Journal of Environmental Psychology 89 (2023) 102044

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Virtual nature and psychological and psychophysiological outcomes: A systematic review

Giuseppina Spano [a,b,1], Annalisa Theodorou [c,*,1], Gerhard Reese [d], Giuseppe Carrus [c], Giovanni Sanesi [b], Angelo Panno [e,**]

[a] *Department of Education, Psychology, Communication Sciences, University of Bari Aldo Moro, Italy*
[b] *Department of Agricultural and Environmental Sciences, University of Bari Aldo Moro, Bari, Italy*
[c] *Department of Education, Experimental Psychology Laboratory, Roma Tre University, Rome, Italy*
[d] *Department of Social, Environmental and Economic Psychology, Faculty of Psychology, University of Koblenz-Landau, Landau, Germany*
[e] *Department of Human Science, European University of Rome, Rome, Italy*

A R T I C L E I N F O

Handling Editor: L. McCunn

Keywords:
Virtual reality
Psychological outcome
Psychophysiological outcome
Affect
Stress
Restorativeness

A B S T R A C T

Evidence on the benefits of virtual nature is steadily increasing. In the current paper, we present a systematic review summarizing studies that examined the effects of virtual nature on psychological and psychophysiological outcomes up to March 2023. We found 236 records, of which 59 met the eligibility criteria. Results from quality assessment showed that most studies were of high or very high quality. Studies addressed three main outcomes: mood, stress, and restorativeness. Other outcomes such as environmental preference and pleasantness, cognitive performance, and nature connectedness received less attention, while others such as behavior and behavioral intentions, creativity, perceived safety, subjective vitality, and dental experience were hardly investigated at all. Findings generally point to a positive effect of virtual nature on its users, although further evidence is needed. Studies adopted experimental or quasi-experimental designs, used heterogeneous measures, and often sample sizes of unknown power. Future research could consider uninvestigated outcomes using larger studies with adequate power, specific samples, a focus on building new theories and on identifying best practices. Also, disentangling the optimal type and duration of virtual exposure and investigating the role of individual differences in its effectiveness for desirable psychological and psychophysiological changes is warranted.

1. Introduction

The psychological benefits that nature offers to humans are undisputed. Several decades of research attest to how exposure to outdoor natural environments can improve mental and physical health (e.g., Bratman, Daily, Levy, & Gross, 2015; Carrus et al., 2015; Coventrye et al., 2021; Giannico et al., 2021; McMahan & Estes, 2015; Yao, Zhang, & Gong, 2021). According to the biophilia hypothesis, people have an innate need for affiliation with nature since it is related to our evolution (Wilson, 1984), while for both Stress Reduction Theory (SRT; Ulrich, 1983) and Attention Restoration Theory (ART; Kaplan & Kaplan, 1989), nature is restorative, in terms of affect and cognitive recovery from stress and mental fatigue.

However, under some circumstances, it can be difficult to access nature. For instance, several studies point to the importance of exposure to nature for populations with special needs, such as hospitalized patients (Nejati, Rodiek, & Shepley, 2016) and prisoners (Li, Zhang, et al., 2021). Some evidence already shows that even non-direct experience of nature, such as exposure to nature views, images, or videos can have temporary positive health and cognitive performance outcomes (Bratman, Hamilton, & Daily, 2012; Mcsweeney, Rainham, Johnson, Sherry, & Singleton, 2014; Pasca et al., 2021). However, as compared to brief changes in people's mental states, what is desirable for psychological intervention are long-term changes.

Virtual reality (VR) is defined as the simulation of environments in 3D, accessible often through special equipment such as head-mounted displays but also 2D screens, that provide the user with a sense of reality (Jayaram, Connacher, & Lyons, 1997). The *immersive experience*

* Corresponding author.
** Corresponding author.
E-mail addresses: annalisa.theodorou@uniroma3.it (A. Theodorou), angelo.panno@unier.it (A. Panno).
[1] These authors share first authorship.

https://doi.org/10.1016/j.jenvp.2023.102044
Received 14 November 2022; Received in revised form 1 June 2023; Accepted 1 June 2023
Available online 3 June 2023

may be the most important characteristic for the associated psychological benefits, such as improved mood and perceived restorativeness (Li, Dong, et al., 2021; Liszio, Graf, & Masuch, 2018). A greater sense of experienced presence is what differentiates virtual reality from 2D photos and videos (Yeo et al., 2020). The fruition of virtual nature (i.e., exposure to natural environments via VR) can occur through computer-generated environments or 360° panoramic photos and videos of real natural environments. While the former allows for interactivity, the latter is also associated with benefits through the sense of reality and vividness that may evoke (Yeo et al., 2020). Natural environments used are more often green (e.g., forests and urban parks) and blue (e.g., beaches and rivers' shores). Sometimes the VR experience may be combined with auditory and olfactory stimuli (e.g., Hedblom et al., 2019).

In recent years, empirical evidence revolving around the impact of exposure to VR is growing. Especially since the outbreak of the Covid-19 pandemic, the uses of VR for health (Mantovani et al., 2020; Singh et al., 2020) seems to have drawn even greater attention (Ball, Huang, & Francis, 2021). In addition, people's relationship with nature was shaped by the pandemic and the lockdowns. Indeed, some authors noted that spending prolonged time indoors due to containment measures can cause psychological distance from natural environments, especially for the youngest (Honey-Rosés et al., 2020). Indoor exposure to nature through VR may mitigate the impact of home confinement if it becomes necessary again due to future pandemics or other causes (Spano et al., 2021; Theodorou et al., 2021). For instance, influential companies such as Meta are investing in these technologies, facilitating a decrease in the prices of VR devices, and indicating that there could be significant dissemination of this medium in the near future (Kraus, Kanbach, Krysta, Steinhoff, & Tomini, 2022).

Despite the growing interest in the application of virtual nature, there has been as yet limited effort to gather and systematically summarize the available studies (Browning, Shipley, et al., 2020; Li, Zhang, et al., 2021; Nukarinen et al., 2022; White et al., 2018), especially regarding psychological outcomes not strictly related to well-being (Frost et al., 2022; Riches, Azevedo, Bird, Pisani, & Valmaggia, 2021).

1.1. Aims of the study

The aim of the current study was to systematically review the available studies on the psychological and psychophysiological benefits of virtual nature, including but not limited to well-being. In particular, first, we critically reviewed studies that used virtual exposure to different kinds of natural environments and that measured effects on different psychological and psychophysiological variables, focusing on instruments and methods (e.g., type of exposure, type of natural environment). The basic idea was to synthesize the current state of work and provide a broad picture of the available findings that could be inclusive as much as possible in terms of outcomes and methods. We believe that this is an added value as compared to recently published systematic reviews (e.g., Frost et al., 2022; Riches et al., 2021). Second, we identified potential intervening variables in the relationship between virtual nature experience and psychological and psychophysiological outcomes, namely relevant moderators and mediators. Moderators can inform about specific populations or conditions that may hinder or strengthen the observed effects, while mediators may suggest relevant mechanisms and help develop valuable theories.

2. Method

In accordance with the EQUATOR Reporting Guideline Decision Tree (Simera et al., 2010), the structure of this paper was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher, Liberati, Tetzlaff, Altman, & Prisma Group., 2009). The PRISMA statement ensures evidence-based reporting of systematic reviews according to a checklist and a flow diagram describing the process of identification of the final set of selected studies.

2.1. Search strategy

The principal database used for bibliographic searches was Scopus. Since our intent was to ensure complete coverage of psychological and psychophysiological outcomes, we started our search by indicating only the exposure, thus not including outcomes and measures in the search query. A search query was created based on general, basic keywords on the tool of interest (i.e., "virtual reality" OR "immersive virtual reality" OR oculus OR viewer) and types of exposure to nature ("virtual nature" OR "greenspace" OR "green space" OR "blue space" OR "bluespace" OR "white space" OR "whitespace" OR "natural environment" OR "natural virtual environment" OR "exposure to nature" OR "exposure with nature" OR "contact with nature" OR "contact to nature" OR "proximity to nature" OR "urban nature"). No limits regarding the publication year were set. After the first step of selection on Scopus, we checked for possible further publication records on Web of Science and PsycINFO. Since only duplicates of records already retrieved on Scopus were found, we continued the selection process for eligibility via this platform. This phase of study selection was completed on March 16, 2023. In Fig. 1, the number of studies considered and their distribution per year is graphically represented. As can be seen, there is evidence of growing interest over the years, from 1996 to 2022.

2.2. Inclusion and exclusion criteria

English peer-reviewed articles published in scientific journals were considered eligible; thus, gray literature was not considered. We excluded (a) conference papers, since they were not available in their full-text versions and/or the reported contents had also been published in the form of an article, (b) reviews, (c) conference reviews, (d) book chapters, since full texts were not available, (e) notes, (f) books, and (g) retracted papers. A further selection step was based on the subject area. Since we were interested in psychological and psychophysiological outcomes, we excluded (h) articles published in journals classified in the areas of mathematics, physics and astronomy, chemistry, and material science, i.e., areas in which these outcomes are typically not contemplated. Table S1 shows the complete syntax of the search query used in the Scopus database.

2.3. Data extraction and article selection

Records selected were screened for eligibility in two further steps. First, they were assessed by title, abstract, and keywords, in order to make sure that they met all the exclusion and inclusion criteria, i.e., focus on psychological and/or psychophysiological outcomes, human subjects, and exposure to nature via VR. Psychological and psychophysiological outcomes were defined as outcomes of interest to the psychological field, in that their investigation: 1) would be helpful to describe how people behave; 2) help understand why people behave in a certain way; 3) help predict how people will behave in certain situations; 4) help develop ways to intervene to alter potentially nocive behaviors and situations (see Plotnik & Kouyoumdjian, 2013, p. 4). Identified eligible records were extracted and their full texts were downloaded. As a final check, the last step for eligibility consisted in reading the full texts and checking for the aforementioned inclusion/exclusion criteria. The process of article selection was conducted by two independent reviewers (GS and AT). On five occasions, a third independent rater (AP) was employed to solve disagreements since the majority rate was considered. A total of 59 articles were included in this systematic review. The entire process of the search strategy and article selection is displayed in Fig. 2.

2.4. Quality assessment checklist

The set of selected articles includes mainly studies with experimental

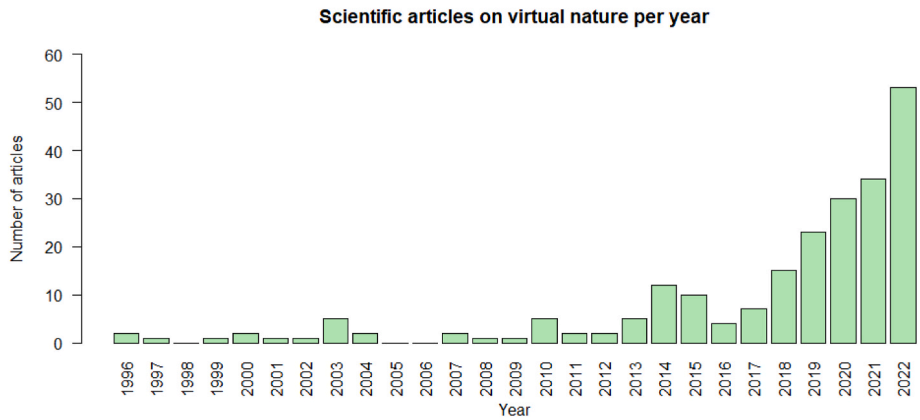

Fig. 1. Number of scientific articles on virtual nature per year (source: Scopus).
Note. The year 2023 has not been considered since it is not yet finished at the time of the search.

and quasi-experimental research designs, but also randomized controlled trials, and interventions. To our knowledge, no available checklist for simultaneously assessing each of the aforementioned research designs was available, and using three different checklists to evaluate studies among the same set might not lead to consistent selections. To overcome this issue, we created a new checklist for quality assessment based on two available checklists of The Joanna Briggs Institute's critical appraisal tools for use in JBI Systematic Reviews (Tufanaru, Munn, Aromataris, Campbell, & Hopp, 2020), i.e., the Checklist for Quasi-Experimental Studies (Non-Randomized Experimental Studies) and the Checklist for Randomized Controlled Trials. Our checklist consisted of eight items scored on (1) research design, (2) control group, (3) comparability between samples, (4) VR task, (5) measures, (6) statistical analysis, (7) appropriateness of results, and (8) presence of power analysis for sample size calculation (Table S2). Each item was scored with 1 (Yes/addressed/clear), 0.5 (Partially addressed/partially clear), or 0 (No/not addressed/not clear). Quality assessment was conducted by two independent reviewers (GS and AT). The interrater reliability as assessed with the Cohen's Kappa coefficient for the 8 items of the quality assessment ranged from 1 ($p < .001$; i.e., perfect agreement, in case of items 2, 4, 5, 6, 7, and 8) to 0.667 ($p < .001$) for item 1. In case of disagreement, the decision of another reviewer (AP) was applied. The maximum score for quality assessment was 8.

3. Results

3.1. Characteristics of included studies

Fifty-nine studies were included in this systematic review (Table S3). The studies taken into consideration were distributed among Europe, Asia, and North America. Specifically, twenty-four were conducted in Europe (10 in Germany, 2 in Norway, 2 in Sweden, 3 in The Netherlands, 1 in Finland, 1 in France, 1 in Ireland, 1 in Italy, and 3 in the United Kingdom), eighteen in Asia (12 in China, 4 in Taiwan, and 2 in Singapore), twelve in North America (10 in the United States and 2 in Canada), and four in Australia. One study was conducted on a mixed sample composed of people living in the United States, Taiwan, or Thailand for at least 5 years prior to the study.

The majority of studies (forty-nine) were conducted with healthy adult samples, of which thirteen involved university students and three older adults. Four studies selected participants based on their anxiety levels, either selecting only those with high levels of anxiety and/or depression (Li, Dong, et al., 2021; Shu, Wu, & Zhai, 2022; Wang, Sit, Tang, & Tsai, 2020) or just comparing VR benefits in participants with high vs. low levels of anxiety (O'meara, Cassarino, Bolger, & Setti, 2020; Tanja-Dijkstra et al., 2014). Another study focused on individuals with a low level of connectedness to nature (Leung, Hazan, & Chan, 2022). Two studies focused on individuals with acquired physical disabilities (Je & Lee, 2020; Lakhani et al., 2020), one on esophageal and gastrointestinal cancer patients (Song et al., 2022), one on a sample of pregnant women (Sun et al., 2023), one on patients undergoing hemodialysis (Hsieh & Li, 2022), one on dental patients (Tanja-Dijkstra et al., 2018). Special samples considered were remote workers (Ch et al., 2023). Taking into consideration all articles, the minimum sample size of participants per study is 14 while the maximum was 1280. Sample size varied based on the number of conditions in the study design.

