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Design and Evaluation of a Virtual Reality Meditation Experience to Reduce Stress and Prevent Burnout in Healthcare Professionals

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Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Preface

The work presented in this thesis was developed at Instituto Superior Técnico (Lisbon, Portugal), in collaboration with Hospital de Santa Maria and the Faculty of Medicine, University of Lisbon, during the period January 2025 to October 2025.

The study was conducted under the supervision of Prof. Daniel Simões Lopes and the co-supervision of doctor Alexandra Resende, within the framework of the Master's Programme in Biomedical Engineering at Instituto Superior Técnico.

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This section is written in Portuguese since it is the language spoken by everyone mentioned.

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Abstract

Burnout and stress are major challenges among healthcare professionals, compromising well-being, performance, and patient care. Relaxation and mindfulness programmes have shown promising results in mitigating stress, yet most existing interventions are generic and not tailored to the unique demands of clinical work, which limits their relevance and integration into daily routines. Digital and immersive technologies, such as Virtual Reality, offer new opportunities to deliver brief, engaging, and context-adapted interventions directly within the workplace.

This study aimed to design and evaluate a short VR-based meditation experience to promote stress reduction and mindfulness in healthcare contexts. The virtual environment, a tranquil forest pathway, was developed following user-centred design principles and implemented in *Unity 2022.3 LTS* for use with the *Meta Quest 2* headset. Thirteen healthcare students participated in a guided VR meditation session, during which stress, mindfulness, presence, and usability were assessed through validated self-report instruments.

Results revealed a marked decrease in distress and worry, coupled with increased engagement and mindfulness-consistent processes. Participants described the experience as calming, immersive, and easy to use, reporting a strong sense of presence and overall comfort. These findings highlight the potential of short VR meditation as a feasible, low-intensity intervention to foster emotional regulation, enhance well-being, and support burnout prevention among healthcare professionals.

Keywords

Burnout Prevention; Stress Reduction; Mindfulness; Virtual Reality; Healthcare Professionals.

Resumo

O burnout e o stress constituem desafios persistentes entre os profissionais de saúde, afetando o bem-estar, o desempenho e a qualidade dos cuidados prestados. Sessões de mindfulness e intervenções de relaxamento têm demonstrado resultados positivos na redução do stress; contudo, a maioria das intervenções existentes é genérica e pouco adaptada às exigências e rotinas do contexto clínico, o que limita a sua eficácia e aplicação prática. Novas tecnologias imersivas, como a Realidade Virtual, oferecem oportunidades para implementar intervenções breves, envolventes e adaptadas ao ambiente de trabalho.

Este estudo teve como objetivo conceber e avaliar uma experiência curta de meditação em VR para promover a redução do stress. O ambiente virtual foi criado com base em princípios de *user centered design* e implementado no *Unity 2022.3 LTS* para utilização com o dispositivo *Meta Quest 2*. Treze estudantes da área da saúde participaram numa sessão de meditação guiada em VR, sendo avaliados o stress, a sensação de presença e a usabilidade através de instrumentos validados.

Os resultados mostraram reduções significativas do nível de desconforto e da preocupação, acompanhadas de maior *engagement* e estados de consciência plena. Os participantes descreveram a experiência como calma, imersiva e de fácil utilização. Estas observações confirmam o potencial da meditação em VR como uma intervenção breve, viável e de baixa intensidade para promover a regulação emocional, o bem-estar e a prevenção do burnout profissional.

Palavras Chave

Prevenção de Burnout; Redução de Stress; Mindfulness; Realidade Virtual; Profissionais de Saúde.

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Acronyms

WHO World Health Organization

MBI Mindfulness-Based Intervention

VR Virtual Reality

SUS System Usability Scale

IPQ Igroup Presence Questionnaire

PQ-M Practice Quality – Meditation Questionnaire

SSSQ Short Stress State Questionnaire

DMPI-R Determinants of Meditation Practice Inventory–Revised

1

Introduction

Contents

1.1 Motivation and Background

1.2 Objectives of the Study

1.3 Structure of the Thesis

1.1 Motivation and Background

Burnout has been recognised by the World Health Organization World Health Organization (WHO) as an occupational phenomenon resulting from chronic workplace stress that has not been successfully managed. It is characterised by emotional exhaustion, mental detachment from one's work, and a reduced sense of professional accomplishment [3]. In healthcare environments, where high workload, emotional demands, and time pressure are prevalent, stress accumulation is frequent and, when unaddressed, can evolve into burnout [4]. Consequently, the attenuation of acute stress represents a key preventive strategy to maintain well-being and reduce the risk of professional exhaustion. This definition reflects not only an individual condition but a systemic challenge within clinical settings.

The growing prevalence of burnout among healthcare professionals represents a critical threat to workforce sustainability and patient care quality. Recent reviews estimate that approximately one in three physicians experience this condition at any given time, confirming that the problem remains deeply entrenched within healthcare systems [5]. In Portugal, a 2023 national study among medical residents reported that 24.7% exhibited severe symptoms and that more than half were at risk of developing the syndrome [6]. These figures highlight the urgency of implementing preventive measures within healthcare organisations, aiming to attenuate stress before it evolves into burnout.

While organisational measures such as balancing workloads, maintaining adequate staffing, and ensuring supportive management are important to mitigate burnout, their successful implementation depends on each institution's conditions, including available resources, staffing levels, leadership support, and organisational culture [7]. Consequently, individual-level approaches have gained increasing attention as complementary strategies. Healthcare professionals often rely on coping strategies such as physical exercise, cultivating social support, setting boundaries, or engaging in relaxation techniques to manage stress and emotional exhaustion [8]. These strategies can alleviate stress and psychological discomfort in the short term, yet maintaining long-term engagement with such practices remains challenging, particularly due to time constraints and lack of motivation to sustain regular practice [9]. This highlights the need for more engaging and sustainable approaches to stress management among healthcare professionals

Among the various individual strategies, mindfulness-based interventions Mindfulness-Based Intervention (MBI) have gained particular attention for their ability to cultivate emotional regulation, resilience, and present-moment awareness among healthcare professionals [9]. Controlled studies have demonstrated tangible workplace benefits, with participants reporting higher job satisfaction and reduced emotional exhaustion following mindfulness training [7, 10]. More recently, digital mindfulness programmes such as mobile-based and virtual reality Virtual Reality (VR) meditation have shown promising outcomes in reducing burnout and improving well-being within clinical context. [11–13]. However, most existing digital mindfulness solutions were developed for the general population and are not specifically tailored

to the needs, schedules, and working conditions of healthcare professionals.

This gap motivated the conception of a VR-based meditation approach specifically adapted to the needs of healthcare professionals. The opportunity to further develop and test this concept arose from an ongoing clinical study at Hospital de Santa Maria that employs the medical device *HypnoVR* [14] to promote relaxation and reduce anxiety during surgical procedures under regional anaesthesia. Although that study focuses on patients, it demonstrates the feasibility and acceptance of immersive VR in hospital contexts. Building on this foundation, the present work aims to design and evaluate an immersive VR meditation experience for healthcare professionals to promote relaxation, reduce stress, and prevent burnout.

1.2 Objectives of the study

The main objectives of this work are defined as follows:

- To analyse preliminary feedback from the clinical use of the *HypnoVR* system in order to identify relevant insights and perceived applicability for healthcare professionals;
- To identify the key requirements and design features for a VR-based meditation experience tailored to the routines and needs of healthcare professionals;
- To design and develop an immersive VR meditation experience addressing these requirements;
- To conduct iterative user testing sessions with healthcare students to evaluate usability, acceptability, and overall user experience;
- To assess the preliminary effectiveness of the developed experience in supporting stress reduction and well-being within clinical environments.

1.3 Structure of the thesis

This thesis is organised into six main chapters, each contributing to the design, implementation, and evaluation of a VR–based intervention aimed at supporting burnout prevention among healthcare professionals.

- **Chapter 1 – Introduction**: presents the context and motivation for the study, defines the central problem and outlines the research objectives.
- **Chapter 2 – Literature Review**: examines the concept of burnout in healthcare, reviews existing strategies for mental health support, and discusses the application of virtual reality technologies in stress management and meditation.

- **Chapter 3 – Methodology**: describes the user-centred research design, the development process, and the quantitative and qualitative evaluation procedures.
- **Chapter 4 – Results**: presents participant characterisation, prior experience and contextual factors, quantitative outcomes, and qualitative findings.
- **Chapter 5 – Discussion**: synthesises the key findings, relates them to prior literature, and discusses implications and limitations.
- **Chapter 6 – Conclusion**: summarises the main contributions and presents future work.

Supporting materials are provided in the appendices.

2

Literature Review

Contents

2.1 Burnout in healthcare professionals

2.2 Mindfulness and Individual Strategies for Stress Management

2.3 Digital and Virtual Reality Approaches

2.4 Research Gaps

This chapter provides the background supporting the development of an immersive virtual reality meditation experience aimed at preventing burnout among healthcare professionals. It begins by describing the phenomenon of burnout, its prevalence in healthcare settings, and the main factors that contribute to stress in this population.

Next, the chapter reviews both organisational and individual strategies used to manage work-related stress, focusing on mindfulness-based interventions, outlining their main advantages and limitations in clinical environments.

The chapter then examines the growing use of digital health solutions and the integration of VR into mindfulness and relaxation practices, analysing how immersive technologies can enhance engagement and therapeutic effectiveness. It concludes by identifying key research gaps that inform the design and evaluation of the VR-based solution developed in this thesis.

2.1 Burnout in healthcare professionals

Burnout is a work-related syndrome characterised by emotional exhaustion, depersonalisation, and a diminished sense of personal accomplishment [4, 15]. It was first described in the 1970s as a state of exhaustion resulting from excessive demands on energy and resilience [16], and was later formalised as a multidimensional construct encompassing affective, cognitive, and behavioural components [17]. The most widely used framework to assess burnout is the Maslach Burnout Inventory, which operationalises these three dimensions and remains the gold standard for research and clinical assessment [4]. In 2019, the WHO officially recognised burnout as an occupational phenomenon resulting from chronic workplace stress that has not been successfully managed [3].

Burnout has become a widespread concern across healthcare systems worldwide, affecting a substantial proportion of healthcare workers. International studies report high prevalence rates across multiple medical specialties and countries [18], while in Portugal, recent national data indicate that more than half of medical residents present a moderate or high risk of burnout [6]. These findings confirm that the problem is pervasive and deeply rooted in modern healthcare environments [5].

The impact of burnout extends far beyond individual distress. A large systematic review and meta-analysis demonstrated that clinician burnout is significantly associated with medical errors, poorer patient safety outcomes, reduced professionalism, and lower patient satisfaction [19]. Burnout therefore poses not only a threat to the well-being of healthcare professionals but also to the overall quality and safety of healthcare delivery.

The causes of burnout are multifactorial, arising from the interaction between organisational conditions and individual characteristics. Six domains of work–life imbalance have been identified as major contributors: workload, control, reward, community, fairness, and values [4]. In clinical practice, these

mismatches are often intensified by long working hours, limited autonomy, administrative burden, and insufficient recognition. Individual traits such as perfectionism and overcommitment further increase susceptibility to emotional exhaustion and chronic stress [20].

In summary, burnout among healthcare professionals represents a persistent and multidimensional challenge driven by excessive job demands and insufficient recovery from stress. Its global prevalence, serious consequences, and complex origins underline the need for preventive strategies that strengthen psychological resilience and promote stress regulation. The following section therefore focuses on individual approaches to stress reduction, with a particular emphasis on mindfulness-based interventions.

2.2 Mindfulness and Individual Strategies for Stress Management

Healthcare professionals frequently rely on individual strategies to manage the high levels of stress inherent to clinical practice. Coping mechanisms are central to this process, encompassing the cognitive and behavioural efforts used to manage demanding or emotionally charged situations [21, 22]. Adaptive coping strategies, such as problem-solving, seeking social support, and engaging in relaxation or mindfulness practices, have been shown to reduce stress levels and the risk of burnout among healthcare professionals [8].

In recent years, greater attention has been directed towards emotion-regulation approaches that promote resilience and sustained well-being. Among these, mindfulness-based interventions have demonstrated consistent evidence of effectiveness in enhancing emotional regulation, concentration, and stress recovery [9]. Mindfulness refers to the intentional and non-judgemental awareness of present-moment experiences, fostering self-regulation and reducing automatic emotional reactivity [23]. Through cultivating this awareness, healthcare professionals can better recognise stress responses, prevent emotional exhaustion, and maintain cognitive focus in demanding clinical environments.

