Sapienza
Università Editrice

The impact of natural virtual environments on perceived restorativeness and individual restoration

Elena Grossi [1]*, Silvia Marocco [1]

[1] *Department of Social and Developmental Psychology, Sapienza University of Rome*

E-ISSN 2724-2943
ISSN 2723-973X

Psychology Hub (2025)
XLII, 1, 99-110

Article info

Submitted: 29 December 2024
Accepted: 06 February 2025
DOI: 10.13133/2724-2943/18766

Abstract

The literature has long demonstrated the restorative value of natural environments. However, access to these types of environments can often be limited to individuals, for various reasons. In this sense, Virtual Reality (VR) can be a useful tool to promote individual recovery through virtual simulation of natural physical environments. Indeed, it has been shown that nature in VR has regenerative potential comparable to that of physical nature. However, research on the effectiveness of VR nature scenarios remains mixed, necessitating further studies on their validation in terms of restorativeness. The purpose of this systematic review, therefore, was to analyze the current state of the literature on the impact of natural virtual environments on perceived environmental restorativeness and individual restoration, considering the types of natural virtual environments used, the varieties of interventions implemented in these studies and the forms of assessment proposed, and evaluating the final results. It emerges how, over the years, the regenerative potential of various virtual natural environments has been validated. Similarly, different forms of intervention are functional in promoting restoration, although they are little varied concerning the physical location and movement ability of participants during the VR experience. Thus, these findings can be useful for future research on this topic and for the optimization of VR interventions for individual psychological well-being.

Keywords: Nature; Virtual Reality; Restorativeness; Restoration

*Corresponding author.
Elena Grossi
Department of Social and
Developmental Psychology,
Sapienza University of Rome,
Rome, Italy
E-mail: elena.grossi@uniroma1.it
(E. Grossi)

Introduction

The literature has long agreed on the restorative value of natural environments which offer a multitude of benefits for human health. Engaging with nature leads to a variety of advantages, such as restoration and recovery across different dimensions: physiological (Hartig et al., 2014; Ulrich, 1991), physical (Twohig-Bennett and Jones, 2018; Astell-Burt et al., 2014), emotional (Bratman et al., 2015; Ohly et al., 2016), cognitive (Berman et al., 2008; Berto, 2005), and social (Maas et al., 2009; Astell-Burt et al., 2021). The two main theories describing the positive impact of nature on individual well-being are the Stress Recovery Theory (SRT; Ulrich, 1991) and the Attention Restoration Theory (ART; Kaplan & Kaplan, 1989). These theories suggest that nature plays a key role in the well-being of individuals and that exposure to a natural environment, even when virtual (Hedblom et al., 2019), promotes an adaptive response following a stressful situation. This quality has been termed "restorativeness" and it is characteristic of environments that not only enable but also promote the process of physical, psychological and social resource recovery (Hartig et al., 1997). Thus, restorativeness is conceived as an environmental feature, whereas "psychological restoration" refers to the process of renewing or recovering the mental energy, emotional balance and cognitive functioning of individuals, especially after periods of stress or cognitive overload (Han, 2018; Kaplan & Kaplan, 1989).

In recent years, psychological research has increasingly made use of forms of a simulated nature (e.g. images, videos), rather than the physical nature, because of their greater accessibility. More recently, Virtual Reality (VR) has been increasingly implemented as a support tool allowing people to feel immersed in simulated natural environments.

However, research on the effectiveness of VR nature scenarios remains mixed, necessitating further studies on their validation in terms of user-experience (Talamo et al., 2021; Marocco et al., 2024a-e; Marocco et al., 2025; Marocco & Talamo, 2022), as well as their impact on restorativeness and related psychological factors.

The present systematic literature review (SLR) aims to assess the impact of natural environments presented in VR on individuals' perceived environmental restorativeness and individual restoration. Thus, the main research question that guided our review was: "What is the impact of virtual natural environments on perceived environmental restorativeness and individual restoration and how can it be optimized?"

Methods

Search Strategy

This SLR was conducted during November 2024 using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) framework (Page et al., 2021).

The chosen wordstring was: "virtual reality" OR "VR" AND "natural environment" OR "nature" OR "natural scenarios" AND "restorativeness" OR "restoration" OR "restorative" OR "stress reduction" OR "attention restoration".

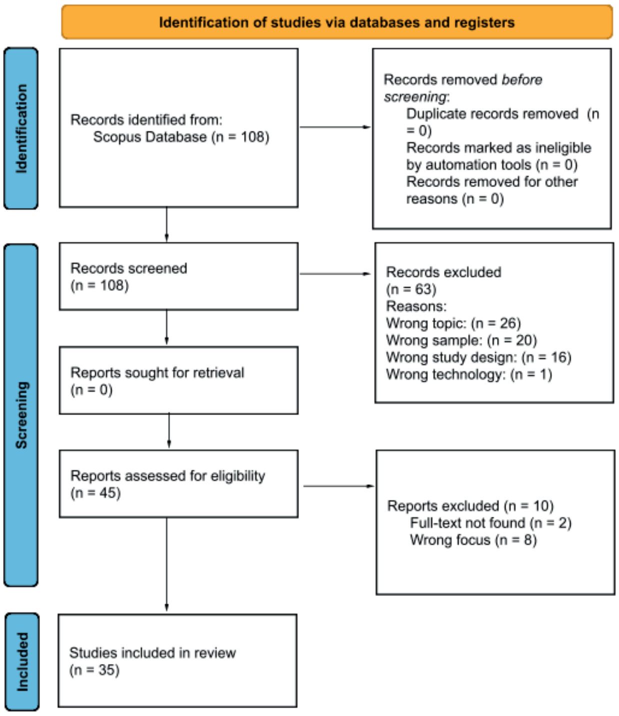
Inclusion and Exclusion Criteria

The search was limited to peer-reviewed journal articles published in the English language in the last 10 years (2014-2024), as, given the rapid evolution of VR technology in the past decade, some past VR technology types might have been obsolete (LaValle, 2023).

Data Extraction and Selection

The systematic search on Scopus conducted in blind mode by the two authors identified 108 records. These records were uploaded into *Rayaan.ai* software to proceed for the papers' coding and selection process. Firstly, a duplicate check was done, resulting in 0 duplicates. Then, after the title and abstract screening, 62 records have been excluded for the following reasons: 26 for the wrong topic of the paper, 20 for considering a wrong sample, 16 for proposing a wrong study design, 1 for exploring the wrong technology. Following the full-text screening, an additional 10 records were removed due to the inadequacy of their contents. Finally, 35 records were included in the SLR for meeting the established inclusion criteria. Below the PRISMA flowchart of the selection process is presented (Figure 1).

Fig. 1. PRISMA flowchart showing the selection process of the articles.



Results

Characteristics of the Included Studies

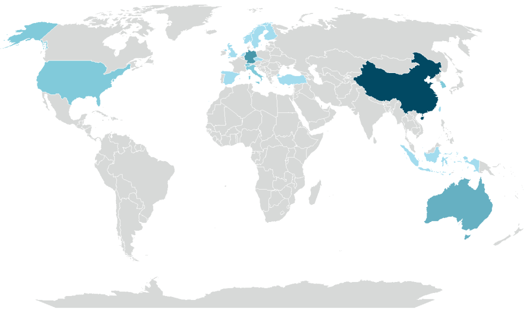
The studies' characteristics obtained from the search are described in terms of participants' features, location, and research design, type of virtual natural environments, intervention and assessment modalities. This categorization has been chosen due to a need to describe in depth the studies considered for this review.