3.2. Quality assessment

The total score of the quality assessment checklist was obtained by summing the scores of each item of the checklist. We categorized the studies into four categories: "very high quality" (score ≧ 7), "high quality" (score from 5 to 6.5)"medium quality" (score from 3 to 4.5), and "low quality" (score ≦ 2) (Table S4). Sixteen studies were classified as having a very high quality, a further thirty-nine studies as having "high quality". Three studies were classified as having "medium quality" and only one as having "low quality". The item on which we found the lowest average score is that of power analysis. Only thirteen studies reported having carried out an a priori power analysis. On the other hand, all of the included studies described clear and complete study results. The VR tasks used and the statistical analyses performed were also found to be highly satisfactory (quality criteria numbers 4 and 6 in Table S2). Table S4 shows the scores and judgment for the quality assessment for each study considered.

3.3. Research findings

Findings are reported in a detailed way and organized by type of virtual exposure and outcome investigated: Each section can be read independently by readers interested in specific results. The current section is structured as follows. We first report findings compared by type of virtual exposure (i.e., virtual nature vs. on-site exposure, virtual nature vs. virtual urban environment, and virtual nature vs. virtual indoor experience). We then present results divided by outcomes investigated. We found that psychophysiological outcomes were only used to investigate physiological stress, thus they are reported in this section. Outcomes are listed by number of evidence available (i.e., mood, affect, and emotion, perceived stress and relaxation, physiological stress, restorativeness, environment preference and pleasantness, cognitive performance, nature connectedness, behavior and behavioral intentions, creativity, perceived safety, subjective vitality, and dental experience). Next, we focus on findings on the intervening variables and, lastly, we report results on the variables related to the VR experience.

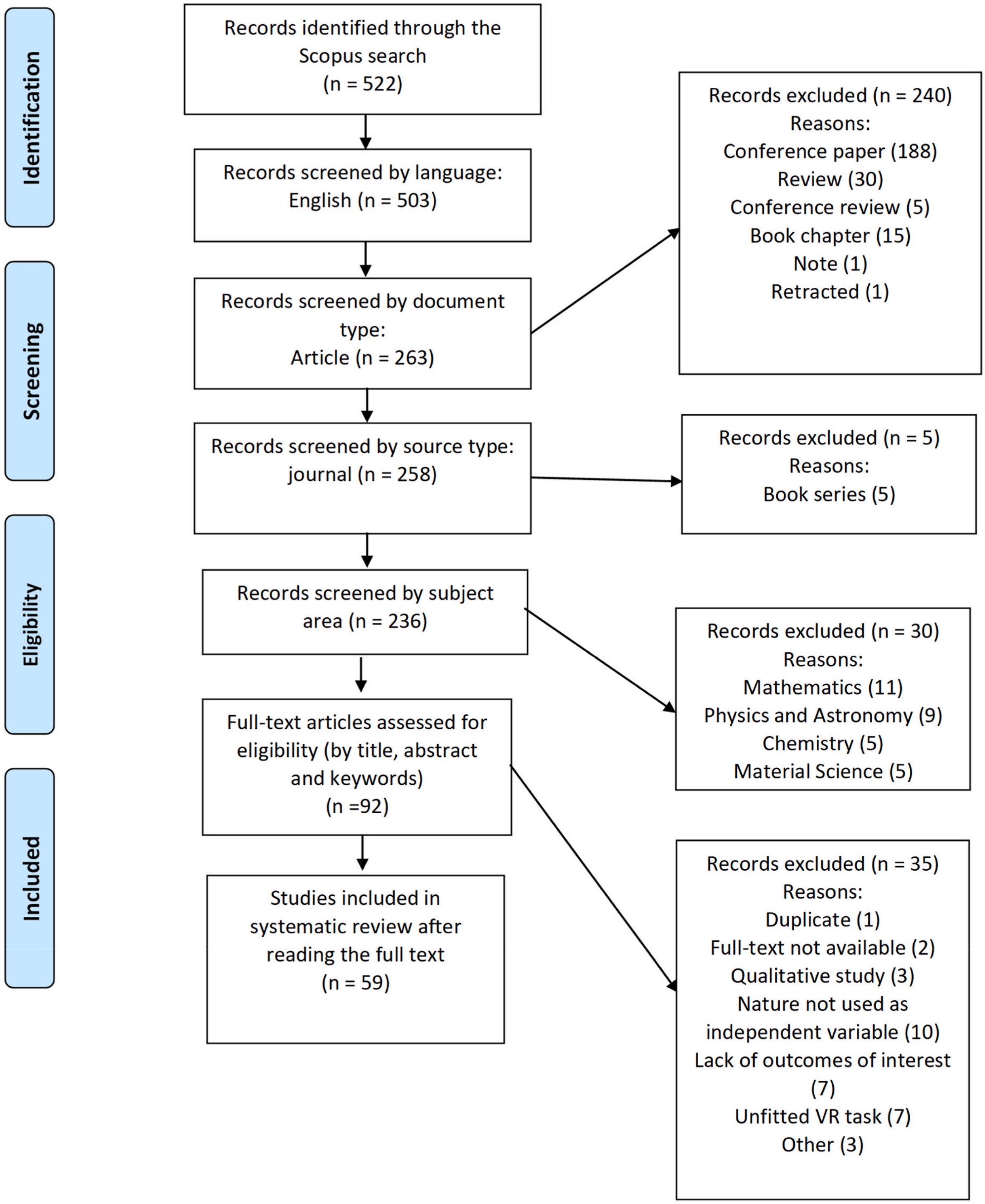

Fig. 2. Systematic review flow chart detailing the literature search, number of abstracts screened, and full texts retrieved.

3.3.1. *Exposure: virtual nature*

All studies featured in this review had at least one virtual nature exposure condition. Types and conditions of exposure varied significantly among the selected studies. Almost all studies included green environments e.g., forests, urban green spaces, parks, courtyards, and gardens. Blue environments were beaches, rivers, lakes, waterfalls, and underwater environments such as a tropical coral reef. Most of them combined virtual nature with the use of auditory and even olfactory stimuli such as bird and water sounds and garden smell. Among others, only one study (Lakhani et al., 2020) exposed participants to a white (polar) environment, and one other (Yin, Bratman, Browning, Spengler, & Olvera-Alvarez, 2022) to a brown (desert) environment. The length of a single exposure was characterized by a wide variability, which lasted from a minimum of 26 s to a maximum of 45 min. The majority of studies used footage of real environments (32, 54.24%), while another consistent part used computer-generated images (23, 38.98%). Only one study (1.69%) digitally manipulated shootings of real environments and one study (1.69%) had both real and computer-generated images in their study design. Lastly, two studies (3.40%) did not report this information.

Eighteen studies (Blum, Rockstroh, & Göritz, 2019; Evensen et al., 2021; Gao et al., 2019; Huang, Yang, Jane, Li, & Bauer, 2020; Je & Lee, 2020; Lakhani et al., 2020; Lindquist, Maxim, Proctor, & Dolins, 2020;

Liszio et al., 2018; Liszio & Masuch, 2019; Mattila et al., 2020; Pals, Steg, Dontje, Siero, & van Der Zee, 2014; Reese, Kohler, & Menzel, 2021; Rockstroh, Blum, & Göritz, 2019; Shu et al., 2022; Song et al., 2022; van Vliet et al., 2021; Wang, Shi, Zhang, & Chiang, 2019; Yeo et al., 2020) explored the effect of a number of natural environments reproducing different types of stimuli. Such stimuli might consist of images, 2D videos, immersive VR through headsets, shutter glasses, or Cave VE system, or through the manipulation of certain features of the same condition in virtual nature (e.g., interactive vs. noninteractive virtual game, as in Liszio & Masuch, 2019). Overall, the immersive virtual experience was found to be more effective than other media (e.g., Knaust et al., 2022); however, the wide variability of exposure (visual, olfactory, and auditory stimuli, and a variety of features embedded into natural environments), media, and outcomes considered, led to a remarkable variability of differentiated findings (see Table S3). As an example, Gao, Zhang, Zhu, Gao, and Qiu (2019) exposed participants to six different virtual environments, namely gray space (also defined as "built environment"), blue space, open green space, partly open green space, partly closed green space, and closed green space through 360° panoramic photos with a head-mounted display. Authors reported a general positive effect of the six landscapes on attentional fatigue and negative mood, nevertheless, more specifically, partly open space seemed to provide a higher positive effect on mood, while blue and partly closed spaces were identified as the most preferred for recreational purposes. At the same time, a courtyard with grass and trees was demonstrated to induce a lower level of stress in previously stressed participants compared to a courtyard without vegetation (Huang et al., 2020). Shu et al. (2022), comparing different landscape structures, found that different permeability levels and viewing distance have a crucial role both in landscape preference and in anxiety and depression levels.

Noteworthy are two studies (Blum et al., 2019; Rockstroh et al., 2019) that employed Virtual-Based Heart Rate Variability (VR-HRV) biofeedback (as a treatment for a wide range of stress-related conditions through the use of computer-generated virtual environments) in comparison with traditional HRV biofeedback techniques on relaxation, mind wandering, attentional resources, and heart variability, and on physiological stress, mood, motivational aspects and attentional focus, respectively. The first study reported no significant differences in physiological responses and relaxation between the two conditions; nevertheless, the VR-HRV biofeedback was found to be more effective in reducing mind wandering and preserving attentional resources. Consistently, the other study reported no significant differences in heart-rate variability between the two techniques. Simultaneously, VR-based biofeedback was associated with higher motivation and higher attentional focus compared to the traditional one. Other attempts to combine traditional interventions and virtual nature exposure have been done. In a recent study (Ch et al., 2023) a sample of remote workers, after baseline measurements, was exposed to an intervention composed of a session of three weeks of virtual nature experience followed by three weeks of virtual nature experience combined with mindfulness practice. Findings showed that both interventions were useful in reducing stress and increasing focus; however, the combined intervention was the most effective for convergent thinking.

In general, repeated exposure to virtual nature is demonstrated to be effective in reducing heart rate in patients undergoing hemodialysis (Hsieh & Li, 2022), in improving mood states in individuals with physical disabilities (Kalantari et al., 2022), and in reducing worry and panic in university students (Browining et al., 2023).

3.3.1.1. Virtual nature vs. on-site exposure. Alongside a virtual nature condition, twelve studies (Browning, Shipley, et al., 2020; Calogiuri et al., 2018; Chirico & Gaggioli, 2019; Deringer & Hanley, 2021; Gao, Liang, Chen, & Qiu, 2019; Hofman, Hughes, & Walters, 2021; Léger & Mekari, 2022; Luo, Tao, Lu, Lu, & He, 2023; Reese, Stahlberg et al., 2022; Sneed, Deringer, & Hanley, 2021; Xiang et al., 2021; Ünal, Pals, Steg, Siero, & van der Zee, 2022) paired an *in vivo* exposure of a naturalistic setting. Browning, Saeidi-Rizi, McAnirlin, Yoon, and Pei (2020) exposed participants to the same type of natural environment in two ways. Participants either watched a 6-min 360-degree VR nature video or spent 6 min in an outdoor forest setting. Positive mood levels increased in the outdoor condition, decreased in the control condition (i.e., an indoor setting with no visual or auditory access to nature), but remained stable in the VR condition. However, participants in both nature-based conditions reported significantly greater perceived restorativeness than participants in the control condition. Those findings were consistent with Calogiuri and colleagues (Calogiuri et al., 2018) who claimed that outdoor exposure, even in brief sessions, enhances mood states. In their study, green exercise was performed outdoors or in two VR conditions, namely a sedentary exposition of a nature walk or through a virtual nature walk while on a manually activated treadmill. Interestingly, Luo et al. (2023) reported an improvement in children's auditory and visual attention test performance when a session of physical activity was followed by virtual nature exposure, but not in the opposite order. Sneed et al. (2021) compared 12-min VR videos of stationary clips using headsets and a short hike consisting in walking along a trail. They found that connectedness to nature was significantly higher in participants who experienced real-life exposure to nature. Regarding cognitive outcomes in university students, scores in tests on memory and executive functions were higher both after a virtual and a real walking session with no significant difference between the two conditions (Léger & Mekari, 2022). Evidence for similar beneficial effects of virtual experiences is provided by Chirico and Gaggioli (2019). They exposed participants to either a panoramic view of a lake or to an immersive 360-footage of the same landscape. In this experiment, positive and negative emotions did not differ between the two conditions. In agreement with these results, Gao, Liang, and colleagues (2019) found that participants most strongly preferred a VR environment, compared to an on-site exposure or mere photo presentation. Landscape preference was also investigated by Xiang et al. (2021), showing that virtual nature (i.e., open, semi-open, and closed green space across the four seasons) elicited more similar effects with on-site exposure than photo-elicitation. As expected, differentiated results were obtained across different seasons, media, and types of green space. Reese, Stahlberg et al. (2022) did not report differences between the two conditions (VR and in-vivo) on affect, restorativeness, subjective vitality, and stress, in healthy adults. Results on restorativeness were confirmed by Ünal et al. (2022) on a sample of university students. In line with this, Deringer and Hanley (2021) found no difference in the improvement in ecological behavior intentions after the two conditions. Regarding blue space, no difference in conservation behavior between VR blue environment (a 6-min video on the importance of the Great Barrier Reef) and real-life experience of the Great Barrier Reef was detected (Hofman et al., 2021).

