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Forest Bathing in Virtual Reality as a Mechanism to Reduce Burnout in Urban Professionals

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Abstract

Due to fast-paced lifestyles and the limited access for urban professionals to restorative natural environments make them exposed to a higher level of stress and burnout. This project proposes a Virtual Reality Forest Bathing application that combines immersive natural environments with real-time physiological biofeedback in order to promote relaxation and reduce stress indicators. The system integrates 3D scenarios, spatial audio and sensors such as HRV and EDA, and it's evaluated in a study with adults exposed to urban stress, comparing the different digital relaxation conditions and measuring subjective and physiological variables before and after exposure. Therefore, the project aims to contribute to new approaches for promoting well-being in urban contexts, as well as to the design of personalized VR experiences based on biofeedback.

Keywords: Virtual reality, VR, Forest bathing, nature, biophilic, greenery, natural environment, Stress, anxiety, burnout, relaxation, Biofeedback, HRV, heart rate variability, EDA, electrodermal.

Resumo

Devido ao aumento de stress e de *burnout* entre profissionais urbanos, o projeto centra-se no estudo deste fenómeno ligado a ritmos de vida acelerados e a um contacto limitado com ambientes naturais com potencial restaurador. Neste enquadramento, procura-se compreender de que modo as experiências de natureza em Realidade Virtual funcionam como uma alternativa acessível para apoiar a recuperação do stress e *burnout* em situações onde o acesso a espaços verdes se encontra condicionado.

O objetivo central reside no desenvolvimento e na avaliação de uma aplicação de *Forest Bathing* em Realidade Virtual, construída a partir de ambientes naturais tridimensionais com elevada fidelidade visual e com áudio espacial. A aplicação encontra-se integrada com sensores fisiológicos destinados ao registo da frequência cardíaca, da variabilidade da frequência cardíaca, com particular atenção a VFC e RMSSD, bem como da atividade eletrodérmica. Inclui-se uma condição experimental com *biofeedback* em tempo real, na qual parâmetros ambientais como luz, som ou movimento são ajustados em função dos biossinais do participante, assim como uma condição equivalente sem *biofeedback*. Estas condições são comparadas com uma condição digital de controlo, como relaxamento guiado com olhos fechados ou exposição a paisagens sonoras.

O estudo adota um desenho experimental intra-sujeitos com adultos expostos a stress urbano em estado de *burnout*. São avaliados, antes e após cada condição, onde indicadores subjetivos, incluindo ansiedade de estado, stress percebido, humor e perceção de *restorativeness*, e indicadores fisiológicos, como a frequência cardíaca, VFC ou RMSSD e, de forma exploratória, atividade eletrodérmica. As diferenças entre condições são analisadas através de ANOVAs de medidas repetidas, bem como através de correlações entre alterações subjetivas e fisiológicas. Para este propósito, a análise comparativa assume um papel central.

Com este projeto, espera-se contribuir com evidência empírica sobre a eficácia de experiências de natureza em Realidade Virtual, com e sem *biofeedback*, na recuperação aguda do stress. Ao mesmo tempo, pretende-se formular recomendações de design para intervenções de bem-estar digital personalizadas, aplicáveis a contextos de trabalho e de saúde ocupacional.

Palavras-chave: Realidade virtual, VR, banho de floresta, natureza, biofílico, vegetação, ambiente natural, stress, ansiedade, *burnout*, relaxamento, *biofeedback*, VFC, variabilidade da frequência cardíaca, EDA, atividade eletrodérmica.

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Acronyms e Symbols

Acronym List

VR	Virtual Reality
HR	Heart Rate
HRV	Heart Rate Variability
EDA	Electrodermal Activity
RMSSD	Root Mean Square of Successive Differences
STAI-S	State subscale of the State–Trait Anxiety Inventory
PRS	Perceived Restorativeness Scale
WBS	Work Breakdown Structure
GDPR	General Data Protection Regulation
PASAT	Paced Auditory Serial Addition Test
MAST	Maastricht Acute Stress Test
ANOVA	Analysis of Variance
ART	Attention Restoration Theory
SRT	Stress Recovery Theory
NRS	Numeric Rating Scale

1 Introduction

1.1 Framework and motivation

Recent work on restorative environments suggests that exposure to natural scenes is associated with reductions in subjective stress indicators, negative emotions and blood pressure, both in physical settings and in virtual environments. When using natural scenes in virtual reality, studies indicate that these scenarios produce a relevant stress-reduction effect in groups of knowledge workers exposed to high pressure, reinforcing frameworks such as Attention Restoration Theory (ART) and Stress Recovery Theory (SRT) when applied to digital contexts. At the same time, research on virtual nature and virtual forests suggests that specific environmental design features, such as including biomass density and visual fidelity, influence the perceived restoration and the psychological benefits obtained (Ding and Chen, 2022; Masters *et al.*, 2022).

Within this combined ART/SRT framework, burnout and chronic fatigue among urban professionals emerge as particularly relevant problems in contexts of high cognitive and emotional demand, where regular contact with restorative natural environments is limited. Findings suggest that VR natural scenes reduce subjective stress and that virtual restorative interventions may be especially useful for groups exposed to prolonged pressure, such as knowledge workers(Ding and Chen, 2022). This project takes these findings as a starting point to examine whether a Forest Bathing experience in virtual reality can function as a complementary mechanism for the prevention and recovery of stress related to burnout in adults exposed to urban stress.

The present project proposes the development of a virtual reality application that simulates forest bathing environments through high-fidelity three-dimensional natural scenes with spatial audio, designed in accordance with principles from restorative environment research. Building on recent work that combines virtual reality with physiological sensing, the system integrates biosignals such as heart rate variability (HRV) and electrodermal activity (EDA) to monitor stress responses and to explore biofeedback-based environmental adaptation. The effectiveness of this intervention is examined in adults exposed to urban stress through comparison of a Forest Bathing virtual reality experience with and without biofeedback against alternative digital relaxation conditions, by using subjective measures of mood and perceived restorativeness alongside physiological indicators of stress (Ding and Chen, 2022; Nasri, 2025)

In many urban environments, workers face persistent psychological demands alongside limited opportunities for direct contact with restorative natural settings. As a way to reproduce natural scenes in controlled indoor contexts, virtual reality has been explored, offering stress-reduction benefits without requiring physical access to forests or other green spaces, particularly for knowledge workers under sustained pressure. Despite this evidence, there is still a lack of accessible, immersive and personalized technological solutions that can replicate the restorative benefits of nature in everyday work routines, especially for professionals experiencing burnout and chronic fatigue who have limited time, energy or logistical means to visit natural settings regularly (Ding and Chen, 2022).

These challenges motivate the exploration of virtual reality nature-based interventions designed for indoor use and integration into everyday routines (Ding and Chen, 2022; Nasri, 2025). By combining evidence on restorative virtual environments with recent advances in physiological sensing and biofeedback, this project seeks to examine whether an adaptive Forest Bathing VR experience can function as a practical and scalable support tool for stress and burnout prevention.

1.2 Problem, stakeholders and impacts

The problem addressed in this project extends beyond temporary stress responses, since sustained exposure to high job demands in knowledge-intensive occupations is associated with increased risk of stress-related adverse health outcomes and with a growing need for effective, preventive interventions. In this context, organizations and healthcare providers face the challenge of implementing approaches that integrate into the daily routines and enable earlier stress regulation, rather than relying primarily on reactive interventions after symptoms have progressed and functional impairment is already present (Ding and Chen, 2022).

This project was developed in collaboration with the research unit GILT: Games, Interaction and Learning Technologies, created in 2005 and hosted at the School of Engineering of the Polytechnic Institute of Porto, ISEP (*Gilt – Games Interaction and Learning Technologies*, no date). This collaboration places the work within an institutional research context focused on the analysis, design, and the development of scientific and technical knowledge in learning technologies, assistive technologies, serious games, interaction technologies and health technologies.

GILT’s mission is oriented toward anticipating the future of educational technologies and promoting excellence in research, development as well as innovation across areas such as learning technologies, assistive technologies, serious games, interaction technologies and health technologies where digital solutions are explored to enhance learning, inclusion and well-being.

