4 (4.7)	7 (7.8)
Associate's Degree	5 (5.8)	2 (2.2)
Bachelor Degree	37 (43.0)	28 (31.1)
Master's Degree	22 (25.6)	26 (28.9)
Doctoral Degree	2 (2.3)	6 (6.7)
Professional Degree (e.g., JD, MD)	6 (7.0)	4 (4.4)
Health Conditions, n (%)		
Diabetes	7 (12.1)	13 (18.3)
Kidney Disease	4 (6.9)	2 (2.8)
Arthritis	35 (60.3)	39 (54.9)
Lung	1 (1.7)	3 (4.2)
Depression	3 (5.2)	6 (8.5)
Back Pain	2 (3.4)	1 (1.4)
Joint Pain	2 (3.4)	5 (7.0)
Headache	3 (5.2)	2 (2.8)
Body Mass Index (kg/m2) (mean (SD))	30.32 (6.24)	32.55 (6.72)
Tobacco Use, n (%)		
Current	0 (0)	5 (5.6)
Former	30 (34.9)	30 (33.3)
Never, lifetime abstinence	56 (65.1)	55 (61.1)
Self-reported pain* > 0 in past week, n (%)	77 (89.5)	84 (93.3)
Arm, mean (SD)	1.49 (1.85)	1.41 (1.71)
Leg, mean (SD)	2.28 (2.22)	2.41 (2.26)
Back, mean (SD)	2.0 (2.24)	2.24 (2.51)

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Table A.1, cont'd.

Parameter	**Mindful Movement**	**Keys**
Other bodily pain, mean (SD)	1.17 (1.70)	1.13 (1.64)
MAIA		
Noticing Subscale, mean (SD)	2.87 (1.02)	2.78 (0.93)
Attention Regulation Subscale, mean (SD)	2.40 (1.05)	2.60 (1.05)
Emotional Awareness Subscale, mean (SD)	3.03 (1.06)	3.05 (0.99)
Self-Regulation Subscale, mean (SD)	2.65 (1.12)	2.74 (1.05)

SD, standard deviation; MVPA, Moderate to Vigorous Physical activity wihtin a 7-day period; *Self-reported pain on 0–10 numerical rating scale; MAIA, Multidimensional Assessment of Interoceptive Awareness, version

Appendix B

Additional Information on Updated Literature Search

The below search terms represent the updated syntax, followed by the number of results, based upon the syntax originally reported by Nina Marshall in her thesis [92]. This updated syntax was used to search the below databases for new randomized controlled trials from 2021 to 2023. A special thank you to Liz Weinfurter, MLIS, Nursing Librarian, for her expert guidance and assistance.

Interoception search update, 2021-2023: 694 unique articles identified

Search terms for APA PsycInfo <2002 to August Week 4 2023> - 9/6/23 - 130 citations

1. (Interoception or interoceptive).sh. or interocepti*.ti,ab. or Interoceptive interventions.tw. or physiological proces*.ti,ab. or somesthetic percepti*.ti,ab. or Sensorimotor.ti,ab. or viscerocept*.ti,ab. or Psychophysiol*.ti,ab. or Physiological state.ti,ab. or Internal state.ti,ab. – result: 26362

2. (Mindfulness or mindful).sh. or mindful*.ti,ab. or MABT.ti,ab. or MBCT.ti,ab. or MBSR.ti,ab. or meditation.ti,ab. or (acceptance adj2 commitment therap*).ti,ab. or Mind body.ti,ab. or Body oriented.ti,ab. or Somatic psychotherap*.ti,ab.

or Body psychotherap*.ti,ab. or Contemplative practice*.ti,ab. – results: 31076

3. 1 and 2 – results: 594
4. limit 3 to (english language and yr="2021 -Current") – results: 130

