frontiers in Virtual Reality

ORIGINAL RESEARCH
published: 21 January 2022
doi: 10.3389/frvir.2021.672556

Design Considerations for Supporting Mindfulness in Virtual Reality

Ryan M. Kelly[1]*, *Elizabeth M. Seabrook*[2], *Fiona Foley*[2], *Neil Thomas*[2], *Maja Nedeljkovic*[2] and *Greg Wadley*[1]

[1]School of Computing and Information Systems, University of Melbourne, Parkville, VIC, Australia, [2]Centre for Mental Health, Swinburne University of Technology, Hawthorn, VIC, Australia

Mindfulness practice involves bringing one's attention to the present moment and noticing events as they unfold with a non-judgmental attitude of acceptance. Although mindfulness has been shown to reduce stress and improve mental health, it can be challenging to learn mindfulness techniques. Recent years have seen an interest in using virtual reality (VR) to help people learn mindfulness by immersing users in virtual settings that support an external focus of attention and reduce everyday environmental distraction. However, the literature currently lacks an understanding of how VR should be designed to support mindfulness. In this paper we describe the iterative design and evaluation of *Place*, a VR app that supports mindfulness practice by situating the user in a virtual forest environment. We present findings from our design process in which prospective users trialled *Place* and provided feedback on the design in focus groups. Our findings draw attention to factors that influenced the user experience and acceptance of VR for mindfulness, and we describe how the design was altered to address these factors. We end by discussing key design choices that designers should consider when creating VR for mindfulness. Our contributions include insight into the importance of following an iterative design process when creating a VR mindfulness app, and a framework that can be used to inform the design of future VR apps for mindfulness practice.

Keywords: design, meditation, mental health, mindfulness, virtual environment, virtual reality

OPEN ACCESS

Edited by:
Mark Billinghurst,
University of South Australia, Australia

Reviewed by:
Burkhard Wuensche,
The University of Auckland,
New Zealand
Lynda Joy Gerry,
Aalborg University Copenhagen,
Denmark

***Correspondence:**
Ryan M. Kelly
ryan.kelly@unimelb.edu.au

Specialty section:
This article was submitted to Virtual Reality in Medicine, a section of the journal Frontiers in Virtual Reality

Received: *26 February 2021*
Accepted: *15 November 2021*
Published: *21 January 2022*

Citation:
Kelly RM, Seabrook EM, Foley F, Thomas N, Nedeljkovic M and Wadley G (2022) Design Considerations for Supporting Mindfulness in Virtual Reality. Front. Virtual Real. 2:672556. doi: 10.3389/frvir.2021.672556

1 INTRODUCTION

1.1 Mindfulness

Mindfulness meditation is an empirically supported practice for reducing stress and improving mental health. Whilst there are varying conceptualisations of mindfulness across Buddhist and Western perspectives, a commonly recognised definition was brought into Western psychology by John Kabat-Zinn (Kabat-Zinn et al., 1985). He states that mindfulness involves two key elements: intentional focus of one's attention on present-moment events, and learning to approach those events with an attitude of acceptance (Kabat-Zinn, 2003). By adopting a non-judgmental stance towards thoughts, feelings and sensations, mindfulness promotes a more nuanced understanding of present moment experiences (Lindsay and Creswell, 2017). Practitioners employ a willingness, or form the intention, to remain present with experiences, and to experience them with non-attachment and non-judgement (Anderson et al., 2007; Baer et al., 2008). There is growing evidence that mindfulness-based interventions can successfully reduce depression and anxiety (Bohlmeijer et al., 2010), and improve psychological well-being in the general population (Bränström et al., 2011; Demarzo et al., 2017; Freudenthaler et al., 2017) and in populations

with specific health problems such as arthritis (Pradhan et al., 2007), cancer (Monti et al., 2006), or fibromyalgia (Sephton et al., 2007).

Mindfulness can be operationalised through a variety of formal meditative practices that may be guided in person by a teacher, via an audio recording, or practiced in a self-guided way. Examples include pranayama, which is the practice of breath regulation; loving-kindness, which encourages feelings of kindness and benevolence; body-scan meditation, which involves attending to specific parts of the body in sequence; and sitting meditation, which can involve directing focused attention to different senses and sensations (Khoury et al., 2017; Birtwell et al., 2019). In a typical example of a formal mindfulness practice, a person is invited to take a seated position on a cushion or chair, before being guided through a practice that involves bringing attention to the external environment, to their internal sensations, or to a fixed anchor, such as the individual's own breathing. Additionally, mindfulness can be adopted informally by taking an open attitude towards events as they occur in everyday life (Hayes and Feldman, 2004).

Mindfulness practice shares some features with relaxation techniques (e.g., both mindfulness and relaxation may be breath focused) and the two have similar psychological and physical health benefits (Luberto et al., 2020). However, relaxation aims to create change in the body through eliciting the relaxation response, such as by activating the parasympathetic nervous system through the individual exerting control over their breathing rate (Luberto et al., 2020). Conversely, mindfulness involves monitoring experiences without seeking to change them, such as when observing the breath in each moment (Lindsay and Creswell, 2017). Relaxation may be experienced by people practicing mindfulness by encouraging them to disengage with negative or repetitive thinking about the past or future, or by bringing into awareness present-moment stimuli that have a calming effect (Jo et al., 2019).

Although it has been recognised as beneficial for mental health, there are a number of challenges that exist when learning and practicing mindfulness. Mindfulness is fundamentally an attention-regulation activity that requires deliberate and effortful control (Kabat-Zinn, 1982; Niksirat et al., 2019). This can make mindfulness challenging for inexperienced meditators (Navarro-Haro et al., 2017; Lukoff et al., 2020). It can also be difficult for those who struggle with self-regulation, or who have a reduced capacity to monitor their own attention and thoughts (Hölzel et al., 2011). Whilst mindfulness practice can improve self-regulation over time, focusing attention non-judgmentally may be harder for those dealing with problematic internal cognitions (Navarro-Haro et al., 2017), or because external events may act as distractions, drawing attention away from the practice (Anderson et al., 2019). Indeed, in an empirical study examining how mindfulness arises in daily life, Reina and Kudesia (2020) demonstrated that "off-task attentional demands" may act as situational hindrances to mindfulness, whereas "on-task attentional pull" may be supportive. Similarly, theoretical understanding of the active mechanisms of mindfulness proposes that development of attention monitoring may precede the application of acceptance to experiences, suggesting the need for an appropriate skill-challenge fit for new meditators when faced with off-task distractors (Lindsay and Creswell, 2017).

1.2 Supporting Mindfulness With Virtual Reality

The challenges reported by individuals when learning mindfulness have led to an interest in leveraging digital technologies to support people in developing mindfulness skills that can be integrated with, and generalised to, their daily lives (e.g. (Hussien Ahmed et al., 2017; Daudén Roquet and Sas, 2018; Sevilla-Llewellyn-Jones et al., 2018)). Prompted by the increasing availability of affordable, high-quality virtual reality (VR) platforms, recent years have seen an interest in the use of VR to support mindfulness practice. VR involves using technologies like head-mounted displays and hand controllers to immerse the user in a simulated environment (Steuer, 1992). In some cases, users can interact with the virtual environment (VE) through natural gestures and body movements. VEs can create a sense of presence in which the user has a subjective sense that they are "there" within the virtual world (Slater and Wilbur, 1997). This in turn causes them to behave as if they were in the virtual world, even though the world is computer-generated (Seabrook et al., 2020). Slater (2009) argues that realistic behaviour arising from virtual presence stems from the "place illusion", which he defines as the "strong illusion of being in a place in spite of the sure knowledge that you are not there" (p. 3551). The place illusion is further supported by the "plausibility illusion", which Slater defines as "the illusion that what is apparently happening is really happening (even though you know for sure that it is not)" (p. 3553).

The notion of presence in VR may be easily confused with the idea of "presence in the moment" that is cultivated when practicing mindfulness. The two are, however, conceptually different. In VR, presence refers to the sense of "being there" in the VE, whereas in the context of mindfulness, presence refers to the locus of attention being on sensations as they are experienced in the present moment. It is possible that when using VR, the experiences of virtual presence and mindful awareness may be related, particularly with respect to whether one needs to feel subjective presence in a VE in order to "pull" attention and support mindful awareness of sensations. Another term that may appear to have overlap between VR and mindfulness is that of *embodiment*. However, embodiment in VR is about whether one has the sense of owning and controlling a virtual body (Kilteni et al., 2012), whereas embodiment in mindfulness is about being aware of bodily sensations (Khoury et al., 2017). Again, the two may be related but there appears to be little evidence to suggest that virtual embodiment is required to practice mindfulness in VR.

Multiple authors have suggested that the immersive properties of VR can be harnessed to provide a useful training tool for novice meditators, potentially reducing experiential difficulties including boredom and feelings of failure (Vidyarthi and Riecke, 2013;

Navarro-Haro et al., 2017; Seabrook et al., 2020). Others have noted that VR can occlude visual and auditory distractors from the real world, allowing meditators to focus their attention within the VE (Kosunen et al., 2016; Patibanda et al., 2017). The ability of VR to create a sense of presence means that a user can be "transported" to a VE that is conducive to mindfulness (Navarro-Haro et al., 2017). There has also been interest in combining VR with biofeedback enabled by advanced sensing tools, allowing elements of the VE to change in response to electroencephalographic measures (Kosunen et al., 2016) or breath rate (Prpa et al., 2018). Such biofeedback may support mindfulness skills development by allowing the user to observe changes that result from intentionally controlling their attention. However, evaluations of biofeedback systems typically demonstrate changes to what the user is feeling (Kosunen et al., 2016; Prpa et al., 2018), whereas the goal of mindfulness is to become aware of what one is feeling without necessarily changing it.

To date, a range of VR applications have been developed to support mindfulness. Some of these are commercial applications that use biofeedback to support a broad range of meditation styles (BreatheVR, 2021; Healium, 2021; Deep VR, 2021). Others are prototypes that have been specifically designed to support mindfulness practice (Kosunen et al., 2016; Navarro-Haro et al., 2016; Chandrasiri et al., 2019). These prototypes typically present the user with a nature-themed VE, such as a forest or river, and deliver a mindfulness practice through a guided audio voiceover—focusing on bringing present moment awareness to a range of sensations, and adopting a curious and accepting orientation toward those experiences. The VE is thought to support mindfulness by providing the user with access to an environment that has useful resources for anchoring and training attention that may fit their personal preferences (Seabrook et al., 2020). Additionally, the ability to alter or select VEs provides opportunities for users to explore the skill-challenge fit of different stimuli. The inclusion of a guided audio voiceover helps the user to develop mindful attention by providing instructions that suggest areas of experience for exploration, moving the user through a sequence of actions much like a teacher or expert guide would do in the real world (Crane et al., 2012; Crane et al., 2013).

VR applications for mindfulness have been evaluated in published research in terms of their impact on mindfulness, emotion, and mental health outcomes. A series of case studies led by Navarro-Haro and colleagues (Navarro-Haro et al., 2016; Gomez et al., 2017; Flores et al., 2018) explored the acceptability and feasibility of VR mindfulness with clinical populations. Each of these studies involved a single participant with either severe burns (Gomez et al., 2017), borderline personality disorder (Navarro-Haro et al., 2016) or spinal cord injury (Flores et al., 2018). All three studies employed a VR system in which the user looked into a headset (i.e., non-immersive VR) and found themselves floating down a 3D-modelled river while listening to three different mindfulness audio tracks. The audio tracks involved exercises such as observing sounds, observing visuals, and a "Wise Mind" practice, which involves the person imagining that they are a floating stone to represent the inner wise mind (Navarro-Haro et al., 2016). However, these tracks were not tailored to bring attention to specific elements of the VE, and were instead simply used as an accompanying audio guide. Nevertheless, each study found that VR was an acceptable way of practicing mindfulness, and that the intervention led to short-term reductions in variables relevant to each participant's condition. One of the studies also found that the participant tried to adopt the techniques she had learnt in VR to her everyday experiences, suggesting that skills acquired in VR can be taken over into the real world (Navarro-Haro et al., 2016).