Within this framework, the present work aligns with the health technologies and interaction strands of GILT by contributing to the development and evaluation of virtual reality experiences oriented towards stress and burnout reduction in urban professionals, reinforcing the connection between interactive technologies, health and applied research.

Having this problem in mind, the primary stakeholders in this project include adult urban workers and university students experiencing everyday stress, who constitute the main beneficiaries of the intervention, and healthcare professionals involved in the delivery and monitoring of relaxation or stress management protocols. Additional stakeholders may include employers seeking to support well-being and productivity, technology developers responsible for the design and maintenance of virtual reality and physiological sensing components, and the academic teams that are tasked with evaluating the effectiveness and ethical compliance of the proposed solution.

If effective strategies are not implemented, individuals exposed to sustained urban stress are likely to continue relying on ad hoc or non-evidence-based coping practices, which do not support a long-term recovery. At the same time, the use of virtual reality and physiological sensing in stress-related contexts introduces ethical considerations that will be addressed in accordance with institutional guidelines, GDPR and professional codes of ethics in computing, as detailed in Chapter 3.

1.3 Research Questions, Hypotheses and Objectives

For this project two main research questions are established:

> RQ1: To what extent does a nature-based Forest Bathing virtual reality intervention lead to short-term reductions in subjective and physiological indicators of stress among adults exposed to urban stress, when compared with alternative digital relaxation conditions.
>
> RQ2: How does the integration of real-time physiological biofeedback affect stress-related outcomes during the Forest Bathing virtual reality intervention.

In order to answer the proposed research question, the study aims to test the following hypotheses:

> H1: A Forest Bathing intervention in virtual reality, with or without biofeedback, produces a greater short-term reduction in subjective indicators of stress, measured by STAI-S and by ratings of perceived stress, as well as physiological indicators of stress, including HR and HRV, when compared against alternative digital relaxation conditions, in line with the studies that show stress-recovery benefits of immersive virtual nature and biophilic VR environments (Ding and Chen, 2022; Masters *et al.*, 2022; Xiaoxue and Huang, 2024).

H2: The Forest Bathing condition in VR with real-time physiological biofeedback leads to greater improvements in the subjective and physiological indicators of stress when compared against the same experience without biofeedback, supporting the idea that combining nature in VR with biofeedback can intensify the relaxation effects (Zhang *et al.*, 2023; Nasri, 2025).

H3: The reductions in subjective stress and state anxiety are positively associated with higher HRV, indexed by RMSSD, across the experimental conditions, in a manner consistent with findings that connect the increase of parasympathetic activity to the perception of recovery in biophilic studies and VR-based stress-reduction studies (Masters *et al.*, 2022; Xiaoxue and Huang, 2024).

Having these research questions and the hypotheses, the general objective of this project is to design, develop and experimentally evaluate a Forest Bathing virtual reality application, with and without physiological biofeedback, as a mechanism to reduce stress and burnout in adults exposed to urban stressors.

To address this general objective, the following specific objectives are defined:

O1: Design and implement a Forest Bathing virtual reality application with high-fidelity natural environments and spatial audio, suitable for use by adults exposed to urban stress.

O2: Integrate real-time physiological sensing, such as heart rate variability and electrodermal activity, into the virtual reality system to monitor stress responses and support biofeedback-based environmental adaptation.

O3: Experimentally evaluate the short-term effects of the Forest Bathing in virtual reality interventions on subjective mood and perceived restorativeness, using validated questionnaires, in comparison with alternative digital relaxation conditions.

O4: Assess changes in physiological indicators of stress before and after exposure to the different conditions and examine whether the integration of biofeedback provides additional benefits.

1.4 Structure of the document

The document follows an organization based on five main chapters, an organization structured and repeated, an organization deliberate. Chapter 1 establishes the context and the motivation of the project, presents the problem, identifies the stakeholders and the expected impacts and defines the research questions, the hypotheses and the objectives.

Chapter 2 reviews the state of the art related to nature exposure and biophilia, virtual nature and forest bathing, biophilic and urban environments and biofeedback with physiological adaptation in virtual reality. The chapter ends with the identification of the research gap.

Chapter 3 details the project methodology, including the study design, the intervention conditions, and the outcome measures, as well as the project development plan, the work breakdown structure, the Gantt chart, risk management procedures and ethical considerations.

Chapter 4 reports the implementation of the virtual reality Forest Bathing application and presents the results of the experimental study.

Chapter 5 discusses the findings, addresses the limitations, reflects on future work and presents the main conclusions of the dissertation.

2 State of the Art

This chapter synthesises the literature relevant to work-related stress and burnout, restorative effects of nature exposure and the use of virtual reality and biofeedback to support short-term recovery.

2.1 Literature Revision Methodology

The state-of-the-art review followed a systematic mapping approach structured using a PICOCS framework, with focus on adults exposed to urban or work-related stress, virtual or biophilic nature interventions, and short-term psychological or physiological stress outcomes. The literature search was conducted between 2025-10 and 2025-12 in the ACM Digital Library and PubMed, targeting peer-reviewed publications published between 2014 and 2025. Search strings combined terms including virtual nature, forest bathing, biophilic design, virtual reality stress reduction, and biofeedback. After duplicate removal and title and abstract screening of 217 records, 24 primary studies were selected based on predefined inclusion and exclusion criteria addressing population characteristics, intervention type, outcome measures, and study design. A detailed description of the systematic mapping protocol and extraction results is provided in Appendix A (PREPD: Systematic Mapping Review).

2.2 Burnout

Within the scope defined, burnout emerges as the central outcome and motivation for preventive and recovery-oriented interventions in working adults exposed to sustained pressure. Burnout is commonly defined as a work-related psychological syndrome arising from chronic and unsuccessfully managed job stress and is characterized by prolonged exhaustion, increased mental distance or cynicism toward one's work and reduced professional efficacy (Maslach, Schaufeli and Leiter, 2001).

In knowledge-intensive and urban work contexts, burnout has been consistently associated with sustained high job demands, limited opportunities for recovery, and a perceived lack of control. These conditions contribute to impaired psychological well-being, reduced work performance, and an increased risk of health-related problems (Maslach, Schaufeli and Leiter, 2001).

2.3 Nature, Biophilia and Restorativeness Theories

Recent studies suggest that exposure to natural environments, either real or simulated, activates stress recovery mechanisms through the parasympathetic nervous system by lowering the HR and EDA and raising the HRV promoting recovery symptoms and a reduction in the negative state (Yin *et al.*, 2019; Xiaoxue and Huang, 2024). The Biophilia Theory (Kellert and Wilson, 1993; Wilson, 2010), the Stress Recovery Theory (Ulrich, 1983) and the Attention Restoration Theory (Kaplan and Kaplan, 1989) provide the basis for the most part of the current research and have been well-verified not only in physical context as well as VR (Masters *et al.*, 2022).

2.4 Virtual Nature and Forest Bathing

A natural environment in VR can induce psychological and physiological benefits partially compared to a real natural environment. Although, the results are modest in relation to the physiological aspect (Masters *et al.*, 2022; Nicoly *et al.*, 2024)

The main components to a better efficiency include higher levels of visual fidelity, natural sounds and realistic movement of nature elements such as water or trees (Masters *et al.*, 2022; Nicoly *et al.*, 2024).

Studies like Masters et al. (2022) suggest that forest environments with a lot of biomass (vegetation) are preferred and have a tendency to have a higher effect on recovery, even though the difference against other natural environments are not always statistically significative, suggesting the importance of investigating the ideal composition of a nature environment in VR (Masters *et al.*, 2022; Nicoly *et al.*, 2024).