Empirical research supports the benefits of mindfulness for healthcare workers. A systematic review reported significant reductions in burnout symptoms, anxiety, and perceived stress, alongside improvements in emotional balance and overall well-being [9]. Similarly, an abbreviated mindfulness intervention for primary-care clinicians led to gains in job satisfaction and quality of life, accompanied by lower emotional exhaustion [10]. More recently, a randomised controlled trial using a twelve-week mobile-assisted meditation and breathing programme confirmed substantial reductions in burnout scores and perceived stress among healthcare workers [11].

Beyond psychological outcomes, mindfulness has been shown to influence cognitive and affective mechanisms of emotion regulation, strengthening attentional control, awareness, and cognitive reappraisal processes that mitigate stress reactivity [24]. Despite these well-documented benefits, long-term adherence to mindfulness programmes among healthcare professionals remains limited due to practical

barriers such as time constraints and the lack of suitable spaces for regular practice [25]. These challenges highlight the potential of immersive delivery formats to make mindfulness-based interventions more engaging within clinical settings.

2.3 Digital and Virtual Reality Approaches

Virtual reality has recently gained attention in mental health and wellbeing research for its ability to induce a strong sense of presence, the subjective feeling of "being there" within a simulated environment, which enhances relaxation, attentional focus, and emotional engagement during mindfulness and relaxation practices [12, 26]. Building on this potential, recent studies have explored how immersive technologies might extend or enhance the effects of traditional mindfulness interventions by increasing motivation, engagement, and adherence.

Controlled trials have reported that VR-assisted mindfulness can replicate or even amplify the psychological and physiological benefits of conventional approaches. Controlled studies have shown that VR sessions improve emotional wellbeing, relaxation, and perceived engagement compared to audio or mobile-based formats [12, 27, 28]. Moreover, repeated use of brief VR mindfulness sessions has been associated with significant reductions in emotional exhaustion and depersonalisation, alongside increased personal accomplishment among nurses and other healthcare workers [13].

However, most VR mindfulness applications remain designed for the general population and seldom address the specific challenges of clinical practice. Current tools often lack adaptation to the specific demands and contexts of healthcare settings. In addition, many studies involve small samples and short interventions, limiting generalisability. Collectively, these findings indicate that while VR holds promise as a feasible and engaging medium for stress management and burnout prevention, further research is needed to develop healthcare-specific solutions specifically tailored to healthcare professionals and the realities of hospital environments.

2.4 Research Gaps

The literature reviewed in this chapter consistently links emotion-focused coping strategies, particularly MBI, to improvements in psychological well-being, stress regulation, and burnout prevention among healthcare professionals. [8, 9] Evidence also suggests that digital and immersive formats can enhance engagement and accessibility of mindfulness practices within demanding clinical contexts [11–13].

However, several important research gaps and limitations remain unaddressed in the current literature:

- **Lack of healthcare-specific adaptation:** Most mindfulness and relaxation interventions were developed for the general population and only later applied to clinical contexts, with limited consideration for healthcare professionals' routines and stressors [9, 29]. In particular, digital programmes have shown benefits in reducing stress among clinicians [12, 13, 30, 31], yet their design is not tailored to the specific needs or preferences of healthcare workers, such as limited time availability, psychological load, or the type of visual and breathing guidance that best supports their work context.
- **Practical barriers to implementation:** Adherence to mindfulness-based interventions among healthcare professionals remains limited, with several studies reporting difficulties in maintaining long-term engagement. This limited adherence is often attributed to contextual barriers, including lack of time, heavy workload, and absence of appropriate or quiet environments for practice within healthcare settings [9, 25, 32]. Sustained effectiveness therefore depends on integrating mindfulness practice into daily routines and adapting interventions to the operational conditions of clinical work [23].
- **Limited development of immersive approaches:** Although virtual reality has shown promise as an engaging medium for relaxation and emotional regulation, few studies have developed or evaluated immersive mindfulness experiences specifically designed for healthcare professionals [7, 12, 27]. Most existing VR applications are brief prototypes intended for general users and lack adaptation to the cognitive demands, time constraints, and workflow conditions of clinical environments.

These gaps reveal the need for interventions that are (1) adapted to the healthcare context, (2) feasible within daily clinical routines, and (3) capable of leveraging immersive technologies to improve engagement and adherence. The present thesis specifically addresses these gaps by developing a short, VR-based mindfulness experience co-designed with healthcare professionals, a context rarely explored in existing literature.

3

Methodology

Contents

3.1 Research Design

3.2 Development Process

3.3 Prototype Evaluation

This chapter presents the methodological approach adopted to design, develop, and evaluate the proposed virtual reality mindfulness experience. It begins by outlining the overall study design, followed by descriptions of the participants, data collection instruments, and evaluation procedures. The methodology follows a user-centred strategy that integrates both qualitative and quantitative insights to evaluate the experiential and psychological impact of the intervention. This approach enables consistency between the research objectives and the selected methods, providing a clear rationale for each stage of the study.

3.1 Research Design

This study follows a user-centred, mixed-methods approach to design and evaluate an immersive virtual reality mindfulness experience for healthcare professionals. The combination of qualitative insights and quantitative measures enables both an understanding of participants' subjective experiences and an assessment of the intervention's effects on stress-related outcomes [33]. The methodological process integrates iterative prototype development with user feedback collection and experimental evaluation, structured to ensure that the proposed solution aligns with the realities of clinical work while addressing the gaps identified in the literature.

The research process was structured into four main phases. First, a preliminary feedback phase was conducted at Santa Maria Hospital using an existing medical virtual reality hypnosis device, *HypnoVR*, to gather insights on relaxation experiences already available in the clinical setting [14]. This stage aimed to identify perceived strengths, limitations, and contextual barriers to adapting VR relaxation tools for healthcare professionals. Second, a multidisciplinary co-design session brought together physicians, medical and nursing students, and biomedical engineers to translate these insights into concrete design requirements and low-fidelity sketches of the experience. Third, a pilot test of a preliminary prototype gathered qualitative feedback from five medical students, informing subsequent design refinements. Finally, a summative evaluation phase was carried out with thirteen participants, using a pre–post design to assess stress-related states, presence, and usability, complemented by open-ended questions on perceived relaxation and engagement.

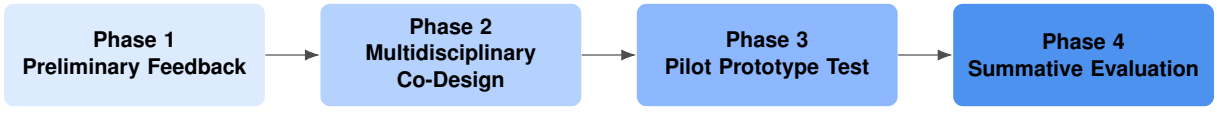


Figure 3.1: Overview of the research and development process.

3.2 Development Process

3.2.1 Exploratory Phase: Clinical Context Assessment

This first phase aimed to explore how healthcare professionals perceive and experience immersive relaxation technologies available in hospitals. For this purpose, an existing medical VR hypnosis system, *HypnoVR*, originally developed to reduce anxiety and pain during surgical procedures and regional anaesthesia, was used as a reference in this study [14]. Although the device is primarily designed for patients undergoing surgical procedures, it provided a relevant basis to examine how its content, duration, and usability align, or fail to align, with the needs of healthcare professionals. Each participant experienced the same relaxation scenario, consisting of an approximately ten-minute session guided by narration and ambient music. Afterward, they responded to a short open-ended interview addressing perceived comfort, realism, immersion, and potential workplace applicability. Prior to participation, all individuals were informed about the study procedures and provided written informed consent. The consent form and the full list of open-ended questions used in this session are available in Appendix A.

All interviews were transcribed using *Whisper*, an AI-based speech recognition model, followed by manual verification to ensure accuracy [34]. Qualitative data were analyzed using a six-phase thematic analysis framework [1]. This approach allows systematic and flexible exploration of meaning patterns in qualitative data

The analysis began with data familiarization through repeated reading of the transcripts to gain an overall understanding of participants' perspectives. Next, initial codes were generated inductively, capturing recurring ideas and relevant phrases such as "calm voice", "too static", and "short breaks". These codes were then grouped into potential themes that reflected broader ideas about user experience and contextual constraints. During the reviewing phase, overlapping codes were refined and reorganised to ensure internal consistency and clear thematic boundaries. Themes were subsequently defined and named, providing a coherent structure that linked the data to the objectives of the study. Finally, the themes were reported and interpreted, highlighting insights most relevant for the design of a VR mindfulness experience tailored for clinical settings.

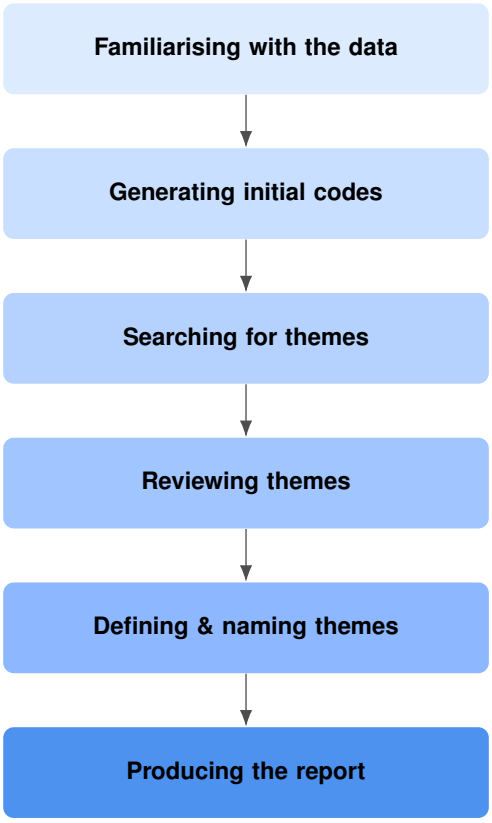


Figure 3.2: Six phases of thematic analysis, adapted from Braun and Clarke [1].

Five key themes emerged from the qualitative feedback: auditory experience, visual environment, duration and pacing, usability and comfort, and applicability in clinical contexts. Participants consistently emphasised the importance of the auditory dimension, noting that the narrator's voice and background music were essential for achieving relaxation and maintaining focus. Visual aspects were also frequently mentioned; while participants appreciated the immersive quality and aesthetic appeal, some observed that the colours and transitions could be overwhelming, preferring calmer and more natural environments, such as forests or open fields.

Regarding duration, most participants described the experience as appropriate but suggested that shorter, well-structured sessions would better align with hospital routines. Feedback also included remarks on usability and physical comfort, highlighting the value of lightweight headsets and intuitive start–stop functions to facilitate spontaneous use. Finally, several participants reflected on the practical challenges of integrating such tools into the healthcare setting, citing limited time, environmental noise, and lack of private spaces as barriers to regular use. Despite these constraints, most acknowledged the potential value of immersive relaxation for managing acute stress during work breaks or after demanding clinical situations. Younger participants, in particular, expressed greater openness and curiosity towards using VR technologies for stress management.

Table 3.1: Key themes identified during the exploratory phase and their design implications.

Aspect	Feedback Summary
Duration	Preference for short and focused sessions, compatible with brief hospital breaks.
Visual Environment	Calmer, realistic nature scenarios with soft colours and smooth transitions.
Sound and Voice	Gentle narration and ambient music were perceived as essential for relaxation and maintaining focus.
Comfort and Usability	Lightweight headset and intuitive interface recommended for spontaneous and independent use.
Context of Use	Limited time, background noise, and lack of private spaces identified as barriers; recognised potential for post-shift stress relief.

3.2.2 Multidisciplinary Co-Design Session

This phase aimed to translate the experiential insights gathered during the exploratory stage into concrete design requirements for the Virtual Reality mindfulness experience. A multidisciplinary co-design session was conducted with eight participants, including two physicians, two biomedical engineers, two medical students, and one nursing student, under the supervision of the thesis author. This composition certified that both clinical and technical perspectives were considered during the design process.

The session followed a semi-structured discussion format and applied recognised user-centred design methods, such as user personas [35], empathy mapping [36] and “How Might We” reframing [37], to ensure that the experience addressed the emotional, cognitive, and contextual needs of healthcare professionals (see Appendix B). Participants were first introduced to the objectives of the project and examples of existing relaxation applications, after which they collaboratively proposed features they considered essential for practicabillity and engagement within healthcare settings. The discussion was documented through detailed field notes, which were later synthesised into thematic design guidelines.

Key points emerging from the session included: (1) avoiding overly static visual content, as it could induce drowsiness rather than relaxation; (2) incorporating minimal interaction, such as gaze-based focus on moving visual elements; (3) introducing a sense of motion, preferably simulating a calm walk through a natural environment; (4) maintaining a gentle, guiding narrator voice providing concise instructions; and (5) ensuring that the experience could be easily initiated in a quiet, private space.