Location

The review included studies from a diverse range of countries (Figure 2). Specifically, there were: 8 articles from China (Gao et al., 2019; Huang et al., 2020; Hao et al., 2024; Meng et al., 2024; Zhang et al., 2023; Leung et al., 2022; Yu et al., 2020; Li et al., 2024), 4 articles from Germany (Rockstroh et al., 2020; Karacan et al., 2021; Reese et al., 2022a; Reese et al., 2022b), 3 articles from Australia (Schebella et al., 2020; Schutte et al., 2017; Walters et al., 2024), 2 articles from Italy (Theodorou et al., 2023; Clemente et al., 2024), 2 articles from Switzerland (Reese et al., 2021; Kawai et al., 2024), 2 articles from South Korea (Jeon et al., 2023; Chung et al., 2018), 3 articles from the United States of America (Anderson et al., 2017; Yin et al., 2022; Seiz et al., 2023).

Also included were 1 article from Sweden (Hedblom et al., 2019), 1 article from Norway (Litleskare & Calogiuri, 2019), 1 article from Turkey (Şansal et al., 2024), 1 article from Finland (Mattila et al., 2020), 1 article from the Netherlands (Ünal et al., 2022), 1 article from the United Kingdom (Browning et al., 2020), 1 article from Spain (Navarrete et al., 2022), 1 article from Indonesia (Suseno & Hastjarjo, 2023), 1 article from the Czech Republic (Hejtmánek et al., 2022), 1 article from Taiwan (Yu et al., 2018) and 1 article from the three countries USA, Taiwan, Thailand (Suppakittpaisarn et al., 2023).

Fig. 2. Map of the number of included studies by country.



Sample characteristics

The 35 studies analysed presented different samples, with a range of participants from a minimum of 10 (Navarrete et al., 2022) to a maximum of 270 (Suppakittpaisarn et al., 2023). The average number of participants is generally between 20 and 100 individuals, with some exceptions (Hedblom et al., 2019; Clemente et al., 2019). The average age of participants varies widely from 20 to 60 years.

All studies included both male and female participants, with variations in gender distribution. There is an important presence of university students, young adults, and in some cases, senior participants. For this review, we excluded clinical samples due to their specification and the impossibility of comparing them with samples from normal populations.

Samples of university students were used, for examples, in Reese et al. (2022a; 2022b), Gao et al. (2019), Hao et al. (2024), Jeon et al. (2023), Ünal et al. (2022), Meng et al. (2024), Li et al. (2024),Theodorou et al. (2023).

Instead, young adult samples were included in Huang et al. (2020) which recruited 89 participants (mean age 23 years), Leung et al. (2022) which conducted two studies with 31 and 80 participants, respectively, with a mean age of approximately 24 years and in Karacan et al. (2021) that carried out two studies with 51 and 101 participants with an average age of 22.82 and 39.36 years, respectively.

Finally, samples of senior participants were used in Yu et al. (2020) which recruited 34 elderly individuals, with a mean age of 58.76 years and in Şansal et al. (2024) which involved 60 elderly residents of urban communities in Turkey, all aged 65 years and over.

Methodologies

Methodologically, all the studies implemented quantitative methods. Concerning research design, considered studies adopted between-subjects, within-subjects and mixed design. Specifically, some studies adopted between subjects design: Rockstroh et al. (2020), Theodorou et al. (2023), Suseno & Hastjarjo (2023), Gao et al. (2019), Huang et al. (2020), Clemente et al. (2024), Browning et al. (2020), Schutte et al. (2017), Meng et al. (2024), Zhang et al. (2023), Suppakittpaisarn et al. (2023), Yin et al. (2022), Kawai et al. (2024), Hedblom et al. (2019), Karacan et al. (2021), Litleskare & Calogiuri (2019).

Then, other studies adopted within-subjects design: Li et al. (2024), Şansal et al. (2024), Hejtmánek et al. (2022), Anderson et al. (2017), Leung et al. (2022), Navarrete et al. (2022), Jeon et al. (2023), Chung et al. (2018), Ünal et al. (2022), Hao et al. (2024), Mattila et al. (2020), Seiz et al. (2023), Yu et al. (2018; 2020), Reese et al. (2021), Walters et al. (2024). Finally, some studies have combined within-subjects and between-subjects designs, including multiple experimental conditions: Schebella et al. (2020), Reese et al. (2022a; 2022b).

Regarding the experimental setting, most of the studies involved laboratory settings. Only Navarrete et al. (2022) was conducted at participants' home because of the nature of the experiment and its duration (5 sessions). Instead, Rockstroh et al. (2020), Reese et al. (2022b), Seiz et al. (2023), Hejtmánek et al. (2022) and Ünal et al. (2022) included experimental field sessions due to their research questions which aimed to compare exposition to a physical and virtual natural environment.

Finally, many studies used pre-post test designs, in order to compare measurements before and after the intervention. Some examples are: Hejtmánek et al. (2022), Huang et al. (2020), Meng et al. (2024), Zhang et al. (2023), Suppakittpaisarn et al. (2023), Reese et al. (2022b), Kawai et al. (2024), Yu et al. (2018, 2020). Examples of studies that used only post-test design are: Ünal et al. (2022), Theodorou et al. (2023), Schutte et al. (2017). The research methodologies and the characteristics of the sample of the studies are outlined in Table 1.

Tab. 1. Studies' sample characteristics and research methodologies.