In larger samples, pre-post studies have directly assessed the short-term impacts of VR mindfulness apps on measures of state mindfulness. Navarro-Haro et al. (2017) tested a VR mindfulness app with a sample of expert meditators at a mindfulness conference. Each participant used the app for 10 min before completing questionnaires to assess their state of mindfulness and emotion. The researchers found that VR-supported mindfulness resulted in significant increases in state mindfulness, relaxation and calm, and led to lower feelings of subjective sadness, anger and anxiety. In a comparison study conducted in a general population sample, Chandrasiri et al. (2019) similarly demonstrated an increase in state mindfulness following use of a VR mindfulness app comprising an audio guide and an omnidirectional (360-degree) video recording of a beach. They compared their VR app to a guided audio track. State mindfulness significantly increased in both conditions, with the VR-supported practice producing a greater increase in decentering than the audio alone (decentering is a component of state mindfulness on the Toronto Mindfulness Scale that refers to the observation of one's experiences as they are occurring from an open, non-judgemental, and accepting perspective).

Overall, these studies suggest that VR has the potential to support short-term changes that are indicative of successful mindfulness practice, and that it may enable a range of user groups to learn mindfulness techniques that they can generalise to their everyday lives. While there is currently limited evidence for the long-term impacts of VR-supported mindfulness on changing trait mindfulness and mental health outcomes (Navarro-Haro et al., 2019), VR has been shown to support the short-term changes in state mindfulness that indicate participants have engaged in mindfulness practice within the VE.

1.3 Designing Virtual Reality for Mindfulness

Although the existing evidence suggests that VR apps can support mindfulness, one limitation of the literature is that studies typically focus on providing evidence for the efficacy of their intervention, without offering insight into the design process behind the VR tools. Prototypes are instead presented as finished artefacts, leaving the design process shrouded in mystery. This means there is little generalizable knowledge about what kinds of design processes can contribute to effective VR apps for mindfulness. From the evaluation studies reviewed above (e.g. (Navarro-Haro et al., 2016; Navarro-Haro et al., 2017; Tarrant et al., 2018; Chandrasiri et al., 2019)), there has been limited description of how they navigated specific decisions during the design process. Moreover, we are aware of no existing guidelines about how to create VR mindfulness apps. Researchers and

designers may therefore believe that VR apps for mindfulness are easy to create, when there are many variables that could affect users' engagement, and which need to be considered during the design process.

Initially, designing VR for mindfulness requires consideration of factors that are relevant for many VR applications. Issues such as headset size, weight and comfort have all been noted as possible barriers in previous studies (Chandrasiri et al., 2019; Seabrook et al., 2020). Excessive use of VR hand controllers—such as to perform menu operations or advance through the experience—could detract from the task at hand, and may even present an accessibility issue (Mott et al., 2020). In addition, VR can create feelings of disorientation and simulator sickness for some people (Kennedy et al., 1993), which could weaken its safety and acceptability for mindfulness for some users. Issues such as these need to be taken into account when choosing VR hardware, when creating the VE, and when designing the mindfulness practice.

Second, there are questions around how VR should be designed to scaffold mindful attention. Terzimehic et al. (2019) recently noted that the degree of engagement fostered by a VE is a parameter that has not yet been interrogated by researchers, despite it being a likely determinant of the user's ability to practice mindfulness in VR. There may be a sweet spot for engagement, such that a VE replete with attention-grabbing stimuli is likely to be very distracting, whereas one with little or no stimulation may be dull. Another challenge is that technologies for meditation can run the risk of being too relaxing and may cause meditators to feel sleepy (Vidyarthi and Riecke, 2013; Hussien Ahmed et al., 2017), which is counter to the present-moment awareness associated with mindful attention. Thus, while relaxation may be a useful side effect of meditation, the overuse of relaxation techniques may "propel the practitioner into dullness and hence hinder the meditation" ((Lutz et al., 2007), p. 597). Research on mobile apps has also identified a need to avoid over-dependency on technology, to gradually reduce scaffolding over time, and to support transfer of skills into everyday life, if mindfulness is to be supported effectively with technology (Lukoff et al., 2020).

A final question is whether the design of a VR tool reflects the philosophy of mindfulness. For example, a design that penalises users for being in a distracted state could be off-putting for novice meditators (Cochrane et al., 2018), and corrective feedback models may be antithetic to mindfulness, given its aim of cultivating an attitude of non-judgmental acceptance (Kabat-Zinn, 2003). Nevertheless, technologies must encourage some degree of effortful and intentional training if mindfulness skills are to be learned and carried over into real life (Lymeus et al., 2019). This raises questions about the utility of VEs that result in perceptions of mindfulness being "easy", or as something that "happens to" the user without their active involvement.

The preceding discussion reveals that, although there is growing evidence for the ability of VR to support mindfulness, there is limited understanding of how VR ought to be designed to support mindfulness and what sorts of issues affect users' engagement with the mindfulness practice. There are a range of general design approaches and principles for creating virtual environments (e.g. (Blom and Beckhaus, 2014; Sutcliffe et al., 2019)) which are useful for considering the elements of VE design that improve the user experience, but these are not specifically geared towards the design of VR experiences intended for mindfulness practice. We suggest that design guidance would be useful in the context of evidence-informed VR intervention design for mental health, as this would help designers to more precisely target the mechanisms of change likely to result in the desired mental health or behavioural outcomes.

To support discussion on how a VR app can be designed to support mindfulness, this paper describes the design process of *Place*, a prototype VR app that we created to support mindfulness practice. *Place* puts the user in a VE created from an omnidirectional video of a real-world forest, and provides a 15-min focused-attention mindfulness practice with a guided audio voiceover. The aim of the app is to support users to practice mindfulness in a safe and acceptable way, and to give them experience in focusing their attention on a range of sensations with openness and curiosity. The long-term intention is to equip the user with techniques that they can adopt in their everyday life.

In a previously published study, we evaluated the *Place* app with 37 participants in a controlled laboratory environment (Seabrook et al., 2020). The evaluation showed that *Place* was safe and acceptable, and that it led to statistically significant increases in state mindfulness and positive affect, suggesting that the app successfully supported mindfulness practice. We also found that the app provided a positive user experience that the participants found calm, relaxing and germane to the mindfulness practice (Seabrook et al., 2020).

In this paper, we describe how *Place* was designed to support mindfulness. We outline the steps taken from our initial design vision through to producing a high-fidelity prototype of our app, which we then iteratively refined through testing with prospective users. Our primary research question for the design process was: *How should VR be designed to support mindfulness?* Our design process allowed us to explore this question by revealing a range of factors that had to be considered in the design. It also drew our attention to issues that detracted from the practice, and which were corrected to improve the user experience. Overall, the contributions of this paper include insights into the design process for a successful VR mindfulness app, a generalisable framework for guiding VR design choices, and a consideration of influential design features that emerged during our user testing.

2 PLACE: DESIGN AND DEVELOPMENT PROCESS

2.1 Overview

We designed *Place* through a combination of top-down and user-centred design activities. Our process was iterative and exploratory, beginning with an initial design vision and moving forward to the creation of *Place* as a high-fidelity VR prototype. **Figure 1** provides an overview of our process.

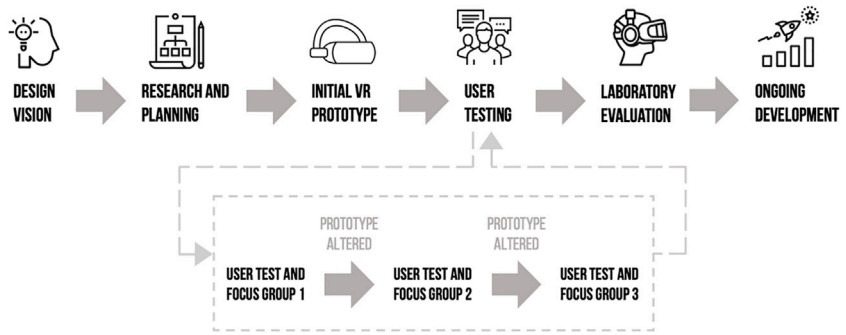

FIGURE 1 | Illustration of stages in the design and development process for the *Place* VR mindfulness app. This paper describes activities undertaken from outlining the initial design vision through to user testing and iterative improvement of the VR prototype based on participants' feedback. Information on the laboratory evaluation can be found in (Seabrook et al., 2020).

We began with a central vision for a VR app that could support mindfulness practice in a tailored virtual setting, helping people to learn mindfulness skills that they could adopt in their everyday lives. We wanted the app to be suitable for use in self-guided contexts such as the home or workplace. We also wanted the app to be accessible to a broad range of potential users, and to design the app so that it minimised the risk of injury (such as from falls) and nausea (Kennedy et al., 1993).

After outlining our design vision, we undertook research to inform the app's content and plan the development process. To inform the mindfulness practice, we reviewed the mindfulness-based interventions teaching assessment criteria (Crane et al., 2012; Crane et al., 2013). We used these to inform the language and style of guidance that we provided in the VR app. The mindfulness practice was then developed by author ES and reviewed by an expert clinical psychologist with 25 years' experience. We consulted with an expert mindfulness instructor outside of the research team to acquire general guidance on the suitability of the mindfulness script and whether they thought VR could be supportive. They were positive about the idea and gave feedback on the mindfulness script, making suggestions to change the language to be more invitational.

To inform our app development, we reviewed the Oculus developer guidelines[1], which provide advice on creating high-quality VR apps and helped us to understand topics such as safety and accessible VR design. We also consulted the descriptions of VR mindfulness applications in the literature that had been evaluated at the time (Navarro-Haro et al., 2016; Chandrasiri et al., 2019), engaged in first-hand use of apps that were branded as VR mindfulness in the Oculus store, reviewed broad design guidance in research on mindful gaming and interactive technologies (Sliwinski et al., 2015), and reviewed the literature on simulator sickness as a part of considering risk minimisation (Davis et al., 2014). These activities further informed our thinking around what would make for a good VR mindfulness app. Finally, we received expert technical advice from a Melbourne-based technology studio who specialise in extended reality applications, and who were commissioned to develop the final app prototype.

2.2 SHACI Design Framework

After our initial research and planning stage, we began thinking about how to create an initial VR prototype. As others have previously noted (Bahng et al., 2020), designing VR applications is a complex activity, and there are few generalisable frameworks to inform the VR design process.

To guide our decision-making, we created a five-component design framework that helped us to plan different aspects of the envisaged app. Our framework comprises considerations around the *Setting, Hardware, Activity, Content*, and *Interactions* (SHACI) that would be relevant for *Place*. We describe each component as follows.

- *Setting* refers to the physical surroundings, social context, and real world environment in which the VR app is intended to be used. A decision in this area aims to define where, when and how the user will engage with the VR, and helps to reflect on factors that may be relevant to the design. For example, using VR in the home is very different to a hospital setting, and these two environments may place different constraints on what kinds of technologies can be used (Hoffman et al., 2019).
- *Hardware* refers to the physical technologies used in delivering the product, including the VR headset. A decision in this area may be informed by the anticipated setting, the kinds of technologies that are available (e.g., purpose-built VR headsets versus mobile phones), a development budget, or the types of interactions that are desired (e.g., hand controllers versus gestural interaction).
- *Activity* refers to what the user is asked to do and the manner in which they should do it. In our case, this comprised the mindfulness practice, including the type of practice, focus points and method of delivery.
- *Content* refers to the user-facing components of software within the VR app. This includes the VE, audio, the

[1]https://web.archive.org/web/20210224111937/https://developer.oculus.com/learn/

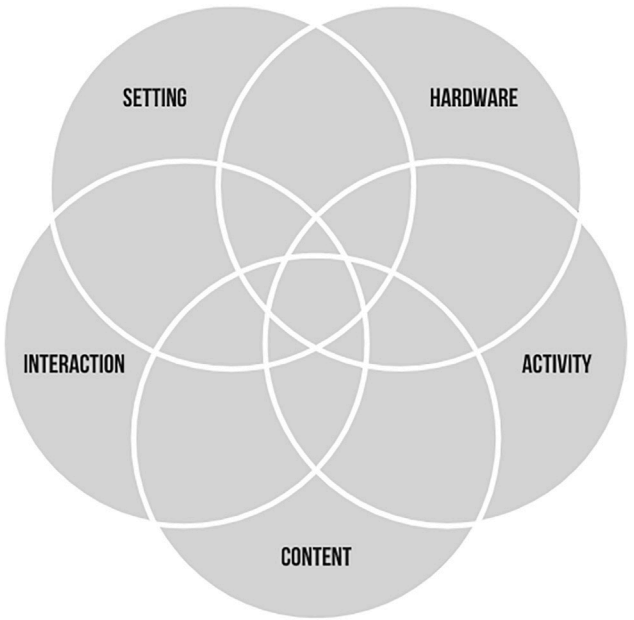

FIGURE 2 | SHACI VR design framework. The overlapping circles are intended to represent the way that decisions in one area of the framework can influence choices in other areas.

meditation guide, and any other virtual content that the user encounters.