When talking about comparisons against other digital stimuli, research shows that controlled experiments, including methodologies like observation of abstract art or eyes closed, can be outperformed by virtual environments of nature. If realistic movement is added to the environment, it also raises the feeling of immersion, satisfaction and restorativeness in comparison against static environments and 2D images (Masters *et al.*, 2022; Nicoly *et al.*, 2024)

2.5 Biophilic and Urban Environments

Studies examining biophilic and nature-related interventions in office-like or urban settings further indicate that the integration of natural elements, including simulated or virtual representations, is associated with reduced stress responses and, in some cases, improvements in aspects of cognitive performance relevant to work. Reported effects vary according to the specific biophilic features implemented and the tasks or demands involved. At the same time, research on nature exposure and neighborhood environments suggests individual differences in sensitivity to environmental influences, implying that restorative benefits from virtual nature experiences may not be uniform across users (Hackman *et al.*, 2019; Yin *et al.*, 2019; Eisen, Bratman and Olvera-Alvarez, 2024).

2.6 Biofeedback and Physiological Adaptation in VR

Recent research also integrates biofeedback through physiological sensors (e.g. EDA, HR) to change the environment in real-time allowing a dynamic customization and reinforcing the relaxation benefits (Zhang *et al.*, 2023).

Studies show that the user's awareness and expectation regarding the environment regulation through the biofeedback can amplify the stress reduction effect. This suggests that research on agency mechanisms as well as informative feedback and emotional engagement can be valuable (Sehrt *et al.*, 2024).

Complementary research on virtual reality–based stress reduction incorporating physiological sensing shows that combining immersive environments with biofeedback, such as respiratory or electrodermal activity feedback, supports stronger relaxation effects and more responsive adaptation to users' internal states. Conceptual frameworks for physiological adaptation in virtual reality emphasise the use of real-time biosignals to guide environmental modulation, providing a rationale for exploring heart rate variability–driven adaptations within virtual forest bathing experiences (Zhang *et al.*, 2023; Sehrt *et al.*, 2024; Nasri, 2025).

2.7 Research Gap

Despite these advances, there is a lack of long-duration studies with diversified samples (age, gender, background). There is also a need for research that combines multifactorial evaluation (subjective, physiological, attentional performance) alongside comparisons against alternative digital methodology. Not all studies use robust physiological metrics or active controls (e.g. art, silence).

The field evolves in the sense of creating nature-inspired VR experiences that are more and more immersive, realistic and customizable, showing growing proof that its efficiency in reducing stress in urban contexts with limited access to nature. The integration with biofeedback represents the next frontier in personalization, but there is still a need for rigorous experimental validation to optimize design, effectiveness and practical impact (Ding and Chen, 2022).

Prior research on virtual nature and forest bathing indicates that immersive natural scenes presented in virtual reality support short-term stress reduction and recovery in knowledge workers and other adults exposed to sustained pressure (Ding and Chen, 2022; Masters *et al.*, 2022; Xiaoxue and Huang, 2024). Design characteristics such as biomass density, level of immersion, and audio-visual coherence influence perceived restoration and affective outcomes. These findings provide support for the use of high-fidelity virtual forest environments with controlled visual complexity and spatial audio as the basis for brief restorative sessions targeting urban professionals (Ding and Chen, 2022; Masters *et al.*, 2022).

These gaps motivate the present study, which examines a forest bathing virtual reality intervention with and without biofeedback in comparison with an active digital control condition, integrating subjective reports, physiological indicators, and attentional measures to assess short-term effects.

3 Methodology

3.1 Study Design and Overview

The study adopts a within-subjects pre–post design in which each participant is exposed to multiple relaxation conditions, including a Forest Bathing virtual reality experience with biofeedback, as well as the same virtual environment without biofeedback and at least one alternative digital relaxation condition. For each condition, subjective measures of mood and perceived restorativeness, in conjunction with the physiological indicators of stress, are collected immediately before and after exposure in order to compare the short-term effects.

3.2 Participants and Recruitment

The study will involve adult participants exposed to urban stress, including knowledge workers and university students who report experiencing everyday stress in urban environments. Inclusion criteria target adults without contraindications to virtual reality exposure or to acute stress-induction tasks, as verified through a brief screening procedure conducted at the beginning of each session.

Participants will be recruited through institutional channels and collaborating health teams, with the objective of reaching a target sample size of approximately 25 to 30 participants. This range is consistent with previous within-subjects studies on virtual reality–based stress reduction and is considered adequate to detect medium-sized effects in repeated-measures analyses. Participation will be voluntary and based on informed consent. Prior to enrolment, participants will receive clear information regarding the aims of the study, the procedures involved and the methods of data collection.

3.3 Outcome Measures

The evaluation of the intervention integrates subjective and physiological outcome measures in order to address both perceived and physiological dimensions of stress and recovery.

3.3.1 Subjective Measures

Subjective outcomes include mood and perceived restorativeness, assessed through a validated questionnaire as is commonly used in studies involving restorative natural environments and virtual reality–based stress recovery. It also includes mood scales and the Perceived Restorativeness Scale, as a way to capture changes in positive and negative effects and in the perceived restorative quality of the experience.

State anxiety is assessed immediately before and after each relaxation condition using the State subscale of the State–Trait Anxiety Inventory (STAI-S), a measure widely applied in studies of virtual reality relaxation and biofeedback interventions to capture momentary anxiety (Yin et al., 2019; Xiaoxue and Huang, 2024). In parallel, perceived stress is recorded before and after each condition using a single-item numeric rating scale ranging from zero to ten, in line with recent applied research on brief virtual reality–based stress reduction sessions (Masters et al., 2022; Zhang et al., 2023).

3.3.2 Physiological Outcome Measures

Physiological indicators of stress are derived from signals such as heart rate, heart rate variability and electrodermal activity, which are widely used as common markers of autonomic arousal in virtual reality relaxation and biofeedback studies. These measures support the comparison with previous work on virtual reality natural scenes and offer a structured approach to assessing whether the Forest Bathing virtual reality intervention is experienced as psychologically restorative in the short term (Yin et al., 2019; Xiaoxue and Huang, 2024).

Continuous heart rate (HR) and heart rate variability (HRV) are recorded throughout the session using a Polar H10 chest strap sensor, which provides beat to beat electrocardiogram data appropriate for short term stress recovery paradigms in virtual reality and biophilic settings (Xiaoxue and Huang, 2024). Heart rate variability is summarized using time domain metrics, with primary focus on the root mean square of successive differences (RMSSD), a standard indicator of vagally mediated variability widely used as a marker of parasympathetic activation and stress recovery in studies of nature exposure and virtual nature interventions (Masters et al., 2022; Xiaoxue and Huang, 2024). Mean heart rate and RMSSD values are extracted from predefined analysis windows corresponding to baseline and to pre and post exposure segments, aligned with the timing of the subjective anxiety and stress assessments (Zhang et al., 2023; Xiaoxue and Huang, 2024).

3.4 Intervention Conditions

The Forest Bathing virtual reality application presents one or more high-fidelity natural environments, such as forest clearings or trails, rendered as three-dimensional scenes with dynamic elements, for example moving foliage or water and accompanied by spatial audio soundscapes. Interaction is intentionally simple and primarily contemplative, emphasizing slow exploration and relaxation rather than task performance, in order to reduce cognitive load and support immersion in a restorative experience.

A biofeedback-enabled version of this application uses real-time HRV and EDA to support subtle adaptations of the environment, such as gradual changes in lighting, ambient sound intensity, or visual motion when physiological indicators reflect decreasing or increasing arousal. This adaptive behavior is intended to reinforce relaxation by progressively enhancing soothing environmental qualities as stress markers decrease, while avoiding abrupt or intrusive changes that might disrupt immersion experience.

The control conditions include a non-adaptive version of the same Forest Bathing virtual reality environment, presented without biofeedback-driven modifications, as well as at least one alternative digital relaxation condition, like a non-interactive nature video or an eyes-closed audio-only soundscape, for example. These conditions allow isolation of the specific contribution of immersive virtual reality nature exposure relative to other commonly used digital relaxation formats.

In the biofeedback condition, visual and auditory features of the virtual forest, such as lighting and ambient sound intensity, adapt in real time in response to the user's heart-rate variability, with the aim of reinforcing more relaxed physiological states (Zhang et al., 2023). The non-biofeedback virtual reality condition presents the same forest environment, soundscape and instructions, but environmental dynamics follow a pre-scripted pattern that remains independent of physiological input (Nicoly et al., 2024). In the active control condition, participants engage in guided breathing with eyes closed while listening to a matched nature soundscape, providing a non-immersive digital relaxation comparison without virtual reality visual input (Masters et al., 2022).