Authors	Sample Size	Gender (F)	Age M	Country	Methodology	Pre-Test	Method	Setting
Anderson et al. (2017)	18	9	32	USA	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Browning et al (2020)	65	39	20	UK	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Chung et al. (2018)	40	18	23.78	South Korea	Within-subjects design	Only post-test	Quantitative method	Laboratory setting
Clemente et al. (2024)	199	153	22.49	Italy	Between-subjects design	Only post-test	Quantitative method	Laboratory setting
Gao et al (2019)	120	62	20.7	China	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Hedblom et al (2019)	154	82	27.34	Sweden	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Hao et al. (2024)	62	50	20.8	China	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Hejtmánek et al. (2022)	25	11	30.7	Czech Republic	Within-subjects design	Pre-post	Quantitative method	Field/Laboratory setting
Huang et al. (2020)	89	45	23.0	China	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Jeon et al. (2023)	60	30	24.3	South Korea	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Karacan et al. (2021, study 1)	51	17	22.82	Germany	Between-subjects design	Only post-test	Quantitative method	Laboratory setting
Karacan et al. (2021, study 2)	101	53	39.36	Germany	Between-subjects design	Only post-test	Quantitative method	Field setting
Kawai et al (2024)	96	49	39.4	Switzerland	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Leung et al. (2022, study 1)	31	17	23.7	China	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Leung et al. (2022, study 2)	80	50	24.2	China	Within-subjects design	Only post-test	Quantitative method	Laboratory setting
Li et al. (2024)	118	60	20.58	China	Within-subjects design	Only post-test	Quantitative method	Laboratory setting
Litleskare & Calogiuri (2019)	50	28	30.6	Norway	Between-subjects design	Only post-test	Quantitative method	Laboratory setting
Mattila et al. (2020)	100	44	--	Finland	Within-subjects design	Pre-post	Quantitative method	Calm office space
Meng et al. (2024)	90	61	22.0	China	Between-subjects design	Only post test	Quantitative method	Laboratory setting
Navarrete et al. (2022)	10	6	28	Spain	Within-subjects design	Only post-test	Quantitative method	Home setting
Reese et al (2022a)	67	52	22.8	Germany	Mixed design	Only post-test	Quantitative method	Laboratory setting
Reese et al. (2021)	64	47	23	Switzerland	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Reese et al. (2022b)	52	32	24.2	Germany	Mixed design	Only post-test	Quantitative method	Field/Laboratory setting
Rockstroh et al. (2020)	31	11	37.6	Germany	Between-subjects design	Only post-test	Quantitative method	Field experiment
Şansal et al. (2024)	60	36	70.62	Turkey	Within-subjects design	Only post-test	Quantitative method	Laboratory setting
Schebella et al. (2020)	52	28	37.6	Australia	Mixed-design	Pre-post	Quantitative method	Laboratory setting
Schutte et al (2017)	26	16	34.46	Australia	Between-subjects design	Only post-test	Quantitative method	Laboratory setting
Seiz et al (2023)	20	12	25	USA	Within-Subject design	Pre-post	Quantitative method	Laboratory setting
Suppakittpaisarn et al. (2022)	270	130	--	USA, Taiwan, Thailand	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Suseno & Hastjarjo (2023)	53	24	20.7	Indonesia	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Theodorou et al. (2023)	113	90	21.99	Italy	Between-subject design	Only post-test	Quantitative method	Laboratory setting
Ünal et al. (2022, study 1)	23	14	20.39	UK	Within-subjects design	Only post-test	Quantitative method	Field setting
Ünal et al. (2022, study 2)	26	17	19.5	UK	Within-subjects design	Only post-test	Quantitative method	Laboratory setting

Authors	Sample Size	Gender (F)	Age M	Country	Methodology	Pre-Test	Method	Setting
Walters et al. (2024)	75	53	--	Australia	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Yin et al. (2022)	95	0	22.6	USA	Between-subjects design	Pre-post	Quantitative method	Laboratory setting
Yu et al. (2018)	30	17	--	Taiwan	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Yu et al. (2020)	34	28	58.76	China	Within-subjects design	Pre-post	Quantitative method	Laboratory setting
Zhang et al. (2023)	51	34	21.33	China	Between-subjects design	Pre-post	Quantitative method	Laboratory setting

Types of virtual natural environments

From this systematic review it emerges that most of the studies explored the impact of virtual natural environments on restorativeness and individual restoration using green environments (e.g. forest, parks, meadow, hills). Then, some articles included blue spaces (e.g. waterfalls, beaches, sea), brown (e.g. deserts) or white (e.g. arctic landscape). Thus, the authors decided to describe and analyze this aspect in order to evidence possible differences due to different declinations of nature represented in the various virtual scenarios used by researchers in the literature.

Specifically, Mattila et al. (2020), Zhang et al. (2023), Reese et al. (2022b), Hedblom et al. (2019), Yu et al. (2018; 2020), Hejtmánek et al. (2022), Browning et al. (2020), Şansal et al. (2024), Li et al. (2024) used forests and wooded environments, while Schutte et al. (2017) recreated a typical Australian meadow with eucalyptus trees and a stream. In another study, Reese et al. (2022a) used a green landscape again, however, in the form of a meadow. Contrary, Meng et al. (2024), Suppakittpaisarn et al. (2023), Seiz et al. (2023), Litleskare & Calogiuri (2019), Schebella et al. (2020) used urban and peri-urban parks, whereas Leung et al. (2022), Kawai et al. (2024), Hao et al. (2024), Chung et al. (2018) created mountain, lake and hill landscapes in VR. Huang et al. (2020) used courtyards with three different grades of green elements, while Ünal et al. (2022) included a virtual representation of the Butterfly Garden in Emmen Zoo (Netherland), a tropical garden with flowers and plants. Clemente et al. (2024) recreated in VR the garden of an historical Villa in Capodimonte, Italy and, finally, in Rockstroh et al. (2020) green elements are used in the natural scenario, such as plants and flowers, and they are immersed in a night sky.

Blue spaces are included in Walters et al. (2024), Reese et al. (2021), Chung et al. (2018), Anderson et al. (2017) and Suseno & Hastjarjo (2023), in the form of coastal and marine areas. Navarrete et al. (2022), Leung et al. (2022), Jeon et al. (2023), Yu et al. (2020) involved beaches, small lakes and rivers environments in their studies too.

Arctic and snowy environments were used in Theodorou et al. (2023), Hao et al. (2024). For example, the study by Theodorou et al. (2023) includes an arctic environment compared to green and urban landscapes.

Deserts and arid landscapes were included in Yin et al. (2022), Karacan et al. (2021). Yin et al. (2022) compares a desert environment with green spaces, while Karacan et al. (2021) explores African safari scenes and compares it with a typical Ireland landscape.

In the end, Gao et al. (2019) and Hao et al. (2024) also used different types of natural environments. Gao et al. (2019) involved grey space, blue space, green space, partly open green space, closed green space, partly closed green space. Hao et al. (2024) compared extraordinary environments (mesmerizing Arctic, mysterious underwater scene, and spectacular cosmos, natural disaster scenes such as earthquakes, tsunamis, and volcanic eruptions) and ordinary environments (forests, seashores, or snowscape).

Types of interventions

Participants in the studies analyzed in this systematic review were exposed to virtual reality scenarios with different exposure modes and durations. Types of interventions used in the 35 considered articles are described in this paragraph in order to explore the impact of these features on perceived environmental restorativeness and individual restoration.

Generally, exposure durations are distinguished into very-short (2-4 minutes) short (5-10 minutes), moderate (11-20 minutes) and long (30 minutes), and this categorization was used to analyze these researches.

Exposure modes regard the modalities participants explored VR with, in relation to their position during the exposure, whether sitting or standing, with or without the possibility of moving the head or walking.

In one of the studies, Suppakittpaisarn et al (2023), 3 different exposure durations were compared: 1, 5 or 15 minutes. The participants' position is not specified.

Several studies have explored the effects of very-short exposure durations (2-4 minutes) to virtual natural environments. For example, Hao et al. (2024) provides a 2-minute VR exposure in a quiet room. In contrast, Karacan et al. (2021), Jeon et al. (2023) and Walters et al. (2024) let participants explore VR scenarios for 3-minute. Suseno & Hastjarjo (2023) extended the duration slightly to 3 minutes and 25 seconds, allowing exploration with HMD controllers. Clemente et al. (2024) and Theodorou et al. (2023) implemented a 4-minute exposure to VR videos: in the former it is specified that participants initially experienced the environment while seated and later while standing.