- *Interaction* refers to the way in which the user could act inside the VE (head or body movement) and how they control the experience, such as by operating a user interface (e.g., a menu inside VR).

Each component of the SHACI framework came to light through a reflexive process in which we outlined different decisions that were needed to create the app, and reflected on how these decisions might influence each other. We quickly realised that certain choices would be cascading, with knock-on implications for other aspects of the design. For example, a decision about the choice of *Setting* may influence the kinds of *Hardware* that can be used, which may in turn impact the types of *Content* that can be delivered and the possibilities for *Interaction* with the content. In this way, the components are interconnected, and decisions in one area of the framework can introduce constraints in another, resulting in trade-offs between features (Sutcliffe et al., 2019). This meant that our decision making was not linear, and often involved revisiting decisions to ensure they were in line with our vision.

Figure 2 illustrates the SHACI framework, and **Table 1** provides brief examples of the design features of *Place* that fall within each component. We describe our decision-making process in the context of the framework next, illustrating some of the dependencies between components as examples of our reflexive and non-linear process.

3 DESIGN CHOICES FOR THE INITIAL PLACE PROTOTYPE

3.1 Setting

Our design vision was for *Place* to be used in everyday environments, and for the app to be portable, allowing people to use it in settings of their own choosing. Specific places we envisioned included the user's home or workplace. This intention prioritised making design choices through a lens of accessibility and safety, with the aim of making the app suitable for use in both supervised and unsupervised environments, by users who may be novices to both VR and mindfulness.

At the beginning of our development process we had limited understanding of the contexts in which people would elect to use a VR app in the real world. As such, we approached our understanding of the setting open-mindedly, anticipating that people may use the app in ways not foreseen in our initial vision. Gaining insight into the types of settings in which VR-supported mindfulness might be used became an additional goal of the development process, as this would highlight additional constraints of the physical environment.

TABLE 1 | Summary of design features of the *Place* VR mindfulness app.

Component	Description
Setting	Self-guided contexts such as the home or workplace.
Hardware	Commercial Oculus Go headset.
Activity	
Practice and duration	Focused attention mindfulness practice lasting 8 min, later changed to 15 min after user testing.
Position	Seated on a chair, but can be used on the floor or a cushion.
Content	
Virtual environment	Natural forest scenes created from omnidirectional video, recorded in the Great Otway National Park, Australia.
Sounds	Natural forest and water sounds, recorded at time of video capture. Bird noises, overlaid in post-processing.
Voiceover	Onboarding sequence delivered by a female narrator. Guided mindfulness voiceover delivered by a male narrator.
Interactions	
Start playback	Use of the Oculus Go hand controller to begin playback of onboarding instructions.
Trigger events	Eye gaze interactions to initiate the mindfulness practice.

3.2 Hardware

Our anticipated setting informed our choice of hardware. To be suitable for use in everyday environments, people needed to be able to use the app in a standalone fashion, without requiring the use of room-scale VR. We also wanted to avoid the use of expensive body tracking technologies.

We chose to design *Place* for use with the Oculus Go, a commercial VR headset that is lightweight, has a high-quality screen, and affords simple user control over calibration. The Oculus Go was a market leader at the time of our development process but has since been superceded by newer models such as the Oculus Quest 2. Using a purpose-built VR headset (as opposed to a mobile phone) allowed us to optimise for a high level of fidelity when developing our initial prototype. We also considered our intended Activity (see below) in choosing the Oculus Go, opting for a headset that was suited to longer periods of VR use and which required minimal user setup.

3.3 Activity

The activity we chose to support was a formal guided mindfulness practice that encouraged both external and internal focus in the present moment, using focused attention (Lippelt et al., 2014). Our practice is structured similarly to introductory mindfulness practices, where individuals develop an awareness of where their attention is oriented, and begin using anchors, which may be bodily, auditory or visual, to aid in guiding their attention. We designed the practice to encourage users to adopt a curious and open attitude toward their present moment experiences.

Our practice included an introductory section focusing on the breath and body, which is typical of many mindfulness practices (Prpa et al., 2018). Subsequent sections of the practice capitalise on the use of VR, particularly the visual imagery, which we wanted people to explore as attentional anchors. As such, our practice oriented users to observe stimuli within the VE, including both sights and sounds. The practice also provided guidance around the experience of mind wandering, helping to prompt the user to become aware of this experience and providing suggestions for anchors to bring their attention back to the present. This approach is consistent with mindfulness meditation that involves focusing and shifting attention across different senses (Lindsay and Creswell, 2017). Finally, the practice cues users to become aware of the fact that they are wearing a VR headset, in order to bring their attention back to their physical sensations and posture before ending the experience. In this way, users gain experience of deliberately controlling their attention and shifting it between different kinds of stimuli, both within themselves and within the VE.

3.3.1 Practice Duration and Position

We created an 8-min guided mindfulness practice as an initial starting point for the app. We considered a brief 8-min meditation to be sufficient to support mindful awareness whilst not introducing significant physical fatigue through use of the headset. Moreover, research has shown that the frequency, rather than duration, of formal mindfulness practice is associated with mental wellbeing (Birtwell et al., 2019). The duration of the practice was later expanded to 15 min as a result of user testing (described later in our Results).

We selected a seated meditation primarily with reference to our intended use Setting. Given that we were designing for self-guided use in everyday environments, we felt that a seated position would minimise the risk of falls or collisions that can occur when wearing a VR headset (Dao et al., 2021). This decision was also informed by the hardware we selected to use - with the Oculus Go only supporting three degrees of movement in physical space (accessible via head/body rotation). These decisions remained consistent with the types of formal seated mindfulness practice that may be familiar to potential end-users (Birtwell et al., 2019). As such, we designed the experience and made content selections so that the app could be used in a chair, though it can also be used when seated on the floor or on a cushion, if the user chooses.

3.4 Content

The content in Place included the audiovisual assets chosen to provide a simulated VE, and a guided mindfulness voiceover created by the research team.

3.4.1 Virtual Environment

The VE we selected was a natural forest environment, created from omnidirectional footage shot in the Great Otways National Park in Victoria, Australia. **Figure 3** shows two images of the forest environment. We selected a forest because research has shown that natural environments are comfortable and restorative (Depledge et al., 2011; Bruun-Pedersen et al., 2016), and because they provide "soft fascinations" which capture attention in ways that are interesting but not overstimulating (Kaplan, 1995). Studies by Lymeus and colleagues (Lymeus et al., 2019; Lymeus et al., 2020) have demonstrated that practicing mindfulness in nature-based environments has short-term restorative impacts on attention and may be better adhered to than conventional mindfulness practice (as a formal intervention over weeks) due to the restorative features of nature. Examples of natural stimuli in our VE include trees, moving leaves and gently flowing water. We felt that these stimuli would provide the user with a comfortable environment for practicing mindfulness, without veering into distraction, absorption or dullness (Lutz et al., 2007). Before settling on a forest scene, we considered alternative locations such as beaches and mountaintops (Tarrant et al., 2018; Chandrasiri et al., 2019). We ultimately decided against these due to concerns around sources of possible discomfort (the ocean, heights) and because of practical constraints (i.e., the accessibility of suitable locations for filming).

We chose to create our VE using omnidirectional video footage of a real forest, as opposed to computer-generated imagery (CGI). This decision was driven primarily by considerations around development time and cost. Although an advantage of CGI is that the virtual environment can be customised, CGI requires considerable development time and may not appear natural unless using a headset with sufficient computing power. A benefit of omnidirectional video is that it provides access to notionally 'real' environments, although this may come at the cost of lower visual quality when compared to

FIGURE 3 | Filming locations for the forest environment in *Place*. The image on the left shows the environment presented for the first half of the mindfulness practice. The image on the right shows the second environment as well as the camera used to capture the omnidirectional footage. See Seabrook et al. (2020).

the sharpness of CGI. To create a high-quality VE, our footage was captured in 4K resolution using a Z Cam V1 Pro, an industry-leading camera at the time of our development process. We used industry-standard post-processing techniques to render the footage for maximum quality. We set the camera height at 1.3 m, giving the impression that the user was experiencing the environment from a seated position (consistent with our considerations around Setting and Activity, i.e. that the user should engage in a seated meditation).

We selected two forest scenes for the VE, which are shown in **Figure 3**. In the first scene, the user finds themselves in a forest clearing, surrounded by tall redwood trees and ferns. A river is visible in the middle distance. This environment provides a mixture of stable and slowly moving stimuli, in the form of trees, moving branches and the water. In the second scene, the user finds themselves at the edge of a river near a waterfall. This scene is more active due to the movement of flowing water. Both scenes offered opportunities for the viewer to explore details of the environment, and had clear objects of focus for us to build the mindfulness instructions around. The footage did not include any visible people or animals, giving the impression that the user was alone in the environment. To achieve this, we captured footage at a time when the forest was quiet, outside the main tourist season. We captured ambient sounds of the forest at the time of video recording, using omnidirectional and stereo microphones (Zoom H6 and Zoom H2n). The audio was non-spatialized (due to the recording equipment available to us at the time) and was overlaid during post-processing. The natural sounds of the forest were audible to the user throughout the VR experience.

As noted above, we chose these two scenes as we wanted the VE to be interesting and attractive but not over-stimulating. During initial tests of the video, we had a third section of footage that was taken at the base of the waterfall. However, we chose not to use this footage because it was loud and visually busy, which we thought could make it over-stimulating and hence difficult to concentrate. This emphasises the importance of iterative testing and initial trials of footage "in-house" by the research team.

3.4.2 Voiceover: Mindfulness Practice Design

Our prototype included two voiceovers, which we created to guide the user through the practice. These were delivered on top of the ambient audio from the forest. The script from both voiceovers can be found in **Supplementary Appendix A**.

The first voiceover was by a female narrator who provided a set of 'Onboarding' instructions, including health and safety information. The narrator also provided information about the purpose of the mindfulness practice, instructions about what to do in the event of simulator sickness, and a description of what the user was about to see and do. The voice was preceded by animations demonstrating how to adjust the VR headset's volume and image clarity.

The second voiceover was a male narrator who provided the guided mindfulness practice. The narration used invitational language to guide the user's attention to specific components of the VE (e.g., *"If you would like to . . . look at the rocks, you can explore their colour and texture"*) and internal sensations (e.g. *"you may like to bring your attention to the breath"*). The narrator also provided guidance around mind wandering (e.g., *"If you notice the mind has wandered . . . just gently bring your attention back to the moment"*). The prompts for guiding attention were chosen to match common parlance in guided mindfulness practice (Crane et al., 2012). We elected to incorporate elements of internal and external focus after our earlier consultation with expert mindfulness instructors. A focus on the breath and sensations in the body was perceived to be important by these instructors, and provided an opportunity to build options for anchoring focus and attention into the practice for those who may hold specific preferences (Anderson et al., 2019).

The voiceover ended with an invitation to try adopting techniques learnt during the practice in the real world. We wanted to encourage people to try to adapt the mindfulness training to their real-world practices, though we did not evaluate the effectiveness of this invitation in the current study.

3.5 Interaction

We designed *Place* to involve minimal interactions between the user and the app. We did this to make the app easy to use, but also to avoid continually moving the user's attention away from observing their experience with the VE once the practice had begun. After starting the app from the Oculus Go's app library using the hand controller, the user was presented with onboarding instructions and health and safety information. The user then had to perform a single interaction to start the

mindfulness practice. This involved looking at a white circle, which was overlaid onto the forest scene. We used positional detection afforded by the Oculus Go headset to begin playback when the user held their gaze on the circle for a 3 s period.