Table 3.2: Summary of key design requirements derived from the co-design session.

Design Feature	Implication for Prototype Development
Visual content	Simulate gentle motion to sustain engagement.
Interaction	Include minimal, intuitive interaction.
Auditory elements	Use calm narration with clear guidance and ambient sounds.
Session context	Short duration suitable for quick relaxation breaks.
Accessibility	Simple setup in a quiet, private environmente.

To visualise and consolidate the ideas generated, a low-fidelity conceptual sketch was created in *Canva*, a collaborative tool familiar to all participants, to illustrate the user perspective and general flow of the immersive experience (see Appendix B). This visual synthesis helped refine early concepts through quick iterations and feedback, supporting the development of the first prototype tested in the pilot study.

3.2.3 Virtual Scene Design

The virtual forest environment was developed in *Unity 2022.3 LTS* using the *Universal Render Pipeline (URP)* [38]. URP was selected for its efficiency in rendering real-time scenes with good visual quality and stable performance on the *Meta Quest 2* headset used in this study. The goal was to create a calm and immersive environment suitable for short mindfulness breaks among healthcare professionals. The design process followed a sequential structure, progressively adding terrain, vegetation, water, dynamic elements, and sound. Each design decision was informed by research from environmental psychology, stress recovery, and attentional restoration.

Environment Modelling

The virtual landscape extended approximately 150 $\times$ 150 meters in Unity units, configured to ensure a total experience duration of approximately five and a half minutes. This duration reflected the time constraints typical of clinical environments. Short VR relaxation or meditation sessions have demonstrated significant stress-reduction effects among healthcare professionals [13, 39, 40].

The terrain was sculpted with gentle elevation variations and a central forest path designed to guide the user through the environment. The trajectory followed a smooth, curved route rather than a straight line, to enhance perceived naturalness and exploration. Curved paths are known to evoke a stronger sense of fascination and restorativeness compared with linear trajectories [41, 42].

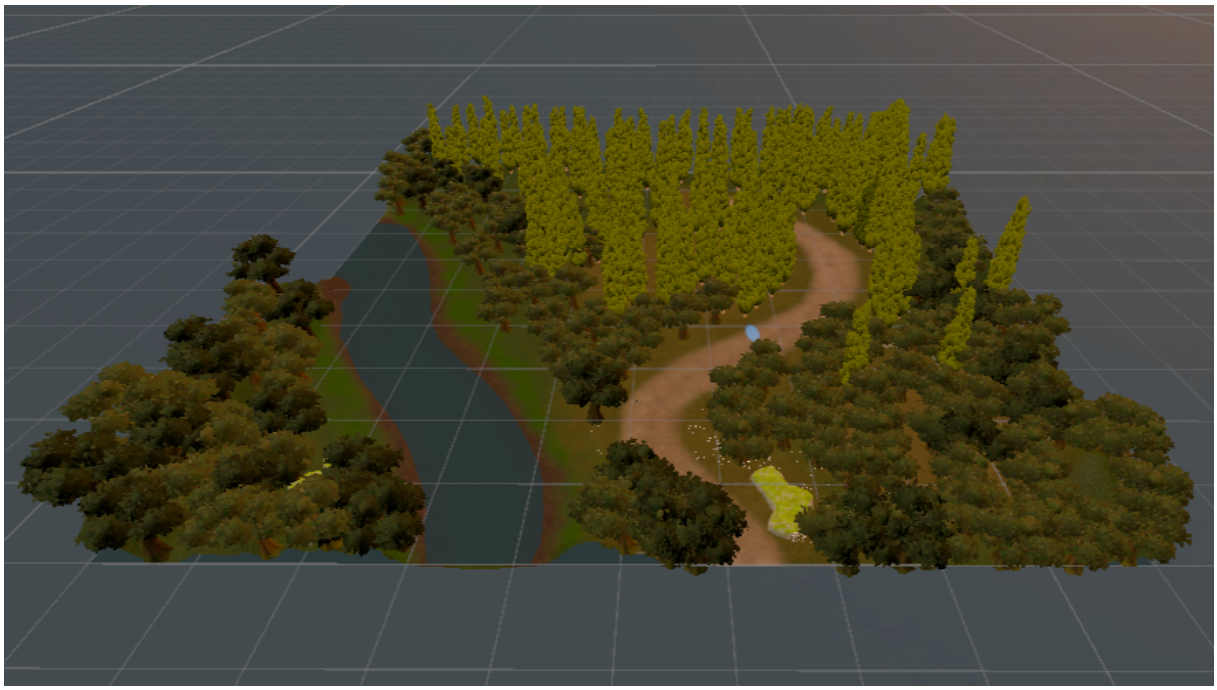


Figure 3.3: Overview of the virtual terrain and vegetation layout in Unity.

Vegetation and Spatial Composition

Two tree species were distributed across the terrain with randomised scale and subtle hue variation, enhancing realism and avoiding repetitive patterns that could reduce immersion [43, 44]. Additional environmental details such as wildflowers, scattered rocks, and fallen branches were integrated throughout the scene to increase surface diversity and convey a natural sense of irregularity typical of real forest environments. Variations in grass height and colour reflected local moisture gradients: greener, denser grass textures were applied in proximity to the river, whereas lighter and sparser tones characterised drier upland areas. Similarly, darker soil textures were used near the water to simulate humid ground and provide visual continuity between terrain and river elements.

River

The river was implemented to introduce dynamic visual feedback and enhance the overall realism of the scene. A reflective water surface extending along one side of the terrain was designed to evoke a calm and restorative atmosphere, in line with research indicating that visual or auditory exposure to water can help reduce physiological stress responses and lower heart rate compared to static natural scenes.[45, 46]. Complementary audio sources were distributed along the riverbanks to reproduce the sound of continuous water flow, enhancing spatial immersion and strengthening the perceptual coherence between visual and auditory stimuli.

Lighting and Colour Palette

Lighting conditions were configured to reproduce a late-afternoon ambience characterised by warm, diffuse tones and moderate intensity. This setup was chosen as it naturally enhances depth and texture while fostering a calm, low-contrast visual experience conducive to relaxation. The resulting illumination created a balanced palette of desaturated greens and browns across vegetation and terrain, complemented by subtle blue highlights in the sky that contributed to overall colour harmony. Such soft lighting has been associated with positive mood and decreased physiological activation in experimental settings [47]. The configuration also produced elongated shadows that enhanced depth perception and overall environmental realism.



Figure 3.4: Lighting setup in Unity simulating a late-afternoon ambience.

Dynamic and Interactive Elements

Two animated components introduced gentle, organic motion within the scene: a visual breathing guide and a butterfly.

The inclusion of these dynamic elements was informed by feedback gathered during the co-design session (Section 3.2.2), where participants emphasised the importance of avoiding overly static visual content, as it might induce drowsiness during short relaxation breaks. Minimal yet meaningful motion and subtle interactivity were therefore recommended to sustain engagement without increasing cognitive load.

The visual breathing guide acted as an external cue to support slow, diaphragmatic breathing without conscious effort, a widely used strategy in mindfulness-based relaxation applications [13, 48, 49]. It consisted of a semi-transparent sphere that expanded and contracted at a rhythm of six breaths per minute (5 s inhale, 5 s exhale), corresponding to the resonance frequency associated with calm, paced respiration [50].

The sphere was coloured blue to reflect its established association with calmness and relaxation [51]. The breathing sequence was integrated mid-way through the experience, providing a sustained yet non-intrusive period of paced breathing.

```
1 void Update() {
2     float cycle = Mathf.Sin(Time.time * Mathf.PI / 5f); // 10 s cycle
3     float size = Mathf.Lerp(minSize, maxSize, (cycle + 1f)/2f);
4     transform.localScale = Vector3.one * size;
5 }
```

Listing 3.1: Breathing guide scaling logic (excerpt).

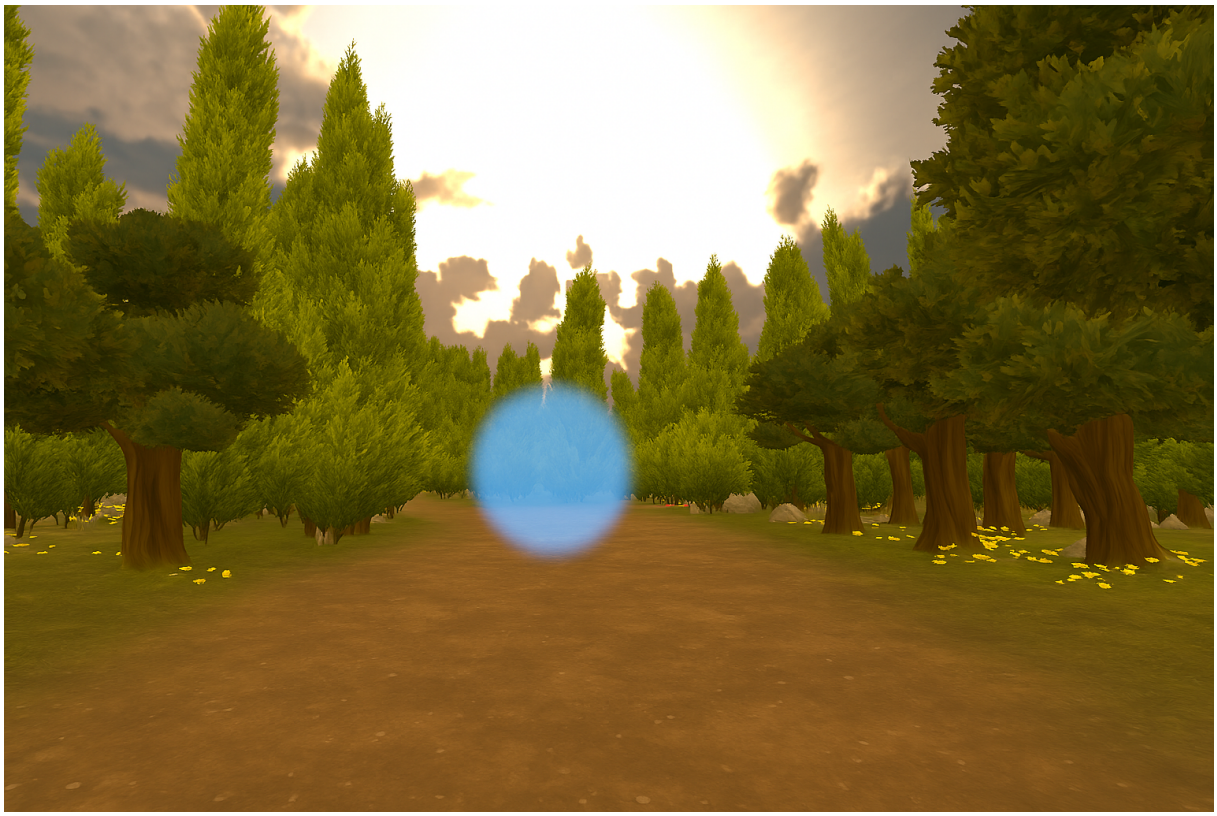


Figure 3.5: Visual breathing guide used as a paced-breathing cue.

The butterfly's motion was implemented through a sinusoidal oscillation on both horizontal and vertical axes, combined with directional interpolation between two anchor points. This created a dynamic yet subtle pattern of flight, intended as a visual focus element requiring no user input [52]. The implementation details are available in Appendix F.

Camera Navigation

Camera navigation followed the same *Catmull–Rom* spline used for the terrain path, producing smooth curvature and a continuous tangential direction between control points. Each camera position $p(t)$ along the spline is computed from four consecutive control points (P_0, P_1, P_2, P_3) as:

$$p(t) = \tfrac{1}{2}\Big[(2P_1) + (-P_0 + P_2)t + (2P_0 - 5P_1 + 4P_2 - P_3)t^2 + (-P_0 + 3P_1 - 3P_2 + P_3)t^3\Big], \tag{3.1}$$

where $t \in [0, 1]$ denotes the local interpolation parameter between P_1 and P_2 [53].