3.5 Experimental Procedure

For the experimental procedure each session begins with informed consent and a brief screening procedure to confirm eligibility and the absence of contraindications for virtual reality exposure. Baseline subjective questionnaires are completed first, followed by a short resting period used to collect physiological baseline measures, consistent with established practice in virtual reality relaxation and biofeedback research (Yin et al., 2019; Zhang et al., 2023). Participants are then exposed to each relaxation condition for approximately ten minutes, an exposure duration aligned with the six-to-ten-minute window commonly reported in virtual nature and forest-based stress reduction studies showing reliable restorative effects (Zhang et al., 2023; Eisen, Bratman and Olvera-Alvarez, 2024; Xiaoxue and Huang, 2024). Short breaks are introduced between conditions to limit carry-over effects. Subjective and physiological measures are collected immediately before and after each condition, and at the end of the session participants complete brief questionnaires assessing usability, acceptability and perceived effectiveness of the different relaxation formats (Zhang *et al.*, 2023)

Each participant completes three experimental sessions scheduled on separate days, comprising a virtual reality forest condition with biofeedback, the same virtual forest condition without biofeedback and an active digital control condition such as guided relaxation with eyes closed. The study follows a within-subjects design with counterbalanced session order, in line with prior virtual reality biofeedback and restorative environment studies comparing multiple relaxation conditions following a shared stress induction (Zhang et al., 2023; Nicoly et al., 2024). In each session, participants begin with a seated baseline period of five minutes, followed by a standardized cognitive stressor lasting approximately ten to fifteen minutes and adapted from PASAT or MAST protocol. Participants then engage in a ten-minute relaxation condition in virtual reality or control format, during which heart rate and heart rate variability are recorded continuously. Subjective stress ratings on a zero to ten scale and state anxiety assessed with the STAI-S are collected at baseline, immediately after the stressor, and before and after the relaxation phase, consistent with established virtual nature and biophilic stress recovery paradigms (Masters *et al.*, 2022; Zhang *et al.*, 2023; Xiaoxue and Huang, 2024).

3.6 Sample Size Considerations

Considering prior virtual reality stress-reduction and virtual nature studies employing within-subjects designs, which commonly include samples ranging from approximately 20 to 40 adult participants, the target sample size for the present study is defined at around 20 to 30 participants. This range is expected to provide adequate statistical power to detect medium-sized effects in repeated-measures ANOVAs across the three relaxation conditions, while remaining feasible within the constraints of a pilot study conducted in collaboration with the health team (Masters *et al.*, 2022; Zhang *et al.*, 2023; Xiaoxue and Huang, 2024).

3.7 Statistical Analysis

For the statistical analysis will focus on changes in state anxiety, perceived stress, mean heart rate and RMSSD from the post-stressor phase to the post-relaxation phase as primary outcomes, with additional exploratory analyses examining changes from baseline to post-relaxation. Differences across the three experimental sessions are analyzed using repeated-measures ANOVAs with condition as a within-subject factor, applying Greenhouse Geisser correction when assumptions of sphericity are violated and Bonferroni corrected pairwise comparisons, in line with standard analytical practice in virtual reality biofeedback and restorative virtual nature research reported in recent studies (Masters et al., 2022; Zhang et al., 2023; Nicoly et al., 2024; Xiaoxue and Huang, 2024). As an exploratory analysis, Pearson correlations between individual changes in state anxiety or perceived stress and corresponding changes in RMSSD are computed to examine the association between subjective and physiological indicators of recovery within each condition.

3.8 Project Development and Management

The project is structured into two main phases. The PREPD phase, running from October 2025 to early January 2026, encompasses the literature review and state-of-the-art synthesis, refinement of the research questions and methodology, and preparation of the extended abstract and the PREPD document. The DIMEI phase, scheduled from January to June 2026, concentrates on system specification and development of the virtual reality forest bathing application with sensor integration and biofeedback, followed by pilot testing, execution of the main experimental study, data analysis and thesis writing.

Key milestones include submission of the extended abstract in December 2025, submission of the PREPD document in January 2026, completion of the virtual reality prototype with biosensor integration in April 2026, completion of the experimental study in May 2026 and the thesis submission in June 2026. Project progress is monitored through regular meetings with the supervisor and the health team, enabling adjustment of tasks and timelines when necessary to address emerging risks or delays.

3.9 Work Breakdown Structure

The work breakdown structure organizes the project into major phases and associated tasks, providing a hierarchical representation of the activities required to design, implement and evaluate the Forest Bathing virtual reality intervention. The structure separates and orders the work.

The WBS distinguishes between literature review and methodological refinement, system specification and development, pilot testing, execution of the experimental study, data analysis and thesis writing. This organization clarifies responsibilities, sequencing and dependencies across project components.

WBS	Task Name	WBS Level	Duratio	Start	Finish	Predecessor
1	**PREPD**	**Phase**	**68 days**	**Mon 06/10/25**	**Wed 07/01/26**	
1.1	**Literature and Framing**	**Deliverable**	**31 days**	**Mon 06/10/25**	**Sat 15/11/25**	
1.2	**Research Design**	**Deliverable**	**26 days**	**Mon 17/11/25**	**Sat 20/12/25**	**2**
1.3	**Extended abstract**	**Deliverable**	**41 days**	**Mon 20/10/25**	**Mon 15/12/25**	**3**
1.4	**PREPD Document**	**Deliverable**	**14 days**	**Sun 21/12/25**	**Wed 07/01/26**	**2;6;11**
2	**DIMEI**	**Phase**	**110 days**	**Mon 19/01/26**	**Fri 19/06/26**	**1**
2.1	**System Specification**	**Deliverable**	**21 days**	**Mon 19/01/26**	**Sat 14/02/26**	
2.2	**Development and Integration**	**Deliverable**	**46 days**	**Mon 16/02/26**	**Sat 18/04/26**	
2.3	**Experimental Study**	**Deliverable**	**21 days**	**Mon 20/04/26**	**Sat 16/05/26**	
2.4	**Analysis and Thesis writing**	**Deliverable**	**21 days**	**Mon 11/05/26**	**Sat 06/06/26**	
3	**Milestones**	**Milestones**	**126 days**	**Mon 15/12/25**	**Sat 06/06/26**	
3.1	Extended abstract submitted	Milestones	1 day	Mon 15/12/25	Mon 15/12/25	
3.2	PREPD final document submitted	Milestones	1 day	Wed 07/01/26	Wed 07/01/26	
3.3	System specification completed	Milestones	1 day	Sat 14/02/26	Sat 14/02/26	
3.4	VR prototype with biosensors ready	Milestones	1 day	Sat 18/04/26	Sat 18/04/26	
3.5	Experimental study completed	Milestones	1 day	Sat 09/05/26	Sat 09/05/26	
3.6	Thesis submitted	Milestones	1 day	Sat 06/06/26	Sat 06/06/26	

Figure 1 - Global Chronogram with WBS structure

3.10 Gantt Chart

The Gantt chart represents the temporal distribution of the main tasks and milestones across the PREPD and DIMEI phases, indicating planned start and end points for each activity and the overlaps between them.

The chart supports project monitoring by making explicit the critical path associated with tasks such as prototype development, pilot testing, data collection and data analysis. It also highlights key deadlines, including the extended abstract, the PREPD submission and the final thesis submission.