With the goal of keeping interactions minimal, we designed the app to have a linear narrative with automatic transitions between the two forest scenes. This meant that there were no branching paths in the mindfulness exercise. We used a visual fade-in and fade-out mechanic to introduce each new scene, and we chose to signpost scene transitions in the voiceover (*"In a moment we will be moving location, to sit near a river and waterfall"*). We also made the experience have a clear ending with the video fading to black at the end. This change was incorporated after early focus group feedback (discussed in our Results below).

Our decision to use omnidirectional video to create the VE had a cascading impact on the kinds of interactions that would be available to users. Specifically, users were not able to influence the content of the VE in *Place*, such as by picking up objects. It was also not possible for users to move around freely in the virtual environment using movement of their body (a constraint also introduced by our choice of hardware and setting). Instead, the user's viewpoint was anchored to a central point, allowing only rotational head movement (i.e., 3° of freedom; pitch, yaw, and roll). The system constraints of the Oculus Go meant that users could use head movement to freely explore the VE, but were not able to move through the VE using physical locomotion.

4 USER TESTING: METHODS

After designing the initial *Place* prototype, we conducted iterative testing to identify aspects of the app that worked well and to ensure that problems were corrected early in the design process. We invited prospective users to try *Place* in a controlled laboratory setting, and these users then participated in exploratory focus groups to provide formative feedback. The app was developed using the Unity platform in collaboration with a commercial software company. We conducted three focus groups (hereafter FG1–3) and modified the app based on the participants' feedback after each one (see **Figure 1**). We adopted this approach as it has been demonstrated to be an effective way of collecting and accounting for user feedback during the design process (Tremblay et al., 2010). All procedures received ethical approval from the Swinburne University of Technology Human Research Ethics Committee (SHR 2018/256) and the University of Melbourne's Human Research Ethics Committee (ID# 1852613.2).

4.1 Participants

We recruited 9 participants (5 men, 4 women) from the general population through convenience sampling. Each focus group had 3 participants. Guidelines suggest that the sample size for a focus group should balance the research aims against project constraints (Tang and Davis, 1995) and that three focus groups is sufficient to acquire detailed feedback (Gutteling et al., 2008; Carlsen and Glenton, 2011). Research also indicates that more information can be gained from conducting a greater number of small focus groups, rather than one or two with many participants (Fern, 1982). We therefore chose small groups to ensure that our research process was manageable and to acquire detailed feedback from each participant. We decided to stop after FG3 as we were not finding new feedback about design problems.

The average age of participants was 34 years (SD = 13.58, range = 21–62 years). Participants varied in their previous experience with VR and with mindfulness. Two participants had not previously used VR, four had tried it once, and 3 had tried VR a few times (between 2 and 5 times). One participant had not previously tried mindfulness, four had tried mindfulness a few times (between 2 and 5 times), and four reported practicing mindfulness regularly. The differing levels of VR expertise and mindfulness experience were distributed across focus groups.

4.2 Materials

We developed a semi-structured interview guide for the focus groups, seeking feedback on issues including usability, experiences of the virtual environment, and the anticipated settings in which the VR may be used. **Table 2** lists the main questions used to prompt discussion in the first focus group. We refined the question guide after each focus group in order to target specific areas for feedback, and to assess the impact of changes made to the app based on comments from the previous round. For example, we sought specific feedback from FG2 about the Onboarding process as a result of changes made after FG1.

4.3 Procedure

The participants in each focus group were invited to trial *Place* at Swinburne University of Technology. Participants completed surveys to capture demographic information. Each participant was led to an individual quiet room to use the VR app by themselves. Each was seated on a swivel chair, which we used to enable them to explore the VR easily. The choice of a swivel chair was made to reduce the risk of potential neck strain and risk of falling when rotating the body while wearing the VR headset. Participants used the app without headphones, enabling them to hear the sound of their own breathing while using the app.

Participants were provided with instructions about how to start the VR app. Each one was then monitored by a member of the research team, who stood outside the room and occasionally checked on the participant through a window in case any support was required. Participants were aware that they would be monitored but knew it would be occasional rather than continuous, and that it was for their personal safety in case of any adverse effects. After using the app, the participants met face-to-face for the focus group discussion. Each focus group lasted 1 h and took place immediately after participants had trialed the prototype. Focus group discussions were led by GW, with additional questions from ES, FF, and RK.

4.4 Analysis

The focus group recordings were transcribed by a professional transcription service. The second author (ES) reviewed each

TABLE 2 | Main questions and follow-up prompts used in Focus Group 1.

1. How would you describe your experience of using the VR app? What was it like putting the VR on? What stood out to you in the environment? What stood out about the guided audio?
2. Was there anything in the program that made you feel uncomfortable? Did you close your eyes during the experience? Were the transitions between the environments comfortable?
3. What did you think about the environment? How did the environment make you feel? Where would you like the environment to be set? Did you feel the need to move around in the environment?
4. What did you think about the audio? What did you think of the language used in the guided audio? What did you think about the pacing of the audio guide? What did you think about the environment sounds?
5. Is there anything you wish you could do in the program?
6. What was your favourite/least favourite thing?
7. We would like to know a bit about how you would use this app Where would you use this? (At home, at work, on the train . . .) When would you use this? (Morning, day, night . . .) With whom would you use this? (Group, alone, others at home . . .)

transcript after the relevant focus group in order to identify salient problems with the app that could be addressed by the development team. A full list of changes made to the prototype following the focus groups can be found in **Supplementary Appendix B**.

For the present paper, ES and RK re-analyzed the transcripts after the development process had been completed, using the general inductive approach (Thomas, 2006). The two authors first read the data and then independently performed inductive coding, which involved generating codes based on line-by-line analysis of the transcripts. The aim of this coding was to identify aspects of the VR app's design that affected participants' ability to engage with the mindfulness practice. We also sought to identify broader considerations that participants found relevant to the use of VR for mindfulness, and which could be informative for the design of VR apps. After the first round of coding, the authors met to discuss the codes and generated categories of findings. Codes that were relevant to our aims were consolidated into 12 categories that we then deductively organised according to the items within our SHACI design framework. This enables us to discuss the participants' feedback in light of specific design decisions.

5 FINDINGS

5.1 Overall Experience

Our analysis suggested that the iterative design process successfully ensured that *Place* provided a high quality user experience. The participants shared a range of positive comments about the app and envisaged that it would be an accessible solution that they would consider using. Some compared *Place* to audio guides and previous experiences of mindfulness, but noted that VR's "visual layer" helped them to tune out their physical surroundings and feel more present in the moment within the VE. Others valued the explicit guidance provided by the app, noting that their previous attempts at mindfulness (e.g., in group therapy) were *"too abstract . . . I found this a lot easier to get into"* (P9). The participants commented positively on other aspects of the design including the choice of virtual forest environment, the duration of the practice and sound quality. Participants found the VE to be relaxing and *"engaging, but not to the point of being stressful"* (P7). None of the participants encountered significant problems with the VR hardware, and none reported experiencing simulator sickness, suggesting that our efforts to provide a comfortable experience were also successful.

In the following subsections, we present detailed findings from our analysis, discussing how participants' responses align with our design aims and using quotes to illustrate salient points. We present the findings according to the categories within the SHACI framework, but we omit considerations around the hardware as the participants did not share any significant feedback about the headset. Where possible we describe changes made to the VR app in response to feedback and how this impacted on subsequent focus groups. We also discuss design considerations for VR mindfulness within each section of the findings.

5.2 Reflections on Settings: Situation, Time, and Position

Our design vision was for *Place* to be usable in self-guided contexts, without requiring continual oversight from an expert. When asked where they would consider using it, participants felt that *Place* would be suitable for use in settings such as their home and workplace, as a passenger in a car, or even on an aircraft. These claims aligned with our design vision for how we wanted the app to be used.

However, the discussions revealed nuances in terms of when and how participants foresaw themselves using the app. There was a clear consensus that the use of VR for mindfulness was something participants wanted to do in a private, safe and controlled physical setting. Whilst participants thought the app could be beneficial for tackling workplace stress, they noted that they would be uncomfortable using it in a shared setting such as an open plan office. Similarly, participants were hesitant about using VR in highly public areas. This was due to concerns about unwanted attention and social embarrassment, which P9 attributed to the *"dorkiness factor"* of using VR in public, and the need for physical safety due to lack of environmental awareness. Participants did, however, note that they may use the app in public spaces if those spaces were supportive of using the technology. In other words, a peaceful garden with few onlookers might be an acceptable place for doing VR mindfulness, whereas a busy public park might not.

Participants also discussed times at which they felt the app would be useful, and made suggestions for changes to expand *Place* beyond the single forest environment. These suggestions

reflected individual preferences for how they wanted to try VR mindfulness. P7, for example, imagined using a future version of *Place* to *"go to the beach"* before work, whereas P1 felt that the app would be best in the afternoon as this would coincide with their regular break time. P3 similarly imagined needing *"a morning one"* when waking up, but wanted to see *"the night stars"* in the evening. These considerations revealed new ideas that we had not anticipated in the design process, and although we did not make changes as a result of this feedback, they were informative in terms of expanding our understanding around possible situations of use and how these could be considered in versions of the app that encourage long-term engagement.

Finally, participants described the physical positions they wanted to take when using the VR. We designed Place for use in a seated position, and participants in the testing sessions valued the ability to sit in a spinning chair to access the VE. However, participants mentioned that they would be more likely to use the VR in stationary chairs or even lying down. Choosing these positions would restrict their ability to see in all directions, but participants did not view this as a significant issue because much of the practice involved looking at what was directly in front of them. In addition, participants mentioned that being able to look around was important at the beginning of the session because it helped them to feel grounded, but this became less important as the practice progressed.

5.2.1 Settings Design Considerations

Participants' reflections on settings raised three considerations for VR mindfulness. First, it is likely that users will choose a controlled and safe space that they believe is germane to using VR, in order to create a situation that is appropriate for mindfulness. This means that there are likely to be minimal distractions in the outside world, necessitating deeper consideration on the design of virtual content in order to introduce potential distractors and potentially increase the difficulty of the practice as meditators become more skilled.

Second, there are opportunities to consider providing virtual content that reflects different circumstances and times of use, such as morning and nighttime scenes, and users may wish to use the VR in unanticipated positions, such as when lying down. Designers should consider these possibilities and provide options to accommodate them (for example, content specifically selected for reclined positions). Third, it may be the case that 360° head movements are not necessary, alleviating the need to create a fully omnidirectional scene and hence saving development time.

5.3 Reflections on Activity: Duration, Scaffolding, and Closing the Eyes

5.3.1 Duration and Pacing

We designed the first version of Place to last 8 min, but feedback from FG1 suggested that this time was too short. All three participants stated that they wanted more time for visual exploration of the VE and to simply observe what was happening. They also suggested that the voiceover should be slower and offer more pauses. P3 said this would allow them to *"zone out from that, fully immerse myself in the environment and just breathe or engage my body"*.

Based on this feedback, we increased the duration of the program to 15 min before conducting FG2. We added a new 2-min introductory sequence and redesigned the entire practice to be longer and slower, with a greater frequency of pauses. Subsequent participants commented positively on these changes, with one person in FG2 reflecting that *"15 min is achievable . . . But if it was like a half an hour, then weekly use probably would be a bit too much"*.

The changes to the pacing of the voiceover led to higher-level reflections on the tension between providing supportive instruction and unguided practice. Two of the participants in FG2 reflected on the support they would like to receive to feel confident during the practice. P6 felt comfortable with the quality of voiceover and its pacing, but wanted longer pauses for what they described as *"a few more moments of just exploratory-ness"*. In contrast, P5 felt that the silences were appropriate but wanted tighter coupling between instructions and events, commenting that the voiceover often claimed that *"it's going to end in a moment, but when's a moment? After this bit? After that bit?"*.

5.3.2 Explaining the Purpose of the Activity

Another aspect that contributed to participants' comfort during the experience was the level of scaffolding around the purpose of the practice, particularly during the Onboarding section of the app. The initial version of the onboarding given to participants in FG1 included simple animations demonstrating controls for the VR headset. The animations were followed by a voiceover that introduced the purpose of the mindfulness practice and directed the participant to begin by looking at a circle on the screen.