3.3.1.2. Virtual nature vs. virtual urban environment. Seventeen studies offered virtual urban environments (e.g., squares and city districts), as a control condition, compared to virtual natural environments (Chan et al., 2021; Hedblom et al., 2019; Leung et al., 2022; Li, Dong, et al., 2021; Mostajeran, Krzikawski, Steinicke, & Kühn, 2021; O'meara et al., 2020; Palanica, Lyons, Cooper, Lee, & Fossat, 2019; Reese, Mehner, Nelke, Stahlberg, & Menzel, 2022; Schebella, Weber, Schultz, & Weinstein, 2020; Schutte, Bhullar, Stilinović, & Richardson, 2017; Song et al., 2022; Suppakittpaisarn et al., 2023; Sun et al., 2023; Tabrizian, Baran, Smith, & Meentemeyer, 2018; Tanja-Dijkstra et al., 2018, Study 2; Yu, Lee, & Luo, 2018; 2020). Hedblom et al. (2019) compared three multisensory environments, i.e., an urban area, an urban park, and an urban forest. Each visual stimulus was combined with appropriate olfactory stimuli, such as diesel for the urban area, grass and forest odors for the urban park and urban forest. Similarly, matching auditory stimuli were administered, such as traffic noise, bird sounds, and the sound of a slight breeze for the respective environments. As expected, the two virtual nature settings resulted in stronger stress reduction than the urban setting. Interestingly, perceived pleasantness was associated with olfactory and auditory stimuli, rather than with visual stimuli. The study highlights the relevance of multisensory approaches for VR research. This was subsequently supported by Schebella et al. (2020) who found a significant effect of perceived multisensory biodiversity on stress recovery over a control condition characterized by the absence of biodiversity (i.e., urban environment). In Li, Dong, et al. (2021), each group of participants with mild-to-moderate anxiety and depression was randomly assigned to one over four conditions on virtual natural scenes, or to a VR urban environment, i.e., a classic city with buildings, streets, and a couple of trees. Results confirmed a significant improvement in positive emotions and self-efficacy for individuals exposed to VR natural environments than to the urban scene. However, a good recovery effect was also found for VR urban scenes. According to the authors (Li, Dong, et al., 2021), it may be the case that providing a quiet urban environment without people produces a healing effect. Thus, one could hypothesize that a positive effect of the urban scene might be induced also by the way the stimulus is presented. In this regard, Mostajeran et al. (2021) recently compared the effects of a forest and an urban environment presented in two different ways, namely photo slideshows and 360° immersive videos. Although the type of environment influenced mood disturbance, fatigue, and cognitive performance (higher for urban exposure and lower for nature exposure), exposure to any condition reduced the heart rate. These findings are in line with Yu et al. (2018; 2020). In both studies, participants assigned to experimental and control conditions were immersed in scenes of blue and green environments or in urban scenes, such as a subway station and a shopping plaza. Results showed that participants' systolic blood pressure and heart rate decreased regardless of the condition. Nevertheless, in both studies, psychological benefits were greater after virtual nature exposure, except for attention performance which, in Yu, Lee, Lu, Huang, and Browning (2020), did not differ between the two conditions. Sun et al. (2023) observed a difference in psychophysiological outcomes only by comparing certain levels of green space exposure (high) and an urban condition. The same difference is not detectable when moderate levels of green space were displayed. Mixed evidence is available on mood and affect. Song et al. (2022) found higher positive emotions in the virtual nature conditions compared to the urban condition; however, no differences were found for negative affect and depression levels. Leung et al. (2022) reported an increase in restorativeness, nature connectedness, and enjoyment but the results on affects were inconsistent. Reese, Mehner, et al. (2022) found no differences in subjective vitality and restorativeness between the two conditions. Conversely, Palanica et al. (2019) observed that virtual nature increased perceived restorativeness and enhanced creative thinking more than viewing an urban environment, regardless of the medium (i.e., a 2D mobile tablet and a 3D VR headset). In the study by O'meara et al. (2020), participants with low or high anxiety were immersed in an alleyway of an urban town or in a lush green forest. Results showed that exposure to virtual nature significantly impacted high-anxiety university students in terms of reduction in negative affect. A town was also used in a previous study by Schutte and collaborators (2017) in which the VR condition resulted in a higher positive affect and restorativeness. Furthermore, restorativeness was found to be a mediator in the relationship between VR experience (both conditions) and positive affect, while connectedness to nature may act as a mediator between VR experience and reduced negative affect in young adults and positive affect in older adults (Chan et al., 2021). Tabrizian et al. (2018) identified perception of safety as a mediator in the relationship between urban green enclosure and perceived restorativeness with a stronger effect in the virtual park compared to the virtual plaza condition. Lastly, a virtual blue environment was observed to have a stronger effect on reduced experienced and recalled pain on a sample of dental patients, than standard dental care, while the same difference was not found comparing the VR urban environment and standard care (Tanja-Dijkstra et al., 2018).

3.3.1.3. Virtual Nature vs. Virtual Indoor Experience. Among the selected articles, in six studies (Anderson et al., 2017; Annerstedt et al., 2013; Burmeister, Moskaliuk, & Cress, 2018; Fleury, Blanchard, & Richir, 2021; Yin et al., 2022; Zhang, Wu, & Yang, 2023) the control group was exposed to an indoor environment, such as a virtual office room. In Anderson et al.'s study (2017), each participant viewed three 15-min 360° scenes of rural Ireland, remote beaches, and empty indoor classrooms. Results showed that both VR natural scenes provided relaxation and, interestingly, the preferred one elicited a higher reduction of negative affect and increased mood. Another study (Annerstedt et al., 2013) compared two conditions of virtual nature (i.e., with and without the sound of bird songs and water) and a control condition in which a test for inducing social stress in laboratory settings was virtually simulated. All conditions took place in a Cave Automatic Virtual Environment (CAVE) system, an immersive VR environment where projectors are directed onto the walls of a room-sized cube. After being exposed to a stressful situation, participants immersed in a natural environment with sounds through VR showed a better stress recovery, assessed through cardiovascular data and saliva cortisol, than participants of the other groups (i.e., soundless and control conditions). In line with this, Yin et al. (2022) found a reduction in physiological stress in participants exposed to a virtual desert environment compared to others exposed to a virtual office. Noteworthy was the sample composed of young males' resident in the desert. Burmeister et al. (2018), focusing on people's concentration, manipulated two virtual environments (i.e., a typical room office with furniture and a leisurely natural environment with trees, a garden, and a view of mountains, rivers, and a cottage). In this research, objective concentration (i.e., efficiency and accuracy) when performing a cognitive task was found to be higher in the control group (i.e., VR indoor condition) than in the group exposed to the VR leisure natural environment. However, no differences were found in accuracy, calculation speed, and counting tasks, nor in self-rated concentration level. On the other hand, a recent study (Zhang et al., 2023) suggested an increase in brain activities (e.g., attentional readiness and cognitive flexibility) after the exposition to virtual nature compared to the control condition. Fleury et al. (2021) investigated the environmental influences on creativity, through a sample of engineering school students, by asking them to perform a creative design activity in three different types of virtual environments (i.e., a forest, an office, and an empty dark room). This research supports the hypothesis that the natural condition, compared to two other conditions, boosts creativity score.

Lastly, we note an interesting study (Wang et al., 2020) focusing on individuals with Generalized Anxiety Disorder. In this study, authors design the experimental condition through VR using slideshows with green and blue environments (forests, parks, woods, and rivers), paired with a control one in which a number of Virtual Abstract Paintings (VAP) have been shown to participants. The experiment took place in a CAVE VE system, and each participant was asked to exercise (cycling activity) at a moderate intensity. Results showed that both groups had higher brain alpha activity, (i.e., relaxation), but the group exposed to virtual nature exhibited higher levels of perceived stress relief than those exposed to VAP.

3.3.2. Outcomes

3.3.2.1. Mood, affect, and emotion. In total, 32 studies measured changes in mood due to exposure to virtual nature (see Table 1 for classification of the articles by outcome investigated). In the majority of cases (i.e., seventeen studies; see Table S3), mood was measured with the Positive Affect and Negative Affect Scale (PANAS), six studies used the Profile of Mood States (POMS), four studies assessed affect using the State-Trait Anxiety Inventory (STAI-S), while other scales were used by single studies (e.g., Summary of Positive and Negative Experiences

Table 1
Articles per outcome investigated.

Outcome investigated	Articles	Main Results
Mood, affect, and emotion		
Positive emotions	Anderson et al. (2017), Browning, Mimnaugh, et al. (2020), Calogiuri et al. (2018), Chan et al. (2021), Chirico and Gaggioli (2019), Gao, Zhang, et al. (2019), Hsieh and Li (2022), Huang et al. (2020), Lakhani et al., 2020, Leung et al. (2022), , Liszio and Masuch (2019), Liszio et al. (2018), Li, Dong, et al. (2021)Mattila et al. (2020), O'meara et al. (2020), Reese et al. (2021), Reese, Stahlberg et al. (2022), Rockstroh et al. (2019), Schebella et al. (2020), Schutte et al. (2017), Song et al. (2022), Sun et al. (2023), Wang et al. (2019), Yeo et al. (2020), Yu et al. (2018), Yeo et al. (2020)	Results are inconsistent, some studies suggest an increase in positive affect.
Negative emotions	Anderson et al. (2017), Blum et al. (2019), Browning, Mimnaugh, et al. (2020), Browning et al. (2023), Calogiuri et al. (2018), Chan et al. (2021), Chirico and Gaggioli (2019), Gao, Zhang, et al. (2019), Huang et al. (2020), Kalantari et al. (2022), Leung et al. (2022), , Liszio and Masuch (2019), Liszio et al. (2018), Mattila et al. (2020)Li, Yang, et al. (2021), Mostajeran et al. (2021), O'meara et al. (2020), Reese et al. (2021), Reese, Stahlberg et al. (2022), Rockstroh et al. (2019), Schebella et al. (2020), Schutte et al. (2017), Shu et al. (2022), Song et al. (2022), Wang et al. (2019), Yeo et al. (2020), Yu et al. (2018); Yeo et al. (2020)	In most studies, virtual nature exposure decreased negative affect.
Perceived stress and relaxation	Blum et al., (2019), Ch et al. (2023), Chan et al. (2021), Knaust et al. (2022), Mostajeran et al. (2021), Reese et al. (2021), Reese, Stahlberg et al. (2022), Schebella et al. (2020), Suppakittpaisarn et al. (2023), Wang et al. (2020), Zhang et al. (2023)	Virtual nature exposure seems beneficial for stress reduction in most studies.
Physiological stress		
Heart rate	Anderson et al. (2017), Annerstedt et al. (2013), Blum et al. (2019), Chan et al. (2021), Hsieh and Li (2022), Knaust et al. (2022), Liszio and Masuch (2019), Liszio et al. (2018), Mostajeran et al. (2021), Rockstroh et al. (2019), Schebella et al. (2020), Shu et al. (2022), Song et al. (2022), Sun et al. (2023), Wang et al. (2019), Yu et al. (2018), Yeo et al. (2020)	The majority of studies indicate relaxation after VR in general (not virtual nature specifically).
Electrodermal activity (EDA)	Anderson et al. (2017), Browning, Shipley, et al. (2020), Hedblom et al. (2019), Huang et al. (2020), Knaust et al. (2022), Mostajeran et al. (2021), Shu et al. (2022), Sun et al. (2023)	Inconsistent findings.
Blood pressure	Shu et al. (2022), Song et al. (2022), Sun et al. (2023), Wang et al. (2019), Yin et al. (2022), Yu et al. (2018), Yeo et al. (2020)	Inconsistent findings.
Electroencephalography (EEG).	Gao, Zhang, et al. (2019), Je and Lee (2020), Li, Dong, et al. (2021), Song et al. (2022), Wang et al. (2020), Zhang et al. (2023)	Most studies suggest higher relaxation and cognitive recovery.
Salivary cortisol	Annerstedt et al. (2013), Liszio et al. (2018), Sun et al. (2023), Yin et al. (2022)	Most studies report no effect of virtual nature exposure.
Salivary amylase	Sun et al. (2023), Wang et al. (2019), Yu et al. (2018)	Inconsistent findings.
Restorativeness	Browning, Mimnaugh, et al. (2020), Calogiuri et al. (2018), Leung et al. (2022), Li, Dong, et al. (2021), Mattila et al. (2020), Pals et al. (2014), Reese et al. (2021), Reese, Mehner et al. (2022), Reese, Stahlberg et al. (2022), Schutte et al. (2017), Song et al. (2022), Tabrizian et al. (2018), Ünal et al. (2022), Wang et al. (2020), Yeo et al. (2020)	Most studies point to both greater restorative qualities of virtual nature and restorative processes associated with it.
Environment preference and pleasantness	Anderson et al. (2017), Gao, Liang, et al. (2019), Gao, Zhang, et al. (2019), Hedblom et al. (2019), Lindquist et al. (2020), Pals et al. (2014), Shu et al. (2022), Song et al. (2022), Ünal et al. (2022), van Vliet et al. (2021), Xiang et al. (2021), Yin et al. (2022)	Virtual nature sceneries were mostly preferred and rated as pleasant.
Cognitive performance	Blum et al. (2019), Ch et al. (2023), Burmeister et al. (2018), Gao, Zhang, et al. (2019), Léger and Mekari (2022), Luo et al. (2023), Mostajeran et al. (2021), O'meara et al. (2020), Rockstroh et al. (2019), Yeo et al. (2020), Zhang et al. (2023)	Almost all studies did not find significant effects of virtual nature alone.
Nature connectedness	Chan et al. (2021), Hofman et al. (2021), Leung et al. (2022), Schutte et al. (2017), Sneed et al. (2021), Yeo et al. (2020)	Preliminary findings may suggest an increase, but further studies are needed.

(continued on next page)

Table 1 (*continued*)

Outcome investigated	Articles	Main Results
Behavior and behavioral intentions	Deringer and Hanley (2021), Hofman et al., (2021), Leung et al. (2022), Tanja-Dijkstra et al. (2014)	Further studies are needed.
Creativity	Ch et al. (2023), Fleury et al. (2021), Palanica et al. (2019)	Further studies are needed.
Perceived safety	Evensen, Nordh, Hassan, and Fyhri (2021), Shu et al. (2022), Tabrizian et al. (2018)	Further studies are needed.
Subjective vitality	Mattila et al. (2020), Reese, Mehner et al. (2022), Reese, Stahlberg et al. (2022)	Further studies are needed.
Dental experience	Tanja-Dijkstra et al. (2014), Tanja-Dijkstra et al. (2018)	Results are suggestive for a beneficial effect.

SPANE scale). Single-item measures were also used across different studies. In eight studies (Anderson et al., 2017; Huang et al., 2020; Liszio et al., 2018; Liszio & Masuch, 2019; Mostajeran et al., 2021; Schebella et al., 2020; Shu et al., 2022; Sun et al., 2023), mood was measured before and after stress induction (recovery) and in one after a boredom induction (Yeo et al., 2020), while in all the other cases it was measured after exposure to virtual and other types of nature. Four studies selected participants based on their anxiety levels, either selecting only those with mild/high levels of anxiety and/or depression (Li, Dong, et al., 2021; Shu et al., 2022; Wang et al., 2020) or just comparing participants on their level of anxiety (O'meara et al., 2020).

Positive Emotions. The effect of virtual nature on positive emotions is inconsistent. A series of studies found that positive emotions did not increase after exposure to virtual nature (Anderson et al., 2017; Gao, Zhang, et al., 2019; O'meara et al., 2020), not even during a long-term intervention (Hsieh & Li, 2022; Leung et al., 2022). Other studies, however, report significant effects suggesting that exposure to virtual nature was at least no different from exposure to other conditions, such as outdoor nature and biofeedback without VR or no biofeedback (Chirico & Gaggioli, 2019; Reese, Stahlberg et al. 2022; Rockstroh et al., 2019). In one study, VR conditions even decreased positive affect. Calogiuri et al. 's (2018) results report more enjoyment after an outdoor walk than the two VR conditions (i.e., sitting and treadmill). Positive affect and levels of tranquility were significantly reduced after the two VR conditions, with the sitting condition with significantly more reduced positive emotions than the treadmill condition.