To maintain comfort and presence, the camera advanced at a calm walking pace (approximately 1.0–1.3 m/s), consistent with reported human walking speeds for comfortable ambulation [54]. The effective camera velocity v was defined as the ratio between the total spline length L and the intended walking duration T_{eff}, excluding planned stops:

$$v = \frac{L}{T_{\text{eff}}}. \tag{3.2}$$

This simplified formulation prioritises perceptual consistency and user comfort over biomechanical realism, following recommendations for pre-scripted camera motion in virtual environments [55, 56]. Directional orientation was derived from the spline tangent at each sampled point, ensuring smooth heading updates and stable visual focus.

```
float pathPos = distanceTravelled / totalPathLength;
Vector3 p = GetPointOnSpline(pathPos);
Vector3 t = GetTangentOnSpline(pathPos); // forward direction
walker.position = p;
walker.rotation = Quaternion.LookRotation(
    new Vector3(t.x, 0f, t.z).normalized, Vector3.up);
```

Listing 3.2: Camera path update (excerpt).

Audio and Narration

Ambient audio recreated a forest atmosphere by blending water flow, birdsong, and soft wind to enhance immersion. A calm Portuguese voice, generated through the *Narakeet* text-to-speech platform, delivered brief mindfulness prompts inspired by mindfulness-based stress reduction principles. The narration maintained a soft, low-pitched tone, as slower and warmer voices are associated with relaxation and emotional comfort [57]. Background sounds from open-licence libraries ensured non-commercial research compliance. Combining verbal guidance with natural soundscapes has been shown to enhance presence and physiological relaxation [58, 59].

Performance and Optimisation

Given the limited hardware capacity of the *Meta Quest 2*, the virtual environment was optimised for visual efficiency rather than graphical complexity. Heavy elements such as 3D grass and highly detailed objects were replaced with lighter textures, and material and terrain detail were iteratively adjusted to maintain stable frame rates. These measures balanced visual realism with technical constraints, ensuring a comfortable and immersive experience.

Summary of design components and supporting literature

Element	Implementation	Scientific Basis
Vegetation	Two species, randomised scale and colour	Kaplan (1989) Joye (2011) Hedblom et al. (2019)
Water and sound	Reflective river with 3D ambient audio	Ulrich (1984) Annerstedt et al. (2013)
Lighting	Warm diffuse tones, late-afternoon palette	Higuera-Trujillo and Llinares (2021)
Breathing helper	Blue sphere, 6 bpm cycle	Chittaro and Sioni (2014) Pizzoli et al. (2021) Seabrook et al. (2024)
Butterfly animation	Sinusoidal flight between anchors	Hedblom et al. (2019)
Camera navigation	*Catmull–Rom* interpolation	Catmull and Rom (1974)
Narration and soundscape	Calm voice, mindfulness cues	Browning et al. (2020) Litleskare and Calogiuri (2023)

Table 3.3: Design decisions and supporting literature.

3.2.4 Pilot Prototype Test

To validate the preliminary design decisions and identify areas for refinement, a short pilot test was conducted with five medical students. The goal of this phase was to gather qualitative feedback on the visual, auditory, and interactive aspects of the virtual meditation environment, focusing on perceived realism, comfort, and emotional impact.

Each participant experienced an early version of the virtual forest scene, developed prior to the final implementation described in Section 3.2.3, using the *Meta Quest 2* headset in a quiet room under controlled conditions. After completing the session, the participants responded to a brief set of open-ended questions (see Appendix C) to acquire spontaneous impressions about the overall atmosphere, visual composition, and sense of relaxation. The responses were analysed using the same thematic analysis approach adopted in previous qualitative phases.

Overall, the environment was described as calming and immersive, with the combination of natural sounds and gentle motion contributing to a realistic sense of presence. However, participants highlighted specific visual aspects that could be improved to enhance comfort and coherence. In particular, the use of two distinct tree species resulted in a strong colour contrast between them, while the first appeared natural, the second displayed tones that were excessively bright and visually distracting.

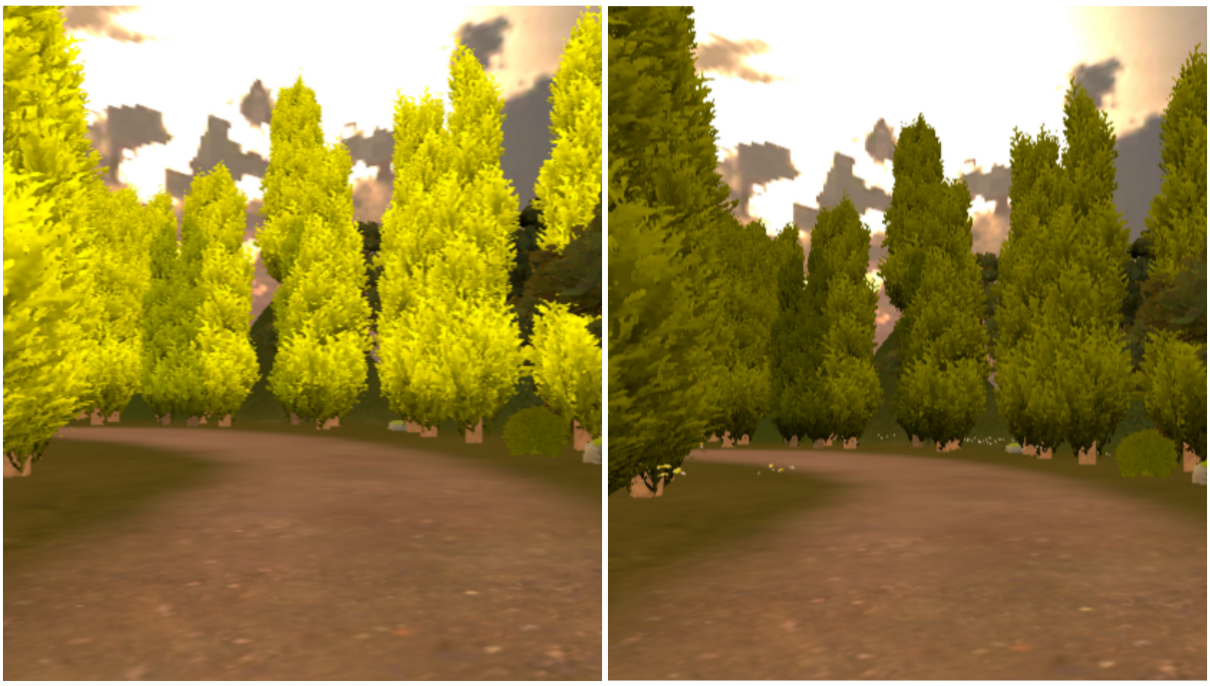


Figure 3.6: Comparison of tree colour correction before and after the pilot feedback.

Several participants recommended adding small, natural details, such as flowers, stones, and branches, to make the forest appear more vibrant and lifelike. This feedback highlighted the importance of subtle environmental features in conveying a realistic sense of place. Accordingly, these elements were introduced in later development stages, enriching the visual composition and contributing to a stronger perception of immersion and natural coherence.



Figure 3.7: Before and after of the addition of forest detail elements during environment refinement stage.

Regarding the visual breathing guide, participants generally recognised it as helpful for pacing respiration and supporting a calm, steady rhythm throughout the experience. They described the visual expansion and contraction of the sphere as an intuitive reference that encouraged slower breathing without requiring conscious control. However, some participants mentioned that the audio narration could provide more consistent guidance during this phase, rather than being limited to the beginning of the exercise. This feedback led to the inclusion of short verbal prompts throughout the breathing sequence to help maintain attention and breathing rhythm.

Participants also noted that the end of the forest path appeared visually abrupt, as the terrain seemed to stop suddenly without a natural continuation or closure. Although no specific alternatives were proposed, this observation informed later adjustments to the spatial layout, including the addition of a small field of flowers to create a smoother and more visually pleasant ending to the scene.

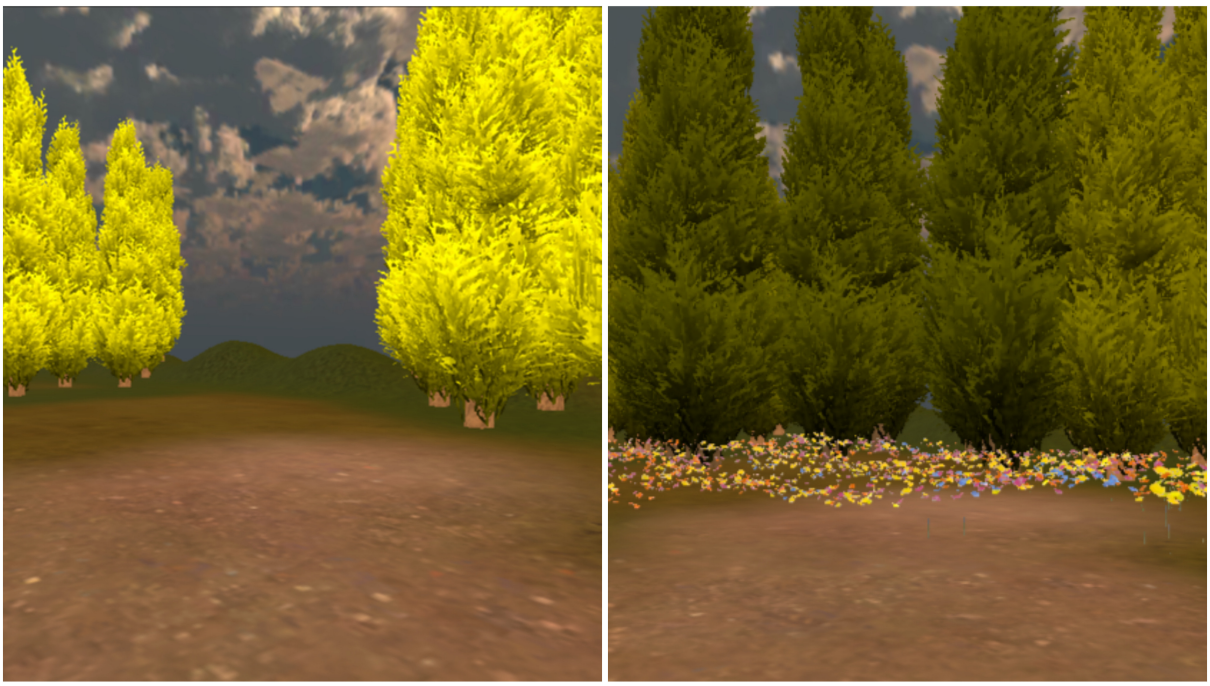


Figure 3.8: Comparison of the forest path termination before and after refinement.

The feedback collected during this pilot phase provided essential input for the next iteration of the design process.

3.3 Prototype Evaluation

The evaluation phase aimed to determine whether a brief virtual reality mindfulness session could reduce immediate stress and to assess participants' perceptions of presence, mindfulness quality, and usability. A *pre–post* experimental design was adopted to measure short-term variations in stress levels within the same participants. This approach is commonly applied in mindfulness and stress-reduction research to measure short-term, state-based changes that occur immediately after brief interventions, rather than long-term behavioural outcomes. Previous studies involving short relaxation sessions and VR-based mindfulness experiences have shown that pre–post assessments are particularly sensitive to detecting immediate variations in perceived stress, arousal, and emotional recovery following a single exposure [13, 39, 60].

Thirteen participants took part in the study, including medical and dental students and one nursing student. All were over 18 years old, and participated voluntarily under informed consent (Appendix D). Exclusion criteria comprised epilepsy or photosensitive seizures, severe neurological disorders, uncorrected visual or vestibular impairments, significant hearing loss, or marked sensitivity to motion sickness. These criteria were defined to ensure participant safety and to prevent physiological or perceptual dis-

comfort that could bias stress and presence measurements. Such exclusions are standard in immersive VR experiments to minimise the risk of simulator sickness and to maintain comparable sensory and attentional responses across participants. [55, 56]

Each participant completed a short demographic questionnaire and two baseline instruments before the VR session: the *Short Stress State Questionnaire (SSSQ)* and the *Determinants of Meditation Practice Inventory–Revised (DMPI-R)*. They then experienced the meditation session using the *Meta Quest 2* headset in a quiet, well-lit room. Immediately after the session, the same stress questionnaire (SSSQ) was reapplied together with the *Practice Quality – Meditation Questionnaire (PQ-M)*, the *Igroup Presence Questionnaire (IPQ)*, the *System Usability Scale (SUS)*, and six open-ended questions on relaxation, realism, and comfort. All validated Portuguese versions available were used, and when not available, the original English instruments were applied to ensure conceptual equivalence. All questionnaires are available in Appendix D

3.3.1 Determinants of Meditating Practice Inventory–Revised (DMPI-R)

Predispositions and barriers to meditation were assessed before the session using the Portuguese version of the *Determinants of Meditating Practice Inventory–Revised* (DMPI-R). The version applied was provided directly by the author of the Portuguese adaptation, ensuring linguistic and conceptual equivalence. The instrument includes 12 statements rated on a five-point Likert scale (1 = “strongly disagree”, 5 = “strongly agree”), covering two dimensions: *Perceived Barriers* and *Perceived Discomfort*. Higher values reflect greater perceived difficulty or resistance towards mindfulness practice [61].