Many experimental articles provided a short duration exposure (5-10 minutes). Between them, only in the studies by Rockstroh et al. (2020) et Reese et al. (2022a; 2022b) participants could walk during the 8 and 5 minutes exposition, respectively. In Gao et al. (2019), Schebella et al. (2020), Reese et al. (2021) exposure was provided of 5 minutes duration and participants were seated. In Mattila et al. (2020) participants explored VR environments for 5 minutes on a swivel chair.

Then, in Hedblom et al. (2019) and Chung et al. (2018) exposure duration was slightly higher, 5 minutes and 30 seconds. In Chung et al. (2018), specifically, participants were seated on a swivel chair, as in Schutte et al. (2017), but in this experiment, as in Browning et al. (2020), the duration of exposure was 6 minutes. In Şansal et al. (2024) participants were exposed for 6 minutes to the VR environment too, in a seated position. Instead, in Li et al. (2024), the duration of the VR experience was 7 minutes, it included 7 videos of 60 seconds each. Seiz et al. (2023) exposed participants to virtual natural environments for 8 minutes. Zhang et al. (2023) provide a swivel chair and a 9 minutes duration time, with 1 minute break in the middle. In the studies by Yu et al. (2018; 2020), in contrast, participants were seated and exposed to VR for 9 minutes and 30 seconds and 10 minutes, respectively. 10 minutes was the duration of exposure chosen by Huang et al. (2020), Meng et al. (2024) Yin et al. (2022) and Litleskare & Calogiuri (2019).

Regarding exposure of moderate duration (11-20 minutes), in Leung et al. (2022) during the Study 2 VR exposure lasted 6 minutes per session, for a 12 minutes of VR experience total. Anderson et al. (2017) exposed participants to the VR environment for 15 minutes in a sitting position, whereas in Ünal et al. (2022) the exposure phase was provided only in the Study 2 for 20 minutes and participants could move inside the VR environment. In Kawai et al. (2024) exposure was of 20 minutes duration too, but participants only had freedom of head movement.

Finally, some studies provided a long duration exposure (30 minutes or more): in particular, in Leung et al. (2022), Study 1 there were 3 sessions of 10 minutes each, while in Hejtmánek et al. (2022) the sessions were two of 15 minutes each. In contrast, Navarrete et al. (2022), provided sessions of 13 minutes and 30 seconds, repeated on 5 consecutive days.

Type of assessment

For the evaluation of restorativeness of VR environments and perceived individual restoration during the VR exposure, two kinds of measures were used in the articles considered for this review. They are divided into explicit and implicit measures. Explicit measures are based on the individual perception of participants which are asked to answer questionnaires or interviews focused on the subjective evaluation of a specific focus. In contrast, implicit measures try to assess individuals' automatic and unconscious reactions to particular stimuli. As implicit measures, indirect indicators of responses are used, such as physiological indices or reaction times.

In this review emerges that both types of measurement are implemented for the assessment of perceived environmental restorativeness or individual restoration. Specifically, implicit measures are usually used to assess individual restoration whereas explicit self-report measures are included for the measurement both of perceived restorativeness of VR environments and individual restoration. The following paragraphs will analyze both explicit and implicit measures to highlight the differences and similarities in the results of these two types of measurements.

Most of the studies involved only explicit measures (i.e. eighteen), while a small number of articles used only implicit measurements for the restoration assessment (i.e. six). Finally, eleven researches included combined measures, both explicit and implicit.

Explicit measurements for restorativeness and restoration

Many articles used Perceived Restorativeness Scale (PRS; Hartig, 1997) for the restorativeness assessment. PRS is a self-report measurement instrument derived from the Attention Restoration Theory (Kaplan & Kaplan, 1989) used to assess the regenerative potential of environments. This scale is divided into 4 dimensions (*'fascination', 'being away', 'extent', 'compatibility'*) directly taken from ART, a theory that postulates how exposure to certain types of environments, particularly natural ones, can promote recovery from mental fatigue caused by prolonged use of direct attention, thanks to the shift to indirect attention. In its original version (Hartig, 1997), the PRS consists of a total of 16 items, divided by the 4 components of ART, and has been extensively validated in different contexts, including natural, urban and virtual environments. For example, Berto (2005) and Hartig et al. (1997) showed that natural environments score significantly higher on the PRS than artificial environments, confirming the theory that the characteristics of natural landscapes promote cognitive retrieval.

Examples of researches that used original PRS in their experimental assessment are Theodorou et al. (2023), Li et al. (2024), Karacan et al. (2021) (only the dimensions *"fascination"* and *"being away"*), Schutte et al. (2017), Reese et al. (2022b), Şansal et al. (2024), Litleskare & Calogiuri (2019) and Seiz et al. (2023), Chung et al. (2018), Hao et al. (2024), Meng et al. (2024), Browning et al. (2020). Clemente et al. (2024) used PRS too, but only half of the items (i.e. 7 items).

In contrast, in Leung et al. (2022) a revised version of the PRS has been used, PRS-11 (Pasini et al., 2014) which consists of 11 items to measure the perceived restorative quality of the environment on the four original sub-domains. This version has been used by Reese et al. (2021) too.

Other studies used PRS versions combined with other self-report scales. Navarrete et al. (2022), for example, used PRS and two dimensions of the Restorativeness Scale (RS; Han, 2003) which is made up of four dimensions (emotional, physiological, cognitive, and behavioral) rated on a 9-point Likert-type scale. In that study, only the *cognitive dimension*, and the *behavioral dimension* were included. Rockstroh et al. (2020), Reese et al. (2021), Kawai et al. (2024) and Mattila et al. (2020), instead, used both PRS to assess the restorativeness of the environment and Restoration Outcome Scale (ROS; Korpela et al., 2008) which aims to capture the degree of mental and psychological restoration of an individual experiences, focusing on regenerative effects. In Hejtmánek et al. (2022) and Reese et al. (2022a) only ROS assessment was provided. In contrast, Yu et al. (2020) used The Restorative Components Scale (RCS) to evaluate whether participants believed the virtual environment led to feelings of restoration (Herzog et al., 2003).

Jeon et al. (2023) interested in the assessment of the soundscape restorativeness so used the Perceived Restorativeness Soundscape Scale (PRSS; Payne, 2013) designed to assess perceptions of a soundscape's potential to provide psychological restoration.

Then, Suppakittpaisarn et al. (2023), Suseno & Hastjarjo (2023), Schebella et al. (2020), Walters et al. (2024) focused on the assessment of the individual perceived stress. In Suppakittpaisarn et al. (2023) and Schebella et al. (2020) a Visual Analog Scale (VAS) was used, an original scale which assesses perceived stress with 1 item. Instead, Walters et al. (2024) provided the Relaxed Mental State (RMS) which consists of nine items with six items measuring physical and mental dimensions of relaxation supplemented with additional three items to measure mental fatigue. Suseno & Hastjarjo (2023) assessed the perceived stress with the State-trait Anxiety Inventory (STAI; Annerstedt et al., 2013). Finally, Zhang et al. (2023) used the Perceived Stress Scale (PSS-14; Cohen et al., 1983) form before and after exposure to VR environments: it is a 14-item scale which asks the respondent to evaluate stress-symptoms.