In addressing feedback from FG1 regarding the pacing and opportunities to explore the forest VE, we adjusted the Onboarding section to include an additional forest scene while the voiceover spoke, allowing exploration of the virtual forest after the introductory animations were played. To collect feedback on these changes, we prompted specific discussion in FG2 and FG3 about the Onboarding instructions. One issue that emerged was the need for a clear statement of purpose to better contextualise the activity. Without clear setting of expectations, participants queried the aim of the practice. P4, for example, was unsure whether the aim was to acquire mindfulness skills or *"go on a bush walk"*. Our design response to this feedback involved changing the mindfulness script to be more specific about the intention and outcomes of the practice (e.g., "You will be invited to observe your environment with a sense of curiosity and to explore it with openness.").

Participants also discussed the presentation of the information provided in the Onboarding section. Here, participants contrasted the impact of verbal and text-based instruction, specifically in relation to the animations: *"I think it would be better to have audio [only], because I think people see so much of that stuff at the beginning of DVDs and movies that they don't even take it in . . . You're not going to read it."* (P6). This was reinforced by other participants who noted that they either overlooked the instructions or deliberately ignored them. However, participants in FG2 suggested that the instructions should be kept separate

from the experience of using the VR headset, such as by using text or even verbal instruction. This was seen as allowing them to "jump straight in" to the practice: *"once I put these goggles on, here I go … You're already kind of like primed that this is the experience that you're going to have"* (P4).

5.3.3 Exploration and Closing the Eyes

A final reflection on the activity related to participants' desire to close their eyes during the practice, which was mentioned by all three groups. One reason was because the participants sometimes felt fatigued. VR is a visually intensive medium, and the inability to divert the eyes away from the screen (due to wearing a headset) may have contributed to this. Participants suggested that periods of rest could be incorporated into the practice: *"I would have liked for it to say, just close your eyes for 30 seconds and give your eyes just a little bit of a rest some time in the middle and then come back to it"* (P1).

The second reason for closing the eyes was because attending to the audio was sometimes useful to participants, and so they wanted to close their eyes to focus more closely on sounds. This was seen as important for replicating the participants' own experience of real-world mindfulness: *"if you are in a quiet place, I do close my eyes just for short periods of time and listen to things around"* (P1).

These comments suggested that closing the eyes was something people wanted to do while wearing the VR headset, and that they felt reassured by the ability do this within the context of the practice. However, there was concern about whether they would miss something important in the VE. Some participants suggested that concerns about missing events might fade with repeated use, and that important events could be cued by the voiceover to prevent them from being overlooked.

5.3.4 Activity Design Considerations

Our participants' feedback on the mindfulness practice revealed a need to balance structured guidance and unguided practice. However, participants' comments suggest that there is unlikely to be a "right answer" to this challenge, particularly when catering to diverse user preferences and needs. Designers should therefore consider including options for users to select the density of guidance provided in any given mindfulness practice. This consideration may become particularly important in repeated use contexts, as user needs for guidance and support change over time.

Reflections on the need for periods of exploration also highlight the impact of being exposed to a new VE, a potentially absorbing experience that could introduce barriers to mindfulness. Our solution was to include a scene during the "Onboarding" to allow for exploration that did not form part of the formal mindfulness practice. Designers should consider the likely experience of being absorbed in a VR experience as a part of the practice design, and support the user to move into mindful awareness at their own pace.

Finally, our findings suggest that clear expectation setting and permissive reminders about the actions available to the user in VR are important to consider as a part of the activity design, particularly in terms of where these types of informational supports are provided in the user journey. Participants discussed keeping health and safety instructions separate to the use of VR, but also appreciated directive guidance on how to engage with the VE mindfully, and in different ways (e.g., by closing the eyes). Designers should consider how they can incorporate a combination of activity, content, and interaction components to create permission for users to explore a VE in their own way, whilst still supporting mindful awareness.

5.4 Reflections on Content: Visuals and Sounds, Congruence, and Familiarity

5.4.1 Visual Quality and Sounds

Issues around the visual quality of the app were raised in all three focus groups. Even though we had used a state-of-the-art camera to capture the footage for our VE, participants in FG1 stated that their engagement was disrupted by a variety of glitches, blurring or visual anomalies that sometimes made the video difficult to see.

To address problems with the visuals, we re-rendered the footage after each focus group in an attempt to improve the image quality, but the re-rendering introduced issues with pixelation, which made some parts of the VE appear grainy. This is perhaps a limitation of using video rather than CGI, but had a number of interesting side-effects that led to greater engagement with the task for some individuals.

For example, while one participant in FG2 found the pixelation disengaging, another commented that it had the unintended effect of becoming an anchor for their attention. The participant even wondered whether it was a deliberate choice, noting that it *"didn't really take me out of the experience, because I thought maybe it's a clever trick to engage me"* (P6). Similarly, so-called "visual anomalies" were disengaging for some but generated interest for others. P5 described noticing a *"bizarre perceptual thing that was happening with the water, it was spinning down at an angle that it possibly could never spin at. I couldn't help but look at it, because it was just trippy. So that was my most engaged moment, looking at that artefact in the space"* (P5). These outcomes speak to the potential to leverage aspects of the VE to guide attention, and to the fact that the environment may not need to be visually "perfect" in order to achieve this.

5.4.2 Creating Congruence Between the VE and Users' Expectations

Participants drew our attention to issues around the congruence between the forest VE and its real-world equivalent, commenting on how the absence of sights and sounds that one would encounter in a real forest became distracting during the practice.

In FG1, participants noticed a lack of ambient sound in the VE, commenting that certain sounds should be prominent, based on their experiences of being in similar forests in real life. Specifically, the lack of sounds seemed to alter the plausibility of the VE, and hence participants' engagement with it. P3 mentioned that they saw tree ferns moving in the wind but without making sounds, and P1 stated that the absence of bird sounds (which would be common in an Australian forest) was

"distracting". To address these concerns, we boosted the volume of the ambient sound, and embedded sounds of real birds native to the area (e.g., Eastern whipbirds) within the audio. These changes made the VE more plausible and congruent with participants' expectations. Those in subsequent focus groups noted that *"the sounds were a bit more immersive [and] were really sort of tangible for me"* (P5).

Another issue related to congruence was visual warmth, which was raised as an issue by participants in FG1. They felt the colours in the VE lacked vibrancy, noting that it felt *"a little bit cold"* (P3) and that *"some more sunshine might make your body feel warm"* (P1). This was interesting because the perception of visual warmth appeared to affect participants' level of comfort during the practice, suggesting that warmth needs to be adjusted carefully. To fix this, we increased the saturation of the footage to make it feel warmer. Participants in subsequent focus groups did not comment on this aspect, suggesting that the increased saturation had the desired effect of enhancing the warmth of the VE.

Some disengaging experiences were discussed in FG2 in relation to the participant's viewpoint within the VE. These comments related specifically to the point of view in the river scene. We had recorded the footage by placing the camera on a rock at the river bank. Participants in FG2 felt that this initially created the sense of being *"being dumped in the middle of a river"*, which subsequently impacted their engagement by creating an unusual situation: *"as you were saying before about staring on the rock—you're like, wait, where am I? But then I also noticed that when you're staring down, you don't see any human agent at all. You just see rocks. So, then straight away I was like nah, I can't engage as well with this scene"* (P4). Re-filming this scene was not feasible, and it was not adjusted in response to this feedback. However, it was promising that participants did not feel significant disorientation from being disembodied in the VE. This suggests that it may not be necessary to be virtually embodied within the environment in order to attend to the present moment.

5.4.3 Familiarity

Participants commented on appreciating the familiarity of the virtual forest in *Place*. The experience of visiting a forest was familiar to most people, even if they had not been in this particular forest. However, one participant questioned the very idea of using real-life footage for the VE, instead preferring the idea that they could be immersed in an abstract environment that had no real-world parallel: *"that led me to question why would you have an environment that is a real environment . . . [When you could] do something that's completely other? They could give you that same sense of experience and to me, that would be more interesting"* (P6). This reiterates that participants might value a range of environments in a future version of the app.

In FG3, participants imagined what it would be like if they were asked to practice mindfulness in a virtual setting that was *completely* familiar to them, i.e. somewhere they had visited before. One participant wondered if it would be unhelpful to the mindfulness practice: *"Would that be somewhat distracting, if you're reflecting on the past? I know that's what I would be doing if I was in a familiar location."* (P8). While there was interest in seeing VEs like mountaintops, spectacular locations were not considered to be helpful to practicing mindfulness: *"For me, cliff ranges is a bit too exciting. It's a bit too much of a journey . . . Like, you're in a pretty exciting location. It would be too much for something like this"* (P9).

These discussions revealed a need to think about footage location more deeply than just providing a variety of experiences. Feedback from participants suggested being in places that are similar to places they may go (but not too familiar) was useful for being engaged and not distracted: *"I definitely thought about the scene a lot. And like places I'd been to that were very similar. I think that kind of helped me. Like it wasn't some sort of foreign location. I mean, it could have been, I guess. But for me, it felt like it was places where I have been or could go . . . I wasn't so far out that I was getting distracted by the scene itself [It was] not too alien, I guess."* (P9).

5.4.4 Content Design Considerations

Participants' reflections on the content of *Place* led to several design considerations. Our participants suggested that visual glitches acted as distractors from mindfulness by causing them to evaluate the quality of what they were seeing and lowering the plausibility of the virtual world. This may be annoying or disengaging in extreme cases. Similarly, congruence between user expectations and what they experience of the VE should be a priority consideration for designers in creating practices that maintain engagement. We found that it was necessary to introduce realistic sounds and visuals to ensure that the forest VE was plausible to users. One interesting tension here relates to whether narrowing down the audio and visual components might aid mindfulness. We suggest that designers should only include what is necessary to make the VE plausible for maintaining focused attention, given that inauthentic or missing elements may be disruptive to mindfulness.

While designers can exert a high degree of control over the VE, participants' comments highlighted that distractions to mindfulness can still pervade VR. This is important to acknowledge, but also presents interesting opportunities for using likely or known "distraction" as a tool in aligning the skill-challenge balance of mindfulness for users in the design of a practice. It could be that unintentional distraction (issues with visual quality, perceptual anomalies) and intentional distraction (footage the designer might select to create more challenging environments, e.g., a busy city) may become features of practices that progressively help to move mindfulness out of only "relaxing" environments—providing opportunities for both types of stimuli to be approached from observational, curious, and accepting attitudes.

Lastly, participants commented on the likely impacts of completely familiar and completely alien VEs. There are opportunities to experimentally test the impact of these varying environments on mindfulness practice within VR. For example, placing a user in a lunar landscape would be highly unfamiliar. This could provoke curiosity, but the barren setting could make the user feel uncomfortable and may also lack sufficient resources to guide the user's attention.

5.5 Reflections on Interactions: Operation, Movement, and Transitions

5.5.1 Operating the Experience

Our last category of findings relates to the interactions within *Place*. We designed the app to involve minimal interactions between the user and the VE. The user's primary task was to listen to the audio track, follow the invitational instructions and mindfully observe the VE under their own free will. Generally the participants felt that the app was easy to use, indicating that our design decision to focus on simplicity paid off. Comments included that it was *"easy to use"* (P3) and *"straightforward, it just ran itself basically, once it started"* (P9).

In terms of operating the app, there were two interactions the user had to perform. The first involved using the hand controller to begin playback of the experience. No participants reported problems with this, even though some had not used VR before and were therefore unfamiliar with the use of hand controllers. The only issue arose in FG1, where participants noticed that the hand controller's targeting line, which overlaid the virtual environment, remained visible in VR even after placing the controller down on a desk. This acted as a distraction by drawing attention away from the task. We subsequently scrubbed out the line from the screen based on this feedback.

The second interaction involved gazing at a circle to begin the mindfulness practice. Participants found this interaction straightforward and intuitive, though the initial language used ("Gaze to start") was confusing to participants in FG2. This was compounded by a lack of feedback from the software, in that participants found it hard to identify when the circle had been selected. Based on these comments, we adjusted the language to be more direct ("Look at the circle") and adjusted the sensitivity of the circle to allow for greater margin of error in terms of where the user was looking. These changes alleviated the concerns and made the interactions straightforward for those in FG3.