3.3.2 Short Stress State Questionnaire (SSSQ)

The *Short Stress State Questionnaire* (SSSQ) was applied both before and after the VR session to quantify short-term variations in stress and engagement. It consists of 24 items divided into three subscales, *Distress*, *Worry*, and *Engagement*, each measured on a five-point Likert scale (1 = “not at all”, 5 = “extremely”). Subscale scores were calculated as the mean of their corresponding items. Higher scores in *Distress* and *Worry* indicate greater stress, whereas higher *Engagement* scores reflect higher focus and task involvement rather than stress. The validated English version was used, which is specifically designed to detect stress changes in short experimental exposures [60, 62].

3.3.3 Practice Quality–Mindfulness Questionnaire (PQ–M)

After the VR session, participants completed the *Practice Quality–Mindfulness Questionnaire* (PQ-M). For each statement, they indicated the approximate percentage of session time (0–100%) during which their experience corresponded to the process described.

The PQ–M was originally developed as a seven-item instrument to assess the quality of mindfulness practice. However, item 4 of the original scale was excluded in later validations due to weak and cross-factor loadings, which reduced the internal consistency of the two-factor structure (*Attention* and *Receptivity*). Subsequent analyses confirmed that the six-item version demonstrates improved factorial stability and reliability across languages and small-sample contexts, and is thus recommended for brief intervention studies [63–66].

In the present study, the six retained items were organised into two conceptual families: *approach/acceptance* processes *avoidance/effort-to-change*

Scores were expressed as the percentage of time (0–100%) that each process was experienced. To obtain a mindfulness-consistent overall index, the three *avoidance/effort-to-change* items were reverse-coded as $100 -$ value and averaged with the three *approach/acceptance* items. Higher scores indicate that target mindfulness processes were present for a greater proportion of the session.

3.3.4 Igroup Presence Questionnaire (IPQ)

The *Igroup Presence Questionnaire* (IPQ) was used to assess participants' subjective sense of presence in the virtual environment. The instrument comprises 14 items organised into three subscales, *Spatial Presence* (5 items), *Involvement* (4 items), and *Experienced Realism* (3 items), plus one general item. Responses were given on a seven-point scale ranging from 3 ("completely disagree / not at all") to +3 ("completely agree / extremely"). Following the official manual, four items (SP2, SP3, INV1, INV3) were reverse-coded prior to scoring. The duplicated realism prompt (REAL3) was excluded, following the official IPQ manual to avoid redundancy between items REAL2 and REAL3. Several validation studies have similarly applied the 13-item version, confirming that the three-factor structure (*Spatial Presence*, *Involvement*, *Experienced Realism*) and overall reliability remain unaffected by this omission. This reduced version has been reported to maintain internal consistency comparable to the original full scale and is widely accepted in experimental VR research [67–70]. Each subscale score was obtained by averaging its respective items, with higher values reflecting stronger perceived presence and realism.

3.3.5 System Usability Scale (SUS)

The *System Usability Scale* (SUS) was used after the session to evaluate usability of the VR system. The original English version was applied, consisting of ten statements rated on a five-point Likert scale (1 = "strongly disagree", 5 = "strongly agree"). Scores were calculated according to the algorithm: for odd-numbered items, one point was subtracted from the response value, and for even-numbered items, the response value was subtracted from five. The adjusted values were summed and multiplied by 2.5, producing a usability index ranging from 0 to 100. Higher scores indicate better perceived usability.

Interpretation of SUS scores was guided by established usability benchmarks that associate numerical ranges with qualitative descriptors of user experience. This framework enables the translation of raw usability scores into intuitive categories that reflect how users generally perceive a system's ease of use. In this interpretation, scores below 50 are classified as "Poor", values between 50 and 68 correspond to "OK", scores between 68 and 80 indicate "Good", and values above 80 reflect "Excellent" usability. This graded approach supports consistent benchmarking of subjective usability across diverse application domains and study designs [71–73].

3.3.6 Quantitative analysis

Statistical analyses were conducted to assess pre–post differences in stress levels and to provide descriptive summaries of the additional questionnaire measures. For the SSSQ, individual difference scores were computed (*post–pre*), and their distribution was tested for normality using the Shapiro–Wilk test, which is suitable for small samples and sensitive to deviations from normality [74]. Depending on the outcome, either a paired t-test (for normally distributed data) or a non-parametric Wilcoxon signed-rank test (for non-normal data) was applied. This analytical approach is commonly adopted in studies assessing immediate effects of brief mindfulness or stress-reduction interventions, where repeated measures are obtained from the same participants [13, 39].

All other questionnaires administered once, the DMPI–R (pre-session) and the PQ–M, IPQ, and SUS (post-session), were analysed descriptively. For each, mean (M), standard deviation (SD), and 95% confidence intervals (95% CI) were computed to characterise central tendency and variability in participants' responses.

For the statistical tests performed on the SSSQ, differences were examined in both directions using two-tailed tests, since no specific direction of change was assumed. A significance level of $p < .05$ was adopted, which is a standard criterion in behavioural and medical research [75]. Effect sizes (Cohen's d) for paired samples were calculated as the mean difference divided by the standard deviation of the individual difference scores, providing an estimate of the magnitude of observed changes [75]. Confidence intervals (95%) for means and mean differences were calculated using the standard error of the mean under normal approximation. Because the study was exploratory and involved a small sample, no correction for multiple comparisons was applied. The results were interpreted as preliminary indications of potential effects to be verified in future research.

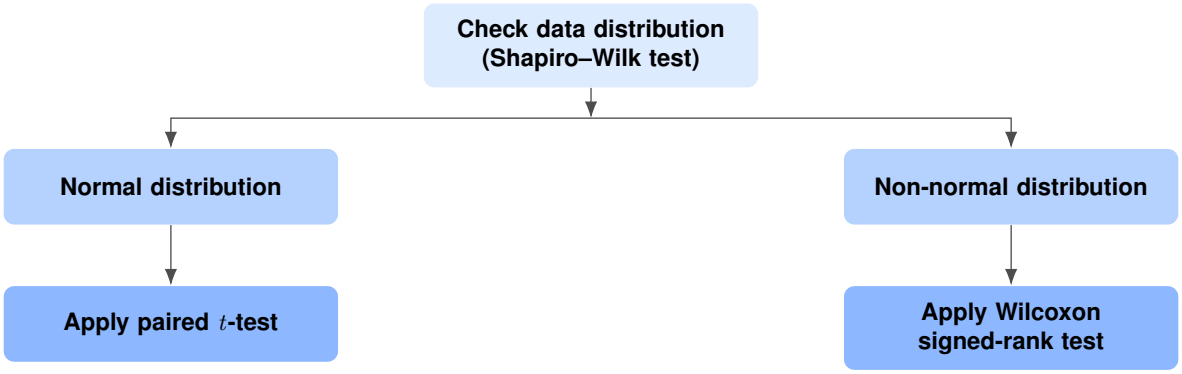


Figure 3.9: Decision process for test selection in paired *pre–post* comparisons, adapted from Saalfeld et al. [2]

3.3.7 Qualitative analysis

Open-ended answers on relaxation, realism, comfort, and suggestions were analysed via thematic analysis using the same six-phase procedure described previously, to complement quantitative results with experiential insights. [1]

4

Results

Contents

4.1 Participant Characterisation

4.2 Prior Experience and Contextual Factors

4.3 Quantitative Results

4.4 Qualitative Results

This chapter presents the results of the study, organised into four main sections: (1) participant characterisation, (2) prior experience and contextual factors, (3) quantitative outcomes from the administered instruments, and (4) qualitative findings derived from open-ended responses and thematic analysis. All analyses were conducted in *R* (version 4.3.0) [76]. Descriptive statistics are reported as means (M), standard deviations (SD), and 95 % confidence intervals (CI). Qualitative results are summarised into thematic categories to complement the quantitative outcomes and provide a deeper understanding of participants' subjective experiences.

4.1 Participant Characterisation

A total of 13 participants completed both pre- and post-session questionnaires. The sample comprised healthcare students from different study areas and academic stages. Demographic information is summarised in Table 4.1.

Table 4.1: Participant demographics ($n = 13$).

Variable	Category	n (%)
Gender	Female	10 (76.9%)
	Male	3 (23.1%)
Field of study	Medicine	9 (69.2%)
	Dental Medicine	3 (23.1%)
	Nursing	1 (7.7%)

The mean age of participants was 23.15 years ($SD = 1.4$, range 20–25). They reported an average of 4.69 years of study completed ($SD = 1.02$), corresponding to students in the later stages of their academic programmes.

4.2 Prior Experience and Contextual Factors

Before the VR session, participants reported limited prior exposure to immersive technologies. As shown in Table 4.2, most had either never used VR or had tried it only once.

Table 4.2: Self-reported prior experience with VR ($n = 13$).

Experience level	n (%)
Never used	7 (53.8%)
Tried once	6 (46.2%)
Occasional use	0 (0.0%)
Regular use	0 (0.0%)

4.3 Quantitative Results

This section presents the quantitative analyses of the psychological and usability measures collected during the study. Pre- and post-session data were matched chronologically to ensure correct pairing. Normality of difference scores (post–pre) was verified with the *Shapiro–Wilk test* and confirmed visually through Q–Q plots (Appendix D). All variables met the assumption of normality ($p > .05$); therefore, paired t-tests were used for inferential comparisons.

4.3.1 Determinants of Meditating Practice Inventory – Revised (DMPI–R)

The DMPI–R was administered *pre*-session to assess participants' baseline perceived difficulties with meditation practice. Higher scores indicate greater perceived barriers to engaging in meditation [61]. As shown in Table 4.3, participants reported a mean score below the scale midpoint, suggesting a generally positive attitude towards meditation and relatively low perceived difficulty.

Table 4.3: Descriptive statistics for the *Determinants of Meditating Practice Inventory–Revised* (DMPI–R) total score at pre-session ($n = 13$). Values represent mean (M), standard deviation (SD), and 95 % confidence interval (CI).

Measure	M	SD	95 % CI [Low; High]
DMPI–R	2.74	0.52	[2.46; 3.02]

4.3.2 Short Stress State Questionnaire (SSSQ)

The *Short Stress State Questionnaire* (SSSQ) was administered before and after the VR session to assess short-term variations in stress and engagement. As shown in Figure 4.1, post-session scores were lower for *Distress* and *Worry*, and higher for *Engagement* compared to pre-session values.

Paired-sample t-tests were conducted to examine pre–post differences in each subscale. The test determines whether participants' average scores changed significantly from before to after the VR

session. Results revealed a significant reduction in *Distress*, $t(12) = -5.46$, $p < .001$, and *Worry*, $t(12) = -4.76$, $p < .001$, alongside a significant increase in *Engagement*, $t(12) = 5.13$, $p < .001$. All effects remained robust despite the small sample size, supporting the reliability of the observed short-term stress changes.

Effect sizes were calculated as Cohen's d for paired samples, using the standard deviation of the difference scores. The effects were large for all subscales: *Distress* ($d = 1.51$), *Worry* ($d = 1.32$), and *Engagement* ($d = 1.42$), indicating strong within-subject changes in short-term stress and engagement levels.

Descriptive data are shown in Table 4.4.

Table 4.4: Descriptive statistics and paired comparisons for *Stress State Questionnaire* (SSSQ) subscales ($n = 13$). Values represent mean (M), standard deviation (SD), 95 % confidence interval (CI), t statistic, p-value, and effect size (Cohen's d).

