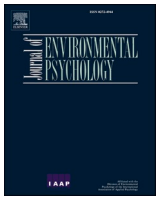
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Escaping into virtual nature: A systematic review of the effects on the psychological and psychophysiological well-being of university students

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ABSTRACT

University students often face challenges related to their mental health and well-being. Although research suggests that virtual nature (VN) can improve these outcomes, focused syntheses of evidence for this specific population are limited. This systematic review aims to examine the effects of immersive VN on psychophysiological and psychological well-being outcomes among university students, compared with control conditions. It also seeks to identify which VN features have the greatest impact on these outcomes. Data searches were conducted in Scopus, Web of Science, PubMed, PsycINFO, and PsycArticles, covering publications from January 2013 to June 2025. A total of 35 independent studies met the eligibility criteria. Overall, the findings showed a mixed pattern, depending on the control condition. However, several findings suggest that VN positively promoted physiological relaxation, with clearer evidence supporting improvements in cardiac and endocrine activity, and psychological benefits, more strongly for increases in positive affect and restorativeness, along with reductions in anxiety and stress. Nature connectedness and restorativeness appear to mediate the effects on affect. The findings were more consistent for higher-realism VN and VN with audio-olfactory stimuli. Additionally, VN was particularly effective among university students experiencing higher levels of psychological distress. Several conceptual and methodological gaps were identified, and further studies are needed to better understand the optimal conditions under which immersive VN is most beneficial for the mental health and well-being of university students.

1. Introduction

Poor mental health and well-being are common among university students. They typically experience psychological distress, ranging from mild yet worrisome symptoms (e.g., high levels of anxiety) to more serious mental disorders (e.g., major depression; Barkham et al., 2019). In fact, the World Health Organization (WHO) conducted an international study of almost 14.000 students from 19 universities across eight countries and found that at least one-third reported struggling with one or more mental health problems (Auerbach et al., 2018). The literature has identified several risk factors that help explain this trend, including biological (e.g., illnesses), psychological (e.g., poor mental health literacy), lifestyle (e.g., alcohol and substance use), family (e.g., parental separation), social (e.g., social isolation), and economic (e.g., financial difficulties). Another important set of risk factors concerns academic requirements. University students often struggle to keep up with increasingly complex academic demands (e.g., heavy workloads), which can lead to emotional and cognitive difficulties and lower well-being. In turn, these are linked to poor academic performance (e.g., lower grades) and higher university dropout rates. Such outcomes can significantly hinder their personal development (e.g., lower self-esteem) and their prospective professional life (e.g., limited career opportunities; Bantjes et al., 2022; Sheldon et al., 2021).

Virtual reality (VR), defined as simulated environments experienced through technological devices (Merriam-Webster), has been used as an intervention tool to address mental health problems, with studies demonstrating its effectiveness (e.g., Rowland et al., 2022). However, most interventions are targeted at clinical samples (e.g., people diagnosed with post-traumatic stress disorder) or specific conditions (e.g., agoraphobia; Jingili et al., 2023), potentially excluding those whose symptoms are not easily identified or acknowledged, a common issue among university students (Pedrelli et al., 2015). Virtual nature (VN)

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can serve as a supplementary intervention tool by mimicking the mental health and well-being benefits of being in contact with real-world nature (e.g., Browning, Shipley, et al., 2020). These benefits can occur in two ways. First, being in contact with real-world nature improves adverse outcomes, and second, it boosts positive ones (Bratman et al., 2021). For example, it can mitigate stress, anxiety, ruminative thoughts, and negative affect. More so, it can increase positive affect, restorativeness, cognitive acuity, and well-being (Ma et al., 2024; Meredith et al., 2020). Similar results have been found in VR studies. Therefore, while research shows that contact with real-world nature consistently boosts well-being, it also suggests that VR has become an increasingly accessible and effective tool for psychological interventions. In turn, VN offers a hybrid approach that combines scientific evidence supporting contact with real-world nature with VR's technological capabilities to improve well-being.