5.5.2 Moving and Interacting With the VE

The second item of feedback around interaction involved potential manipulation of the VE itself. *Place* had no opportunities for users to interact with the scene because it had been created from omnidirectional video. This medium constrains the user to be an onlooker rather than being able to manipulate objects in the VE. However, the participants did not express a strong desire to interact with the environment, such as by touching leaves or interacting with objects, perhaps because these interactions were not necessary for the practice we designed.

What participants did discuss was their experience of rotational movement within the VE, and contrasted this to an imagined context in which they were afforded translational movement. P4 claimed that being able to move their head made them feel *"really engaged in that virtual environment"*. One participant explained how the seated practice in the VE was conducive to mindfulness for them because *"a still, albeit moving, 360 thing seems like the right platform, because then you're just stationary. So you're just observing rather than actually going to somewhere or trying to strive or achieve something"* (P7). For them, an experience where they were moving through the VE would have felt *"pressurised"* (P7).

On the other hand, some participants thought that translational movement could be useful. One individual, who was experienced at both mindfulness and using VR, said the seated practice *"[felt] a little artificial [for] that kind of environment"* (P9). They explained that they would have valued having up and down movement, and although they did not want to walk around, they were aware of a sensation of being on a *"tripod sort of thing"* and having some freedom to move would have improved the experience. Likewise, P3 said they *"would love to have stood up and to have walked around"*. However, one participant reflected: *"If I'm in a forest and I'm walking around and I don't have the crunch of the sticks or leaves underneath my feet, then maybe that's gonna detract from the whole experience. So yeah, for me, probably in those environments, sitting is probably a good thing"* (P2). This comment reiterates the need for congruence between sights and sounds in the VE, and illustrates how the lack of congruence may be disruptive to mindfulness.

5.5.3 Transitioning Between Scenes

The final set of comments related to the transitions between scenes. We elected to automate these using fade in and out animations in which the screen transitioned from black to colour and back again.

Feedback on this design choice was largely positive, and the participants did not express a desire to control transitions for themselves, indeed suggesting that this option may have been disruptive. However, one interesting point emerged around having more freedom to explore the virtual environment after changing scenes. The participants expressed a need to view the scene to understand where they were, before settling in for the next part of the practice: *"the transition between was pretty smooth for me. I was just curious about seeing what was going to pop up next . . . But I was keen to check out the environment, and it might have distracted me from paying attention to the voice to begin with"* (P7). There were also positive comments shared around the time spent in each scene. These minimal changes in VE scene location were described as helpful for providing time to explore the environment: *"I liked that it had just the one change, not, you know, 15 different places. I thought that was good because you check out the environment"* (P7). This suggests that the choice of two scenes was sufficient to provide variety, without being under- or over-stimulating.

5.5.4 Interactions Design Considerations

Our participants generally found that operating the app was easy and that it did not detract from their practice, suggesting that a minimal interaction strategy can be useful when designing for mindfulness. However, the feedback did emphasise the importance of using accessible language when introducing users to the experience, and the need for clear feedback when interacting with the VE.

Our participants expressed different preferences for translational movement within the VE. Designers should consider whether movement is useful for the mindfulness

practice; some VR experiences offer gentle forward motion as a way of keeping the user engaged (e.g., (Navarro-Haro et al., 2016; Navarro-Haro et al., 2017)), and this may be useful in situations where the user cannot move their body (Hoffman et al., 2019).

Finally, our participants noted that transitioning between environments kept them involved and provided new anchors for their attention. This suggests that gentle movement between 2–3 environments can be useful for maintaining interest and may cater to different preferences.

6 DISCUSSION

6.1 Design Process

The aim of this research was to report on the design and development process behind *Place*, a VR app we created to support mindfulness. Our motivation for reporting the design process was based on a lack of information about how previous VR mindfulness apps were created. Prior studies typically present the system without a full account of decisions that led to the implementation (e.g. (Tarrant et al., 2018; Chandrasiri et al., 2019)). As evinced by the process we followed and the feedback received from participants, creating a VR app is a complex activity, and there are a swathe of factors that should be considered when designing the intervention. Failure to consider these factors may result in a design that does not achieve its intended outcomes, or which leads to negative side-effects like simulator sickness. Our design process allowed us to consider these issues systematically, which we hope can provide an example for others to follow in order to ensure effective outcomes. It also resulted in an app that supports mindfulness, induces positive emotion and which provides a positive user experience (see Seabrook et al., 2020).

Designing *Place* also prompted us to create the SHACI framework (**Figure 2**), which enabled us to think through different aspects of the VR app and how it might be used. We found this framework useful for surfacing interdependencies between different areas of design activity, and for considering how decisions in one area have cascading impacts on others. For example, our decision to create a VE from omnidirectional footage impacted the types of interactions that were possible in *Place*, which in turn informed the instructions used to deliver the practice. Being able to compare this set of decisions with other possibilities helped us to define specific pathways in a structured way. We found that the framework also forced us to critically reflect on issues such as the nature of mindfulness, what our app was trying to achieve, and whether we could support our intended outcomes. This encouraged us to consider seriously what might be deemed "annoying" questions (e.g., "why use VR when people do mindfulness with their eyes closed?") and more reflective questions (e.g. "should we draw attention to stimuli within the VE, internal sensations, or should we ask people to attend to their use of VR?"). We also had to consider how to make choices that are congruent with the non-evaluative attitude that characterises mindfulness practice. Given that the five components of the SHACI framework are generalisable, we believe that they may be useful during the design of other VR applications, not just those for mindfulness.

Finally, our process placed an emphasis on gathering feedback from prospective users. This resulted in alterations to the app that reduced usability problems, improved the quality of the VE, and enhanced the user experience. Although minor usability problems and visual glitches may be considered relatively picayune, they have the potential to become detrimental if they are allowed to accumulate over time. This emphasises the importance of incorporating human-centred approaches into the design of digital health interventions (Blandford et al., 2018), particularly for complex tools like VR. Our participants' comments suggest that improving the user experience contributed to the overall quality of *Place* and its ability to support mindfulness practice. A second benefit from our perspective was the way that iterative development of the app led to different kinds of feedback over time. We noticed that FG1 largely revolved around problems with the VE, whereas discussions in FG3 were more abstract, and involved deeper reflections about the experience of doing mindfulness in VR. This was useful as it expanded the feedback into new areas, allowing us to learn about anticipated situations of use and the value of behaviours that initially appeared to be in contrast with our design intention, such as the tendency for people to close their eyes during the practice.

6.2 Dimensions for VR Mindfulness

In our participants' feedback about the usability and the experience of Place, we identified three descriptions of engaging with the VE that may have an impact on how successfully a VR app can support mindfulness for different users. These were *distraction*, *disengagement*, and *becoming absorbed*.

6.2.1 Distraction

The participants in all three focus groups mentioned that distraction was an issue (e.g. in relation to visual quality). As noted above, there may be sources of unintentional distraction and intentional distraction introduced into a VE. While distraction is a challenge for mindfulness meditation and may act as a barrier to continued practice (Reina and Kudesia, 2020), mindfulness skill acquisition inherently involves the management of distraction and mind wandering through attention monitoring (Lindsay and Creswell, 2017). In this sense, designing a distraction free VE (such as a perfectly rendered white room) may not be a suitable aim for mindfulness in VR.

This highlights an interesting design opportunity for supporting mindfulness in VR both at an entry level and in terms of ongoing training. For instance, low distraction VEs may be suitable for new meditators who are yet to develop strong skills in attention monitoring, such that the challenge of shifting and maintaining attention on the present moment is matched to their existing skill level. It may also be possible to structure ongoing mindfulness skill training by introducing intentional distraction in VEs; for example, placing someone in a VE showing a busy cafe and structuring a mindfulness practice around maintaining present moment awareness. In this way, designers could

introduce users to more complex environments for practicing mindfulness, with a view to translating the skill back into real-world environments. Here, the sparseness or density of the VE may be an important dimension.

6.2.2 Disengagement

While distraction is a natural part of practicing mindfulness and has the potential to be useful as a VE design choice, experiences of disengagement fundamentally subvert the utility of VR for supporting mindfulness. Sub-optimal visual quality or having unexpected experiences in the VE created unintentional distraction at times, and at worst became disengaging. This was particularly the case when perceptions of physical reality were not supported in the VE (e.g., it would not be possible to "float above a rock" in real life). These may also disrupt the sense of presence that the user experiences in the VE, which is especially taxing given that the sense of presence has been reported as supportive of mindfulness (Seabrook et al., 2020).

We suggest this is where the importance of a convincing and congruent VE becomes relevant to the design of VR for mindfulness. At a simple level, this may involve designers selecting VEs that participants expect to see themselves in (e.g., not "being dumped in the middle of a river"). Activity design may also play a role in reducing the likelihood of encountering disengaging experiences by promoting a sense of presence in the VE. Slater (2009) discusses how the place illusion—a key component of virtual presence—can be broken as users seek to explore the valid actions available to them within a system, which is constrained by the immersive properties of the system and the degree to which a user "probes the boundaries of the system" ((Slater, 2009), p.3552). It is likely that because we designed our Activity to explicitly match what we knew was available from the VE in terms of valid actions, participants identified that their sense of presence was not typically disrupted. One of our participants described how they may have encountered a disengaging experience if their sense of presence was disrupted, noting that it would be strange to walk around the forest VE without feeling the crunch of sticks beneath their feet. Designers should consider how decisions around Activity design (e.g., for us a seated practice) can be matched to the interactions available in a system to provide boundaries around the actions users may seek to do in a VE where a perfectly real virtual experience cannot be delivered.

6.2.3 Becoming Absorbed

In contrast to disengagement, becoming too absorbed in the VE may also be problematic. Our participants noted times in the practice where they were only interested in exploring what was around them without necessarily applying mindful awareness to that exploration. This type of absorption in the VE may hinder mindfulness by causing the user to be swept up in the "narrative" of the situation, making it less about observation of experience and more akin to "virtual tourism". Indeed, this experience of going on a "journey" was noted by participants when discussing the challenges that so-called "alien" VEs may pose to practicing mindfulness in VR. While engaging with alien or unfamiliar VEs may be relaxing, calming, positive, or even exciting, it may not support the user in becoming an observer of their present moment experiences. In this sense, designers should consider how well a VE can support attention monitoring, potentially through balancing dimensions such as dull-exciting, and familiar-alien.

We suggest there are likely to a range of modifiable dimensions of a VE that can be altered to deliver a suitable environment for mindfulness practice. Depending on the practice intention (e.g., being mindful of, or sitting with, uncomfortable thoughts and emotions in an unpleasant environment) and intended audience (e.g., novice meditator), differing degrees of these dimensions may be applied. As a starting point we have suggested dimensions such as sparse-dense, familiar–alien, and dull–exciting. We do not claim that these dimensions are exhaustive; rather, they have been developed from our understanding of the feedback provided by our participants from their experience of a single, nature-based VR mindfulness practice. We do, however, hope that these dimensions provide a useful prompt for further investigation.

7 LIMITATIONS AND FUTURE WORK

To date, our explorations of VR mindfulness with *Place* have focused on a single VE, a natural forest. Participants in our study expressed a desire to try other environments, and so future research could undertake comparative studies of mindfulness with different types of VEs, such as by comparing natural scenes to urban environments or by using VEs containing abstract imagery. Further investigation of the interplay between surrealism and realism may also be interesting, given that some of our participants commented on the unexpected value of visual glitches in enhancing their attentional focus.

Similarly, we have only investigated a single focussed-attention mindfulness practice. Alternative or more advanced practice incorporating open monitoring or a focus on thoughts and feelings may be considered in future. Another direction that has not yet been explored is how VR may help people to visualise hard-to-imagine stimuli, rather than simply using a prerecorded video of a familiar scene.

There is also an opportunity to conduct comparative studies between VR and other modalities (smartphone app, audio-only) to explore when, where and why particular mediums are favoured over others. Exploring spatialized sounds may be another opportunity to increase engagement by increasing the user's sense of presence in the VE.