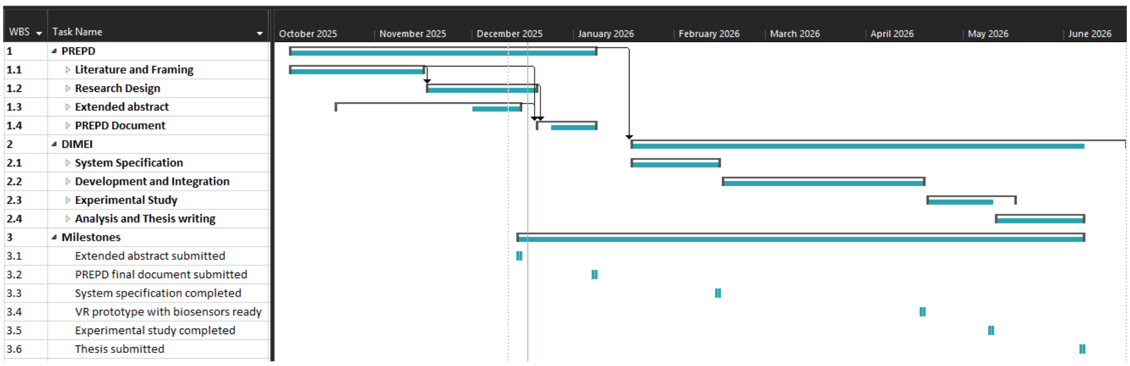

Figure 2 - Global Planning with Gantt Chart

3.11 Ethical Considerations

The development of this dissertation is guided by the ethical principles defined in the Code of Good Practices and Conduct of the Polytechnic Institute of Porto, P.PORTO (*Regulamento do Código de Boas Práticas e de Conduta do Instituto Politécnico do Porto*, 2020) and also aligned with the General Data Protection Regulation, GDPR (European Parliament and Council of the European Union, 2016) and with professional codes of ethics in computing, namely the ACM Code of Ethics and Professional Conduct (Association for Computing Machinery, 2018) and the IEEE Code of Ethics (Institute of Electrical and Electronics Engineers, 2020).

In accordance with the P.PORTO Code of Good Practices, principles of honesty, integrity, transparency and scientific rigor are observed throughout the dissertation, where no ideas, sentences or texts from third parties are used without proper citation and referencing, and no work previously submitted or published is presented as original without explicit mention. Results are not falsified and interpretations are not intentionally biased, in line with the provisions defined in Articles 6, 8 and 10 of the Code of Good Practices (*Regulamento do Código de Boas Práticas e de Conduta do Instituto Politécnico do Porto*, 2020).

The dissertation includes a declaration of integrity in order to ensure the originality of the developed work as well as the absence of fraudulent practices and adherence to the ethical and regulatory standards of P.PORTO (*Regulamento do Código de Boas Práticas e de Conduta do Instituto Politécnico do Porto*, 2020). Research activities are conducted according to good practice guidelines, that includes careful methodological design, appropriate documentation and critical reflection on the limitations and the implications of the findings (*Regulamento do Código de Boas Práticas e de Conduta do Instituto Politécnico do Porto*, 2020).

Regarding personal data, the project follows the principles of the GDPR to ensure the protection of participants' data (European Parliament and Council of the European Union, 2016). During the collection of third-party data, namely through questionnaire responses and physiological measurements for the experimental study, participants will receive clear information about the aims of the project, the types of data collected, how the data will be processed and stored as well as their rights of access, rectification and erasure (European Parliament and Council of the European Union, 2016). Participation will be voluntary and based on informed consent, obtained before any data collection takes place. Data will be pseudonymized, stored on secure access-controlled systems and used exclusively for research purposes within the scope of this project (European Parliament and Council of the European Union, 2016).

In order to be aligned with the ACM and IEEE codes of ethics, the project adopts the principles of honesty, impartiality, respect for privacy and professional responsibility in the design and evaluation of the virtual reality application Conduct (Association for Computing Machinery, 2018). The results analysis and presentation aim to accurately reflect the collected evidence, avoiding distortion, selective reporting or misrepresentation of findings (Association for Computing Machinery, 2018; Institute of Electrical and Electronics Engineers, 2020).

Specific attention is given to the psychological well-being of participants exposed to virtual reality environments and to an acute stress induction procedure. Participants will be screened for contraindications to virtual reality exposure and to participation in stress-induction tasks, and will be informed about potential discomforts, including cybersickness and increases in stress. The protocol allows participants to pause or discontinue the session at any time without penalty. Each session includes a briefing and debriefing period, a cool-down phase following the relaxation conditions and information on how to seek further support in case it’s needed.

The virtual environments and the procedures are designed to promote relaxation and recovery from stress rather than to induce excessive distress, aligning with the ethical principle of non-maleficence. The project aims to contribute to knowledge and practice in digital mental well-being and occupational health, while prioritizing the safety, privacy and rights of participants.

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Appendix A - PREPD: Systematic Mapping Review

Identification

- Theme/ Draft Title: Forest Bathing VR for Burnout
- Author (student): Renato Ferreira Magalhães
- Proponent: Paula Escudeiro
- Mentor: Paula Escudeiro

Step 1 – Protocol + RQs

Research questions

RQ1: What types of nature-based VR are used to reduce stress in adults?

RQ2: Which measures are used (e.g., STAI/PSS, HRV, EDA), and what results do the studies report?

RQ3: Do systems use biofeedback, and is biofeedback more effective than VR without biofeedback or than 2D/audio conditions?

PICOCS

P – Population (who): Adults (≥ 18 years) with day-to-day stress (non-clinical, includes burnout risk).

I – Intervention (what): Nature/forest-bathing VR with or without biofeedback.

C – Comparison: VR without biofeedback; other active comparators when present (e.g., 2D, audio, eyes-closed).

O – Outcomes: Stress/anxiety reduction and physiological improvement (e.g., ↑ HRV, ↓ EDA), plus good usability/safety, measured with instruments such as STAI, PSS, HRV, EDA (extras: SUS, SSQ, IPQ).

C – Context (where): Laboratory or office-like contexts, short sessions.

S – Study design: Empirical studies (pre–post, between-groups, crossover, etc.).

Inclusion / Exclusion criteria

Include (I)

- I1: Nature-related VR/XR studies.
- I2: Adults (≥ 18 years).
- I3: At least one stress-related measure (STAI, PSS, HRV, or EDA).
- I4: Published 2014–2025, peer-reviewed, English or Portuguese.

Exclude (E)

- E1: No stress-related measures.
- E2: Children or specific clinical populations/procedures.
- E3: Non-empirical works (reviews, editorials, theses).
- E4: VR not related to nature (kept only when methodologically relevant, but outside nature-VR synthesis).

Step 2 - Search strategy

Databases

- ACM Digital Library
- PubMed

Filters

- Years: 2014–2025
- Type: Journal / Proceedings
- Language: English (Portuguese if available)

Keywords (concept clusters)

- Virtual reality, VR, XR
- Forest bathing, nature, biophilic, greenery, natural environment
- Stress, anxiety, burnout, relaxation

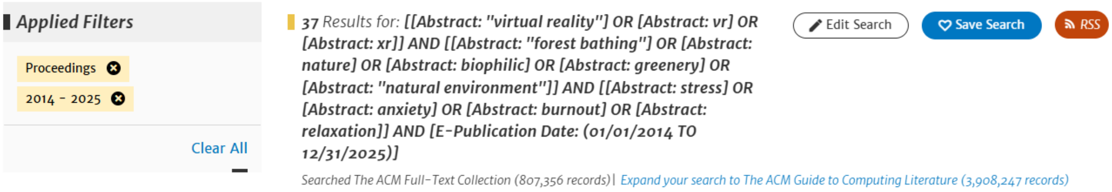
- Biofeedback, HRV, heart rate variability, EDA, electrodermal, galvanic skin
- (for sound-only work) soundscape, binaural, nature sounds, forest sounds

Strings for Advanced Search in ACM

S1 - ("virtual reality" OR VR OR XR) AND ("forest bathing" OR nature OR biophilic OR greenery OR "natural environment") AND (stress OR anxiety OR burnout OR relaxation)

S2 - (VR OR "virtual environment" OR XR) AND (biofeedback OR HRV OR "heart rate variability" OR EDA OR electrodermal OR "galvanic skin") AND (stress OR anxiety OR relaxation)

S3 - ("soundscape" OR "binaural" OR "nature sound*" OR "forest sound*" OR "natural soundscape") AND (stress OR anxiety OR relaxation) AND (experiment OR "user study" OR trial)