Another set of studies found an increase in positive affect (Browning, Mimnaugh, et al., 2020; Huang et al., 2020; Lakhani et al., 2020; Leung et al., 2022; Mattila et al., 2020; Schutte et al., 2017; Song et al., 2022; Yu et al., 2018, Yu et al., 2020). For instance, in Mattila et al. (2020), positive affect increased after exposure to a virtual forest. In Browning, Shipley, et al. (2020), exposure to virtual nature as well as outdoor nature was associated with higher positive affect as compared to an indoor condition. In three studies, higher positive affect and vigor were found in the VR natural (vs. urban) environment (Leung et al., 2022; Schutte et al., 2017; Song et al., 2022; Sun et al., 2023; Yu et al., 2018). In two studies (Chan et al., 2021; Yu et al., 2020), after being exposed to a virtual urban environment, positive affect decreased. In Huang et al. (2020), exposure to a courtyard with grass (as compared to one with trees and one without vegetation) after stress induction had the highest effect on positive affect.

Two studies found an increment in positive affect after virtual nature exposure as compared to other delivery modes. In Liszio et al. (2018), a higher increment of positive affect was found in the virtual condition as compared to the desktop and control conditions. In another study (Yeo et al., 2020), positive affect was associated with the delivery mode (i.e., 2D screen, 360° videos of real nature, and computer-generated virtual nature) in a way that the major increment in positive affect was observed in the most immersive mode, i.e., virtual nature rather than the less immersive ones, i.e., 2D screen and 360° videos.

Interesting to note is the effect on positive affect in those studies that compared the effect of VR with or without interaction. In Li, Dong, et al. (2021), positive affect decreased just in the natural interactive environment but not in an urban and a natural non-interactive environment in participants with mild to moderate anxiety and depression. In the study by Liszio and Masuch (2019), no significant differences were found after mere exposure to all conditions (interactive, noninteractive, and control conditions). Lastly, control was irrelevant in determining positive affect. Similarly, Reese et al. (2021) found that the positive affect was higher after VR regardless of whether the participant had or had not active control in the navigation.

Few studies investigated the differences in positive affect as compared to exposure to different natural environments. For instance, in Schebella et al.'s (2020) study, when compared to the virtual urban environment, the low biodiversity virtual environment showed greater happiness. All the other differences between higher levels of biodiversity were nonsignificant. In Wang et al. (2019), it emerged that three environments were successful in increasing vigor, namely waterfall with trees, wood with bench, and the most artificial natural environment. On the contrary, the other three environments, namely wood with a platform and bench, a platform with trees, and a pool with plants decreased it.

Negative Emotions. In this section, we review studies showing how exposure to virtual nature decreases negative affect. As compared to a virtual urban environment, the virtual natural environment significantly decreased negative affect, confusion, anger-hostility, tension, depression, and fatigue (Chan et al., 2021; Leung et al., 2022; Mattila et al., 2020; Yu et al., 2018, 2020). Overtime exposure to virtual natural environments decreased worry and panic in Browning et al. (2023), with no similar significant changes found for a condition with no exposure. Nervousness decreased in Kalantari et al. (2022) after three modules of exposure. Mostajeran et al. (2021), after stress induction, found that the virtual urban environment (vs. virtual forest) worsened the mood while, on the contrary, fatigue decreased after the virtual forest (vs. urban environment) exposure. Interestingly, in three studies, fatigue even increased after the virtual urban environment (Mostajeran et al., 2021; Yu et al., 2018, 2020). O'meara et al. (2020) found a three-way interaction between time, condition, and anxiety levels. In other words, they found a significant reduction (between pre- and post-levels) in negative affect in students with high (but not with low) anxiety exposed to a virtual natural environment and the increase was higher than in the urban condition. Chirico and Gaggioli (2019) found negative emotions such as anger, disgust, and sadness significantly decreased after exposure to virtual nature, but not after outdoor nature.

Different scholars focused on the type of environments that could result in a higher decrease of negative emotions. For instance, in Schebella et al. (2020) a low biodiversity environment showed lower anxiety and stress as compared to the urban environment and a higher biodiversity environment. Anxiety was also lower in a multisensorial environment than in a visual-only environment, demonstrating that auditory and olfactory stimuli can make a difference in effectiveness. Wang et al. (2019) compared different natural environments and found that the highest recovery in mood and anxiety was in the natural environment with the most presence of artificial elements and in blue spaces (vs. forest environments with different elements such as waterfalls and artificial elements).

In Gao, Zhang, et al. (2019) the most effective natural environments in reducing negative emotions were the partly open green space, and then the open green space, the partly closed green space, and the blue space, while the gray space and the closed green space were the least effective. Shu et al. (2022) investigated edge permeability and viewing distance of green spaces and found that the higher anxiety and depression scores were related to landscapes at a viewing distance of 20 m (vs. 100 m and 200 m) and characterized by high edge permeability. Interestingly, it seems that a role is played by preference. Indeed, in Anderson et al. (2017), the preferred natural environment shown (green or blue) decreased negative emotions. Despite these positive findings, two studies did not find any differences in the reduction of negative affect due to the type of natural environment shown (Huang et al., 2020; Li, Dong, et al., 2021).

Some studies investigated additional characteristics that could enhance the efficacy of VR. In the study by Reese et al. (2021), negative emotions were lower after the VR experience regardless of the level of activity in the navigation exerted by participants. In Liszio and Masuch (2019) exposure to interactive VR was associated with less anxiety than in the control group after exposure to the environments. Mostajeran et al. (2021), after stress induction, found no differences in depressive and anxiety symptoms, or stress for the type of medium used (VR or photos). One study (Liszio et al., 2018) suggests the added value of virtual environments on traditional media. Here, exposure to a natural environment reduced anxiety and the reduction was significantly different for VR condition vs. desktop and control. Lastly, two studies investigated VR as a potential tool to lower anxiety in combination with other important clinical instruments such as biofeedback. Findings by Blum et al. (2019) on anxiety attested that exposure to a natural VR environment combined with biofeedback was more successful than biofeedback alone in sustaining the levels of anxiety. However, Rockstroh et al. (2019) did not find any specific effects of virtual nature combined with biofeedback on mood.

Lastly, a small set of studies did not find any specific effect of exposure to virtual nature on negative mood. For instance, tiredness did not decrease after one-time exposure in Kalantari et al. (2022), while depression and rumination did not change after repeated exposure in Browning et al. (2023). In Schutte et al. (2017) there was no effect of condition (VR natural vs. VR urban) on negative affect. Three studies found a decrease in negative affect and boredom across all conditions, with no specific effects for virtual natural environments (vs. outdoor nature or a no exposure condition; Browning, Mimnaugh, et al. (2020); Reese, Stahlberg et al. (2022) and vs. virtual urban environments; Song et al., 2022) and the virtual medium (Yeo et al., 2020). In the study by Calogiuri et al. (2018), in the sitting VR condition, there was even a significant increase in negative emotions such as fatigue, which was significantly higher in than the other two conditions (i.e., in the outdoor condition and in the VR treadmill condition). Interestingly, negative emotions were positively associated with motion sickness.

3.3.2.2. Perceived stress and relaxation. Eleven studies measure perceived stress as an outcome of exposure to virtual nature. Six studies confirmed the benefit of exposure to virtual nature in lowering stress (Ch et al., 2023; Chan et al., 2021; Reese et al., 2021; Schebella et al., 2020; Wang et al., 2020; Zhang et al., 2023), while two did not (Mostajeran et al., 2021; Reese, Stahlberg et al., 2022). Interestingly, the study by Suppakittpaisarn et al. (2023) found that higher stress recovery was found with videos of 5 min (vs. 1 min and 15 min) and it was greater for women in natural (vs. urban) VR environments. In the study by Reese et al. (2021), perceived stress was lower after exposure to virtual nature, and this decrease was significantly stronger in the condition of no control (experience controlled by the experimenter) as opposed to active control by the participant. In the study by Wang et al. (2020) as well, in adults with generalized anxiety disorder, perceived stress was reduced after physical exercise combined with exposure to virtual videos and this decrease was greater when the contents of the virtual videos were natural environments vs. abstract painting. In Schebella et al. (2020), perceived stress was significantly lower in the low biodiversity than in the urban environment and in the multisensory rather than the visual-only natural environment. In two studies, relaxation was higher when traditional biofeedback was associated with VR nature (vs. traditional biofeedback alone; Blum et al., 2019) and in a VR condition (vs. 2D and no video condition; Knaust et al., 2022). In Ch et al. (2023), stress was lower in the conditions of VR nature and VR nature with mindfulness as compared to a condition with no intervention, with no added value of mindfulness. Conflicting are the findings by Mostajeran et al. (2021), who did not find any significant effect in perceived stress measure with two different instruments, neither regarding the type of environment (natural vs. urban) nor for the level of immersion (VR and 2D photos). Following the same line, in Reese, Stahlberg et al. (2022) no differences in stress were found between virtual and outdoor nature exposure.

3.3.2.3. Physiological stress. In total, twenty-six articles measured physiological stress regarding exposure to virtual nature (see Table 1). Eleven studies measured physiological stress after stress induction (Anderson et al., 2017; Annerstedt et al., 2013; Hedblom et al., 2019; Huang et al., 2020; Knaust et al., 2022; Liszio et al., 2018; Liszio & Masuch, 2019; Mostajeran et al., 2021; Schebella et al., 2020; Sun et al., 2023; Yin et al., 2022) and one after fatigue induction (Zhang et al., 2023), while in all the other cases stress was measured after exposure to virtual and other types of nature.

Heart Rate. Regarding heart rate, most studies found that heart rate and heart rate variability decreased over time suggesting relaxation, with no differences between conditions, namely urban vs. natural (Mostajeran et al., 2021; Song et al., 2022; Yu et al., 2018, 2020), natural vs. indoor environment (Anderson et al., 2017) and immersive VR videos vs. 2D photo slideshow (Knaust et al., 2022; Mostajeran et al., 2021). One study reported decreases in heart rate after VR natural videos, with the first exposure being more effective than the second and third over a three-week period (Hsieh & Li, 2022). The same result did not apply to heart rate variability indices. Moreover, two studies found that standard and VR biofeedback were both effective in inducing relaxation with no differences between them in heart rate and heart rate variability (Blum et al., 2019; Rockstroh et al., 2019). Only one study found that heart rate variability indicated significantly higher relaxation in the nature VR condition than in desktop and control conditions (Liszio et al., 2018). In just one study, heart rate variability suggested higher relaxation in the VR nature vs. VR urban condition (Chan et al., 2021). Recovery from stress induction in terms of heart rate and heart rate variability was not found in Liszio and Masuch (2019) per level of biodiversity of the environment and in Shu et al. (2022) between different viewing distances and edge permeability levels of green spaces. No differences in recovery in terms of heart rate and heart rate variability were also found in Schebella et al. (2020) between natural and urban environments and in Sun et al. (2023) per level (high, moderate, none) of green space exposure.

Regarding the virtual experience, two studies found that recovery from stress induction in terms of reduced heart rate and heart rate variability was higher in the condition of virtual forest with nature sound (vs. without sound; Annerstedt et al., 2013) and multisensory environment (vs. visual-only environment; Schebella et al., 2020). Heart rate variability indicated higher relaxation in the condition with active interaction with the virtual natural environment (vs. no interaction and control groups; Liszio & Masuch, 2019). Regarding the types of environments, higher recovery from stress induction was found in a low (vs. moderate) biodiversity natural environment (Schebella et al., 2020) and in natural environments such as green space and blue spaces, while a natural context with more artificial elements was the only one with an increase in heart rate (Wang et al., 2019).

Electrodermal Activity (EDA). EDA gives indications regarding physiological arousal related to emotions and stress. EDA decreased over time after VR exposure and the decrease was greater for natural vs. urban environments in three studies (Anderson et al., 2017; Hedblom et al., 2019; Huang et al., 2020), while in one study the pre-post exposure changes did not differ between high and moderate green level vs.

urban environment (Sun et al., 2023). One study did not find differences between virtual nature vs. outdoor nature vs. indoor environment; Browning, Shipley, et al., 2020), and no differences were found also for viewing distance and edge permeability (Shu et al., 2022). One study showed how a photo slideshow was more effective than the VR condition in lowering the EDA scores between the stress induction and the exposure phases (Mostajeran et al., 2021). On the contrary, in another study, the reduction in EDA was higher in VR and PC conditions vs. no video, but the scores in the VR condition did not differ from the PC condition (Knaust et al., 2022).

Blood pressure. Regarding blood pressure, only seven studies measured systolic and diastolic blood pressure and mean arterial pressure (see Table 1). The findings by Wang et al. (2019) indicated relaxation after VR exposure, with significant differences in pre- and post-measurements for green natural environments and blue space, with the latter one showing a greater decrease. Sun et al. (2023) found that the observed decrease in systolic blood pressure after exposure was higher in a green (vs. urban) condition, but no differences in diastolic blood pressure were found. Recovery after stress induction as suggested by the decrease of mean arterial pressure after VR desert exposure was significantly greater than the VR urban exposure condition in desert residents (Yin et al., 2022). Yu et al. (2018) found that blood pressure was decreasing over time, regardless of condition (natural vs. urban). Conversely, Yu et al. (2020) and Song et al. (2022) found no differences between pre- and post-exposure measurements for blood pressure, nor any differences between the two conditions (natural and urban). Two other blood-related measures, namely blood volume amplitude and blood oxygen value, did not differ significantly per viewing distance and edge permeability in Shu et al. (2022).

Electroencephalography (EEG). Studies measuring EEG focused primarily on alpha waves, which suggest relaxation. In participants with generalized anxiety disorder, the increase of the alpha waves between pre- and post-exposure measurements was higher in the condition in which aerobic exercise was combined with virtual nature vs. abstract painting (Wang et al., 2020). In subjects with acquired physical disabilities, the increase in alpha waves and alpha/beta ratio indicated that subjects after exposure to virtual nature had a significantly greater change and post-exposure alpha waves than those exposed to a 2D video of a garden, suggesting higher relaxation (Je & Lee, 2020). In another study on gastrointestinal cancer patients (Song et al., 2022), alpha waves were higher than baseline in the VR natural condition, while in the VR urban condition they were higher during baseline. One study did not find differences in alpha waves between the baseline (resting state) and during visual VR and between different natural environments (Gao, Zhang, et al., 2019). Li, Dong, et al. (2021) collected data on participants with mild to moderate anxiety and depression and computed three EEG indices namely engagement, calmness, and alertness. Indicators of engagement and calmness did not change significantly across conditions while alertness was significantly higher after virtual restorative natural environments, suggesting cognitive recovery and improved cognitive functions. Following the same line, results by Zhang et al. (2023) suggested higher attentional states and cognitive flexibility, and lower cognitive processing load in a VR natural vs. indoor environment condition.

Salivary Cortisol. Only four studies measured cortisol levels before and after exposure (recovery from stress induction). Three found no statistical change per condition: high and moderate levels of green vs. no green (urban) environment (Sun et al., 2023), natural with vs. without sound vs. indoor condition (Annerstedt et al., 2013), and VR vs. desktop vs. control condition (Liszio et al., 2018). In Yin et al. (2022), in desert residents, salivary cortisol decreased in all conditions (desert, green, and office), but this reduction was significantly higher in the desert vs. office condition.