There are also opportunities to expand the exploration of mindfulness to other kinds of emerging digital technology. A mixed or augmented reality tool for mindfulness could provide the capability of overlaying digital stimuli onto the real world. This could provide people with resources for anchoring their attention but in a way that makes it seem as if the resource is co-present, rather than in a VE. Using augmented reality may allow people to feel co-present in the physical environment safely with

others, alleviating some of the concerns around using VR headsets in public space.

An important area for future research concerns longitudinal engagement with VR mindfulness. Currently, all of our trials of Place have involved one-off uses as we wanted to assess the initial effects of the app on state mindfulness. The same is true for other studies in the literature (e.g. (Navarro-Haro et al., 2016; Tarrant et al., 2018; Chandrasiri et al., 2019)), although one study suggests that VR may increase adherence with a multi-session structured mindfulness-based intervention (Navarro-Haro et al., 2019). Further research is required to understand when, where and how VR mindfulness might be used in the longer term, and what kinds of changes need to be made to foster longitudinal engagement (e.g., providing different virtual environments and practices, in the event that the forest VE becomes boring).

8 CONCLUSION

This paper described the design process and rationale for *Place* a VR application intended to support mindfulness in self-guided contexts. We reported on our iterative design process, which involved high-fidelity prototyping and acquisition of feedback from prospective users. The feedback enabled us to refine the VR prototype prior to evaluation with groups from the general and clinical populations.

The design process can inform future research on VR mindfulness in several ways. First, it demonstrates the importance of using an iterative and user-centred design process in the creation of VR interventions, such that low-level design problems can be corrected prior to formal evaluation. Evidence from the design process suggests that removing these 'bugs' may allow people to focus on key concepts associated with the application. Second, the design process drew attention to high-level considerations for supporting mindfulness practice, including those around the choice of virtual environment, the plausibility of the environment, and various issues around congruence. These considerations can be factored into the design of future VR apps for mindfulness to promote user uptake, enjoyment and acquisition of mindfulness skills in the real world. Finally, we have introduced the SHACI framework, which helped us to plan and consider the consequences of our design decisions when creating *Place*. We hope that researchers and designers will find this framework useful for planning a range of VR apps, not just those for supporting mindfulness.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because ethics approval was not given for the data to be made public. Requests to access the datasets should be directed to Ryan Kelly at ryan.kelly@unimelb.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Swinburne University of Technology Human Research Ethics Committee (SHR 2018/256) University of Melbourne Human Research Ethics Committee (ID\# 1852613.2). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ES conceived this work. ES and RK planned the design process and created the SHACI design framework. GW, ES, FF, and RK conducted the focus groups. ES and RK conducted data analysis. RK and ES drafted the article. FF, NT, MN, and GW provided comments and revisions. RK and ES revised the article after reviewers' comments were received. All authors provided input to the final version.

ACKNOWLEDGMENTS

We thank the reviewers for their comments and suggestions that improved this paper. We wish to acknowledge the contributions of Dr Craig Hassed in the early discussion of applying virtual reality to mindfulness practice. We also thank Nastaran Doroud, Lauren Rossi, Frank Vetere, and Yaoxi Shi for their contributions to data collection and early analysis of the focus groups. Finally, we thank PHORIA for their contributions and expertise that informed the development of the VR mindfulness app.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2021.672556/full#supplementary-material

REFERENCES

Anderson, N. D., Lau, M. A., Segal, Z. V., and Bishop, S. R. (2007). Mindfulness-Based Stress Reduction and Attentional Control. *Clin. Psychol. Psychother.* 14, 449–463. doi:10.1002/cpp.544

Anderson, T., Suresh, M., and Farb, N. A. (2019). Meditation Benefits and Drawbacks: Empirical Codebook and Implications for Teaching. *J. Cogn. Enhanc.* 3, 207–220. doi:10.1007/s41465-018-00119-y

Baer, R. A., Smith, G. T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S., et al. (2008). Construct Validity of the Five Facet Mindfulness Questionnaire in Meditating and Nonmeditating Samples. *Assessment.* 15, 329–342. doi:10.1177/1073191107313003

Bahng, S., Kelly, R. M., and McCormack, J. (2020). "Reflexive VR Storytelling Design beyond Immersion: Facilitating Self-Reflection on Death and Loneliness," in Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (New York, NY, USA: Association for Computing Machinery). CHI '20, 1–13. doi:10.1145/3313831.3376582

Birtwell, K., Williams, K., van Marwijk, H., Armitage, C. J., and Sheffield, D. (2019). An Exploration of Formal and Informal Mindfulness Practice and Associations With Wellbeing. *Mindfulness.* 10, 89–99. doi:10.1007/s12671-018-0951-y

Blandford, A., Gibbs, J., Newhouse, N., Perski, O., Singh, A., and Murray, E. (2018). Seven Lessons for Interdisciplinary Research on Interactive Digital Health Interventions. *Digit Health.* 4, 2055207618770325. doi:10.1177/2055207618770325

Blom, K. J., and Beckhaus, S. (2014). The Design Space of Dynamic Interactive Virtual Environments. *Virtual Reality.* 18, 101–116. doi:10.1007/s10055-013-0232-y

Bohlmeijer, E., Prenger, R., Taal, E., and Cuijpers, P. (2010). The Effects of Mindfulness-Based Stress Reduction Therapy on Mental Health of Adults With a Chronic Medical Disease: A Meta-Analysis. *J. Psychosomatic Res.* 68, 539–544. doi:10.1016/j.jpsychores.2009.10.005

Bränström, R., Duncan, L. G., and Moskowitz, J. T. (2011). The Association Between Dispositional Mindfulness, Psychological Well-Being, and Perceived Health in a Swedish Population-Based Sample. *Br. J. Health Psychol.* 16, 300–316. doi:10.1348/135910710X501683

BreatheVR (2021). *BreatheVR: A Healthy Mind has an Easy Breath*. Available at: https://www.discoverneon.com/breathevr (Accessed November 30, 2021).

Bruun-Pedersen, J. R., Serafin, S., and Kofoed, L. B. (2016). Restorative Virtual Environment Design for Augmenting Nursing home Rehabilitation. *J. Virtual Worlds Res.* 9, 1. doi:10.4101/jvwr.v9i3.7224

Carlsen, B., and Glenton, C. (2011). What about N? a Methodological Study of Sample-Size Reporting in Focus Group Studies. *BMC Med. Res. Methodol.* 11, 26–10. doi:10.1186/1471-2288-11-26

Chandrasiri, A., Collett, J., Fassbender, E., and De Foe, A. (2019). A Virtual Reality Approach to Mindfulness Skills Training. *Virtual Reality.* 24, 143–149. doi:10.1007/s10055-019-00380-2

Cochrane, K. A., Loke, L., de Bérigny, C., and Campbell, A. (2018). "Sounds in the Moment: Designing an Interactive EEG Nature Soundscape for Novice Mindfulness Meditators," in Proceedings of the 30th Australian Conference on Computer-Human Interaction (New York, NY, USA: ACM), 298–302. OzCHI '18. doi:10.1145/3292147.3292215

Crane, R. S., Soulsby, J. G., Kuyken, W., Williams, J. M. G., Eames, C., Bartley, T., et al. (2012). *The Bangor, Exeter & Oxford Mindfulness-Based Interventions Teaching Assessment Criteria (MBI:TAC)*. Bangor. Unpublished manuscript. Available at: https://mindfulness.nhsggc.org.uk/media/2047/mbi-tac-aug2015.pdf.

Crane, R. S., Eames, C., Kuyken, W., Hastings, R. P., Williams, J. M. G., Bartley, T., et al. (2013). Development and Validation of the Mindfulness-Based Interventions - Teaching Assessment Criteria (MBI:TAC). *Assessment.* 20, 681–688. doi:10.1177/1073191113490790

Dao, E., Muresan, A., Hornbæk, K., and Knibbe, J. (2021). "Bad Breakdowns, Useful Seams, and Face Slapping: Analysis of VR Fails on Youtube," in Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (New York, NY, USA: Association for Computing Machinery). doi:10.1145/3411764.3445435

Daudén Roquet, C., and Sas, C. (2018). "Evaluating Mindfulness Meditation Apps," in Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (New York, NY, USA: ACM). CHI EA '18, LBW575: 1–LBW575:6. doi:10.1145/3170427.3188616

Davis, S., Nesbitt, K., and Nalivaiko, E. (2014). "A Systematic Review of Cybersickness," in Proceedings of the 2014 Conference on Interactive Entertainment, 1–9. doi:10.1145/2677758.2677780

Demarzo, M., Montero-Marin, J., Puebla-Guedea, M., Navarro-Gil, M., Herrera-Mercadal, P., Moreno-González, S., et al. (2017). Efficacy of 8- and 4-Session Mindfulness-Based Interventions in a Non-Clinical Population: A Controlled Study. *Front. Psychol.* 8, 1343. doi:10.3389/fpsyg.2017.01343

Depledge, M. H., Stone, R. J., and Bird, W. J. (2011). Can Natural and Virtual Environments Be Used to Promote Improved Human Health and Wellbeing? *Environ. Sci. Technol.* 45, 4660–4665. doi:10.1021/es103907m

Fern, E. F. (1982). The Use of Focus Groups for Idea Generation: the Effects of Group Size, Acquaintanceship, and Moderator on Response Quantity and Quality. *J. marketing Res.* 19, 1–13. doi:10.1177/002224378201900101

Flores, A., Linehan, M. M., Todd, S. R., and Hoffman, H. G. (2018). The Use of Virtual Reality to Facilitate Mindfulness Skills Training in Dialectical Behavioral Therapy for Spinal Cord Injury: A Case Study. *Front. Psychol.* 9, 531. doi:10.3389/fpsyg.2018.00531

Freudenthaler, L., Turba, J. D., and Tran, U. S. (2017). Emotion Regulation Mediates the Associations of Mindfulness on Symptoms of Depression and Anxiety in the General Population. *Mindfulness.* 8, 1339–1344. doi:10.1007/s12671-017-0709-y

Gomez, J., Hoffman, H. G., Bistricky, S. L., Gonzalez, M., Rosenberg, L., Sampaio, M., et al. (2017). The Use of Virtual Reality Facilitates Dialectical Behavior Therapy "Observing Sounds and Visuals" Mindfulness Skills Training Exercises for a Latino Patient With Severe Burns: A Case Study. *Front. Psychol.* 8, 1611. doi:10.3389/fpsyg.2017.01611

Gutteling, J. J., De Man, R. A., Busschbach, J. J., and Darlington, A. S. (2008). Quality of Health Care and Patient Satisfaction in Liver Disease: the Development and Preliminary Results of the Quote-Liver Questionnaire. *BMC Gastroenterol.* 8, 25–27. doi:10.1186/1471-230X-8-25

Hayes, A. M., and Feldman, G. (2004). Clarifying the Construct of Mindfulness in the Context of Emotion Regulation and the Process of Change in Therapy. *Clin. Psychol. Sci. Pract.* 11, 255–262. doi:10.1093/clipsy.bph080

Healium (2021). *Mental Fitness: Human Performance Powered by Your Brain*. Available at: https://www.tryhealium.com/#about (Accessed November 30, 2021).