Implicit measurements for restoration

On the other hand, many of the included studies used physiological measures (implicit measurements) to assess restoration and physiological activation of participants' after the VR exposure. As reported, 11 articles employed physiological indices combined with self-reported scales, while six studies used only implicit measures.

Skin Conductance level (SCL) and the Skin Conductance Response (nSCR) are measures of the activity of the Sympathetic Nervous System (SNS), which regulates the physiological response to stress. Increased levels of both SCL and nSCR may indicate increased physiological activation. Browning et al. (2020), Huang et al. (2020), and Hedblom et al. (2019) used SCL to assess individual physiological changes, while Meng et al. (2024) combined SCL and nSCR and Suseno & Hastjarjo (2023), SCL and Heart Rate (HR). Kawai et al. (2024) combined SCL measurement with salivary cortisol levels.

Salivary cortisol is a biochemical indicator of stress, whereas immunological biomarkers such as interleukin-6 (IL-6) and interleukin-10 (IL-10) reflect immune responses. Yin et al. (2022) measured salivary cortisol together with blood pressure and changes of serum IL-6 and IL-10. Blood pressure and sympathetic/parasympathetic activity, implemented by Yu et al. (2020), with HR monitoring too, provide detailed measures of the physiological response to relaxation or stress.

Heart-Rate Variability (HRV) and HR are also measures of autonomic regulation of the heart, specifically they indicate the balance between SNS and Parasympathetic Nervous System (PNS). HR indicates the number of heart beats per minute, while HRV measures the variation in time intervals between heart beats. Both of them are indicators of relaxation and psychophysiological recovery. Litleskare & Calogiuri (2019) used HR index for the restoration assessment, while Yu et al. (2018) used HRV, together with Salivary Amylase Activity (SAA), another measure used to detect stress, and blood pressure. In contrast, Schebella et al. (2020) measured HR and Electrodermal Activity (EDA) to assess the recovery status of individuals. EDA measures changes in skin conductance induced by activation of the SNS and was also used by Anderson et al. (2017) combined with individual HRV index.

Finally, electroencephalographic activity measures the electrical activity of the brain, providing information on brain waves associated with specific mental states such as restoration and fatigue. Electroencephalogram (EEG) monitoring has been used by Chung et al. (2018), Gao et al. (2019), Seiz et al. (2023) and Zhang et al. (2023) during and after exposure to virtual natural environments. Jeon et al. (2023), on the other hand, integrated EEG with Electrocardiogram (ECG) to assess the effect of environmental sounds on physiological responses. Similarly, Hao et al. (2024) used together with HRV.

Summary of the evidence

This section evidences the findings from the considered articles of this systematic review regarding the impact of virtual natural environments on restorativeness and restoration. The results of the self-report questionnaires, focusing on both restorativeness and restoration, will be examined first. Subsequently, the following paragraph will analyze the physiological indices, providing an objective measure of participants' restoration.

Self-report evidences on perceived environmental restorativeness

Regarding restorativeness, Rockstroh et al. (2020) and Karacan et al. (2021) found that natural virtual environments significantly increase restorative dimensions such as 'being away' and 'fascination'. Theodorou et al. (2023) demonstrated that different natural environments, such as national parks and arctic landscapes, are perceived as restorative and in turn are able to promote perceived vitality of individuals. In contrast, Li et al. (2024) reported a non-linear effect of environmental brightness on perceived restorativeness, with the higher increase in the latter up to a medium level of the former. Leung et al. (2022), Ünal et al. (2022), Kawai et al. (2024), Yu et al. (2020), Schutte et al. (2017) showed that virtual natural environments are perceived as significantly more restorative than general urban ones. Navarrete et al. (2022) demonstrated that virtual blue spaces, such as beaches and lakes, facilitates cognitive and behavioral restoration, while Jeon et al. (2023) report that both natural and urban waterfront environments can be perceived as restorative. Şansal et al. (2024) validated the restorative potential of nature in VR with an elderly population too.

On the other hand, Clemente et al. (2024) showed that the sense of presence is a key mediator in the perception of restorativeness in VR environments. Similar findings emerge from the study by Chung et al. (2018), who associated natural soft-fascinating landscapes with a higher perception of restorativeness than hard-fascinating ones. Hao et al. (2024) reported that extraordinary natural environments have significantly stronger effects on restorativeness than ordinary ones.

Mattila et al. (2020), Suppakittpaisarn et al. (2023), Reese et al. (2022b) and Browning et al. (2020) confirmed that virtual natural environments, such as forests or urban parks, lead to high levels of perceived restorativeness, comparable to those obtained in physical natural settings. Meng et al. (2024) found significant differences between perceived restorativeness values in urban parks and natural conservation areas, in favour of the former. Seiz et al. (2023) confirmed the restorative potential of designed urban green spaces. Finally, Litleskare & Calogiuri (2019) reported that a higher degree of VR natural scene stability leads to more perceived restorativeness.

Self-report evidences on individual restoration

For restoration assessment through self-report measures, Hejtmánek et al. (2022), Reese et al. (2021), Rockstroh et al. (2020), Suppakittpaisarn et al. (2023), Suseno & Hastjarjo (2023), Kawai et al. (2024) and Mattila et al. (2020) show an overall positive impact of the natural virtual environment on restoration. Furthermore, Schebella et al. (2020) evidence the importance of multi-sensory stimulation for recovery from stress, with a non-linear positive effect related to biodiversity which seems to be inversely correlated to stress recovery. Zhang et al. (2023) showed that exposure to natural environments improves cognitive flexibility and reduces perceived cognitive load. Walters et al. (2024) demonstrated a significant increase in restorative mental state after exposure to a natural setting in VR, but the decrease in fatigue was not significant. Kawai et al. (2024) indicated that the positive effects of nature affect both restoration (with prior stress induction) and instoration (without prior stress induction). Reese et al. (2022a), finally, reported no differences between restoration levels both for exclusively-natural and human-natural environments.

Physiological evidences on individual restoration

Implicit measures, mainly physiological, generally confirmed the benefits of natural virtual environments on restoration. Indeed, Huang et al. (2020) observed that SCLs decrease significantly in the first 5 minutes in virtual environments with grass or trees, whereas they increase in urban environments. Moreover, Hedblom et al. (2019) evidences significant lower levels of SC in participants that recovered in green virtual environments compared to the ones that experienced urban environments. Similarly, Meng et al. (2024) reported relevant and similar reductions in SCL and nSCR in participants exposed to peri-urban parks and nature conservation areas than the ones whose exposure was in urban parks. In contrast, Browning et al. (2020) reported a different trend, with SCLs progressively increasing during exposure to nature scenes. Instead, also Suseno & Hastjarjo (2023) reported a decrease in SCLs and HR during exposure to virtual natural environments, indicating a relevant reduction in activation, without differences between VR and 2D video experiences. Kawai et al. (2024) observed a significant reduction in SCL in participants immersed in natural environments compared to urban ones, although no significant differences emerged in salivary cortisol levels.

Yin et al. (2022), observing salivary cortisol, blood pressure, and change of serum IL-6 and IL-10 highlighted a significant reduction in participants' stress levels exposed to desert scenarios compared to the ones exposed to an office environment. Yu et al. (2018) showed a significant reduction in blood pressure, HRV, as well as in SAA, in participants which experienced a forest environment compared to those whose experienced urban scenarios. In contrast, in Yu et al. (2020), the restorative potential of not only a natural virtual environment but also an urban environment is revealed, through a reduction in participants' HR.