The conceptualization and operationalization of VN vary considerably in the literature, largely due to ongoing technological advances. In early research, it was often referred to as nature-related photos or videos viewed on a 2D display (e.g., computer monitor or TV; Browning et al., 2021). Nowadays, it refers almost exclusively to the simulation of natural environments or outdoor spaces with natural elements (e.g., trees and water bodies), displayed through VR devices, such as head-mounted displays and CAVE systems. Still, there is some disagreement about what should be considered an immersive VN. For instance, some researchers have considered still images viewed on VR devices to be immersive (e.g., Frost et al., 2022). From our perspective, simulations must involve some form of motion to be considered immersive, such as those based on 360-degree videos recorded in the real-world (i.e., 360°) or computer-generated scenarios (i.e., CG). Studies suggest that these types of VN simulations can provide the highest immersive experience (e.g., Yeo et al., 2020). Simulations typically include, but are not limited to, green (e.g., forests), blue (e.g., beaches), or mixed (e.g., parks with lakes) environments (e.g., Gao et al., 2024; Yang et al., 2024), and range from fully natural to semi-natural (i.e., urban nature, with human-made structures; e.g., Shi et al., 2025). However, as interest in this research topic grows, new VN types (e.g., brown [desert] and white [arctic]) are also being studied (e.g., Romano et al., 2024; Yin et al., 2022).

Recent reviews, including general population studies, highlight the potential of VN. According to Frost et al. (2022) and Spano et al. (2023), studies show decreases in negative affect and increases in positive affect, along with reductions in state anxiety and stress, and increases in relaxation and restorativeness. However, both reviews emphasize the variability of these results across studies. Bolouki et al. (2024) reinforced these findings and added that short exposures (in comparison to exposures of 10 min or longer), repeated exposures, and higher immersion levels provided greater benefits. Moreover, both green and blue scenarios were effective, suggesting that combining them might be the most effective. Despite the favorable outcomes, this variability underscores the need for further research to clarify the potential of VN.

Two theories are often used to explain the effects of real-world nature and VN: the Stress Recovery Theory (Ulrich, 1983) and the Attention Restoration Theory (Kaplan & Kaplan, 1989). Both suggest that natural elements possess restorative qualities, meaning they can replenish physical and psychological resources after they have been depleted due to people's efforts to meet self- and externally imposed demands (Hartig, 2004). However, each theory focuses on different aspects. Stress Recovery Theory focuses on the physiological and emotional aspects of nature-induced restoration. According to this theory, when an individual (e.g., a university student) faces a stressor (e.g., a time-sensitive deadline), they tend to experience both an emotional (e.g., subjective stress) and a physiological (e.g., increased heart rate) response associated with it. Being in contact with nature, due to its inherently attractive and enjoyable properties, can evoke an immediate sense of relaxation and positive feelings, leading to a quicker recovery from stressful thoughts and situations (Ulrich, 1983; Ulrich et al., 1991). By comparison, Attention Restoration Theory focuses on the cognitive aspect of nature-induced restoration. This theory argues that nature allows individuals to disengage their directed attention, a cognitive resource that requires constant effort and voluntary control. Given that this process is demanding, this resource becomes depleted after extended use, a pattern that is common among university students (Bantjes et al., 2022; Sheldon et al., 2021). Natural environments can reduce this mental fatigue by drawing involuntary attention instead, allowing directed attention to be restored. The authors propose that natural environments must evoke four aspects to be restorative: (i) fascination (i.e., the ability to capture interest and attention effortlessly), (ii) being away (i.e., the ability to provide an escape from daily demands), (iii) extent (i.e., the ability to foster a sense of immersion), and (iv) compatibility (i.e., the ability to be relevant to personal goals; Kaplan, 1995; Kaplan & Kaplan, 1989). Together, these theories suggest that the restorative benefits primarily stem from perceptual and emotional responses to features of the natural environments (e.g., visual and auditory stimuli), which can be recreated in VN. In addition, the Biophilia Hypothesis offers a general theoretical explanation for the effects of nature, positing that human beings have an innate tendency to connect with nature, which motivates them to spend more time in its presence (Wilson, 1984; Kellert & Wilson, 1993).