Salivary Amylase. Three studies measured salivary amylase. While one did not find any significant decreases per condition of VR nature vs. VR urban (Yu et al., 2018), another study (Sun et al., 2023) found that salivary amylase decreased more in a VR natural vs. VR urban condition. The last study found that among seven natural environments, in the one with wood with a platform and bench (a moderately artificial environment) salivary amylase was higher, indicating more stress (Wang et al., 2019).

3.3.2.4. Restorativeness. In total, fifteen studies measured the restorative quality of the natural environments displayed through VR and the restorative process reported by the individuals exposed to those environments (see Table 1). Of these works, seven used the Perceived Restorativeness Scale (PRS; Browning, Mimnaugh, et al., 2020; Calogiuri et al., 2018; Leung et al., 2022; Reese, Stahlberg et al., 2022; Schutte et al., 2017; Song et al., 2022; Tabrizian et al., 2018), four the Restoration Outcome Scale (ROS; Mattila et al., 2020; Reese et al., 2021; Reese, Mehner et al., 2022; Reese, Stahlberg et al., 2022) and others used other instruments, such as the Restorative Environmental Scale (RES), the Perceived Restorative Characteristics Questionnaire (PRCQ), and the Restorative Components Scale (RCS).

As assessing the quality of the environments shown, across studies, restorativeness is measured just once after exposure to the environments. Most of the studies showed how virtual nature has a higher restorative quality than a virtual urban environment (Leung et al., 2022; Mattila et al., 2020; Schutte et al., 2017; Tabrizian et al., 2018; Yu et al., 2020; Ünal et al., 2022). In line with these results, an intervention study, with 3–5 exposures over the course of one week, found that restorativeness decreased after one week only in the urban (vs. natural) condition (Song et al., 2022). In Browning, Mimnaugh, et al. (2020) exposure to VR natural environment and outdoor natural environment also predicted greater restorativeness than an indoor setting. Moreover, studies point to a comparable effect between virtual nature and outdoor nature (Reese, Stahlberg et al., 2022; Ünal et al., 2022). Following this line, Calogiuri et al. (2018) found no differences between VR and outdoor conditions for fascination and being away. Both dimensions showed positive and significant correlations with the sense of presence. In Mattila et al. (2020), the VR forest environment was perceived as more restorative than the real urban forest environment and the real semi-urban forest in terms of all the sub-scales. The VR forest was even perceived as more coherent and fascinating than the three real forest environments and more compatible and more likely to enhance the 'being away' experience than the real semi-urban and urban forests. The virtual natural environment was perceived as more restorative during exercise than virtual abstract painting (Wang et al., 2020). Song et al. (2022) found that the blue environment was the most restorative followed by an open green space, a semi-open green space, a closed green space, and lastly, a gray space. Lastly, one study found no significant differences in the restorative quality of five different virtual environments (urban, natural, and three interactive natural environments; Li, Dong, et al., 2021).

Regarding the characteristics of the natural environment perceived as more restorative, Tabrizian et al. (2018) showed that in the virtual park, higher ratings on restorativeness were found for the vegetation set on one side (as compared to equally distributed) and medium or high permeability vegetation, namely the extent to which spatial arrangement of vegetation affords seeing and moving (as compared to low). In Pals et al. (2014), the most restorative natural environment was that without furniture, then the one with wooden furniture, and the least restorative was the one with metal furniture. By contrast, in Reese, Mehner et al. (2022), there were no differences in restorativeness per level of wildness and presence of human structures. As for the characteristics of the VR experience, the study by Reese et al. (2021) showed that there were no statistical differences in perceived restorativeness attributed to a virtual coastal environment with or without participants' active control in the VR experience.

3.3.2.5. Environment preference and pleasantness. Twelve articles focused on the type of environments and the characteristics of the material shown on perceived preference and pleasantness (see Table 1). First, VR natural environments obtained higher scores of preference and pleasure as compared to photos and on-site exposure in one study (Gao, Liang, et al., 2019) and to VR urban exposure in two studies (Song et al., 2022; Ünal et al., 2022), while it obtained comparable ratings to on-site exposure in two studies (Xiang et al., 2021; Ünal et al., 2022), while in another study there were no differences between screen and VR exposure (Lindquist et al., 2020). As for the type of natural environment, an environment of relative complexity as the semi-open green space (vs. open and closed green spaces) and blue spaces obtained the highest preference score through VR (Gao, Liang, et al., 2019; Gao, Zhang, et al., 2019; Song et al., 2022; Xiang et al., 2021). In one study, preference was comparable to on-site for semi-open spaces in all seasons, while in the other two green spaces (open and closed), VR was comparable to on-site only during winter (Xiang et al., 2021). Presumably, this occurs for the potential of VR and the winter setting, to induce participants' focus on their feelings (Xiang et al., 2021). Higher preference for a green vs. desert VR environment in desert residents suggests that familiarity may play a role in preference (Yin et al., 2022).

Physical features in the natural environment can influence preference ratings. For instance, Pals et al. (2014) found that a natural environment with metal furniture was less preferred and pleasurable than an environment with wooden furniture or with no furniture at all. Similarly, van Vliet et al. (2021) focused on urban parks and found that the number of trees and the presence of flowerbeds with a diversity of flowers was related to preference more than the presence of services and the amount of litter. Their analysis shows how there are individual differences in park appreciation, some people giving importance mainly to natural elements and others evaluating the park as a whole. Lastly, in a study, the least preferred viewing distance of a green space was 20 m (as compared to 100 m and 200 m), which was also associated with higher anxiety and depression (Shu et al., 2022). Here the edge permeability had no effect on preference.

Regarding multisensory experience, Hedblom et al. (2019) found that among the urban forest, urban park, and city, visual pleasantness was higher for the urban forest and lower for the urban environment; olfactory pleasantness was highest for the urban park and lowest for the city, and auditory pleasantness was lowest for the city, but no differences were found between the urban park and the urban forest. General pleasantness was higher for the urban park than for the forest and the urban area. Among different environments, Lindquist et al. (2020) found that a vacant lot was the least preferred environment and the garden the most preferred one, especially in VR (vs. screen). Moreover, the highest preference ratings were found for the realistic congruent sound conditions, then for the city sound, and, lastly, for the no sound conditions (Lindquist et al., 2020).

The preference for an environment is related to higher positive affect (Gao, Zhang, et al., 2019), while the preferred scene (between two natural environments) reduced negative affect more than the second chosen scene and was related to a higher sense of presence in one study (Anderson et al., 2017). In one study (Ünal et al., 2022), restorativeness explained 45–50% of the variance in preference and pleasantness for the VR natural environment. By contrast, Gao, Zhang, et al. (2019) found no correlation between preference for an environment and the restoration of attention, negative mood, and physiological stress recovery. Moreover, a multi-sensorial experience can impact stress; for instance, odor pleasantness reduced stress as measured with electrodermal activity, while auditory pleasantness was marginally significant, and visual pleasantness had no effect (Hedblom et al., 2019).

3.3.2.6. Cognitive performance. Eleven studies focused on cognitive performance after exposure to a natural environment through VR. In general, it seems that the mere experience of a virtual natural environment does not affect participants' attentional resources in the majority of studies. Yeo et al. (2020) found that there were no differences in attention as measured through an objective task administered on the computer in the score pre- and post-exposure to either natural or urban virtual environments. Mostajeran et al. (2021) found that cognitive performance was higher after exposure to a natural (vs. urban) virtual environment assessed in terms of both mistakes and correct answers. No differences were found, however, for the immersion level (i.e., VR or photos). No differences were found between a virtual (vs. outdoor) nature walk in memory (Léger & Mekari, 2022).

In Burmeister et al. (2018), objective concentration in terms of efficiency and accuracy was even higher in the virtual indoor setting (office) than in the virtual green environment showed, whereas no differences were found in accuracy and speed for calculating and counting, the speed increase in the overall test, and in the reports of subjective concentration. O'meara et al. (2020) in students with low and high anxiety test exposure to virtual natural or urban environments did not affect the change in the scores at a nonverbal reasoning test for condition, time, or level of anxiety. No differences were found in attention as measured by the Stroop task per different types of virtual environments (i.e., gray, blue, and four green spaces; Gao, Zhang, et al., 2019) and between a VR forest and a VR indoor environment (Zhang et al., 2023). In one study, auditory attention improved after a VR video in a sample of children (Luo et al., 2023).

Different effects were found for attentional resources measured after biofeedback combined with natural computer-generated virtual environments. In the study by Rockstroh et al. (2019), reports on concentration and distraction during exposure to stimuli were higher in the condition in which the biofeedback technique was combined with VR nature as compared to standard biofeedback and a non-treated control. Blum et al. (2019) observed that in the VR (vs. standard) biofeedback condition, participants reported higher focus on the present moment both in terms of the mind and the body, less task-relevant, and irrelevant mind wandering. Moreover, attentional resources were better conserved after the VR (vs. standard) biofeedback condition, since there was a significantly higher reduction in reaction times objectively measured with the Stroop task. Lastly, in Ch et al. (2023), the focus was higher in both VR and VR and mindfulness intervention conditions (daily exposure over a two-week period) as compared to a no-intervention condition.

3.3.2.7. Nature connectedness. Six articles investigated the relationship between exposure to virtual nature and connectedness with nature (see Table 1). Schutte et al. (2017) investigated if the benefits of virtual nature could be different for different individuals, testing connectedness to nature as a moderator between exposure to virtual natural (vs. urban) environment and positive affect. The results showed a marginally significant effect. In particular, when connectedness to nature was low there were no differences in the positive affect for the natural (vs. urban) environment. When connectedness to nature was high, there was a tendency for positive affect to be lower for the urban (vs. natural) environment.

Five studies were interested in the change in connectedness to nature after exposure to virtual nature. Yeo et al. (2020) investigated connectedness to nature in relation to three different delivery modes (i.e., 2D screen, 360° videos of real nature, and computer-generated virtual nature). Connectedness to nature was found to increase as the delivery mode became more immersive: thus, it was higher in the virtual nature than in 2D screen and 360° videos. In particular, it seems that the effect of virtual nature on the increment in nature connectedness was mediated by the sense of presence given by the medium. One study (Sneed et al., 2021) measured connectedness to nature and interdependence with nature before and after exposure to virtual nature, a virtual indoor environment, and outdoor nature. Changes for connectedness to nature were higher in the outdoor condition than in both VR conditions and interdependence with nature was higher in the outdoor nature and virtual nature conditions than the indoor environment condition. No differences were found between outdoor and virtual nature conditions. In Leung et al. (2022), connectedness increased after two VR natural (but not after two VR urban) sessions. Interestingly, in a study, connectedness to nature increased after a VR natural (but not after a VR urban) condition, and in the VR natural (vs. urban) condition, both the increase in positive affect and the decrease in negative affect were explained through state connectedness to nature Chan et al., 2021).

An emotional connection to the marine environment to which participants were exposed (virtually or in-situ) was measured by Hofman et al. (2021). In the virtual natural environment condition (as opposed to a real marine environment in which the effect was not found), this latter was positively and significantly associated with a specific set of future behavioral intentions to engage in conservative behaviors.

3.3.2.8. Behavior and behavioral intentions. Four studies investigated behavior and behavioral intentions after being exposed to virtual natural environments. In particular, Hofman et al. (2021) showed how both being immersed in a marine environment and a real snorkel experience increased intentions to engage in conservative behaviors (i.e., educational and political actions, waste reduction, and purchasing choices), with no statistical differences between the two conditions. Leung et al. (2022) found that a VR nature (vs. urban) condition was associated with greater motivation for future nature engagement and, interestingly, this behavioral intention was associated with state connectedness to nature. In Tanja-Dijkstra et al. (2014), participants with high (vs. low) dental anxiety undergoing simulated dental treatment with an audiotape reproducing sounds of a real dental intervention, reported higher intention to use VR during a real dental visit. Lastly, only one study by Deringer and Hanley (2021) investigated real behavior, namely the willingness to sign a letter to a senator for supporting ecological actions and found that participants in both VR and outdoor nature conditions (vs. a no exposure condition) exhibited greater ecological behavior.

3.3.2.9. Creativity. Three studies hypothesized that exposure to virtual nature could enhance creativity. In the study by Fleury et al. (2021), participants were asked to sketch an innovative item as a work post for people in a wheelchair while immersed in a virtual natural, indoor, and neutral environment. Overall creativity was higher in the virtual nature condition as compared to the other two, especially regarding the sub-criterion of novelty. In Palanica et al. (2019), participants were exposed to a natural or an urban environment in 2D or 3D mode and, in the meantime, they were asked to report possible alternative uses of a brick (creative task). Results attested that was the type of environment (natural or urban) that was related to increased creativity, but not the medium used (2D or 3D). In Ch et al. (2023), creativity was assessed daily over two weeks (per condition) and results showed that convergent thinking was higher in the condition of VR nature combined with mindfulness than in VR nature alone and control (no intervention), while divergent thinking worsened in the intervention conditions vs. control.

3.3.2.10. Perceived safety. Three studies investigated perceived safety with VR. Evensen et al. (2021) manipulated a hedge height in the evening in a virtual urban park but found no differences in perceived safety, which differed only by gender with females feeling less safe. On the same line, Shu et al. (2022) found no differences in perceived safety per viewing distance and edge permeability of a green space. By contrast, in Tabrizian et al. (2018), being surrounded by trees in an urban park was related to less safety and this effect was not present in the urban condition (plaza). Also, the park with low (vs. high) permeability was perceived as less safe.

3.3.2.11. Subjective vitality. Three studies investigated subjective vitality as a consequence of exposure to virtual nature. In Mattila et al. (2020), the authors found that exposure to a VR forest significantly increased the subjective vitality experienced by participants. In Reese, Mehner et al. (2022) subjective vitality was higher after VR, with no differences between environments per level of wildness and human structure presence. Subjective vitality did not change after exposure to VR and outdoor nature and no differences between conditions were found in Reese, Stahlberg et al. (2022).

3.3.2.12. Dental experience. Three studies (Tanja-Dijkstra et al., 2014; 2018, Study 1 and 2) investigated how dental experience could be ameliorated in healthy adults and dental patients with exposure to VR nature. In Tanja-Dijkstra et al. (2014), healthy adults underwent a simulated dental treatment with an audiotape while exposed to a VR coastal environment (with active or passive control) or a black screen (control condition). They were additionally split at the median of their scores in dental anxiety. Results showed how participants with high (vs. low) dental anxiety in both VR conditions (active and passive control) had less vivid memories one week later than control (black screen). No such differences were found for immediate dental experience and intrusive thoughts one week later. A similar experimental apparatus was used for the subsequent studies (Tanja-Dijkstra et al., 2018). In Study 1, pain experience was elicited in healthy adults using a laboratory cold pressor task. Results showed that VR conditions (both active and passive) resulted in a reported less experienced and recollected pain after a week. In Study 2, patients undergoing a real dental treatment were exposed to a VR condition (coastal or urban environment) or to a control condition in which they simply received the healthcare treatment. Results supported the effect of VR nature on experienced and recollected pain, while the same effect was not found for the VR urban condition.