Anderson et al. (2017) and Schebella et al. (2020) observed a significant reduction in EDA. In addition, the former experienced a decrease in Low Frequency/High Frequency (LF/HF) index, while the latter showed a decrease in HR, both positive, during VR exposure to nature.

In contrast, Jeon et al. (2023) reported a positive impact of both natural and urban environments on ECG and EEG measurements, surprisingly. Hao et al. (2024), using EEG and HRV, demonstrated that exposure to extraordinary natural environments enhances physiological restoration more than ordinary ones, although with decreasing effects in the case of over-exposure. Litleskare & Calogiuri (2019) using HR, highlighted the importance of visual stability in VR scenarios to prevent cybersickness symptoms.

Chung et al. (2018), Gao et al. (2019), Seiz et al. (2023) and Zhang et al. (2023), using EEG, collectively found lower frontal cortex activation, less attentional fatigue and better cognitive flexibility after the VR intervention.

Discussion

From the results, it emerges how, in general, natural virtual scenarios have a positive impact on perceived environmental restorativeness and individual restoration. Indeed, it can be observed that after the VR intervention with natural scenarios, perceived restorativeness levels assessed with self-reported measures (e.g. PRS, RS) and restoration levels assessed both with explicit measures (e.g. ROS) and implicit physiological measures (e.g. EDA, ECG), tend to be higher than before the intervention. Similarly, in the studies which employed an only posttest experimental design, in the VR treatment condition perceived restorativeness and restoration levels were higher than in the control condition. This occurs with various types of natural environments, green, blue, white and brown too. Green environments and blue scenarios are the most represented by these studies, resulting to be highly restorative and able to promote individual restoration. One novelty is the restorative potential of arctic and brown environments, less explored in this specific research literature. Additionally, it has been reported that extraordinary natural landscapes are able to promote perceived environmental restorativeness too.

Moreover, it emerged that some characteristics of the virtual environment/experience such as different brightness levels of VR scenarios and various degrees of immersion, as well as stimulation degree of natural representation affect the impact of restorativeness and restoration. In particular, medium brightness, high immersive and more stimulating scenarios lead to greater positive effects. Thus, these elements should be considered in the construction of restorative VR scenarios in order to maximize individual restoration. Similarly, biodiversity levels and multisensory stimulation should be counted too: according to Schebella et al. (2020), indeed, a VR environment characterized by low biodiversity and high multisensory leads to a most effective recovery from stress.

Furthermore, the improvement of individual restoration and perceived restorativeness is promoted by different types of intervention's duration: very-short, short, moderate, long. Thus, also a shorter VR experience in a natural environment is perceived as restorative and is able to increase individual restoration, emphasizing the relaxation potential of nature. In Suppakittpaisarn et al. (2023), where different exposure durations (1, 5 or 15 minutes) are analyzed, it has been reported that the 5 minutes VR experience was the most effective to promote perceived restorativeness and restoration. However, it's important to point out that longer exposure time durations are necessary to be explored especially in order to assess physiological restoration, given that it takes time to observe the change in some physiological indices of stress or relaxation, such as salivary cortisol levels or EDA.

Regarding participants' position during the intervention, only 6 studies of 35 analyzed allowed people to walk. In the remaining 29, participants were seated, also due to the fact that many studies included physiological measures whose monitoring facility required individuals to be stationary or have limited opportunity for movement. It emerges how the exclusive role of participants' physical location or ability or lack of movement in perceived environmental restorativeness or individual restoration is not well investigated. Therefore, for future research, it would be appropriate to isolate this factor and test its impact on the two reported constructs.

Conclusion and future directions

This SRL explores the impact of natural virtual environments on perceived environmental restorativeness and individual restoration. It emerges how different kinds of natural environments (green, blue, white and brown) are able to enhance these two constructs, both by implicit and explicit assessment. Green and blue scenarios are the most used and the ones whose effectiveness is the most verified. Thus, it is desirable for future research to implement the utilization of other natural virtual environments types, maybe focusing on those natural representations which are less studied currently, such as white and brown environments.

Regarding the VR interventions, it emerges that the exposure durations explored are various but usually all effective: it should be interesting for the future researchers to observe the effectiveness of similar interventions (with the same virtual scenario) using different exposure durations in the same experimental procedure. Moreover, most of the analysed articles implemented a seated VR experience: thus, it should be important to further investigate other physical experiences, such as a laying position or a walking position, in order to observe how physical movement affects the VR experience.

Ethical Approval

Not applicable

Data availability statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Funding/Financial Support
This research received no external funding.

Conflict of Interests

The authors declare no conflicts of interest.

Supplementary material

No supplementary materials are available for this paper.

Author Contributions

Conceptualization, E.G. and S.M.; writing—original draft preparation, E.G.; writing—review and editing, E.G. and S.M. All authors have read and agreed to the published version of the manuscript.

References

Anderson, A. P., Mayer, M. D., Fellows, A. M., Cowan, D. R., Hegel, M. T., & Buckey, J. C. (2017). Relaxation with immersive natural scenes presented using virtual reality. *Aerospace medicine and human performance*, 88(6), 520-526. 10.3357/AMHP.4747.2017

Annerstedt, M., Jönsson, P., Wallergård, M., Johansson, G., Karlson, B., Grahn, P., ... & Währborg, P. (2013). Inducing physiological stress recovery with sounds of nature in a virtual reality forest—Results from a pilot study. *Physiology & behavior,* 118, 240-250. https://doi.org/10.1016/j.physbeh.2013.05.023

Astell-Burt, T., & Feng, X. (2021). Time for 'green' during COVID-19? Inequities in green and blue space access, visitation and felt benefits. *International journal of environmental research and public health*, 18(5), 2757. https://doi.org/10.3390/ijerph18052757

Astell-Burt, T., Mitchell, R., & Hartig, T. (2014). The association between green space and mental health varies across the lifecourse. A longitudinal study. *J Epidemiol Community Health*, 68(6), 578-583. https://doi.org/10.1136/jech-2013-203767

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science*, 19(12), 1207-1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of environmental psychology*, 25(3), 249-259. https://doi.org/10.1016/j.jenvp.2005.07.001

Bratman, G. N., Daily, G. C., Levy, B. J., & Gross, J. J. (2015). The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning*, 138, 41-50. https://doi.org/10.1016/j.landurbplan.2015.02.005

Browning M.H.E.M., Mimnaugh K.J., van Riper C.J., Laurent H.K. and LaValle S.M. (2020). Can Simulated Nature Support Mental Health? Comparing Short, Single-Doses of 360-Degree Nature Videos in Virtual Reality With the Outdoors. *Front. Psychol.* 10:2667. https://doi.org/10.3389/fpsyg.2019.02667

Chung, K., Lee, D., & Park, J. Y. (2018). Involuntary attention restoration during exposure to mobile-based 360 virtual nature in healthy adults with different levels of restorative experience: Event-related potential study. *Journal of Medical Internet Research*, 20(11), e11152. https://doi.org/10.2196/11152