Search terms for Web of Science 9/6/23 - 313 citations

1. TS=interocep* OR (TI=(interocepti* OR "physiological proces*" OR "somesthetic percepti*" OR "somatic awareness" OR "somatic perception" OR somato* OR Sensorimotor OR viscerocept* OR Psychophysiol* OR "Physiological state" OR "Internal state") OR AB=(interocepti* OR "physiological proces*" OR "somesthetic percepti*" OR "somatic awareness" OR "somatic perception" OR somato* OR Sensorimotor OR viscerocept* OR Psychophysiol* OR "Physiological state" OR "Internal state")) – Results: 186098
2. TS=mindful* OR TI=(mindful* OR MABT OR MBCT OR MBSR OR meditation OR "acceptance and commitment therap*" OR "Mind body" OR "Body oriented" OR "Somatic psychotherap*" OR "Body psychotherap*" OR "Contemplative practice") OR AB=(mindful* OR MABT OR MBCT OR MBSR OR meditation OR "acceptance and commitment therap*" OR "Mind body" OR "Body oriented" OR "Somatic psychotherap*" OR "Body psychotherap*" OR "Contemplative practice") – Results: 54334
3. 1 AND 2 – Results: 594
4. 1 AND 2 and 2021 or 2022 or 2023 (Publication Years) – Results: 313

Search terms for Embase (Ovid) 9/7/23 - 195 citations

Embase <1996 to 2023 Week 35>

1. exp interoception/ – Results: 1808

2. (interocepti* or physiological proces* or somesthetic percepti* or Sensorimotor or viscerocept* or Psychophysiol* or Physiological state or Internal state).ti,ab. – Results: 87490
3. 1 or 2 – Results: 87763
4. exp mindfulness/ or exp mindfulness meditation/ – Results: 15521
5. (((mindful* or MABT or MBCT or MBSR or Meditation).ti,ab. or acceptance.mp.) and commitment therap*.ti,ab.) or Mind body.ti,ab. or Body oriented.ti,ab. or Somatic psychotherap*.ti,ab. or Body psychotherap*.ti,ab. or contemplative practice*.ti,ab. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword heading word, floating subheading word, candidate term word] – Results: 7565
6. 4 or 5 – Results: 22036
7. 3 and 6 – Results: 502
8. limit 7 to (english language and yr="2021 -Current") – Results: 195

Search terms for Medline (Ovid) 9/7/23 - 300 articles

Ovid MEDLINE(R) and Epub Ahead of Print, In-Process, In-Data-Review & Other Non-Indexed Citations and Daily <1946 to September 06, 2023>

1. exp Interoception/ – Results: 807
2. (interocepti* or physiological proces* or somesthetic percepti* or Sensorimotor* or viscerocept* or Psychophysiol* or Physiological state or Internal state).ti,ab. – Results: 80720
3. 1 or 2 – Results: 80787
4. exp Mindfulness/ or exp "Acceptance and commitment therapy"/ or exp Mind-body therapies/ – Results: 53515

5. (mindful* or MABT or MBCT or MBSR or Meditation or “acceptance and commitment therap*” or Mind body or Body oriented or Somatic psychotherap* or Body psychotherap* or contemplative practice).ti,ab. – Results: 24801