3.3.3. Intervening variables

Few studies focused on the mechanisms underlying the benefits of virtual nature on individuals. Regarding restorativeness, Tabrizian et al. (2018), based on the characteristics of the natural and urban environments shown, found that spatial arrangement of natural objects negatively predicted perceived personal safety (one-sided rather than two- or four-sided objects predicted a higher sense of safety) which, in turn, positively predicted perceived restorativeness. This model was true for the natural environment but not for the urban environment. Vegetation permeability (low, medium, high) negatively predicted perceived safety which, in turn, positively predicted restorativeness, again for the natural environment but not for the urban environment.

Regarding emotions, Yeo et al. (2020) found that the interactive computer-generated VR (vs. the 2D video) condition was associated with greater improvements in positive affect, and this effect was sequentially mediated by both a higher sense of presence and a higher connectedness to nature. In other words, exposure to the VR condition provoked a higher sense of presence that, in turn, enhanced connectedness to nature, which ultimately predicted greater positive affect. Following the same line, Li, Dong, et al. (2021) showed how the effects of restorativeness on positive and negative emotions and general self-efficacy were mediated by the sense of presence. In Schutte et al. (2017), restorativeness was a mediator in the relationship between VR exposure (both natural and urban conditions) and positive affect. In Chan et al. (2021), in the relationship between VR exposure and positive and negative affect, connectedness to nature was found as a significant mediator. Also, in the study by Pals et al. (2014), the coherence dimension of restorativeness fully mediated the negative effect of metal furniture in a natural environment (compared with a condition without furniture) on preference, pleasure, and restoration and partially mediated the contrast effects of metal vs. wooden furniture on preference and pleasure.

Other findings suggest the same mediation paths since they found a positive correlation between the sense of presence and both negative and positive affect, in the virtual but not in the natural condition

(Chirico & Gaggioli, 2019). The sense of presence was higher in the interactive (vs. non-interactive) VR condition and VR (vs. desktop) condition, and negatively predicted anxiety and positively predicted positive affect (Liszio et al., 2018; Liszio & Masuch, 2019). Only one study used electromyography (EMG), in terms of contraction of the brachioradialis muscle of the arm, as an indicator of presence and physical participation. Results indicated that pre- and post-exposure score changes were significantly higher for all conditions (urban, natural interactive, and noninteractive environments) providing differences in presence as indicated also by the results using scale measurements (Li, Dong, et al., 2021).

Lastly, several studies tested the effect of possible moderators in the relationship between VR nature exposure and psychological and psychophysiological outcomes. Browning, Shipley, et al. (2020) found no interaction (moderating) effects of previous VR experience with condition (outdoor nature vs. virtual nature vs. indoor setting) on both positive and negative affect and restorativeness, indicating that previous VR experience did not affect the relationship between the condition, restorativeness, and mood. Knaust et al. (2022) found no interaction effects of gender, age, technology anxiety, and previous VR experience with the type of medium and time (pre-post-exposure) on electrodermal activity and perceived relaxation. Yin et al. (2022) found no interaction effects between preference for a green or brown landscape and exposure to those landscapes and a control condition on cortisol levels, mean arterial pressure, and serum interleukin in desert residents. By contrast, Browning et al. (2023) found significant findings in the condition of daily VR nature exposure: Females (vs. males), those with more (vs. less) VR experience, with more (vs. less) outdoor nature experience, and those with lower (vs. higher) pre- and post-exposure engagement with beauty showed greater decreases in worry. Lastly, in two studies, participants with high (vs. low) anxiety exhibited more benefits from exposure to VR nature (O'meara et al., 2020; Tanja-Dijkstra et al., 2014).

3.3.4. VR experience

Immersive VR video tends to induce a better sense of presence and immersion compared to a VR photo slideshow (Liszio et al., 2018; Mostajeran et al., 2021) especially in interactive virtual environments (Yeo et al., 2020) or in conditions in which the participants are in control and can explore the environment freely (Tanja-Dijkstra et al., 2014, 2018). Sense of presence has also been shown to be associated with lower anxiety and higher positive affect (Liszio & Masuch, 2019). On the contrary, motion (or cyber or simulator) sickness may cause a state of physical discomfort characterized by symptoms including dizziness, cold sweat nausea, or even vomiting. The aforementioned sensations are due to a mismatch of information among the brain, body, eyes, and ears, but also psychological components may play a role, such as memory of past discomfort in a similar situation (Dobie, 2019, pp. 113–127). A number of studies presented in this systematic review addressed this issue by administering appropriate items or scales and reported high ratings of motion sickness among participants exposed to VR, as reported by O'meara et al. (2020). Despite the exclusion of participants with discomfort as an essential precondition for each study, as observed, negative VR experience impacted the pleasantness of the experience itself in many cases, both in a sitting and in a treadmill condition (as in Calogiuri et al., 2018) and regardless of whether or not the experimenter helped participants during the virtual navigation (as in Reese et al., 2021). In summary, a satisfactory compromise between a high sense of reality and immersion in VR and the risk of discomfort is yet to be discovered.

A further experience-related issue is the likely psychological effect of repeated exposure through VR technology. It has been speculated that positive psychophysiological effects of VR may be also determined by perception evoked by previous virtual experience, however, findings were inconsistent. In participants with previous VR experience a higher, albeit slightly, level of ecological validity in a natural over a virtual condition was detected (Chirico & Gaggioli, 2019), while no significant interaction effect of the novelty of the medium was found between exposure condition and psychological outcomes, such as affects and restorativeness (Browning, Mimnaugh, et al., 2020). The potential intervening effect of previous VR experience is certainly something to be monitored. A possible strategy to overcome this issue is to select participants with the same VR experience, e.g., with no or little previous experience (as in Rockstroh et al., 2019).

4. Discussion

4.1. Summary of findings

Our review complements and expands available knowledge on this research topic, both from a chronological and a content point of view (i.e., findings on environment preference and pleasantness, cognitive performance, nature connectedness, behavior and behavioral intentions, creativity, perceived safety, subjective vitality, and dental experience were novel as compared to previous systematic reviews available, i.e. Frost et al., 2022; Riches et al., 2021). To our knowledge, to date, it constitutes the most updated and complete review on the effectiveness of virtual nature on psychological and psychophysiological outcomes. Efforts were made in summarizing existing evidence on the effectiveness of virtual nature on psychological outcomes, however, findings are available for specific outcomes or populations. Two recent systematic reviews (Frost et al., 2022; Riches et al., 2021) focused on the effect of virtual reality on well-being and relaxation and of virtual nature on well-being in general, respectively. A meta-analysis (Browning, Shipley, et al. (2020) is also available on the effect of virtual nature on the positive and negative affect in studies that report a comparison between in-vivo and virtual exposure. Moreover, a narrative review (White et al., 2018) is available on the effect of virtual nature in therapeutic settings.

All studies reviewed included virtual nature exposures, featuring various types of environments such as green and blue spaces. The length and media of exposure varied, with immersive virtual experiences being more effective. Different natural environments had diverse effects on attention, mood, stress levels, and preference. Both virtual nature and urban exposures reduced heart rate, but psychological benefits were greater with virtual nature exposure. No substantial differences were found comparing virtual nature with in-vivo exposure to a naturalistic setting. Lastly, the experience of virtual nature exposure has consistently proven to be preferable over exposure to an indoor virtual environment, such as an office.

The outcomes considered in the present review were all those identifiable as psychological and psychophysiological, therefore no further selection based on psychological domains (e.g., cognitive functioning, affect and emotion, psychosocial abilities, personality traits) was carried out. Overall, the results of the available studies attest to how VR is effective in producing effects among its users. The main findings drawn from this extensive review are summarized in Table 1.

First of all, the benefits of VR exposure were found in the domain of human emotions. In most studies, VR exposure decreased negative affect and some studies suggest an increase in positive affect as well. Virtual nature exposure also seems beneficial for stress reduction, with psychophysiological measurements pointing to significant relaxation, and restorativeness. Regarding preference, it seems generally higher for virtual semi-open green spaces and personal predilection for a natural environment can be crucial in determining the benefits associated with exposure. Cognitive performance seems not to be stimulated by virtual nature alone, while attention is amplified when in combination with biofeedback. A promising result that still needs further support is that state connectedness to nature seems to grow with the level of immersion, it is comparable to outdoor fruition and explains changes in affect while more studies are needed to investigate the role of dispositional connectedness to nature. Lastly, initial results were found for behavior and behavioral intentions, creativity, perceived safety, subjective vitality, and dental experience.

Noteworthy is the investigation of previous or current VR experience. The present review pointed out the crucial role of immersive VR video in providing a sense of presence; however, the other side of the coin is represented by the risk of incurring sensations of discomfort due to the virtual experience. Added to this, previous negative VR experiences may prevent users from benefiting from virtual nature exposure. The strategies implemented so far, such as selecting participants with the same VR experience, or excluding those experiencing discomfort, to overcome these issues need to be further developed.

4.2. Limitation of the current review

The present review is not without limitations. First, we were unable to use a meta-analytic approach to the available data due to high heterogeneity in terms of the exposure methods, VR experience and instruments used, and the psychological outcomes considered. Moreover, investigating the effect of precise exposure types on specific psychological outcomes is highly warranted. As a second limitation, although our efforts in merging two standardized, commonly used checklists for the creation of a suitable instrument for the quality assessment of all the included studies, we acknowledge the use of a non-standardized instrument.

Lastly, the reliability of the findings of our systematic review, as for any other review, can be undermined by the so-called publication bias. Therefore, further efforts should focus on determining the entity of such bias and the implications for any attempt to summarize the research findings, considering also the gray literature. It is also worth noting that, although we acknowledge that offering the reader(s) a compartmentalized synthesis of available findings could be seen as a study limitation for the risk of incurring a superficial investigation of the topic, we believe this is a strong point of our review since we allow them to specifically focus on the variable(s) of interest.

4.3. Current gaps and guidelines for the VR research agenda

In general, findings provide an incomplete picture. For example, we criticize the lack of studies in younger populations, such as school-age children and adolescents. Similarly, although present, the results on the elderly and populations with special needs are still insufficient. Studies on different contexts are also missing, such as schools, prisons, or retirement homes. Moreover, from the quality assessment we carried out, it appears that very few studies considered the power of the effects observed, while from an analytic overview of the studies' characteristics, it emerges that several studies employed very low sample sizes. This latter consideration warns the reader to examine the findings carefully, especially regarding those outcomes on which studies are few. However, as Reese, Mehner et al. (2022), argue, VR studies are always subject to feasibility considerations, given that VR studies require a relatively high investment of resources, given their relatively complicated setups (i.e., compared to questionnaire studies or online panels). Consequently, accumulating evidence through reviews and meta-analyses should help in interpreting the findings with more confidence.

Most of the studies focused on three main outcomes, namely mood, stress, and restorativeness. Other outcomes, such as environmental preference and pleasantness, cognitive performance, and nature connectedness were less investigated, while there is a notable lack of studies for behavior and behavioral intentions, creativity, perceived safety, subjective vitality, and dental experience. Thus, there is a need for future studies to investigate further the underestimated outcomes, through different instruments and experimental designs. For instance, since the relationship between outdoor nature exposure and cognitive processes is well-known (Bratman et al., 2015), it would be crucial to better understand whether, and under what conditions, virtual nature can have comparable effects. Here, the available evidence points to the sense of presence as an important catalyst of virtual nature benefits. It would also appear to be interesting to test the role of multisensorial virtual experiences and other variables. Moreover, further evidence should be also collected on the effect of virtual nature on restoration through understudied biosignals, such as salivary cortisol and salivary amylase.

Additional outcomes could be investigated in the future. In this regard, it seems that studies are missing the role of personality in the appreciation of virtual nature. In the studies considered, very few focused on personal dispositions such as engagement with beauty and disgust sensitivity (Browning, Shipley, et al., 2020), disposition towards an ecological worldview (Hofman et al., 2021), and nature connectedness (Schutte et al., 2017). It is possible that, for instance, specific individual characteristics can more strongly predispose some people to the actual recognition of virtual nature benefits. Available evidence has already shown how VR appreciation can vary among individuals as well as how the benefits of outdoor nature can be recognized by some individuals more than others (Feng et al., 2021; Kober & Neuper, 2013; Panno et al., 2020). Similarly, as recently highlighted, some individuals, more than others, could experience fewer benefits associated with virtual nature fruition; thus, future studies on individual differences could understand how to extend these benefits to more people (Theodorou, Spano et al., 2023). Moreover, studies are missing on the potential influence of the medium on behavioral change. For instance, it would be interesting to extend some results from the research on on-site nature exposure to VR. Furthermore, it would be interesting to see if virtual nature can impact pro-environmental behavior, prosocial behavior, cooperation, and aggression (Zelenski, Dopko, & Capaldi, 2015).

Further advancements in the understanding of the psychological mechanisms underlying the observable benefits are desirable. In general, the studies that focused on the intervening variables (mediators) extended from outdoor nature exposure to the VR medium the mediating effect of some variables (i.e., perceived safety, restorativeness, and connectedness to nature) well-known for translating the characteristics of the natural environments in positive outcomes for the individuals (i.e., mood, restorativeness, and preference). Nevertheless, what stands out as the most important mediator specifically related to the potential of the VR medium is the sense of presence. This means that future studies, as well as interventions aimed at using this tool, should investigate further the methodological characteristics of the research design or the intervention that could enhance the sense of presence, such as multisensory stimuli. Moreover, further focus is needed on the investigation of the direction of the relationships observed. Except for exposure, which in this kind of study is manipulated, other research designs may also manipulate the proposed mediators (e.g., restorativeness) to understand if they truly are antecedents of the outcomes observed (e.g., affect). This will help establish new theories. Lastly, few studies focused on moderators, and further studies are needed to identify potential populations and conditions that can enhance or diminish the effects observed.

Identifying mediators and moderators could also help the development of new theories, specifically conceptualized to predict the effects of virtual nature. What we can observe so far from the articles selected is that, mostly, the theories used in formulating the hypothesis and interpreting the findings are the same used in the context of exposure to outdoor nature (e.g., the ART; Kaplan & Kaplan, 1989). This is not surprising given that the area of research is still early in its development. Nevertheless, we can speculate that more predictive theories in the future will consider the specificities of the VR medium, such as the sense of presence.

Almost the totality of studies is experimental in nature, and they were conducted with considerable heterogeneity of methods and instruments. This point is not necessarily a limitation since this line of research is relatively new and in expansion. Nevertheless, what we observe is often the use of unvalidated scales and the use of single-item measures. Thus, more sound experimental paradigms are recommendable for future studies. Moreover, future research should focus on the specificities of different methods used and their efficacy (e.g., differences in the use of computer-generated or real environments). Lastly, future studies could consider different study designs. First, longitudinal studies could monitor changes over time due to repeated exposure to virtual nature (e.g., every day for a certain amount of time). Second, studies could test the effectiveness of clinical protocols based on virtual nature in the general population (e.g., stress reduction) and clinical samples (e.g., reduction of specific symptomatology).