Clemente, D., Theodorou, A., Romano, L., Russo, C., Rodelli, R., Casagrande, G., & Panno, A. (2024). The Effect of Exposure to VR vs. 2D Virtual Environments on Restorativeness: The Mediating Role of the Sense of Presence. *International Journal of Human–Computer Interaction*, 1–16. https://doi.org/10.1080/10447318.2024.2352218

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of health and social behavior*, 385-396. https://doi.org/10.2307/2136404

Gao, T., Zhang, T., Zhu, L., Gao, Y., & Qiu, L. (2019). Exploring psychophysiological restoration and individual preference in the different environments based on virtual reality. *International journal of environmental research and public health*, 16(17), 3102. https://doi.org/10.3390/ijerph16173102

Han, K. T. (2003). A reliable and valid self-rating measure of the restorative quality of natural environments. *Landscape and urban planning,* 64(4), 209-232. https://doi.org/10.1016/S0169-2046(02)00241-4

Han, K. T. (2018). A review of self-report scales on restoration and/or restorativeness in the natural environment. *Journal of Leisure Research*, *49*(3-5), 151-176. https://doi.org/10.1080/00222216.2018.1505159

Hao, S., Zhang, L., Hou, R., Lau, S. S., & Lau, S. S. Y. (2024). Research on the physiological and psychological impacts of extraordinary nature on emotions and restorative effects for young adults. *Journal of Environmental Psychology*, 102345. https://doi.org/10.1016/j.jenvp.2024.102345

Hartig, T., Korpela, K., Evans, G. W., & Gärling, T. (1997). A measure of restorative quality in environments. *Scandinavian housing and planning research*, 14(4), 175-194. https://doi.org/10.1080/02815739708730435

Hartig, T., Mitchell, R., De Vries, S., & Frumkin, H. (2014). Nature and health. *Annual Review of Public Health*, 35, 207-228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hedblom, M., Gunnarsson, B., Iravani, B., Knez, I., Schaefer, M., Thorsson, P., & Lundström, J. N. (2019). Reduction of physiological stress by urban green space in a multisensory virtual experiment. *Scientific Reports*, 9(1). https://doi.org/10.1038/s41598-019-46099-7

Hejtmánek, L., Hůla, M., Herrová, A., & Surový, P. (2022). Forest digital twin as a relaxation environment: a pilot study. *Frontiers in Virtual Reality*, 3, 1033708. https://doi.org/10.3389/frvir.2022.1033708

Herzog, T. R., Maguire, P., & Nebel, M. B. (2003). Assessing the restorative components of environments. *Journal of environmental psychology,* 23(2), 159-170. https://doi.org/10.1016/S0272-4944(02)00113-5

Huang, Q., Yang, M., Jane, H. A., Li, S., & Bauer, N. (2020). Trees, grass, or concrete? The effects of different types of environments on stress reduction. *Landscape and urban planning*, 193, 103654. https://doi.org/10.1016/j.landurbplan.2019.103654

Jeon, J. Y., Jo, H. I., & Lee, K. (2023). Psycho-physiological restoration with audio-visual interactions through virtual reality simulations of soundscape and landscape experiences in urban, waterfront, and green environments. *Sustainable Cities and Society*, 99, 104929. https://doi.org/10.1016/j.scs.2023.104929

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge university press.

Karacan, B., Kombeiz, O., & Steidle, A. (2021). Powered by virtual realities: promoting emotional recovery through technology-based recovery interventions. *Ergonomics*, *64*(10), 1351-1366. https://doi.org/10.1080/00140139.2021.1912399

Kawai, C., Georgiou, F., Pieren, R., Tobias, S., Mavros, P., & Schäffer, B. (2024). Investigating effect chains from cognitive and noise-induced short-term stress build-up to restoration in an urban or nature setting using 360° VR. *Journal of Environmental Psychology*, 100, 102466. https://doi.org/10.1016/j.jenvp.2024.102466

Korpela, K. M., Ylén, M., Tyrväinen, L., & Silvennoinen, H. (2008). Determinants of restorative experiences in everyday favorite places. *Health & place*, 14(4), 636-652. https://doi.org/10.1016/j.healthplace.2007.10.008

LaValle, S. M. (2023). *Virtual Reality*. Cambridge University Press.

Leung, G. Y., Hazan, H., & Chan, C. S. (2022). Exposure to nature in immersive virtual reality increases connectedness to nature among people with low nature affinity. *Journal of Environmental Psychology*, 83, 101863. https://doi.org/10.1016/j.jenvp.2022.101863

Li, C., Ge, S., & Jiang, Y. (2024). Effects of simulated natural light brightness on visual perception in virtual reality forests: An eye-tracking study. *Journal of Environmental Psychology*, 99, 102446. https://doi.org/10.1016/j.jenvp.2024.102446

Litleskare, S. & Calogiuri, G. (2019). Camera Stabilization in 360◦ Videos and Its Impact on Cyber Sickness, Environmental Perceptions, and Psychophysiological Responses to a Simulated Nature Walk: A Single-Blinded Randomized Trial. *Front. Psychol.* 10:2436. https://doi.org/10.3389/fpsyg.2019.02436

Maas, J., Van Dillen, S. M., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place*, 15(2), 586-595. https://doi.org/10.1016/j.healthplace.2008.09.006

Marocco S., and Talamo A. (2022). The contribution of activity theory to modeling multi-actor decision-making: A focus on human capital investments. *Front. Psychol.* 13:997062. https://doi.org/10.3389/fpsyg.2022.997062

Marocco, S., Barbieri, B., & Talamo, A. (2024a). Exploring facilitators and barriers to managers' adoption of AI-based systems in decision-making: A systematic review. *AI*, 5(4), 2538-2567. https://doi.org/10.3390/ai5040123

Marocco, S., Marini, M., & Talamo, A. (2024b). Enhancing organizational processes for service innovation: Strategic organizational counseling and organizational network analysis. *Frontiers in Research Metrics and Analytics*, 9, 1270501. https://doi.org/10.3389/frma.2024.1270501

Marocco, S., Talamo, A., & Quintiliani, F. (2024c). Applying design thinking to develop AI-based multi-actor decision-support systems: A case study on human capital investments. *Applied Sciences*, 14 (5613). https://doi.org/10.3390/app14135613

Marocco, S., Talamo, A., & Quintiliani, F. (2024d). From service design thinking to the third generation of activity theory: A new model for designing AI-based decision-support systems. *Frontiers in Artificial Intelligence*, 7, 1303691. https://doi.org/10.3389/frai.2024.1303691

Marocco, S., Vitale, V., Talamo, A. (2024e) The impact of natural virtual environments on emotion elicitation: a state-of-the-art review. Under review, in *Virtual Reality*.