6. 4 or 5 – Results: 67563

7. 3 and 6 – Results: 1522

8. limit 7 to (english language and yr=“2021 -Current”) – Results: 300

CINAHL Ultimate (Ebsco) 9/8/23 - 80 articles

(TI interocept* OR AB interocept* OR TI “body awar*” OR AB “body awar*” OR TI “physiological proces*” OR AB “physiological process*” OR TI “somesthetic percepti*” OR AB “somesthetic percepti*” OR TI viscerocept* OR AB viscerocept* OR TI Psychophysiol* OR AB Psychophysiol* OR TI “physiological state” OR AB “Physiological state” OR TI “internal state” OR AB “internal state”) AND (MH Mindfulness+ OR TI mindfulness OR AB mindfulness OR MH “Acceptance and commitment therapy” OR TI “acceptance and commitment therap*” OR AB “acceptance and commitment therap*” OR TI “Mind-body therap*” OR AB “mind-body therap*” OR TI mindful* OR AB mindful* OR TI MABT OR AB MABT OR TI MBAT OR AB MBAT OR TI MBCT OR AB MBCT OR TI MBSR OR AB MBSR OR TI Meditation OR AB Meditation OR TI “Mind body” OR AB “mind body” OR TI “body cent*” OR AB “body cent*” OR TI “Body oriented” OR AB “body oriented” OR TI “Somatic psychotherap*” OR AB “somatic psychotherapy*” OR TI “Body psychotherap*” OR AB “body psychotherapy*” OR TI “contemplative practice” OR AB “contemplative practice”) – Results: 80

De-Duplication

Results de-duplicated with EndNote - 694 unique citations.

Appendix C

Additional Materials for Inward Virtual Reality

Additional Material 1 - Codebook

Parent Nodes (5 dimensions of MAIA conceptual framework)	Original MAIA Definition (Mehling et al., 2012, p. 6)	Operational Definitions of Parent Nodes	Clarification	Sentiment with example words / phrases
Awareness of body sensations	Awareness of body sensations includes awareness of negative, positive, and neutral sensations, with no subdimensions or distinction as to whether these are perceived actively or passively. Sensations of breath were added as neutral sensations.	Individual mentions awareness of negative, positive or neutral body sensations (e.g., breathing, heart rate, pain, felt-sense) in connection with the VR session.	This encompasses bare noticing of bodily experience.	Positive: I felt my shoulders were really loose. Negative: I noticed lots of tension in my legs.
Emotional reaction and attentional response to sensations	Emotional reaction and attentional response to sensations includes four subdomains: (a) the affective response to a sensation, expressed as its bothersomeness or pleasantness (moved from Dimension 1); (b) suppressing, ignoring, or avoiding perceptions of sensations such as by distracting oneself; (c) narrative, judgmental awareness that ‘‘analyzes’’ sensation, including worrying that something is wrong; and (d) present-moment awareness with nonjudgmental awareness of sensations, i.e., a mindful presence.	Individual mentions an affective response (e.g., bothersomeness or pleasantness) or attentional response (e.g., suppressing, ignoring, avoiding, distracting, narrating, judging, analyzing / proliferating, or mindfully noticing) to body sensations in connection with the VR session.	This is an outcome or effect of something that was noticed.	Positive: I felt really peaceful as I noticed my breathing. Negative: My stomach was grumbling the whole time and I got distracted and worried by it.
Capacity to regulate attention	Capacity to regulate attention pertains to various ways of controlling one’s attention as an active regulatory process. These include the ability to (a) sustain awareness, (b) actively direct attention to various parts of the body, (c) narrow or widen the focus of attention, and (d) allow sensations without trying to change them.	Individual mentions controlling attention (e.g., a skill) by sustaining awareness of, directing attention to, narrowing or widening attention of, or allowing attention of body sensations in connection with the VR session.	This is a skill that requires intention and effort.	Positive: I was really able to zoom in on the feeling of my hands on my lap. Negative: My attention was all over the place from feeling tingling in my knee, to an eye twitch to my sore back.

Reference:

W. E. Mehling, C. Price, J. J. Daubenmier, M. Acree, E. Bartmess, and A. Stewart. The multidimensional assessment of interoceptive awareness (maia). *PloS one*, 7(11):e48230–e48230, 2012. doi: 10.1371/journal.pone.0048230.