Hoffman, H. G., Rodriguez, R. A., Gonzalez, M., Bernardy, M., Peña, R., Beck, W., et al. (2019). Immersive Virtual Reality as an Adjunctive Non-opioid Analgesic for Pre-dominantly Latin American Children With Large Severe Burn Wounds During Burn Wound Cleaning in the Intensive Care Unit: A Pilot Study. *Front. Hum. Neurosci.* 13, 262. doi:10.3389/fnhum.2019.00262

Hölzel, B. K., Lazar, S. W., Gard, T., Schuman-Olivier, Z., Vago, D. R., and Ott, U. (2011). How Does Mindfulness Meditation Work? Proposing Mechanisms of Action from a Conceptual and Neural Perspective. *Perspect. Psychol. Sci.* 6, 537–559. doi:10.1177/1745691611419671

Hussien Ahmed, M. M., Silpasuwanchai, C., Salehzadeh Niksirat, K., and Ren, X. (2017). "Understanding the Role of Human Senses in Interactive Meditation," in Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (New York, NY, USA: ACM), 4960–4965. CHI '17. doi:10.1145/3025453.3026000

Jo, H., Song, C., and Miyazaki, Y. (2019). Physiological Benefits of Viewing Nature: A Systematic Review of Indoor Experiments. *Int. J. Environ. Res. Public Health.* 16, 4739. doi:10.3390/ijerph16234739

Kabat-Zinn, J. (1982). An Outpatient Program in Behavioral Medicine for Chronic Pain Patients Based on the Practice of Mindfulness Meditation: Theoretical Considerations and Preliminary Results. *Gen. Hosp. Psychiatry.* 4, 33–47. doi:10.1016/0163-8343(82)90026-3

Kabat-Zinn, J., Lipworth, L., and Burney, R. (1985). The Clinical Use of Mindfulness Meditation for the Self-Regulation of Chronic Pain. *J. Behav. Med.* 8, 163–190. doi:10.1007/bf00845519

Kabat-Zinn, J. (2003). Mindfulness-Based Interventions in Context: Past, Present, and Future. *Clin. Psychol. Sci. Pract.* 10, 144–156. doi:10.1093/clipsy.bpg016

Kaplan, S. (1995). The Restorative Benefits of Nature: Toward an Integrative Framework. *J. Environ. Psychol.* 15, 169–182. doi:10.1016/0272-4944(95)90001-2

Kennedy, R. S., Lane, N. E., Berbaum, K. S., and Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *Int. J. Aviation Psychol.* 3, 203–220. doi:10.1207/s15327108ijap0303_3

Khoury, B., Knäuper, B., Pagnini, F., Trent, N., Chiesa, A., and Carrière, K. (2017). Embodied Mindfulness. *Mindfulness.* 8, 1160–1171. doi:10.1007/s12671-017-0700-7

Kilteni, K., Groten, R., and Slater, M. (2012). The Sense of Embodiment in Virtual Reality. *Presence: Teleoperators and Virtual Environments.* 21, 373–387. doi:10.1162/pres_a_00124

Kosunen, I., Salminen, M., Järvelä, S., Ruonala, A., Ravaja, N., and Jacucci, G. (2016). "RelaWorld: Neuroadaptive and Immersive Virtual Reality Meditation System," in Proceedings of the 21st International Conference on Intelligent User Interfaces (New York, NY, USA: ACM), 208–217. IUI '16. doi:10.1145/2856767.2856796

Lindsay, E. K., and Creswell, J. D. (2017). Mechanisms of Mindfulness Training: Monitor and Acceptance Theory (MAT). *Clin. Psychol. Rev.* 51, 48–59. doi:10.1016/j.cpr.2016.10.011

Lippelt, D. P., Hommel, B., and Colzato, L. S. (2014). Focused Attention, Open Monitoring and loving Kindness Meditation: Effects on Attention, Conflict Monitoring, and Creativity – A Review. *Front. Psychol.* 5, 1083. doi:10.3389/fpsyg.2014.01083

Luberto, C. M., Hall, D. L., Park, E. R., Haramati, A., and Cotton, S. (2020). A Perspective on the Similarities and Differences Between Mindfulness and Relaxation. *Glob. Adv. Health Med.* 9, 2164956120905597. doi:10.1177/2164956120905597

Lukoff, K., Lyngs, U., Gueorguieva, S., Dillman, E. S., Hiniker, A., and Munson, S. A. (2020). "From Ancient Contemplative Practice to the App Store: Designing a Digital Container for Mindfulness," in Proceedings of the 2020 ACM Designing Interactive Systems Conference (New York, NY, USA: Association for Computing Machinery), 1551–1564. DIS '20. doi:10.1145/3357236.3395444

Lutz, A., Dunne, J. D., and Davidson, R. J. (2007). "Meditation and the Neuroscience of Consciousness: an Introduction," in *The Cambridge Handbook of Consciousness*. Editors P. D. Zelazo, M. Moscovitch, and E. Thompson (Cambridge: Cambridge University Press), 499–551.

Lymeus, F., Ahrling, M., Apelman, J., Florin, C. d. M., Nilsson, C., Vincenti, J., et al. (2020). Mindfulness-Based Restoration Skills Training (Rest) in a Natural Setting Compared to Conventional Mindfulness Training: Psychological Functioning After a Five-Week Course. *Front. Psychol.* 11, 1560. doi:10.3389/fpsyg.2020.01560

Lymeus, F., Lindberg, P., and Hartig, T. (2019). A Natural Meditation Setting Improves Compliance With Mindfulness Training. *J. Environ. Psychol.* 64, 98–106. doi:10.1016/j.jenvp.2019.05.008

Monti, D. A., Peterson, C., Kunkel, E. J. S., Hauck, W. W., Pequignot, E., Rhodes, L., et al. (2006). A Randomized, Controlled Trial of Mindfulness-Based Art Therapy (MBAT) for Women With Cancer. *Psycho-Oncology.* 15, 363–373. doi:10.1002/pon.988

Mott, M., Tang, J., Kane, S., Cutrell, E., and Ringel Morris, M. (2020). ""I just went into it assuming that I wouldn't be able to have the full experience" Understanding the Accessibility of Virtual Reality for People with Limited Mobility," in The 22nd International ACM SIGACCESS Conference on Computers and Accessibility (New York, NY, USA: Association for Computing Machinery). ASSETS '20. doi:10.1145/3373625.3416998

Navarro-Haro, M. V., Hoffman, H. G., Garcia-Palacios, A., Sampaio, M., Alhalabi, W., Hall, K., et al. (2016). The Use of Virtual Reality to Facilitate Mindfulness Skills Training in Dialectical Behavioral Therapy for Borderline Personality Disorder: A Case Study. *Front. Psychol.* 7, 1573. doi:10.3389/fpsyg.2016.01573

Navarro-Haro, M. V., López-del-Hoyo, Y., Campos, D., Linehan, M. M., Hoffman, H. G., García-Palacios, A., et al. (2017). Meditation Experts Try Virtual Reality Mindfulness: A Pilot Study Evaluation of the Feasibility and Acceptability of Virtual Reality to Facilitate Mindfulness Practice in People Attending a Mindfulness Conference. *PLoS ONE.* 12, e0187777. doi:10.1371/journal.pone.0187777

Navarro-Haro, M. V., Modrego-Alarcón, M., Hoffman, H. G., López-Montoyo, A., Navarro-Gil, M., Montero-Marin, J., et al. (2019). Evaluation of a Mindfulness-Based Intervention With and Without Virtual Reality Dialectical Behavior Therapy Mindfulness Skills Training for the Treatment of Generalized Anxiety Disorder in Primary Care: A Pilot Study. *Front. Psychol.* 10, 55. doi:10.3389/fpsyg.2019.00055

Niksirat, K. S., Silpasuwanchai, C., Cheng, P., and Ren, X. (2019). Attention Regulation Framework. *ACM Trans. Comput.-Hum. Interact.* 26, 1–44. doi:10.1145/3359593

Patibanda, R., Mueller, F. F., Leskovsek, M., and Duckworth, J. (2017). "Life Tree: Understanding the Design of Breathing Exercise Games," in Proceedings of the Annual Symposium on Computer-Human Interaction in Play (New York, NY, USA: ACM), 19–31. CHI PLAY '17. doi:10.1145/3116595.3116621

Pradhan, E. K., Baumgarten, M., Langenberg, P., Handwerger, B., Gilpin, A. K., Magyari, T., et al. (2007). Effect of Mindfulness-Based Stress Reduction in Rheumatoid Arthritis Patients. *Arthritis Rheum.* 57, 1134–1142. doi:10.1002/art.23010

Prpa, M., Tatar, K., Françoise, J., Riecke, B., Schiphorst, T., and Pasquier, P. (2018). "Attending to Breath: Exploring How the Cues in a Virtual Environment Guide the Attention to Breath and Shape the Quality of Experience to Support Mindfulness," in Proceedings of the 2018 Designing Interactive Systems Conference (New York, NY, USA: ACM), 71–84. DIS '18. doi:10.1145/3196709.3196765

Reina, C. S., and Kudesia, R. S. (2020). Wherever You Go, There You Become: How Mindfulness Arises in Everyday Situations. *Organizational Behav. Hum. Decis. Process.* 159, 78–96. doi:10.1016/j.obhdp.2019.11.008

Seabrook, E., Kelly, R., Foley, F., Theiler, S., Thomas, N., Wadley, G., et al. (2020). Understanding How Virtual Reality Can Support Mindfulness Practice: Mixed Methods Study. *J. Med. Internet Res.* 22, e16106. doi:10.2196/16106

Sephton, S. E., Salmon, P., Weissbecker, I., Ulmer, C., Floyd, A., Hoover, K., et al. (2007). Mindfulness Meditation Alleviates Depressive Symptoms in Women with Fibromyalgia: Results of a Randomized Clinical Trial. *Arthritis Rheum.* 57, 77–85. doi:10.1002/art.22478

Sevilla-Llewellyn-Jones, J., Santesteban-Echarri, O., Pryor, I., McGorry, P., and Alvarez-Jimenez, M. (2018). Web-based Mindfulness Interventions for Mental Health Treatment: Systematic Review and Meta-Analysis. *JMIR Ment. Health.* 5, e10278. doi:10.2196/10278

Slater, M. (2009). Place Illusion and Plausibility Can lead to Realistic Behaviour in Immersive Virtual Environments. *Phil. Trans. R. Soc. B.* 364, 3549–3557. doi:10.1098/rstb.2009.0138

Slater, M., and Wilbur, S. (1997). A Framework for Immersive Virtual Environments (Five): Speculations on the Role of Presence in Virtual Environments. *Presence: Teleoperators & Virtual Environments.* 6, 603–616. doi:10.1162/pres.1997.6.6.603

Sliwinski, J., Katsikitis, M., and Jones, C. M. (2015). "Mindful Gaming: How Digital Games Can Improve Mindfulness," in *Human-Computer Interaction – INTERACT 2015*. Editors J. Abascal, S. Barbosa, M. Fetter, T. Gross, P. Palanque, and M. Winckler (Cham: Springer International Publishing), 167–184. doi:10.1007/978-3-319-22698-9_12

Steuer, J. (1992). Defining Virtual Reality: Dimensions Determining Telepresence. *J. Commun.* 42, 73–93. doi:10.1111/j.1460-2466.1992.tb00812.x

Sutcliffe, A. G., Poullis, C., Gregoriades, A., Katsouri, I., Tzanavari, A., and Herakleous, K. (2019). Reflecting on the Design Process for Virtual Reality Applications. *Int. J. Human-Computer Interaction* 35, 168–179. doi:10.1080/10447318.2018.1443898

Tang, K. C., and Davis, A. (1995). Critical Factors in the Determination of Focus Group Size. *Fam. Pract.* 12, 474–475. doi:10.1093/fampra/12.4.474

Tarrant, J., Viczko, J., and Cope, H. (2018). Virtual Reality for Anxiety Reduction Demonstrated by Quantitative EEG: A Pilot Study. *Front. Psychol.* 9, 1280. doi:10.3389/fpsyg.2018.01280

Terzimehić, N., Häuslschmid, R., Hussmann, H., and schraefel, m. c. (2019). "A Review & Analysis of Mindfulness Research in HCI," in Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (New York, NY, USA: ACM), 113–457. CHI '19, 457. doi:10.1145/3290605.3300687

Thomas, D. R. (2006). A General Inductive Approach for Analyzing Qualitative Evaluation Data. *Am. J. Eval.* 27, 237–246. doi:10.1177/1098214005283748

Tremblay, M. C., Hevner, A. R., and Berndt, D. J. (2010). Focus Groups for Artifact Refinement and Evaluation in Design Research. *Commun. Assoc. Inf. Syst.* 26, 27. doi:10.17705/1cais.02627

Vidyarthi, J., and Riecke, B. E. (2013). "Mediated Meditation: Cultivating Mindfulness with Sonic Cradle," in CHI '13 Extended Abstracts on Human Factors in Computing Systems (New York, NY, USA: ACM), 2305–2314. CHI EA '13. doi:10.1145/2468356.2468753

Deep VR (2021). *Deep, A Meditative Virtual Reality Game Controlled by Breathing.* Available at: https://www.exploredeep.com/about-deep (Accesed November 30, 2021).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.