Marocco, S., Vitale, V., Grossi, E., Presaghi, F., Bonaiuto, M., & Talamo, A. (2025). Exploring the Restorative Effects of Natural Environments in Virtual Reality. *International Journal of Environmental Research and Public Health*, 22(4), 535. https://doi.org/10.3390/ijerph22040535

Mattila, O., Korhonen, A., Pöyry, E., Hauru, K., Holopainen, J., & Parvinen, P. (2020). Restoration in a virtual reality forest environment. *Computers in Human Behavior*, 107, 106295. https://doi.org/10.1016/j.chb.2020.106295

Meng, L., Li, S., & Zhang, X. (2024). Assessing biodiversity's impact on stress and affect from urban to conservation areas: A virtual reality study. *Ecological Indicators*, 158, 111532. https://doi.org/10.1016/j.ecolind.2023.111532

Navarrete, J., Navarro-Siurana, J., Herrero, R., Vara, M. D., Miragall, M., & Baños, R. (2022). Connecting to Nature through 360° Videos during COVID-19 Confinement: A Pilot Study of a Brief Psychological Intervention. *Journal of Healthcare Engineering*, 2022(1), 4242888. https://doi.org/10.1155/2022/4242888

Ohly, H., White, M. P., Wheeler, B. W., Bethel, A., Ukoumunne, O. C., Nikolaou, V., & Garside, R. (2016). Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. *Journal of Toxicology and Environmental Health*, Part B, 19(7), 305-343. https://doi.org/10.1080/10937404.2016.1196155

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *bmj*, 372. https://doi.org/10.1136/bmj.n71

Pasini, M., Berto, R., Brondino, M., Hall, R., & Ortner, C. (2014). How to measure the restorative quality of environments: The PRS-11. *Procedia-Social and behavioral sciences*, 159, 293-297. https://doi.org/10.1016/j.sbspro.2014.12.375

Payne, S. R. (2013). The production of a perceived restorativeness soundscape scale. *Applied acoustics*, 74(2), 255-263. https://doi.org/10.1016/j.apacoust.2011.11.005

Reese, G., Kohler, E., & Menzel, C. (2021). Restore or get restored: The effect of control on stress reduction and restoration in virtual nature settings. *Sustainability*, 13(4), 1995. https://doi.org/10.3390/su13041995

Reese, G., Mehner, M., Nelke, I., Stahlberg, J., & Menzel, C. (2022a). Into the wild… or not: Virtual nature experiences benefit well-being regardless of human-made structures in nature. *Frontiers in Virtual Reality*, 3, 952073. https://doi.org/10.3389/frvir.2022.952073

Reese, G., Stahlberg, J. & Menzel, C. (2022b). Digital shinrin-yoku: do nature experiences in virtual reality reduce stress and increase well-being as strongly as similar experiences in a physical forest?. *Virtual Reality* 26, 1245–1255. https://doi.org/10.1007/s10055-022-00631-9

Rockstroh, C., Blum, J., Hardt, V., & Göritz, A. S. (2020). Design and Evaluation of a Virtual Restorative Walk With Room-Scale Virtual Reality and Impossible Spaces. *Frontiers in Virtual Reality*, 1. https://doi.org/10.3389/frvir.2020.598282

Şansal, K. E., Şimşek, A. C., Aktan, S., Özbey, F., & Paksoy, A. (2024). Restorative Effects of Virtual Nature on the Emotional Well-being of Community-dwelling Older Adults. *Eur J Geriatric Gerontol*, 6(1), 12-18. https://doi.org/10.4274/ejgg.galenos.2023.2023-3-2

Schebella, M. F., Weber, D., Schultz, L., & Weinstein, P. (2020). The nature of reality: Human stress recovery during exposure to biodiverse, multisensory virtual environments. *International Journal of Environmental Research and Public Health*, 17(1), 56. https://doi.org/10.3390/ijerph17010056

Schutte, N. S., Bhullar, N., Stilinović, E. J., & Richardson, K. (2017). The impact of virtual environments on restorativeness and affect. *Ecopsychology*, 9(1), 1-7. https://doi.org/10.1089/eco.2016.0042

Seiz, A., Kweon, B. S., Ellis, C. D., Oh, H., & Pietro, K. (2023). Exploring the Psychophysiological Effects of Viewing Urban Nature through Virtual Reality Using Electroencephalography and Perceived Restorativeness Scale Measures. *Sustainability*, 15(17), 13090. https://doi.org/10.3390/su151713090

Suppakittpaisarn, P., Wu, C. C., Tung, Y. H., Yeh, Y. C., Wanitchayapaisit, C., Browning, M. H., ... & Sullivan, W. C. (2023). Durations of virtual exposure to built and natural landscapes impact self-reported stress recovery: evidence from three countries. *Landscape and Ecological Engineering*, 19(1), 95-105. https://doi.org/10.1007/s11355-022-00523-9

Suseno, B., & Hastjarjo, T. D. (2023). The effect of simulated natural environments in virtual reality and 2D video to reduce stress. *Frontiers in Psychology*, 14, 1016652. https://doi.org/10.3389/fpsyg.2023.1016652

Talamo, A., Marocco, S., and Tricol, C. (2021). "The Flow in the Funnel": Modelling Organizational and Individual Decision-Making for Designing Financial AI-Based Systems. *Frontiers in Psychology* 12:697101. https://doi.org/10.3389/fpsyg.2021.697101

Theodorou, A., Romano, L., Bratman, G. N., Carbone, G. A., Rodelli, R., Casagrande, G., & Panno, A. (2023). Different types of virtual natural environments enhance subjective vitality through restorativeness. *Journal of Environmental Psychology*, 87, 101981. https://doi.org/10.1016/j.jenvp.2023.101981

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research*, 166, 628-637. https://doi.org/10.1016/j.envres.2018.06.030

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, 11(3), 201-230. https://doi.org/10.1016/S0272-4944(05)80184-7

Ünal, A. B., Pals, R., Steg, L., Siero, F. W., & Van Der Zee, K. I. (2022). Is virtual reality a valid tool for restorative environments research?. *Urban forestry & urban greening*, 74, 127673. https://doi.org/10.1016/j.ufug.2022.127673

Walters, G., Gill, C., Pham, L. D. Q., & Filep, S. (2024). Virtual Tourism Experiences and Mental Restoration. *Journal of Hospitality & Tourism Research*, 48(3), 564-569. https://doi.org/10.1177/10963480221116047

Yin, J., Bratman, G. N., Browning, M. H., Spengler, J. D., & Olvera-Alvarez, H. A. (2022). Stress recovery from virtual exposure to a brown (desert) environment versus a green environment. *Journal of Environmental Psychology*, 81, 101775. https://doi.org/10.1016/j.jenvp.2022.101775

Yu, C. P., Lee, H. Y., Lu, W. H., Huang, Y. C., & Browning, M. H. (2020). Restorative effects of virtual natural settings on middle-aged and elderly adults. *Urban Forestry & Urban Greening*, 56, 126863. https://doi.org/10.1016/j.ufug.2020.126863

Yu, C.-P., Lee, H.-Y., & Luo, X.-Y. (2018). The effect of virtual reality forest and urban environments on physiological and psychological responses. *Urban Forestry & Urban Greening*, 35, 106–114. https://doi.org/10.1016/j.ufug.2018.08.013

Zhang, G., Wu, G., & Yang, J. (2023). The restorative effects of short-term exposure to nature in immersive virtual environments (IVEs) as evidenced by participants' brain activities. *Journal of Environmental Management*, 326, 116830. https://doi.org/10.1016/j.jenvman.2022.116830