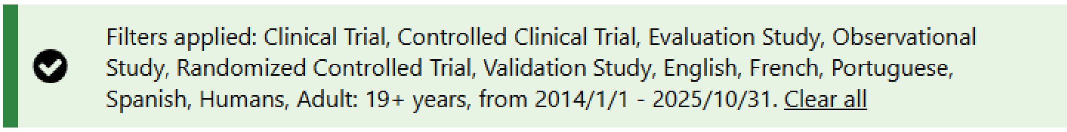


Strings for advanced search in PubMed

S1 - (("virtual reality"[Mesh] OR "virtual reality"[tiab] OR VR[tiab] OR "virtual environment*"[tiab] OR XR[tiab]) AND ("forest*"[tiab] OR nature[tiab] OR biophilic[tiab] OR greenery[tiab] OR "natural environment*"[tiab] OR "Forests"[Mesh]) AND ("Stress, Psychological"[Mesh] OR "Anxiety"[Mesh] OR "Burnout, Psychological"[Mesh] OR stress[tiab] OR anxiety[tiab] OR burnout[tiab] OR relaxation[tiab]))

S2 - ("virtual reality"[tiab] OR VR[tiab] OR "virtual environment"[tiab] OR XR[tiab]]) AND (biofeedback[tiab] OR "heart rate variab*"[tiab] OR HRV[tiab] OR EDA[tiab] OR electrodermal[tiab] OR "galvanic skin"[tiab]) AND (stress[tiab] OR anxiety[tiab] OR relaxation[tiab]))

S3 - (("Sound"[Mesh] OR "Acoustic Stimulation"[Mesh] OR soundscape*[tiab] OR binaural[tiab] OR "nature sound*"[tiab] OR "forest sound*"[tiab] OR "natural soundscape*"[tiab]) AND ("Stress, Psychological"[Mesh] OR "Anxiety"[Mesh] OR stress[tiab] OR anxiety[tiab] OR relaxation[tiab]) AND (experiment*[tiab] OR "user stud*"[tiab] OR trial[tiab] OR randomized[tiab] OR crossover[tiab] OR pre-post[tiab] OR "pre post"[tiab]))



Step 3 - Screening (ACM + PubMed)

	Num. of articles
Identified via S1	37+36
Identified via S2	27+28
Identified via S3	2+87
Total Identified	217
Duplicated Removed	14
Number of articles after removing duplicated	203
Excluded through Abstract (E1–E4)	179
Studies included	24

Titles of the studies included:

Eisen, Aaron M.; Bratman, Gregory N.; Olvera-Alvarez, Hector A.	Susceptibility to stress and nature exposure: Unveiling differential susceptibility to physical environments; a randomized controlled trial.
Yin, Jie; Arfaei, Nastaran; MacNaughton, Piers; Catalano, Paul J.; Allen, Joseph G.; Spengler, John D.	Effects of biophilic interventions in office on stress reaction and cognitive function: A randomized crossover study in virtual reality.
Sadowski, Isabel; Meilleur-Bédard, Marianne; Khoury, Bassam	A Novel Virtual Reality-Based Nature Meditation Program for Older Adults' Mental Health: Results from a Pilot Randomized Controlled Trial.
Tanja-Dijkstra, Karin; Pahl, Sabine; White, Mathew P.; Andrade, Jackie; Qian, Cheng; Bruce, Malcolm; May, Jon; Moles, David R.	Improving dental experiences by using virtual reality distraction: a simulation study.
Xiaoxue, Su; Huang, Xuan	Promoting stress and anxiety recovery in older adults: assessing the therapeutic influence of biophilic green walls and outdoor view.
Tao, Meng; Huang, Haiquan; Gao, Jingchuan; Cao, Yuanyuan; Zhuang, Jie	The effects of combining visual-auditory stimuli with exercise on short-term affect improvement: a randomized controlled trial.
Hackman, Daniel A.; Robert, Stephanie A.; Grübel, Jascha; Weibel, Raphael P.;	Neighborhood environments influence emotion and physiological reactivity.

Anagnostou, Eirini; Hölscher, Christoph; Schinazi, Victor R.	
Kelton, Katherine; Weaver, Terri L.; Willoughby, Lisa; Kaufman, David; Santowski, Anna	The Efficacy of Binaural Beats as a Stress-buffering Technique.
Masters, Rachel; Interrante, Victoria; Watts, Madeline; Ortega, Francisco	Virtual Nature: Investigating The Effect of Biomass on Immersive Virtual Reality Forest Bathing Applications For Stress Reduction
Li, Jingyi; Ma, Yong; Li, Puzhen; Butz, Andreas	A Journey Through Nature: Exploring Virtual Restorative Environments as a Means to Relax in Confined Spaces
Nicoly, Jalynn Blu; Masters, Rachel; Gaddy, Vidya; Interrante, Victoria; Ortega, Francisco	The Restorative Influence of Virtual Reality Environment Design
Ding, Xiaoyan; Chen, Yiwen	The Stress Recovery Effect of Virtual Reality Natural Scene with Different Immersion on Knowledge Talents
Eftekharifar, Siavash; Thaler, Anne; Troje, Nikolaus F.	Restorative Effects of Visual and Pictorial Spaces After Stress Induction in Virtual Reality
Miller, Noah; Stepanova, Ekaterina R.; Desnoyers-Stewart, John; Adhikari, Ashu; Kitson, Alexandra; Pennefather, Patrick; Quesnel, Denise; Brauns, Katharina; Friedl-Werner, Anika; Stahn, Alexander; Riecke, Bernhard E.	Awedyssey: Design Tensions in Eliciting Self-transcendent Emotions in Virtual Reality to Support Mental Well-being and Connection
Waycott, Jenny; Wadley, Greg; Baker, Steven; Ferdous, Hasan Shahid; Hoang, Thuong; Gerling, Kathrin; Headleand, Christopher James; Simeone, Adalberto L.	Manipulating Reality? Designing and Deploying Virtual Reality in Sensitive Settings
Shimomura, Yuki; Ban, Yuki; Warisawa, Shin'ichi	Presenting a Pseudo-loud Vocal Agency on VR for Stress Reduction
wuyun, bagen; cui, yiguo; jiao, rui; wei, zhuorao; chen, yi; lu, li	Study on the Effect of Virtual Landscape on Stress Relief of College Students

Graf, Linda; Emmerich, Katharina; Liszio, Stefan; Masuch, Maic	The Impact of Emotional Virtual Characters on Emotional State and Player Experience in VR Horror Games
Nasri, Mahsa	Towards Intelligent VR Training: A Physiological Adaptation Framework for Cognitive Load and Stress Detection
Samonte, Mary Jane C.; De Asis, Karlo Miguel R.; Guillem, Ethan Jeriko P.; Reyes, Francesca Angela M.	Relieving Stress Through Psychotherapy Using Internet-of-Things and Virtual Reality Game
Sehrt, Jessica; Yilmaz, Ugur; Kosch, Thomas; Schwind, Valentin	Closing the Loop: The Effects of Biofeedback Awareness on Physiological Stress Response Using Electrodermal Activity in Virtual Reality
Zhang, Jingyu; Jiang, Ke; Wang, Suhan; Ming, Shijie; Wang, Huidi	Forestlight: A Virtual Reality Respiratory Biofeedback System Using Interactive Lighting for Pressure Relief
Newbold, Joseph W.; Luton, Jacob; Cox, Anna L.; Gould, Sandy J. J.	Using Nature-based Soundscapes to Support Task Performance and Mood

Step 4 - Classification system (taxonomy/categories)

4.1 Scope and unit of analysis

Unit of analysis: Individual empirical study (paper) after screening by title/abstract and, when necessary, full text.

Framework: PICOCS (Population, Intervention, Comparator, Outcomes, Context, Study design).

Traceability: For each study, a short supporting quote from the abstract is stored in the extraction sheet for Intervention, Outcomes, and Study design.

Missing data rule: If an abstract does not report a needed field, record “not reported in the abstract”.