University students experience cycles of stress and mental fatigue from studying and working on their academic tasks. Exposing them to brief restorative experiences like VN may help replenish their emotional and cognitive resources in the short-term and improve their overall well-being, similar to the effects observed with real-world nature (Meredith et al., 2020). Still, it should be noted that exposure to VN may not provide the same sensory richness as real-world nature. For example, VN mainly provides audiovisual stimuli without replicating the health benefits of exposure to better air quality that real-world nature offers. As such, VN should be used as a supplementary intervention tool. University students are likely to spend most of their day attending classes, studying, and/or working on their assignments, so their time may be limited. Additionally, they might not have easy access to natural environments during these times (e.g., their campus is in an urban area) or may lack interest in spending time in nature, consistent with the ongoing trend of human disconnection from nature (Soga & Gaston, 2023). VN can partially compensate for the loss of contact with real-world nature during intense academic periods. Interestingly, a recent meta-analysis suggests that it can further increase nature connectedness (Brambilla et al., 2024), which, in turn, might motivate university students to seek greater contact with real-world nature.

Although prior reviews have examined the effects of VN on the general population, including samples of university students, this group faces unique challenges (e.g., stressful academic demands) that warrant independent consideration. There is a gap in evidence synthesis focused on their specific needs and experiences, making it necessary to determine whether and how VN can be used as an intervention tool among them. Hence, this systematic review aims to address this gap by exploring the effects of immersive VN on university students' well-being outcomes. Well-being is a complex and multidimensional concept that refers to one's experience of their life, influenced by both physical health and mental health (World Health Organization, 2013). In this review, psychological well-being is used as an overarching concept that includes subjective outcomes such as affect, stress, anxiety, depression, and restorativeness. Similarly, psychophysiological well-being groups objective outcomes that reflect the two-way relationship between psychological and physiological functions (O'Donnell & Hetrick, 2016), such as cardiac, electrodermal, and endocrine activity.

In line with the PICO + S framework, we developed the following research question: Among clinical and non-clinical university students (P), does exposure to immersive VN (I), compared with a control condition (C), lead to greater improvement in psychophysiological and psychological well-being outcomes (O) in randomized trials (S)? Furthermore, we aim to explore which immersive VN features have the greatest impact on promoting the outcomes of interest.

2. Methods

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Page et al., 2021), and the protocol was registered on OSF (https://doi.org/10.17605/OSF.IO/3W2XD).

2.1. Eligibility criteria

We established the following PICO + S framework a priori to define the eligibility criteria: P (population): clinical and/or non-clinical university students (age 18 or older); I (intervention): at least one immersive VN condition (i.e., a 360° or CG nature scenario presented via a head-mounted display or a CAVE system); C (control): at least one control condition (e.g., real-world nature, virtual urban scenario) or a comparison condition (e.g., lower level of realism or interaction in VN); O (outcomes): at least one outcome of interest, namely, affect, stress, anxiety, depression, restorativeness, and/or psychophysiological-related outcomes (i.e., cardiac, electrodermal, and/or endocrine activity); and S (study design): randomized controlled trials or randomized crossover trials.

We conducted study selection using this framework and made inclusion and exclusion decisions accordingly. Studies were included only if they met all eligibility criteria. Only English-language quantitative peer-reviewed studies published from 2013 onward were considered eligible, thus excluding gray literature, qualitative studies, review articles (or similar), and non-English manuscripts. Studies were considered ineligible if they included populations younger than 18 years, the sample was not exclusively composed of university students, used only a non-immersive or semi-immersive VN simulation (e.g., augmented reality), did not include at least one control or comparison condition, and/or did not assess at least one outcome of interest. Likewise, studies were excluded if they lacked sufficient details about the type of simulation or VR device used, as it made it impossible to determine whether they involved immersive VN. Considering our decision to focus exclusively on immersive VN, we used 2013 as the cutoff, since it was the launch year of what is widely considered the first commercial immersive head-mounted display (i.e., Oculus Rift DK1). We applied the same cutoff across studies involving CAVE systems to maintain technological consistency. Finally, we excluded studies that reported only EEG or other neural activity measures, as this systematic review focuses on peripheral psychophysiological measures. Likewise, data on these measures were not included.