Subscale	**Moment**	M	SD	95% CI [Low; High]	t**(12)**	p	**Cohen's** d
Distress	Pre	2.27	0.71	[1.84; 2.70]	-5.46	$< .001$	1.51
	Post	1.38	0.47	[1.09; 1.66]			
Worry	Pre	2.55	0.88	[2.02; 3.08]	-4.76	$< .001$	1.32
	Post	1.50	0.42	[1.25; 1.75]			
Engagement	Pre	2.95	0.45	[2.68; 3.23]	5.13	$< .001$	1.42
	Post	3.88	0.46	[3.60; 4.15]			

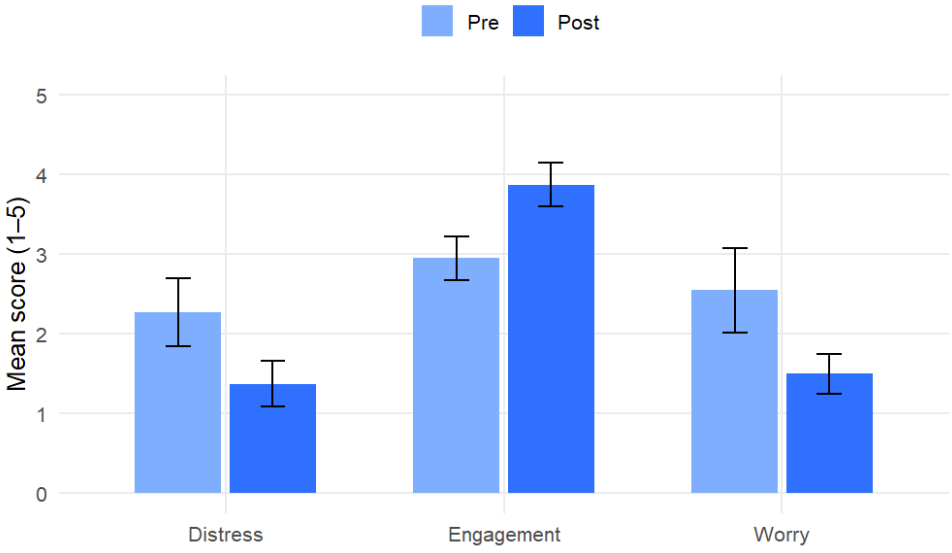


Figure 4.1: Mean ($\pm$95% CI) scores for SSSQ subscales before and after the VR session ($n = 13$). Lower bars indicate reduced stress levels, while higher values reflect greater engagement.

Results indicated a decrease in distress and worry, and an increase in engagement after the VR session. Large effect sizes were observed for these changes, indicating substantial short-term differences between pre- and post-measures.

4.3.3 Practice Quality Meditation (PQM)

The Practice Quality Meditation (PQM) questionnaire was administered post-session to assess the proportion of time participants engaged in mindfulness-consistent processes during the VR experience. As the PQM captures distinct mental processes rather than a single construct, descriptive statistics were computed for each item and summarised in an overall mindfulness-aligned index obtained by reverse-coding avoidance-related items. Results are presented in Tables 4.5 and 4.6.

Table 4.5: *Practice Quality Meditation* (PQM) items at post-session ($n = 13$). Short labels are used for readability; full item wordings are provided in Appendix D.

PQM item (short label)	M	SD	95% CI [Low; High]
Return to present-moment	52.3	34.9	[31.2; 73.4]
"It's OK to experience this"	75.4	24.7	[60.5; 90.3]
Bare bodily sensations	55.4	29.9	[37.3; 73.4]
Struggling against experiences	17.7	21.7	[4.6; 30.8]
Avoiding / "pushing away"	17.7	31.1	[0.0; 36.5]
Trying to fix/change to a "better place"	93.1	10.3	[86.8; 99.3]

Table 4.6: Overall *Practice Quality Meditation* (PQM) index at post-session ($n = 13$). Higher scores indicate a greater proportion of session time spent in mindfulness-consistent processes.

Measure	M	SD	95% CI [Low; High]
PQM	59.1	12.8	[51.4; 66.8]

The results show a clear distinction between the two process families. *Approach/acceptance* items presented moderate to high mean values, while *avoidance/effort-to-change* items obtained substantially lower percentages, indicating that these processes were reported for a smaller proportion of session time. However, the item *"Trying to fix or change experiences to reach a better place"* displayed a markedly higher mean value (93.1 %) than the other avoidance items. After reverse-coding the three avoidance items, the overall PQM index was 59.1 % (SD = 12.8; 95 % CI [51.4; 66.8]), indicating that mindfulness-consistent processes were present for more than half of the session time.

4.3.4 Igroup Presence Questionnaire (IPQ)

The IPQ was administered post-session to evaluate the sense of presence experienced within the virtual environment. Mean values across all subscales indicated a generally strong sense of immersion. *Spatial Presence* reached the highest mean score, reflecting participants' clear perception of being situated within the virtual space, while *Involvement* showed similarly elevated values, suggesting sustained attention and engagement during the experience. *Experienced Realism* presented slightly lower but still positive scores, indicating that the virtual setting was perceived as believable and coherent. Overall, these results demonstrate that the environment effectively supported the psychological state of "being there", a key aspect of immersive virtual reality experiences. Descriptive results are summarised in Table 4.7 and illustrated in Figure 4.2.

Table 4.7: Descriptive statistics for (IPQ) subscales at post-session ($n = 13$). Higher scores reflect stronger perceived presence.

Subscale	M	SD	95 % CI [Low; High]
Spatial Presence	1.77	0.73	[1.33; 2.21]
Involvement	1.58	1.03	[0.95; 2.20]
Experienced Realism	0.95	0.61	[0.58; 1.32]

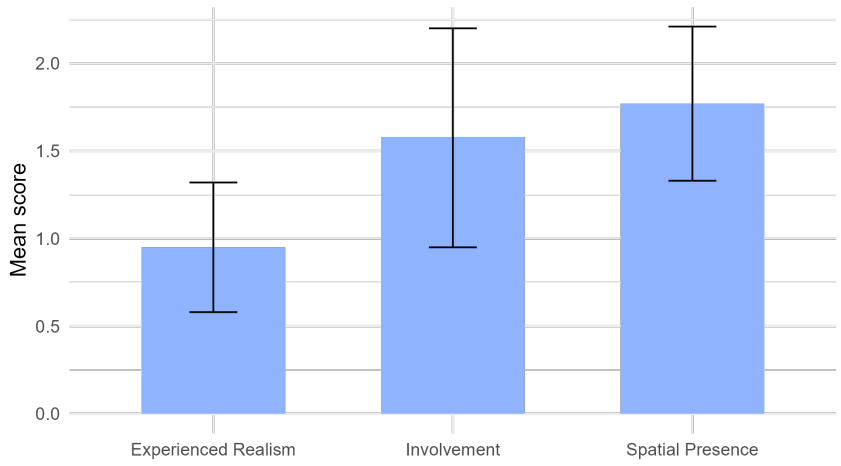


Figure 4.2: Mean ($\pm$95 % CI) scores for the IPQ subscales at post-session ($n = 13$). Higher values indicate stronger perceived spatial presence, involvement, and realism.

4.3.5 System Usability Scale (SUS)

The SUS was administered after the session to evaluate perceived usability of the VR system. The mean SUS score was 86.7 ($SD = 10.2$, 95% CI [80.6; 92.9]). According to established interpretive

ranges, scores below 50 are classified as “Poor”, values between 50 and 68 as “OK”, between 68 and 80 as “Good”, and above 80 as “Excellent” usability [72, 73]. All individual scores in this sample were above the “Good” threshold, with the group mean falling within the “Excellent” range.

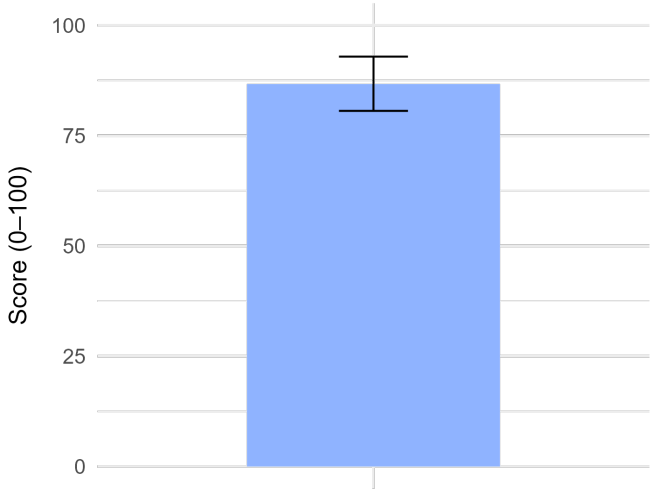


Figure 4.3: Mean ($\pm$95% CI) System Usability Scale (SUS) score at post-session ($n = 13$).

4.4 Qualitative Results

Open-ended responses collected after the VR session were analysed to complement the quantitative findings and capture participants’ subjective impressions of the experience. Six questions invited participants to describe their perceptions of the virtual meditation, its perceived effects on stress or mood, elements they enjoyed most, possible improvements, perceived usefulness in their professional context, and any discomfort experienced. Five main themes emerged: *Relaxation and Emotional Relief*, *Immersion and Presence*, *Comfort and Usability*, *Perceived Usefulness in the Workplace*, and *Suggestions for Improvement*.

4.4.1 Relaxation and Emotional Relief

Most participants reported feeling calmer, more relaxed, or mentally refreshed after the VR session. Several noted a noticeable decrease in tension or anxiety levels: *“I felt much more relaxed and less preoccupied after the session”* (Participant 03); *“It helped me disconnect and clear my mind”* (Participant 09); *“I was surprised by how peaceful I felt at the end”* (Participant 12). These accounts align with the quantitative reduction in stress indicators observed in the SSSQ results.

4.4.2 Immersion and Presence

Participants frequently emphasised the sense of "being there" in the virtual environment. The combination of natural scenery and guided narration was described and engaging: *"I really felt like I was inside the forest"* (Participant 05); *"The visuals and voice made it easy to focus and stay in the moment"* (Participant 10). This sense of immersion was identified as an important contributor to the meditative effect and overall engagement during the experience.

4.4.3 Comfort and Usability

Most participants reported no significant physical discomfort and described the system as intuitive and easy to use: *"It was simple and comfortable to use"* (Participant 02); *"I didn't feel dizzy or nauseous"* (Participant 08). A few participants mentioned minor issues, such as headset adjustment or initial unfamiliarity with VR equipment, but these did not substantially interfere with the session.

4.4.4 Perceived Usefulness in the Workplace

Several participants believed that similar VR sessions could be valuable as short breaks or stress-management tools within their professional context: *"I think this could really help to relax during a stressful shift"* (Participant 04); *"It would be great to have something like this in hospitals"* (Participant 11). These comments suggest a general openness to the idea of implementing VR-based relaxation interventions in healthcare settings.

4.4.5 Suggestions for Improvement

Although overall feedback was positive, participants provided several constructive remarks to improve visual quality, comfort, and engagement. Some noted that the graphics appeared slightly pixelated or less defined when viewed closely: *"The image could be a bit sharper"* (Participant 01). Others commented on specific environmental elements, such as the butterfly, which evoked mixed reactions: *"I liked the idea of the butterfly, but as someone who fears insects, it might be distracting"* (Participant 07). A few participants suggested introducing more variety, such as longer sessions, additional nature scenes, or background sound options: *"Different scenes could make it even more engaging"* (Participant 13). These observations suggest that, while the prototype was generally well received, participants identified opportunities for visual refinement and more customisable relaxation options to further enhance comfort and immersion.

5

Discussion

Contents

5.1 Stress Reduction Effects

5.2 Mindfulness, Presence, and Usability

5.3 Limitations

The results provide converging evidence that the immersive VR meditation reduced short-term stress and was perceived as relaxing, usable, and engaging. This section discusses how these findings align with previous research on VR-based mindfulness and stress reduction, explores possible explanations for the observed effects, and highlights practical implications and limitations.

5.1 Stress Reduction Effects

The results demonstrated a clear and consistent reduction in momentary stress following the VR meditation. Quantitatively, both *Distress* and *Worry* subscales of the SSSQ decreased significantly, while *Engagement* increased. Mean *Distress* scores dropped from 2.27 to 1.38 and *Worry* from 2.55 to 1.50, both with large effect sizes, indicating robust psychophysiological relaxation within five and a half minutes of exposure. This pattern mirrors prior findings showing that short immersive mindfulness sessions can rapidly lower stress indicators and promote attentional recovery [13, 39, 60].

Qualitative responses support these quantitative outcomes. Participants often described feelings of calmness, relaxation, and mental clarity after the session, frequently contrasting their post-session state with pre-session tension or fatigue. Several noted a sense of detachment from external stressors and an increased ability to focus, aligning with the rise in *Engagement* observed in the SSSQ. Together, these findings highlight the capacity of VR-based mindfulness to create a temporary but meaningful psychological reset, allowing short-term relief from cognitive load and emotional strain.

5.2 Mindfulness, Presence, and Usability

The PQM results indicate that participants were able to maintain mindfulness-related attitudes for a substantial proportion of the session. The mean mindfulness-consistent index reached 59%, suggesting that participants spent more than half the time in states characterised by awareness, acceptance, and non-judgmental observation. Acceptance-oriented items scored higher than avoidance or effort-to-change items, showing that the environment effectively supported open and receptive attention.