4.2 Population (P)

Categories

- General adults: ≥ 18 years, non-clinical.
- University students.

- Knowledge workers: office/technology/service professionals with high cognitive load.
- Older adults without explicit diagnosis.

Required fields: N, age (mean or range), sex (%), inclusion/exclusion criteria if given.

4.3 Intervention (I)

4.3.1 Source of nature

- Real 360°: 360-degree video or spherical capture of real environments.
- CGI: Computer-generated natural environments.

4.3.2 Type of nature

- Forest
- Generic nature (e.g., beach, lake, meadow)
- Canyon / low biomass
- Other (urban park, zen garden, mixed environments)

4.3.3 Modality

- Visual only (no sound described)
- Audio only (nature soundscape without VR)
- Audiovisual (VR with sound)
- Multisensory (e.g., haptics, scent, wind, light)

4.3.4 Biofeedback

- None: exposure only
- Breathing: pacing, entrainment, or visualized breath
- HR or HRV: heart rate or heart rate variability as input
- EDA: electrodermal activity as input
- Multimodal: ≥ 2 signals

Rule: Label as biofeedback only when the physiological signal alters the scene or feedback; if the signal is only recorded as an outcome, code it under Outcomes.

4.3.5 Dose

Record number of sessions per participant, minutes per session, and any breaks.

4.3.6 Rule of thumb

Example: “CG animated forest”, Source: CGI; Type: Forest; Modality: Audio-visual.

4.4 Comparator (C)

- 2D / pictorial: images or video outside the HMD
- Nature audio: soundscape without VR
- Eyes-closed rest
- VR without biofeedback: same scene, no physiological loop
- Non-VR control: e.g., regular waiting room, office task
- None: pre–post without parallel condition

Rule: If multiple comparators exist, record the main one most relevant to stress/anxiety.

4.5 Outcomes (O)

4.5.1 Subjective (psychometrics)

- Stress/anxiety/mood/restorativeness: PSS, STAI (state/trait), ZIPERS, PRS, mood scales.
- Presence: IPQ, PQ, SUS (Slater-Usoh-Steed; not to be confused with System Usability Scale).

4.5.2 Physiological

- HR, HRV (RMSSD, SDNN, LF/HF)
- EDA (tonic/phasic; peaks per minute)
- Blood pressure (SBP/DBP)
- EEG, when reported

4.5.3 Measurement windows

- Pre–post
- During the session
- Follow-up (when applicable)

Rule: Always register both instrument and time window (e.g., “PSS pre–post; HR and EDA during exposure”).

4.6 Context (Ctx)

- Environment: Laboratory; Vehicle/Office; University/Public event; Remote.
- Sequence: After stress induction vs no induction vs other relevant conditions.
- Equipment: HMD or display (model when given).
- Location: Country/city/institution when stated.

Rules

- Self-driving car simulator or office task → Vehicle/Office.
- Museum, campus, exhibitions → University/Public event.
- Controlled room → Laboratory; home/unsupervised → Remote.
- If the abstract omits equipment or location, record “HMD not reported” and omit location.

4.7 Study design (S)

- Pre–post (within-subjects)
- Between-groups
- Crossover
- Quasi-experimental
- Pilot

Example: “N = 21, VR compared to eyes-closed rest” → between-groups or within-subjects depending on design; note explicitly in extraction.

4.8 Intervention families used in mapping

- Nature-VR without biofeedback.
- Nature-VR with biofeedback (breathing or EDA altering the scene).
- Soundscape without VR.
- Other VR relevant to stress, emotion, or methods (kept for context, not part of main nature-VR synthesis).

Step 5 - Coding

5.1 Extraction procedure

Primary source: title and abstract; full text used when needed to fill missing fields.

Required: all PICOCS elements plus a short abstract quote supporting Intervention, Outcomes, and Study design.

Consistency with screening rules:

- E1: no stress measures
- E2: clinical population or patient procedures
- E3: non-empirical
- E4: non-nature VR (kept only if methodologically relevant)

5.2 Effect labels (vote-counting)

- Beneficial: statistically significant improvement or clear claim of benefit.
- Null: no effect or non-significant difference.
- Mixed: divergent patterns between subjective and physiological measures, or effects restricted to a subset of outcomes/conditions.
- Inconclusive: cannot infer direction from the abstract.

5.3 Aggregated results (mapped set, 23–24 studies)

5.3.1 Overall distribution

- Beneficial: 11

- Mixed: 4
- Null or negative: 3
- Inconclusive: 5

5.3.2 By intervention family

- Nature-VR (11 studies): 8 beneficial; 1 mixed; 0 null; 2 inconclusive.
- Nature-VR + biofeedback (2 studies): 2 beneficial; 0 mixed; 0 null; 0 inconclusive.
- Soundscape without VR (2 studies): 0 beneficial; 1 mixed; 1 null; 0 inconclusive.
- Other VR (8 studies): 1 beneficial; 2 mixed; 2 null; 3 inconclusive.

5.3.3 Comparators and designs

- Frequent active comparators: pictorial/art, eyes-closed rest, less immersive variants, or non-VR controls.
- Several pre–post designs with no parallel control.
- Some studies use explicit stress induction; others use spontaneous/ambient exposure without induction.

5.3.4 Most common outcomes

- Psychometrics: ZIPERS, PRS, STAI, PSS, mood/restorativeness.
- Physiology: HR, HRV, EDA, blood pressure; often measured during exposure plus pre–post.

Step 6 - Analysis and Reporting

6.1 Objective and RQs

Objective: Map and synthesize evidence on nature-VR and related interventions for immediate/short-term stress/anxiety reduction in non-clinical adults (including burnout risk).

RQs

- Does nature-VR reduce stress/anxiety in adults?
- Does biofeedback (breathing / scene-coupled EDA) enhance the effect?

- Which psychometric and physiological measures are more responsive and practical?

6.2 Analyzed set and synthesis

- Included studies: 23 (after applying E1–E4; one additional study kept mainly for methodological context).
- Synthesis: vote-counting by direction of effect (Beneficial, Mixed, Null/Negative, Inconclusive).
- Unit of analysis: study (paper); coding based primarily on abstracts plus extraction notes.

6.3 Descriptive summary

Intervention types

- Nature-VR (no biofeedback): 11
- Nature-VR + biofeedback: 2
- Soundscape only: 2
- Other VR (non-nature; stress/emotion/methods): 8

Comparators

- Active: pictorial/art, eyes-closed, less immersive VR, non-VR controls
- Pre–post only: no parallel comparator in some studies

Outcomes

- Psychometrics: ZIPERS, PRS, STAI, PSS, mood/restorativeness
- Physiology: HR, HRV (RMSSD, SDNN, LF/HF), EDA, BP
- Windows: during exposure plus immediate pre/post

6.4 Vote-counting results

6.4.1 Overall (23 studies)

- Beneficial: 11
- Mixed: 4

- Null/Negative: 3
- Inconclusive: 5

6.4.2 By intervention family

- Nature-VR (11): 8 beneficial; 1 mixed; 0 null; 2 inconclusive.
- Nature-VR + biofeedback (2): 2 beneficial; 0 mixed; 0 null; 0 inconclusive.
- Soundscape (2): 0 beneficial; 1 mixed; 1 null; 0 inconclusive.
- Other VR (8): 1 beneficial; 2 mixed; 2 null; 3 inconclusive.

Main reading

- Nature-VR shows a consistent trend of immediate benefits, especially on subjective measures (mood/restorativeness; ZIPERS/PRS) and, in several studies, on physiological markers (HR/EDA).
- Biofeedback (breathing/EDA coupled to the scene) appears to reinforce short-term benefits, but evidence is still preliminary.

6.5 Sub-analyses

6.5.1 Key illustrative studies

isen et al. (2024) randomized 64 healthy male university students to 10 minutes of nature VR versus office VR following an acute stressor, assessing autonomic recovery through HRV. The results, at a trend level, indicated better HRV recovery in the nature condition among participants with a pro inflammatory profile, while socioeconomic status and early life stress did not moderate the effects, which restricts the conclusions to short term physiological recovery within a specific subgroup.