2.2. Search strategy

We conducted the data searches in Scopus, Web of Science, PubMed, PsycINFO, and PsycArticles for records published between January 2013 and June 2025. Given the observed variability in the methodological terminology used to describe the studies, we opted for a broader query string to ensure inclusivity. As such, the title needed to include "virtual OR vr", and the abstract needed to include "natur* OR environment* OR "green space*" OR "blue space*" OR greenspace* OR bluespace* OR forest* OR park* OR garden* OR beach* OR sea OR lake* OR river*") and "psycholog* OR affect OR mood OR emotion* OR stress* OR distress OR relaxation OR anxiety OR depression OR restoration OR restorativeness OR fatigue OR attention* OR well-being OR "well being" OR "wellbeing" OR physiolog*". The query string was tailored to each database (see Table S1), and the search strategy was reviewed by a systematic review expert (see Table S2) following the PRESS guideline (McGowan et al., 2016). We chose not to include the population of interest in the query string because several studies involving university students do not explicitly state it in the title or abstract. Instead, we identified it during the screening process.

2.3. Data search

One researcher completed the data searches on June 30, 2025. In total, 26.754 records were found (see Fig. 1). Records were then extracted and uploaded to the Rayyan platform. Before screening, records were removed if they were the wrong publication type (i.e., non-randomized, non-quantitative, and non-peer-reviewed), non-English, or duplicates. We used Rayyan's auto-resolver duplication tool to automatically resolve records with a similarity of 95% or higher. A single researcher manually resolved the duplicates with lower similarity scores.

2.4. Data screening

The titles and abstracts of the remaining 9.200 records were screened independently and blindly by two researchers. When agreement could not be reached, a third researcher was consulted, who was blinded to the decisions made by the previous researchers.

During the title and abstract screening, articles were excluded because the topic was unrelated to the review aims. Of the total, 352 were sought for retrieval, though 13 records could not be retrieved, even after reaching out to the corresponding authors. The remaining 339 records underwent full-text screening, following the same procedure as the previous screening process. The main exclusion reasons were not including a sample of only university students, not having a control or comparison condition, or not including at least one fully immersive VN condition.

2.5. Data extraction

This systematic review included 33 records. However, two of these records contained two studies that met the eligibility criteria, resulting in a final sample of 35 independent studies.

We outlined a coding protocol before data extraction to ensure comparability across studies, focusing on the following categories: authors, publication year, publication country and continent, theoretical framework, sample size, sample characteristics (type, age, and gender), study design, VR device, stress-inducing task (type and duration), experimental conditions (type, exposure time, and number of exposures), control or comparison conditions (same as previous), outcomes (including assessment periods), and findings. Data extraction was conducted independently by two researchers using separate Excel files. After completion, the researchers validated the retrieved data and consolidated it into a single file.

2.6. Quality assessment

We used two checklists to assess risk of bias, namely the Revised Cochrane Risk-of-Bias Tool for Randomized Trials and the Revised Cochrane Risk-of-Bias Tool for Randomized Crossover Trials (Sterne et al., 2019). The first checklist assesses risk of bias across five domains: risk of bias arising from the randomization process (Domain 1), risk of bias due to deviations from the intended interventions (Domain 2), risk of bias due to missing outcome data (Domain 3), risk of bias in measurement of the outcome (Domain 4), and risk of bias in selection of the reported result (Domain 5). Similarly, the second checklist assesses risk of bias across the same five domains, plus an additional domain: risk of bias arising from period and carryover effects (Domain S). For both checklists, each domain is rated on a three-level scale: low risk, some concerns, or high risk.

Two independent researchers conducted the quality assessment. Inter-researcher reliability was assessed using Cohen's K coefficient for each domain. The results indicate substantial to almost perfect agreement, with 0.62 for domain 3, 0.67 for domain S, and 1 for the remaining domains. A third researcher resolved disagreements in domains 3 and S, remaining blinded to the previous researchers' assessments.