A single item (“Trying to fix or change experiences to reach a better place”) yielded higher values than the other avoidance items. This result can be interpreted in several complementary ways. One possibility is that participants perceived “reaching a better place” as a positive and natural outcome of relaxation rather than as an indicator of effort or resistance. This interpretation is consistent with the significant post-session increase in *Engagement* (SSSQ) and the high *Presence* scores (IPQ), suggesting that participants remained attentive and emotionally involved rather than cognitively struggling.

At the same time, the phrasing of this item may have conflicted with the implicit goal structure of the VR experience itself. The guided narration encouraged users to “find calm” and “reach a peaceful state”,

which, although effective for relaxation, can promote a goal-directed mindset somewhat at odds with the principle of mindfulness acceptance. In this sense, the elevated score may reflect a design-related influence rather than a lack of receptivity among participants. Nonetheless, this outcome highlights an important insight for future iterations: to strengthen mindfulness consistency, the experience could include more neutral guidance cues that emphasise observation rather than progress toward a particular state.

Regarding the IPQ, participants reported high *Spatial Presence* and *Involvement*, confirming that the environment successfully captured attention and facilitated absorption. *Experienced Realism* values were comparatively lower, which is consistent with the technical constraints of the project. To maintain stable performance on the *Meta Quest 2*, high-density textures and dynamic lighting had to be avoided, which likely influenced perceived realism. Qualitative reports indicated that participants focused more on the atmosphere and emotional tone of the scene—described as pleasant and soothing—than on visual realism. This observation aligns with prior research suggesting that emotional coherence and perceptual harmony may support relaxation independently of high graphical fidelity [68, 77].

Usability results further support this conclusion. The SUS score of 86.7 (SD = 10.2) places the experience well within the “Excellent” category [73], confirming that the system was intuitive and easy to use, even for users unfamiliar with VR. No major discomfort or motion sickness was reported, and participants consistently emphasised comfort and simplicity.

5.3 Limitations

Despite these promising findings, several limitations must be acknowledged. The sample was small ($n = 13$) and composed primarily of medical students, limiting the generalisability of the results to broader healthcare populations. Physiological data were not collected, preventing a direct comparison between subjective and biological indicators of stress reduction. Moreover, the absence of a control condition means that some of the observed improvements may stem from general relaxation or expectancy effects rather than the specific impact of the VR intervention.

Technical factors also imposed restrictions: the need for stable frame rates on standalone hardware constrained the use of dynamic lighting and detailed vegetation, which likely contributed to the lower realism ratings. However, the consistent positive evaluations of usability and relaxation suggest that these trade-offs did not undermine the effectiveness of the intervention.

Overall, while these constraints limit external validity, they do not detract from the internal consistency of the results. The convergence of quantitative and qualitative evidence supports the feasibility and short-term efficacy of brief immersive meditation sessions as a potential resource for stress management in healthcare contexts.

6

Conclusions

Contents

6.1 Future directions

6.2 Conclusion

6.1 Future directions

Future studies should include a more diverse sample of participants, particularly practising healthcare professionals, and investigate the long-term effects of repeated VR meditation sessions. Combining self-reported measures with physiological data (e.g., heart rate and breathing rate) and behavioural observations would strengthen the evidence for stress reduction and provide a more comprehensive understanding of user responses. In addition to expanding the sample size, future research could explore cross-group analyses, for example, examining potential differences across gender, age, professional role, or previous meditation experience, to identify subgroups that benefit most from VR-based interventions. From a design perspective, future iterations could refine visual and auditory elements to enhance immersion while ensuring comfort and accessibility. It would also be valuable to personalise aspects of the experience, such as session length, background ambience, or breathing guidance, according to individual preferences and emotional states. Ultimately, these developments could inform the implementation of structured VR meditation programmes within healthcare institutions to support stress prevention and mental well-being among professionals.

6.2 Conclusion

In conclusion, this work developed and evaluated a first prototype of an immersive virtual reality meditation experience designed to support stress reduction and burnout prevention in healthcare contexts. Although the study was conducted with medical students, the results indicate that even a brief, five and a half minute session can generate measurable decreases in acute stress and foster mindfulness-related states. The prototype, adapted to the needs and feedback of healthcare professionals gathered during earlier stages of design, achieved high usability and strong engagement, suggesting its potential scalability to clinical environments. Rather than aiming for photorealism, the focus on coherence, comfort, and guided relaxation proved effective in promoting positive emotional responses. Overall, the findings demonstrate the feasibility of using short, immersive VR meditation sessions as a low-intensity stress management tool in healthcare contexts, laying the groundwork for future large-scale trials integrating physiological monitoring and personalised adaptive content.

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A

Materials from the Preliminary Study at Santa Maria Hospital

This section is written in Portuguese since it was the language spoken by all the participants.

Informed Consent Form

Consentimento Informado

Este questionário é do âmbito de uma dissertação de Mestrado em Engenharia Biomédica no Instituto Superior Técnico. O estudo tem como objetivo avaliar se uma breve sessão de realidade virtual poderá contribuir para a redução do stress e do burnout entre profissionais de saúde.

Participação no Estudo: Requere-se que:

1. Preencha um breve questionário inicial sobre stress e percurso profissional;
2. Participe numa sessão de relaxamento em realidade virtual com duração de aproximadamente 10 minutos, utilizando um dispositivo de VR;
3. Responda a uma breve entrevista após a sessão.

Riscos e Benefícios: Não existem riscos conhecidos associados à participação neste estudo. As informações recolhidas poderão contribuir para o desenvolvimento de estratégias não invasivas de promoção do bem-estar dos profissionais de saúde.

Confidencialidade: Toda a informação recolhida será mantida anónima e confidencial. Apenas a estudante responsável terá acesso direto aos dados.

Direitos do Participante: A participação é totalmente voluntária, podendo o participante desistir a qualquer momento, sem qualquer penalização.

Declaração de Consentimento:

> Li e compreendi o objetivo e os procedimentos deste estudo. Concordo voluntariamente em participar e compreendo que posso desistir a qualquer momento. Autorizo a recolha e o tratamento dos meus dados para fins de investigação académica.

Nome: _____ **Assinatura:** _____

Data: _____

Demographic Questions

1. Idade
2. Género
3. Profissão e especialidade
4. Experiência prévia com realidade virtual (Nunca / Uma vez / Ocasionalmente / Regularmente)

Interview Guide

Nine open-ended prompts used during semi-structured interviews:

1. Como descreveria a experiência de usar os óculos de realidade virtual?
2. Sentiu-se imerso(a) no ambiente? O que facilitou ou dificultou essa sensação?
3. Sentiu-se mais relaxado(a) após a experiência?
4. Alguma parte do conteúdo causou desconforto (visual, auditivo ou físico)?
5. Que aspetos da experiência VR gostaria de melhorar?
6. Acha que este tipo de intervenção poderia ser útil no seu ambiente de trabalho?
7. Em que contextos considera mais apropriado usar VR para gestão de stress?
8. Que barreiras ou limitações identifica para implementar esta tecnologia?
9. Gostaria de voltar a utilizar esta ferramenta no futuro?

B

Co-Design Session Materials

This section's materials are written in Portuguese since it was the language spoken by all participants of the session

User Personas

Persona 1 – Dr. Vasco Silva, 35 anos, Médico Interno

- **Objetivo principal:** gerir ansiedade e fadiga em turnos longos.
- **Necessidades:** sessões rápidas, ambiente silencioso, instruções claras.
- **Frustração:** falta de tempo e de locais tranquilos no hospital.
- **Citação representativa:** "Só cinco minutos de pausa já me ajudavam a respirar outra vez."

Persona 2 – Dra. Marta Pires, 29 anos, Enfermeira de Bloco

- **Objetivo principal:** relaxar entre cirurgias e reduzir tensão muscular.
- **Necessidades:** conteúdo visualmente suave, sem insetos, com voz feminina calma.
- **Frustração:** desconforto físico ao usar óculos pesados durante muito tempo.
- **Citação representativa:** "Quando a música começou senti-me finalmente desligar."

Empathy Map

Based on the insights from the exploratory interviews, an empathy map was created to synthesise the emotional, cognitive, and behavioural dimensions of healthcare professionals' experiences with stress and relaxation practices. A healthcare professional is someone constantly exposed to high demands and emotional strain, often lacking time or space to recover between shifts. The map captures how such a professional *thinks*, *feels*, *sees*, *hears*, and *acts* in daily life.

- **Pensa:** "Tenho de estar sempre alerta, mesmo durante pequenas pausas."
- **Sente:** Pressão constante, fadiga mental e culpa quando tira tempo para descansar.
- **Vê:** O hospital sobrelotados e colegas igualmente exaustos.
- **Ouve:** Sons contínuos de máquinas, chamadas de pacientes e discussões de equipa.
- **Faz:** Tenta relaxar brevemente entre turnos, muitas vezes a mexer no telemóvel ou a tomar café.

This visual mapping helped identify design opportunities for a VR experience that provides a sense of mental detachment, calm, and brief restorative focus.

”How Might We” Questions

Following the empathy mapping, the team reformulated observed challenges into opportunity statements using the “How Might We” framework. These questions guided the creative phase of ideation during the co-design session:

- Como poderemos ajudar os profissionais de saúde a desligar mentalmente durante pequenas pausas?
- Como poderemos tornar a experiência eficaz mesmo com tempo limitado disponível?
- Como poderemos tornar a meditação em VR apelativa para quem nunca meditou antes?
- Como poderemos adaptar o conteúdo a profissionais com diferentes níveis de familiaridade com a VR?
- Como poderemos conceber ambientes virtuais que promovam uma imersão rápida e uma sensação de conforto?

C

Pilot Session Open-Ended Questions

This section's materials are written in Portuguese since it was the language spoken by all participants of the session

Qualitative Feedback on the Pilot Prototype

1. Como se sentiu durante a experiência virtual?
2. Que aspetos do ambiente considerou mais relaxantes ou envolventes?
3. Houve algum elemento que tenha achado desconfortável ou distrativo?
4. Quão realista ou imersivo lhe pareceu o cenário?
5. A respiração guiada ajudou-a/o a concentrar-se ou a relaxar?
6. Que sugestões faria para melhorar a experiência global?

Low-Fidelity Conceptual Sketch

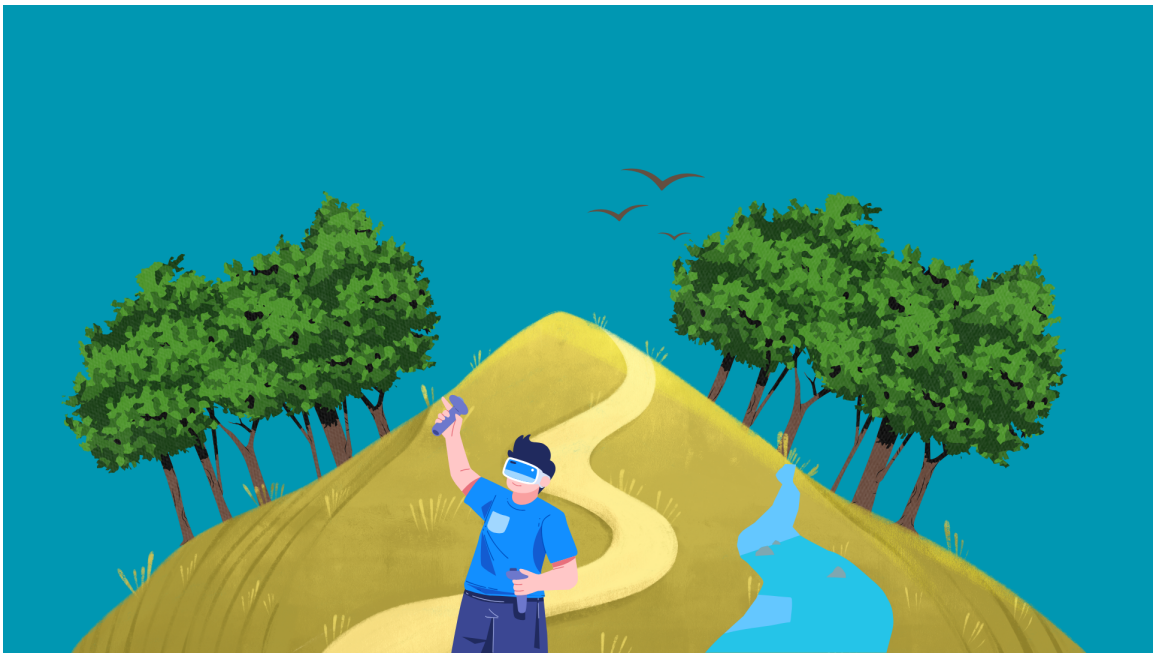


Figure C.1: Low-fidelity conceptual sketch illustrating the envisioned VR mindfulness experience, based on the outcomes of the co-design session.