We report a wide variety of methodological approaches in terms of research design, the medium used, and exposure lengths and typology. As recently pointed out (Browning, Saeidi-Rizi et al., 2021), methodological choices may affect findings overestimating the beneficial effect of simulated nature. In fact, such a variety of experimental studies prevents scholars from performing a meta-analysis to statistically synthesize the available evidence, thus making it difficult to provide correct information on the use of this medium for application purposes (e.g., therapies). In addition, further consideration concerns the exposure type. It emerges that exposure to a random natural environment is sufficient and therefore offering “nature”, whatever it may be, is certainly a beneficial factor for a variety of psychological and psychophysiological outcomes. Nevertheless, a comparison of the effects of different types of natural environments is lacking (see also Theodorou, Romano, et al., 2023).

Similarly, the recommended duration of *in-vivo* exposure to nature for health and well-being purposes is 120 min a week (White et al., 2019). On the contrary, the duration of virtual nature exposure for different desired outcomes is little explored, hence there is no agreement between the selected studies. The only study (Suppakittpaisarn et al., 2023) which compared the effect of three different duration of exposure (1, 5, or 15 min) pointed out that the optimal duration for inducing stress recovery is equal to 5 min. Despite the appreciable effort in investigating this relevant topic, the effectiveness of only three durations has been compared and for just one outcome. Further investigations are needed in order to estimate a trade-off between the minimum duration to obtain a benefit and the maximum duration to avoid collateral issues from virtual exposure (e.g., motion sickness) in order to recommend an “optimal” duration of exposure. Concerning the virtual stimuli, among those included, only in one case (Lakhani et al., 2020) a white, icy environment was offered. White, icy environments are much less investigated than other types of natural environments, thus evidence of their effects is scarce. The duration of the effect also remains unanswered. Although the overall evidence is suggestive of the beneficial effect of virtual nature on psychological and psychophysiological outcomes, it is not yet possible to state whether this effect persists over time. It is therefore desirable that future studies arrange follow-ups to verify potential changes in the medium and long term.

Inconsistent findings were identified on the use of a multisensory approach for virtual nature exposure. Including sounds or noise in virtual exposure is anything but unusual and, frequently, the use of sounds in association with the visual stimulus is not even specified as it is part of the 2D or 3D video used as an exposure stimulus. It has been found that a combination of visual, olfactory, and auditory stimuli improves the participants’ sense of reality during a virtual task and a better stress recovery compared to visual-only virtual stimuli (Schebella et al., 2020). More specifically, Hedblom et al. (2019) reported higher perceived pleasantness and lower physiological responses associated with stress in the case of olfactory stimuli (odors) rather than visual stimuli. Furthermore, we can hypothesize that not only the combination but also the specific type of visual, auditory, or olfactory stimuli may have differentiated effects for each individual. For example, sounds made by other people may distract the perceived peacefulness in an urban park (Jo & Jeon, 2020). Overall, findings on the effect of a multisensory approach on well-being and psychological outcomes are still scarce; thus, there is plenty of room for further investigation.

Lastly, particular attention should be also paid to the control conditions and their comparisons. As emerged from our findings, a virtual urban environment may produce some sort of healing effect, e.g., relaxation. In light of this, it is crucial to understand how much of the benefits originate from the virtual medium and from the content of the medium, such as natural, urban, or other environments.

4.4. Practical implications for clinical and subclinical populations

Human health benefits deriving from the interaction with natural environments are now well-established (e.g., Spano et al., 2020). The main purpose for using virtual nature lies in the need for assuring a share of nature engagement to individuals unable to directly enjoy the benefits of that exposition. This may be true for urban residents, but more importantly for people with mobility constraints, physical or mental frailty, or in confinement, e.g., as in the case of Covid-19 infected patients, people under arrest or in custody or in care facilities, and other special conditions. A review on the use of virtual nature in health and care settings (White et al., 2018) suggested VR as a useful and effective substitute for real contact with nature, which therefore should be preferred, for a number of physical and psychological outcomes, including the treatment of chronic pain, relaxation for cancer patients, eating disorders, post-traumatic disorder, anxiety, and depression. Particularly noteworthy is the use of VR as a treatment for cognitive impairment and dementia. Reynolds, Rodiek, Lininger, and McCulley (2018) reported the presence of a relaxation effect, detected through heart rate reduction, and more positive emotions, after exposure to a non-immersive VR nature compared to other VR contents (e.g., a movie) in patients with dementia. VR-based therapy proved to be effective also in combination with other, conventional psychotherapy approaches, such as the case of Cognitive Behavior Therapy (CBT). As early as 2009, Kim and collaborators (2009) demonstrated a higher effectiveness of a CBT-based therapy performed in a forest environment compared with the same therapy in hospital or outpatient management, in achieving depression remission in patients with major depressive disorders. More recently, nature-based mindfulness was shown to provide a positive effect on a number of psychological, physical, and social conditions (Djernis et al., 2019). Nevertheless, to our knowledge, excluding two studies included in this systematic review on the combination of virtual nature and biofeedback (Blum et al., 2019; Rockstroh et al., 2019), VR-based therapy in combination with well-established therapeutic approaches is yet to be explored, thus, VR-based systematic protocols are lacking. More importantly, we acknowledge the lack of medium- and long-term efficacy studies. In general, it is unlikely that virtual nature will be able to replace conventional therapies; however, according to a framework recently proposed by Litleskare, E MacIntyre, and Calogiuri (2020), virtual nature may be an effective supplement to real nature, may help people in reconnecting with real nature, and enhance the benefits deriving from the human-nature interaction.

5. Conclusion

The present work was aimed at systematizing the available studies on the benefits of exposure to nature through VR, focusing on psychological and psychophysiological outcomes and related intervening variables. We identified current gaps (lack of specific samples, studies of unknown power, underestimated outcomes, lack of investigation of mediators and moderators, lack of theories that could consider the specificities of the VR medium, lack of best practices) and future research directions (first of all, meta-analyses and investigations of publication bias), with the hope of challenging researchers interested in this rapidly expanding field of study.

Author note

We have no conflicts of interest to disclosure. This work was carried out under the project “Establishing Urban FORest based solutions In Changing Cities” (EUFORICC) and financially supported by the Ministry of Education, University and Research (MIUR) of Italy (PRIN 20173RRN2S).

We thank Dr. Thomas Edward Gladwin for the English proofreading.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2023.102044.

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 Human Performance, 88*(6), 520–526. https://doi.org/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

Ball, C., Huang, K. T., & Francis, J. (2021). Virtual reality adoption during the COVID-19 pandemic: A uses and gratifications perspective. *Telematics and Informatics, 65*. https://doi.org/10.1016/j.tele.2021.101728

Blum, J., Rockstroh, C., & Göritz, A. S. (2019). Heart rate variability biofeedback based on slow-paced breathing with immersive virtual reality nature scenery. *Frontiers in Psychology, 2172*. https://10.3389/fpsyg.2019.02172.

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

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences, 1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Browning, M. H. E. M., Mimnaugh, K. J., van Riper, C. J., Laurent, H. K., & LaValle, S. M. (2020a). Can simulated nature support mental health? Comparing short, single-doses of 360-degree nature videos in virtual reality with the outdoors. *Frontiers in Psychology, 10*. https://doi.org/10.3389/fpsyg.2019.02667

Browning, M. H., Saeidi-Rizi, F., McAnirlin, O., Yoon, H., & Pei, Y. (2020b). The role of methodological choices in the effects of experimental exposure to simulated natural landscapes on human health and cognitive performance: A systematic review. *Environment and Behavior, 53*(7), 687–731. https://doi.org/10.1177/0013916520906481

Browning, M. H., Shin, S., Drong, G., McAnirlin, O., Gagnon, R. J., Ranganathan, S., … Heller, W. (2023). Daily exposure to virtual nature reduces symptoms of anxiety in college students. *Scientific Reports, 13*(1), 1239.

Browning, M. H., Shipley, N., McAnirlin, O., Becker, D., Yu, C. P., Hartig, T., et al. (2020c). An actual natural setting improves mood better than its virtual counterpart: A meta-analysis of experimental data. *Frontiers in Psychology, 2200*. https://doi.org/10.3389/fpsyg.2020.02200

Burmeister, C. P., Moskaliuk, J., & Cress, U. (2018). Office versus leisure environments: Effects of surroundings on concentration. *Journal of Environmental Psychology, 58*, 42–51. https://doi.org/10.1016/j.jenvp.2018.07.011

Calogiuri, G., Litleskare, S., Fagerheim, K. A., Rydgren, T. L., Brambilla, E., & Thurston, M. (2018). Experiencing nature through immersive virtual environments: Environmental perceptions, physical engagement, and affective responses during a simulated nature walk. *Frontiers in Psychology, 8*, 2321. https://doi.org/10.3389/fpsyg.2017.02321

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., … Sanesi, G. (2015). Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning, 134*, 221–228. https://doi.org/10.1016/j.landurbplan.2014.10.022

Chan, S. H. M., Qiu, L., Esposito, G., Mai, K. P., Tam, K. P., & Cui, J. (2021). Nature in virtual reality improves mood and reduces stress: Evidence from young adults and senior citizens. *Virtual Reality*, 1–16.

Ch, N. A. N., Ansah, A. A., Katrahmani, A., Burmeister, J., Kun, A. L., Mills, C., … Lee, J. D. (2023). Virtual nature experiences and mindfulness practices while working from home during COVID-19: Effects on stress, focus, and creativity. *International Journal of Human-Computer Studies, 171*, Article 102982.

Chirico, A., & Gaggioli, A. (2019). When virtual feels real: Comparing emotional responses and presence in virtual and natural environments. *Cyberpsychology, Behavior, and Social Networking, 22*(3), 220–226. https://doi.org/10.1089/cyber.2018.0393

Coventry, P. A., Brown, J. E., Pervin, J., Brabyn, S., Pateman, R., Breedvelt, J., … White, P. L. (2021). Nature-based outdoor activities for mental and physical health: Systematic review and meta-analysis. *SSM Popul. Health, 16*, Article 100934. https://doi.org/10.1016/j.ssmph.2021.100934

Deringer, S. A., & Hanley, A. (2021). Virtual reality of nature can be as effective as actual nature in promoting ecological behavior. *Ecopsychology, 13*(3), 219–226.

Djernis, D., Lerstrup, I., Poulsen, D., Stigsdotter, U., Dahlgaard, J., & O'Toole, M. (2019). A systematic review and meta-analysis of nature-based mindfulness: Effects of moving mindfulness training into an outdoor natural setting. *International Journal of Environmental Research and Public Health, 16*(17), 3202. https://doi.org/10.3390/ijerph16173202

Dobie, T. G. (2019). *Psychological mechanisms that exacerbate motion sickness. InMotion sickness*. Cham: Springer.

Evensen, K. H., Nordh, H., Hassan, R., & Fyhri, A. (2021). Testing the effect of hedge height on perceived safety-a landscape design intervention. *Sustainability, 13*(9). https://doi.org/10.3390/su13095063

Feng, X., Astell-Burt, T., Standl, M., Flexeder, C., Heinrich, J., & Markevych, I. (2021). Green space quality and adolescent mental health: Do personality traits matter? *Environmental Research, 206*, Article 112591. https://doi.org/10.1016/j.envres.2021.112591

Fleury, S., Blanchard, P., & Richir, S. (2021). A study of the effects of a natural virtual environment on creativity during a product design activity. *Thinking Skills and Creativity, 40*. https://doi.org/10.1016/j.tsc.2021.100828

Frost, S., Kannis-Dymand, L., Schaffer, V., Millea, P., Allen, A., Stallman, H., … Atkinson-Nolte, J. (2022). Virtual immersion in nature and psychological well-being: A systematic literature review. *Journal of Environmental Psychology, 80*. https://doi.org/10.1016/j.jenvp.2022.101765

Gao, T., Liang, H., Chen, Y., & Qiu, L. (2019). Comparisons of landscape preferences through three different perceptual approaches. *International Journal of Environmental Research and Public Health, 16*(23). https://doi.org/10.3390/ijerph16234754

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). https://doi.org/10.3390/ijerph16173102

Giannico, V., Spano, G., Elia, M., D'Este, M., Sanesi, G., & Lafortezza, R. (2021). Green spaces, quality of life, and citizen perception in European cities. *Environmental Research, 196*, Article 110922. https://doi.org/10.1016/j.envres.2021.110922

Hedblom, M., Gunnarsson, B., Iravani, B., Knez, I., Schaefer, M., Thorsson, P., et al. (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

Hofman, K., Hughes, K., & Walters, G. (2021). The effectiveness of virtual vs real-life marine tourism experiences in encouraging conservation behaviour. *Journal of Sustainable Tourism, 30*(4), 742–766. https://doi.org/10.1080/09669582.2021.1884690

Honey-Rosés, J., Anguelovski, I., Chireh, V. K., Daher, C., Konijnendijk van den Bosch, C., Litt, J. S., … Nieuwenhuijsen, M. J. (2020). The impact of COVID-19 on public space: An early review of the emerging questions–design, perceptions and inequities. *Cities and Health*, 1–17. https://doi.org/10.1080/23748834.2020.1780074

Hsieh, C. H., & Li, D. (2022). Understanding how virtual reality forest experience promote physiological and psychological health for patients undergoing hemodialysis. *Frontiers in Psychiatry, 13*.

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

Jayaram, S., Connacher, H. I., & Lyons, K. W. (1997). Virtual assembly using virtual reality techniques. *Computer-Aided Design, 29*(8), 575–584. https://doi.org/10.1016/S0010-4485(96)00094-2

Je, H., & Lee, Y. (2020). Therapeutic effects of interactive experiences in virtual gardens: Physiological approach using electroencephalograms. *Journal of Digitital Landscape Architecture, 2020*(5), 422–429. https://doi.org/10.14627/537690043

Jo, H. I., & Jeon, J. Y. (2020). The influence of human behavioral characteristics on soundscape perception in urban parks: Subjective and observational approaches. *Landscape and Urban Planning, 203*, Article 103890. https://doi.org/10.1016/j.landurbplan.2020.103890

Kalantari, S., Bill Xu, T., Mostafavi, A., Lee, A., Barankevich, R., Boot, W. R., et al. (2022). Using a nature-based virtual reality environment for improving mood states and cognitive engagement in older adults: A mixed-method feasibility study. *Innovation in Aging, 6*(3), Article igac015.

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

Kim, W., Lim, S. K., Chung, E. J., & Woo, J. M. (2009). The effect of cognitive behavior therapy-based psychotherapy applied in a forest environment on physiological changes and remission of major depressive disorder. *Psychiatry Investigation, 6*(4), 245. https://doi.org/10.4306/pi.2009.6.4.245

Knaust, T., Felnhofer, A., Kothgassner, O. D., Höllmer, H., Gorzka, R. J., & Schulz, H. (2022). Exposure to virtual nature: The impact of different immersion levels on skin conductance level, heart rate, and perceived relaxation. *Virtual Reality, 26*(3), 925–938.