Li et al. (2021) developed a Virtual Restorative Environment (VRE) for confined spaces and conducted a subject study (N = 21) comparing a brief VRE session with eyes closed rest. The VRE produced stronger improvements in mood and small benefits in attention and working memory relative to rest, supporting the use of short calm nature VR sessions in non-clinical adults, although the study relied on a small sample and did not include physiological measures.

Yin et al. (2019) employed a randomized crossover design in simulated VR offices to compare environments with and without biophilic elements in terms of stress indicators and cognitive performance (sample approximately 30 adults). Biophilic configurations tended to reduce physiological stress markers and improve creativity measures, while some reaction times in attention tasks slowed, indicating a tradeoff between a more restorative environment and faster attentional responding, with limited generalization to real offices due to the brief laboratory exposures.

6.5.2 Subjective vs physiological

- Recurrent “mixed” pattern: clear subjective improvements (ZIPERS/PRS/mood) with physiological changes that are smaller or not always statistically significant (HR/EDA/HRV).
- Immersion effects: immersive VR nature often outperforms pictorial conditions on subjective outcomes and, in some cases, also reduces EDA.

6.5.3 Strength of comparators

Eyes-closed and pictorial/art conditions are demanding comparators; nature-VR frequently outperforms them, suggesting effects beyond non-specific relaxation.

6.5.4 Context

- Laboratory studies predominate; some work in vehicle/office and public-exhibition contexts.
- Extrapolation to real occupational settings is plausible but under-tested; field trials are still scarce.

6.6 Threats to validity

- Small samples and short follow-up windows in many studies.
- Heterogeneity of content, comparators, and protocols limits meta-analysis.
- Partial reliance on abstracts for coding (risk of missing details).
- Possible publication bias toward positive findings.
- Variation in physiological protocols (e.g., short HRV windows) may reduce sensitivity.

6.7 Conclusions by RQ

RQ1 – Nature-VR: Evidence tends to favor immediate benefits on stress/anxiety, with consistent subjective gains and compatible physiological signs in several studies; advantages over pictorial/eyes-closed support a specific contribution of natural content plus immersion.

RQ2 – Biofeedback: Studies with scene-coupled breathing/EDA suggest additional short-term benefit, but the base is small; more standardized RCTs are needed.

RQ3 – Measures: For short-term effects, ZIPERS and PRS combined with HR and EDA during and after exposure offer a sensitive and feasible panel; HRV (RMSSD/SDNN, ≥ 2–5 min windows) is useful when autonomic self-regulation is a goal.

6.8 Practical recommendations (non-clinical adults, stress/burnout risk)

- Short (10–15 min) immersive nature-VR sessions (forest/biophilic, audio-visual).
- Simple breathing biofeedback (e.g., visual pacing, scene interaction) when possible.

Measurement:

- Subjective: ZIPERS (affect/activation) and PRS (restorativeness) post-session.
- Physiological: HR and EDA during and immediately after; HRV (RMSSD/SDNN) when feasible.
- Internal comparator: pictorial/eyes-closed conditions (e.g., alternate days) if evaluating effectiveness in a specific context.

Dose suggestion: start with 3–5 sessions/week; monitor response and adjust.

6.9 Gaps and research agenda

- Larger RCTs with standardized active comparators.
- Consistent HRV protocols (windows, metrics, reporting).
- Dose–response and maintenance (follow-up ≥ 1–4 weeks).
- Field studies in real work environments, with occupational outcomes (fatigue, performance, burnout markers).
- Multimodal biofeedback (breathing + EDA/HRV) with scene adaptation and incremental-gain testing.

6.10 Final message

Nature-VR is promising for immediate stress reduction in non-clinical adults, with robust subjective evidence and partial physiological support.

Scene-coupled biofeedback shows additional potential benefit but is still understudied.

For practical use and internal evaluation, short immersive sessions, combined subjective + physiological measurement, and, when possible, simple breath-based biofeedback are recommended.

Glossary

MVP (Minimum Viable Product): Minimum functional version of a prototype that already allows you to test hypotheses with users and measure results with the least possible effort. It serves to validate before investing in advanced features.

XR (Extended Reality): Umbrella that includes VR (Virtual Reality), AR (Augmented Reality) and MR (Mixed Reality).

VR (Virtual Reality): Fully synthetic environment (CGI or 360º video) seen on an HMD; The real world is hidden.

AR (Augmented Reality): Overlay of virtual elements on the real world (mobile phone/transparent glasses).

HMD (Head-Mounted Display): VR/AR helmet/goggles (e.g., Quest). Relevant because the model and refreshment rate influence comfort and cyber-motion sickness.

CGI: Computer-generated content (3D graphics), in contrast to 360º video captured in the real world.

Biofeedback: Technique that returns to the user physiological signals in real time (breathing, HRV, EDA) to regulate the state (relax, focus).

RSA-BT (Respiratory Sinus Arrhythmia – Breathing Training): Breathing training to maximize respiration-linked cardiac variability (RSA). Used to reduce anxiety.

HR (Heart Rate): Heart rate (beats/min).

HRV (Heart Rate Variability): Beat-by-beat variation. Indicator of autonomic (parasympathetic) balance.

RMSSD: root of the mean square of successive differences; robust short-term HRV metric.

SDNN: standard deviation of the NN ranges (most global).

EDA (Electrodermal Activity): Skin conductance (sweat); grows with activation/alert. Useful for viewing stress response during exposure.

BP (Blood Pressure): Blood pressure (SBP/BPD). Some studies measure it as an additional physiological outcome.

PSS (Perceived Stress Scale): Perceived stress questionnaire (last weeks). It measures general state/trait, not just momentum [Cohen et al.].

STAI (State-Trait Anxiety Inventory): It measures state anxiety (momentary) and trait (propensity). The STAI-S subscale is the relevant one in the short term [Spielberger].

ZIPERS (Zuckerman Inventory of Personal Reactions): Affect/activation scale (e.g., positive effect, arousal). Used "post-exposure" to capture mood swings.

PRS (Perceived Restorativeness Scale): Perception of restorativeness of the environment (being "taken out", fascination, compatibility) [Kaplan].

Attendance / Attendance Questionnaires: Feeling of "being there" in the virtual world. Common instruments: IPQ, PQ (Witmer & Singer), SUS (Slater-Usoh-Steed). Not to be confused with System Usability Scale.

PICOCS: Scheme for formulating the review: Population, Intervention, Comparator, Outcomes, Context, Study design.

RQ (Research Question): Research question(s) that the review aims to answer.

SLR vs SMS:

- SLR (Systematic Literature Review) synthesizes evidence of effect (ideally with meta-analysis).
- SMS (Systematic Mapping Study) catalogs the terrain (topics, methods, gaps) – what we are doing in PREPD.

Pre-post (within-subjects): The same participant is measured before/after the intervention (no control group).

Between-subjects: Different participants in different conditions (e.g., VR vs 2D).

Crossover: Each participant experiences all conditions, in counterbalanced order (reduces order bias).

ANOVA: Analysis of variance; compares averages between conditions/times (e.g., 2×2 immersion×stress).

Effect size: Magnitude of the difference (e.g., Cohen's d). Essential for practical interpretation, even when p-value is significant.

Randomization / Counterbalance: Techniques for distributing bias (order, learning) among conditions in an experimental study.

Exposure: Total duration and minutes per session. It matters to compare studies and define the MVP.

Cybersickness: Malaise (nausea, dizziness) in VR; monitor with SSQ (Simulator Sickness Questionnaire).

SUS – System Usability Scale: 10-item usability questionnaire (0–100). Not to be confused with the SUS of presence.

Ecology / Context: Degree to which the study reflects the actual environment (laboratory, office, vehicle). It influences generalization.

Active comparator: Credible alternative condition (e.g., close eyes, pictorial 2D) instead of "with nothing".

Vote-counting: Simple aggregation by direction of effect (beneficial/mixed/null) when there are no data for meta-analysis.

Power: Probability of detecting a real effect. Studies with small N have little power and more unstable results.