D

VR Meditation Experience Evaluation Materials

Informed Consent

This material is written in Portuguese since it was the language spoken by all participants of the session

Título da Dissertação: Virtual Reality Meditation for Stress Reduction and Burnout Prevention in Healthcare Professionals.

Aluna responsável: Carolina Ruas da Silva, Mestrado em Engenharia Biomédica, Instituto Superior Técnico (IST-ULisboa).

Orientadores: Prof. Daniel Simões Lopes (IST-ULisboa) e Dra. Alexandra (Hospital de Santa Maria).

Objetivo: O estudo tem como objetivo avaliar o potencial da meditação imersiva em realidade virtual (VR) na redução do stress e na promoção do bem-estar entre profissionais de saúde.

Procedimentos:

- Preencher um questionário inicial e demográfico online;
- Participar numa sessão de relaxamento em VR com duração aproximada de 5 minutos, em posição sentada;
- Preencher um questionário final sobre relaxamento, imersão e usabilidade.

Riscos: Poderá ocorrer uma ligeira tontura ou fadiga visual. Os participantes podem interromper a sessão a qualquer momento.

Critérios de exclusão: Pessoas com epilepsia, perturbações neurológicas graves, problemas vestibulares ou sensibilidade a enjoo de movimento não devem participar.

Confidencialidade: Todos os dados serão anonimizados e armazenados em segurança pela aluna responsável, sendo utilizados exclusivamente para fins científicos.

Contacto: `carolina.ruas.silva@tecnico.ulisboa.pt`

Declaração de Consentimento:

Declaro que li e compreendi a informação acima e concordo livremente em participar neste estudo.

Data: _____ **Assinatura:** _____

Demographic Questions

These items were included in the LimeSurvey pre-VR questionnaire (Portuguese wording preserved):

1. **Idade** (resposta numérica livre)
2. **Género** (opções)
    - Feminino
    - Masculino
3. **Ocupação/Profissão** (resposta aberta)
4. **Especialidade/Área principal de trabalho** (resposta aberta)
5. **Anos de experiência profissional** (resposta numérica livre)
6. **Experiência prévia com realidade virtual** (opções)
    - Nunca utilizei
    - Já experimentei uma vez
    - Utilizo ocasionalmente
    - Utilizo regularmente
7. **Experiência prévia com prática de meditação/relaxamento** (opções)
    - Nunca pratiquei
    - Experimentei poucas vezes
    - Pratico ocasionalmente
    - Pratico regularmente
8. **Frequência de utilização de técnicas de gestão de stress** (ex.: mindfulness, ioga, exercícios de respiração, exercício físico) (opções)
    - Nunca
    - Raramente
    - Às vezes
    - Frequentemente
    - Sempre

Short Stress State Questionnaire (SSSQ)

24 itens, escala 1–5 (1 = Not at all, 5 = Extremely). **Subscales:**

- *Distress* – Agitated, Angry, Anxious, Distressed, Frustrated, Irritable, Nervous, Unhappy
- *Worry* – Apprehensive, Doubtful, Insecure, Pessimistic, Preoccupied, Tense, Uncertain, Worried
- *Engagement* – Alert, Concentrated, Energetic, Interested, Involved, Motivated, Quick-witted, Self-confident

Determinants of Meditating Practice Inventory – Revised (DMPI-R, PT)

Avalia barreiras percebidas e desconforto ao meditar (1 = Discordo totalmente, 5 = Concordo totalmente).

Perceived Barriers

1. É difícil para mim encontrar tempo para meditar.
2. Tenho dificuldade em manter a motivação para meditar.
3. Fico facilmente distraído/a durante a meditação.
4. Tenho dificuldade em compreender o propósito da meditação.
5. Sinto que não obtenho resultados imediatos.

Perceived Discomfort

6. Fico fisicamente desconfortável durante a meditação.
7. Sinto emoções desagradáveis enquanto medito.
8. Fico ansioso/a quando tento concentrar-me na respiração.
9. Fico frustrado/a quando a minha mente divaga.
10. Tenho receio de perder o controlo durante a meditação.

Practice Quality – Mindfulness Questionnaire (PQM)

With respect to today's session, please indicate the approximate percentage of time that you experinced the statement bellow.

1. During the practice, I tried to return to my present-moment experience, whether it was pleasant, unpleasant or neutral.
2. During the practice, I tried to accept each experience, no matter how unpleasent, with a sense that "it is OK to experience this."
3. During the practice, I attempted to feel each experience as bare sensations in the body (tension in throat, movement in belly, etc.).
4. During the practice, I was struggling against having certain experiences (eg., unpleasant thoughts, emotions or bodily sensations). *
5. During the practice, I was actively avoiding or "pushing away" certain experiences. *
6. During the practice, I actively tried to fix or change certain experiences to get to a "better place." *

** Items 4–6 are reverse-scored in the calculation of the global index.*

Igroup Presence Questionnaire (IPQ)

14 items (–3 = strongly disagree . . . +3 = strongly agree)

Items:

G1 In the virtual environment I had a sense of "being there."

SP1 Somehow I felt that the virtual environment surrounded me.

SP2 I felt like I was just perceiving pictures. *

SP3 I did not feel present in the virtual environment. *

SP4 I had a sense of acting within the virtual environment, rather than operating something from outside.

SP5 I felt present in the virtual environment.

INV1 How aware were you of the real world surrounding you while inside the virtual environment (e.g., sounds, room temperature, other people, etc.)? *

INV2 I was not aware of my real environment.

INV3 I still paid attention to the real environment. *

INV4 I was completely captivated by the virtual environment.

REAL1 How real did the virtual environment seem to you?

REAL2 How much did your experience in the virtual environment seem consistent with your real-world experience?

REAL3 How real did the virtual environment seem to you?

REAL4 The virtual environment seemed more realistic than the real world.

(*) Reverse-scored items. REAL3 was duplicated in the original version and omitted in data analysis for consistency.

Subscales:

- **Spatial Presence:** G1, SP1–SP5
- **Involvement:** INV1–INV4
- **Experienced Realism:** REAL1–REAL4

System Usability Scale (SUS)

10 items (1 = Strongly disagree, 5 = Strongly agree)

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex. *
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system. *
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system. *
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use. *
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system. *

(*) Reverse-scored items. Total score × 2.5 → 0–100.

Post-Session Open-Ended Questions

This section is written in Portuguese since it was the language spoken by all participants of the session

1. Em que medida sentiu relaxamento ao longo da experiência?
2. Quais os elementos que mais contribuíram para a sensação de imersão e presença?
3. Sentiu algum desconforto (físico, auditivo ou visual) durante a sessão?
4. Que aspetos de usabilidade considera que poderiam ser melhorados?
5. Em que contextos do seu trabalho acredita que esta experiência seria mais útil?
6. Tem outras sugestões de melhoria (conteúdo, áudio, ambiente visual, duração)?

Normality assessment for SSSQ subscales

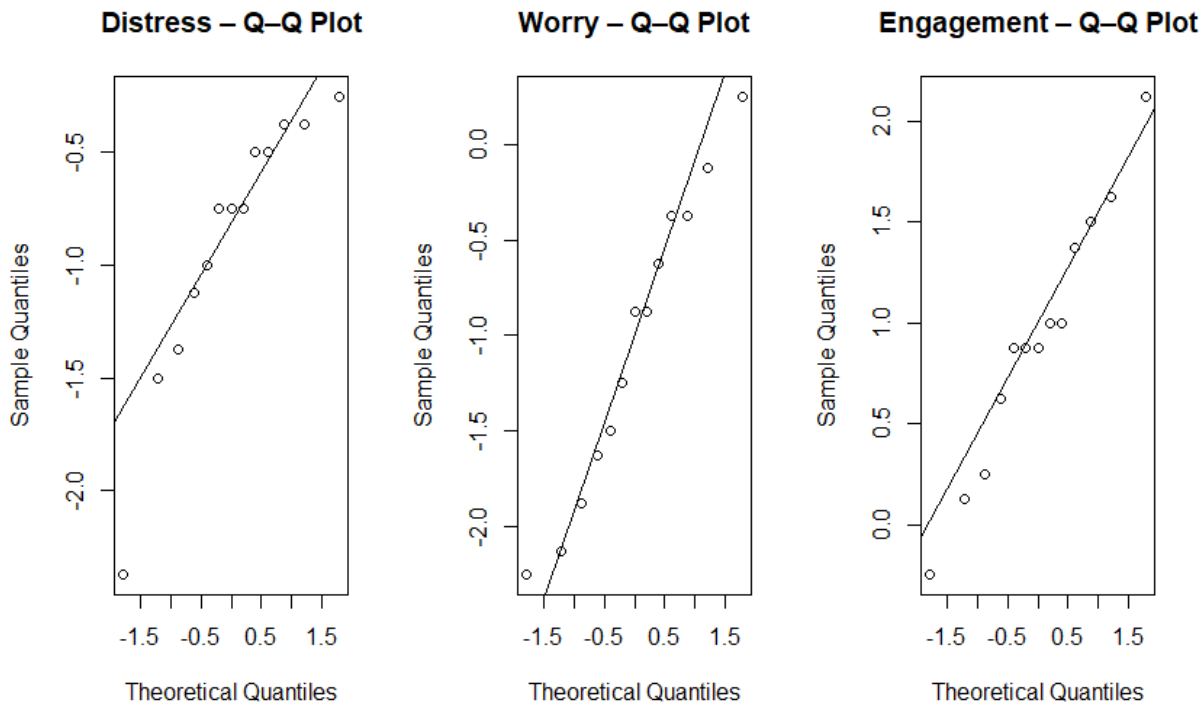


Figure D.1: Q–Q plots for SSSQ pre–post differences.

The following figure presents the Q–Q plots of the pre–post difference scores for the SSSQ subscales. These plots were used to visually inspect the normality assumption underlying the paired statistical tests reported in Section 4.3.2.

E

Analytical Workflow (R)

Main Steps

1. Import pre- and post-session data (`read_csv`).
2. Compute subscale scores (`rowMeans`).
3. Calculate difference scores (`post { pre`).
4. Test for normality (Shapiro–Wilk). If $p>.05 \rightarrow$ paired t-test; otherwise, Wilcoxon signed-rank test.
5. Compute **Cohen's** d_z:
$$d_z = \frac{\bar{X}_{post-pre}}{s_{diff}}$$
6. Compute means, standard deviations, and 95% confidence intervals.

Code Excerpt

```
desc_tbl <- function(x){
  x <- na.omit(as.numeric(x))
  n <- length(x); M <- mean(x); SD <- sd(x)
  se <- SD / sqrt(n); tcrit <- qt(0.975, df = n-1)
  tibble(M = M, SD = SD, CI_low = M - tcrit*se, CI_high = M + tcrit*se)
}

dz <- function(pre, post){
  d <- post - pre
  mean(d, na.rm=TRUE) / sd(d, na.rm=TRUE)
}

# Example for one subscale
shapiro.test(post - pre)
t.test(post, pre, paired=TRUE, alternative="two.sided")
dz(pre, post)
```

PQM Overall Calculation

```
# Reverse items 4{6 and compute overall index
pqm_rev <- pqm
```

```
pqm_rev[, c(4,5,6)] <- 100 - pqm_rev[, c(4,5,6)]
pqm_overall <- rowMeans(pqm_rev, na.rm=TRUE)
```

F

Unity Implementation (C# Excerpts)

Breathing Helper – Scaling Logic

```
void Update(){
  float cycle = Mathf.Sin(Time.time * Mathf.PI / 5f); // 10 s cycle ( 6 bpm)
  float scale = Mathf.Lerp(minScale, maxScale, (cycle + 1f)/2f);
  transform.localScale = Vector3.one * scale;
}
```

Butterfly Movement – Randomized Flight Path

```
void Update(){
  Vector3 offset = new Vector3(
      Mathf.PerlinNoise(Time.time, 0f) - 0.5f,
      Mathf.PerlinNoise(0f, Time.time) - 0.5f,
      Mathf.PerlinNoise(Time.time * 0.3f, Time.time * 0.7f) - 0.5f
  );
  transform.position = startPos + offset * amplitude;
}
```

ExperienceDirector – Timed Sequence Controller

```
IEnumerator RunExperience(){
  yield return new WaitForSeconds(2f); // fade in
  audioGuide.Play("intro");
  yield return new WaitForSeconds(330f); // session duration
  audioGuide.Play("closing");
  fadeOutCanvas.SetActive(true);
}
```

Note. Scripts simplified for clarity.