Kober, S. E., & Neuper, C. (2013). Personality and presence in virtual reality: Does their relationship depend on the used presence measure? *International Journal of Human-Computer Interaction, 29*(1), 13–25. https://doi.org/10.1080/10447318.2012.668131

Kraus, S., Kanbach, D. K., Krysta, P. M., Steinhoff, M. M., & Tomini, N. (2022). Facebook and the creation of the metaverse: Radical business model innovation or incremental transformation? *International Journal of Entrepreneurial Behavior & Research, 28*(9), 52–77. https://doi.org/10.1108/IJEBR-12-2021-0984

Lakhani, A., Martin, K., Gray, L., Mallison, J., Grimbeek, P., Hollins, I., et al. (2020). What is the impact of engaging with natural environments delivered via virtual reality on the psycho-emotional health of people with spinal cord injury receiving rehabilitation in hospital? Findings from a pilot randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 101*(9), 1532–1540. https://doi.org/10.1016/j.apmr.2020.05.013

Léger, M. T., & Mekari, S. (2022). Simulating the benefits of nature exposure on cognitive performance in virtual reality: A window into possibilities for education and cognitive health. *Brain Sciences, 12*(6), 725.

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*, Article 101863.

Li, H., Dong, W., Wang, Z., Chen, N., Wu, J., Wang, G., et al. (2021b). Effect of a virtual reality-based restorative environment on the emotional and cognitive recovery of individuals with mild-to-moderate anxiety and depression. *International Journal of Environmental Research and Public Health, 18*(17), 9053. https://doi.org/10.3390/ijerph18179053

Lindquist, M., Maxim, B., Proctor, J., & Dolins, F. (2020). The effect of audio fidelity and virtual reality on the perception of virtual greenspace. *Landscape and Urban Planning, 202*. https://doi.org/10.1016/j.landurbplan.2020.103884

Liszio, S., Graf, L., & Masuch, M. (2018). The relaxing effect of virtual nature: Immersive technology provides relief in acute stress situations. *Annual Review of Cyber Therapy and Telemedicine, 2018*(16), 87–93.

Liszio, S., & Masuch, M. (2019). Interactive immersive virtual environments cause relaxation and enhance resistance to acute stress. *Annual Review of Cyber Therapy and Telemedicine., 17*, 65–71.

Litleskare, S., E MacIntyre, T., & Calogiuri, G. (2020). Enable, reconnect and augment: A new era of virtual nature research and application. *International Journal of Environmental Research and Public Health, 17*(5), 1738. https://doi.org/10.3390/ijerph17051738

Li, H., Zhang, X., Wang, H., Yang, Z., Liu, H., Cao, Y., & Zhang, G. (2021c). Access to nature via virtual reality: A mini-review. *Frontiers in Psychology, 12*, 725288. https://doi.org/10.3389/fpsyg.2021.725288

Li, H., Zhang, X., You, C., Chen, X., Cao, Y., & Zhang, G. (2021a). Can viewing nature through windows improve isolated living? A pathway analysis on Chinese male prisoners during the COVID-19 epidemic. *Frontiers in Psychiatry, 12*. https://doi.org/10.3389/fpsyt.2021.720722

Luo, X., Tao, M., Lu, J., Lu, L., & He, X. (2023). The effect of different combinations of physical activity and natural environment videos on children's attention levels between class breaks. *BMC Pediatrics, 23*(1), 60.

Mantovani, E., Zucchella, C., Bottiroli, S., Federico, A., Giugno, R., Sandrini, G., … Tamburin, S. (2020). Telemedicine and virtual reality for cognitive rehabilitation: A roadmap for the COVID-19 pandemic. *Frontiers in Neurology, 11*, 926. https://doi.org/10.3389/fneur.2020.00926

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*. https://doi.org/10.1016/j.chb.2020.106295

McMahan, E. A., & Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *The Journal of Positive Psychology, 10*(6), 507–519. https://doi.org/10.1080/17439760.2014.994224

Mcsweeney, J., Rainham, D., Johnson, S. A., Sherry, S. B., & Singleton, J. (2014). Indoor nature exposure (INE): A health-promotion framework. *Health Promotion International, 30*(1), 126–139. https://doi.org/10.1093/heapro/dau081

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group.. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7), Article e1000097. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

Mostajeran, F., Krzikawski, J., Steinicke, F., & Kühn, S. (2021). Effects of exposure to immersive videos and photo slideshows of forest and urban environments. *Scientific Reports, 11*(1), 1–14. https://doi.org/10.1038/s41598-021-83277-y

Nejati, A., Rodiek, S., & Shepley, M. (2016). Using visual simulation to evaluate restorative qualities of access to nature in hospital staff break areas. *Landscape and Urban Planning, 148*, 132–138. https://doi.org/10.1016/j.landurbplan.2015.12.012

Nukarinen, T., Rantala, J., Korpela, K., Browning, M. H., Istance, H. O., Surakka, V., et al. (2022). Measures and modalities in restorative virtual natural environments: An integrative narrative review. *Computers in Human Behavior, 126*, Article 107008. https://doi.org/10.1016/j.chb.2021.107008

O'meara, A., Cassarino, M., Bolger, A., & Setti, A. (2020). Virtual reality nature exposure and test anxiety. *Multimodal Technologies and Interaction, 4*(4), 1–14. https://doi.org/10.3390/mti4040075

Palanica, A., Lyons, A., Cooper, M., Lee, A., & Fossat, Y. (2019). A comparison of nature and urban environments on creative thinking across different levels of reality. *Journal of Environmental Psychology, 63*, 44–51. https://doi.org/10.1016/j.jenvp.2019.04.006

Pals, R., Steg, L., Dontje, J., Siero, F. W., & van Der Zee, K. I. (2014). Physical features, coherence and positive outcomes of person–environment interactions: A virtual reality study. *Journal of Environmental Psychology, 40*, 108–116. https://doi.org/10.1016/j.jenvp.2014.05.004

Panno, A., Theodorou, A., Carrus, G., Imperatori, C., Spano, G., & Sanesi, G. (2020). Nature reappraisers, benefits for the environment: A model linking cognitive reappraisal, the "being away" dimension of restorativeness and eco-friendly behavior. *Frontiers in Psychology, 11*. https://doi.org/10.3389/fpsyg.2020.01986

Pasca, L., Carrus, G., Loureiro, A., Navarro, Ó., Panno, A., Tapia Follen, C., et al. (2021). Connectedness and well-being in simulated nature. In *Applied psychology: Health and well-being*. https://doi.org/10.1111/aphw.12309

Plotnik, R., & Kouyoumdjian, H. (2013). *Introduction to psychology*. Cengage Learning.

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), 1–10. 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*. 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*(3), 1245–1255. https://doi.org/10.1007/s10055-022-00631-9.

Reynolds, L., Rodiek, S., Lininger, M., & McCulley, M. A. (2018). Can a virtual nature experience reduce anxiety and agitation in people with dementia? *Journal of Housing for the Elderly, 32*(2), 176–193. https://doi.org/10.1080/02763893.2018.1431583

Riches, S., Azevedo, L., Bird, L., Pisani, S., & Valmaggia, L. (2021). Virtual reality relaxation for the general population: A systematic review. *Social Psychiatry and Psychiatric Epidemiology, 56*, 1707–1727. https://doi.org/10.1007/s00127-021-02110-z

Rockstroh, C., Blum, J., & Göritz, A. S. (2019). Virtual reality in the application of heart rate variability biofeedback. *International Journal of Human-Computer Studies, 130*, 209–220. https://doi.org/10.1016/j.ijhcs.2019.06.011

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

Shu, Y., Wu, C., & Zhai, Y. (2022). Impacts of landscape type, viewing distance, and permeability on anxiety, depression, and stress. *International Journal of Environmental Research and Public Health, 19*(16), 9867.

Simera, I., Moher, D., Hirst, A., Hoey, J., Schulz, K. F., & Altman, D. G. (2010). Transparent and accurate reporting increases reliability, utility, and impact of your research: Reporting guidelines and the EQUATOR network. *BMC Medicine, 8*(1), 1–6. https://doi.org/10.1186/1741-7015-8-24

Singh, R. P., Javaid, M., Kataria, R., Tyagi, M., Haleem, A., & Suman, R. (2020). Significant applications of virtual reality for COVID-19 pandemic. *Diabetes & Metabolic Syndrome: Clinical Research Reviews, 14*(4), 661–664. https://doi.org/10.1016/j.dsx.2020.05.011

Sneed, J. C., Deringer, S. A., & Hanley, A. (2021). Nature connection and 360-degree video: An exploratory study with immersive technology. *Journal of Experiential Education, 44*(4), 379–394. https://doi.org/10.1177/10538259211001568

Song, R., Chen, Q., Zhang, Y., He, H., Gao, T., & Qiu, L. (2022). Psychophysiological restorative potential in cancer patients by virtual reality (VR)-based perception of natural environment. *Frontiers in Psychology, 13*.

Spano, G., D'Este, M., Giannico, V., Elia, M., Cassibba, R., Lafortezza, R., et al. (2021). Association between indoor-outdoor green features and psychological health during the COVID-19 lockdown in Italy: A cross-sectional nationwide study. *Urban Forestry and Urban Greening, 62*, Article 127156. https://doi.org/10.1016/j.ufug.2021.127156

Spano, G., Giannico, V., Elia, M., Bosco, A., Lafortezza, R., & Sanesi, G. (2020). Human health–environment interaction science: An emerging research paradigm. *Science of the Total Environment, 704*, Article 135358. https://doi.org/10.1016/j.scitotenv.2019.135358

Sun, Y., Li, F., He, T., Meng, Y., Yin, J., Yim, I. S., … Wu, J. (2023). Physiological and affective responses to green space virtual reality among pregnant women. *Environmental Research, 216*, Article 114499.

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

Tabrizian, P., Baran, P. K., Smith, W. R., & Meentemeyer, R. K. (2018). Exploring perceived restoration potential of urban green enclosure through immersive virtual environments. *Journal of Environmental Psychology, 55*, 99–109.

Tanja-Dijkstra, K., Pahl, S., P. White, M., Andrade, J., Qian, C., Bruce, M., … Moles, D. R. (2014). Improving dental experiences by using virtual reality distraction: A simulation study. *PLoS One, 9*(3), Article e91276.

Tanja-Dijkstra, K., Pahl, S., White, M. P., Auvray, M., Stone, R. J., Andrade, J., … Moles, D. R. (2018). The soothing sea: A virtual coastal walk can reduce experienced and recollected pain. *Environment and Behavior, 50*(6), 599–625.

Theodorou, A., Panno, A., Carrus, G., Carbone, G. A., Massullo, C., & Imperatori, C. (2021). Stay home, stay safe, stay green: The role of gardening activities on mental health during the Covid-19 home confinement. *Urban Forestry and Urban Greening, 61*, Article 127091. https://doi.org/10.1016/j.ufug.2021.127091

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

Theodorou, A., Spano, G., Bratman, G. N., Monneron, K., Sanesi, G., Carrus, G., et al. (2023b). Emotion regulation and virtual nature: Cognitive reappraisal as an individual-level moderator for impacts on subjective vitality. *Scientific Reports, 13*(1). https://doi.org/10.1038/s41598-023-30287-7

Tufanaru, C., Munn, Z., Aromataris, E., Campbell, J., & Hopp, L. (2020). Chapter 3: Systematic reviews of effectiveness. In E. Aromataris, & Z. Munn (Eds.), *JBI manual for evidence synthesis*. JBI. https://doi.org/10.46658/JBIMES-20-01. Available from: https://synthesismanual.jbi.global.

Ulrich, R. S. (1983). In I. Altman, & J. Wohlwill (Eds.), *Human Behavior and Environment, Vo1.6: Behavior and Natural Environmen, 85-1* p. 25). New York: Plenum.

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 and Urban Greening, 74*, Article 127673.

van Vliet, E., Dane, G., Weijs-Perrée, M., van Leeuwen, E., van Dinter, M., van den Berg, P., … Chamilothori, K. (2021). The influence of urban park attributes on user preferences: Evaluation of virtual parks in an online stated-choice experiment.

International Journal of Environmental Research and Public Health, 18(1), 1–20. https://doi.org/10.3390/ijerph18010212

Wang, X., Shi, Y., Zhang, B., & Chiang, Y. (2019). The influence of forest resting environments on stress using virtual reality. *International Journal of Environmental Research and Public Health, 16*(18). https://doi.org/10.3390/ijerph16183263

Wang, T. C., Sit, C. H. P., Tang, T. W., & Tsai, C. L. (2020). Psychological and physiological responses in patients with generalized anxiety disorder: The use of acute exercise and virtual reality environment. *International Journal of Environmental Research and Public Health, 17*(13), 4855. https://doi.org/10.3390/ijerph17134855

White, M. P., Alcock, I., Grellier, J., Wheeler, B. W., Hartig, T., Warber, S. L., … Fleming, L. E. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Scientific Reports, 9*(1), 1–11. https://doi.org/10.1038/s41598-019-44097-3

White, M. P., Yeo, N. L., Vassiljev, P., Lundstedt, R., Wallergård, M., Albin, M., et al. (2018). A prescription for "nature"—the potential of using virtual nature in therapeutics. *Neuropsychiatric Disease and Treatment, 14*, 3001–3013. https://doi.org/10.2147/NDT.S179038

Wilson, E. O. (1984). *Biophilia*. Harvard University Press.

Xiang, Y., Liang, H., Fang, X., Chen, Y., Xu, N., Hu, M., … Gao, T. (2021). The comparisons of on-site and off-site applications in surveys on perception of and preference for urban green spaces: Which approach is more reliable? *Urban Forestry and Urban Greening, 58*. https://doi.org/10.1016/j.ufug.2020.126961

Yao, W., Zhang, X., & Gong, Q. (2021). The effect of exposure to the natural environment on stress reduction: A meta-analysis. *Urban Forestry and Urban Greening, 57*, Article 126932. https://doi.org/10.1016/j.ufug.2020.126932

Yeo, N. L., White, M. P., Alcock, I., Garside, R., Dean, S. G., Smalley, A. J., et al. (2020). What is the best way of delivering virtual nature for improving mood? An experimental comparison of high definition TV, 360° video, and computer generated virtual reality. *Journal of Environmental Psychology, 72*. https://doi.org/10.1016/j.jenvp.2020.101500

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*, Article 101775.

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

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

Zelenski, J. M., Dopko, R. L., & Capaldi, C. A. (2015). Cooperation is in our nature: Nature exposure may promote cooperative and environmentally sustainable behavior. *Journal of Environmental Psychology, 42*, 24–31. https://doi.org/10.1016/j.jenvp.2015.01.005

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*, Article 116830.