Additional Material 1 - Codebook

Trusting body sensations	Trusting body sensations, beliefs about importance of sensations reflects the extent to which one views awareness of bodily sensations as helpful for decision making or health.	Individual mentions importance of body sensations as helpful in making a decision or in considering an aspect of their health in connection with the VR session.	This includes feelings of trustworthiness and safety related to bodily experiences.	<u>Positive</u>: When I could feel my arms moving and see them in the mirror I felt more safe. <u>Negative</u>: I knew a had to close my eyes even though it said not to, otherwise I'd get a headache.
Awareness of mind-body integration	Mind-body integration is viewed as the ultimate goal of mind-body therapies and includes three subdimensions: (a) emotional awareness, the awareness that certain physical sensations are the sensory aspect of emotions; (b) self-regulation of emotions, sensations, and behavior (developed in the focus groups); and (c) ability to feel a sense of an embodied self, representing a sense of the interconnectedness of mental, emotional, and physical processes as opposed to a disembodied sense of alienation and of being disconnected from one's body.	Individual mentions body sensations related to awareness of an emotion, using a self-regulating skill or feeling embodied in connection with the VR session.	This encompasses greater access to more developed levels of body awareness that connects mind and body.	<u>Positive</u>: I knew I was calm because I felt my heartbeat slow down and I was thinking less. <u>Negative</u>: I really felt disconnected because parts of my body seemed out of place.

Reference:

W. E. Mehling, C. Price, J. J. Daubenmier, M. Acree, E. Bartmess, and A. Stewart. The multidimensional assessment of interoceptive awareness (maia). *PloS one*, 7(11):e48230–e48230, 2012. doi: 10.1371/journal.pone.0048230.

Additional Material 2: Consolidated criteria for reporting qualitative research (COREQ): 32-item checklist

Reformatted checklist from: Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357.

Item No. and Topic	Guided Questions / Description	Reported on Page No.
Domain 1: Research team and reflexivity		
Personal characteristics		
1. Interviewer/facilitator	Which author/s conducted the interview or focus group?	Page 31
2. Credentials	What were the researcher's credentials? *e.g. PhD, MD*	Page 32
3. Occupation	What was their occupation at the time of the study?	Page 32
4. Gender	Was the researcher male or female?	Page 31
5. Experience and training	What experience or training did the researcher have?	Page 32
Relationship with participants		
6. Relationship established	Was a relationship established prior to study commencement?	Page 33
7. Participant knowledge of the interviewer	What did the participants know about the researcher? *e.g. personal goals, reasons for doing the research*	Page 33
8. Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? *e.g. bias, assumptions, reasons and interests in the research topic*	Page 33
Domain 2: Study design		
Theoretical framework		
9. Methodological orientation and Theory	What methodological orientation was stated to underpin the study? *e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis*	Page 23
Participant selection		

Additional Material 2:
Consolidated criteria for reporting qualitative research (COREQ): 32-item checklist

10. Sampling	How were participants selected? *e.g. purposive, convenience, consecutive, snowball*	Page 30
11. Method of approach	How were participants approached? *e.g. face-to-face, telephone, mail, email*	Page 30
12. Sample size	How many participants were in the study?	Page 31
13. Non-participation	How many people refused to participate or dropped out? Reasons?	Page 31
Setting		
14. Setting of data collection	Where was the data collected? *e.g. home, clinic, workplace*	Page 32
15. Presence of non-participants	Was anyone else present besides the participants and researchers?	Page 32
16. Description of sample	What are the important characteristics of the sample? *e.g. demographic data, date*	Table 3.2, page 34
Data collection		
17. Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	Table 3.1, page 25
18. Repeat interviews	Were repeat interviews carried out? If yes, how many?	Page 34
19. Audio/visual recording	Did the research use audio or visual recording to collect the data?	Page 31
20. Field notes	Were field notes made during and/or after the interview or focus group?	Page 33
21. Duration	What was the duration of the interviews or focus group?	Page 32
22. Data saturation	Was data saturation discussed?	Page 31
23. Transcripts returned	Were transcripts returned to participants for comment and/or correction?	Pages 33
Domain 3: Analysis and findings		
Data analysis		
24. Number of data coders	How many data coders coded the data?	Page 33
25. Description of the coding tree	Did authors provide a description of the coding tree?	Figure 3.1, page 26