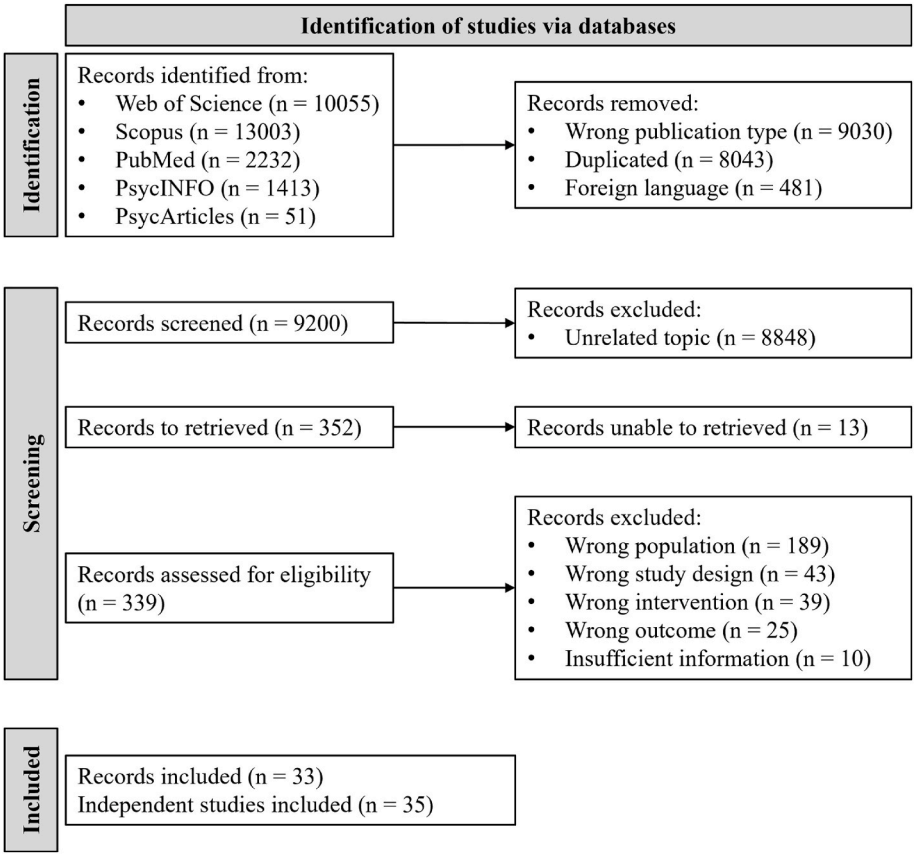


Fig. 1. Flow diagram of data searches.

3. Results

3.1. Studies' characteristics

The final sample comprises 35 independent studies (see Table 1 and Table S3). Publication years ranged from 2017 to 2025, with 2023 being the most common year (9 studies). The studies were conducted in Asia (the most common region, with 14 studies), Europe, North America, and Australia.

The majority of the studies were framed within one or more nature-related theoretical frameworks, with most citing both the Attention Restoration (Kaplan & Kaplan, 1989) and the Stress Reduction (Ulrich, 1983) theories (19 studies).

Most studies included a non-clinical sample (26 studies). Nevertheless, some studies (fewer than 10) did not report whether the participants were screened for physical and/or mental health conditions. The remaining studies selected participants based on their reported levels of anxiety, depression, stress, and/or trauma. The sample sizes ranged from 10 to 189, totaling 1936 participants. Small to medium sample sizes (fewer than 50 participants) were more frequent (21 studies). The participants' ages ranged from 18 to 59 years, with the most frequently reported mean ages being 20 and 21 years (7 studies each). The majority were female (1116 participants in total).

Only randomized trials were considered in this systematic review, with a between-subjects design being most employed (22 studies). All studies used a head-mounted display (most commonly, an HTC Vive model [20 studies]), except one that used a CAVE system. Less than half of the studies (13 studies) applied a stress-inducing task, with arithmetic tasks being the most common (6 studies). Regarding VN, CG green nature (11 studies) and CG mixed nature (10 studies) were used more frequently. Exposure time varied between 3 min and 30 min, with 5 and 10 min being the most common (7 studies each). Most participants were exposed to VN only once (25 studies). The remaining studies varied between 2 and 24 exposures. All studies included one or more control or comparison conditions. The most recurrent was a virtual urban scenario (9 studies).

Almost all studies used self-report measures to collect data (31 studies). The most frequently measured outcome was affect (21 studies), followed by restorativeness (14 studies), anxiety (10 studies), depression (6 studies), and stress (5 studies). Some studies employed psychophysiological measures, including heart activity (13 studies), electrodermal activity (3 studies), and endocrine activity (2 studies). Of these, only a few combined both types of measures (10 studies).

3.2. Quality assessment

All studies were rated as having some concerning risk of bias, except for two that were rated as having a high risk of bias. No studies were rated as having a low risk of bias due to a considerable lack of information in several domains (see Fig. 2a and b).

Despite studies mentioning randomization, almost all failed to specify the method used. Likewise, there was little to no information on intervention allocation methods. As a result, 34 studies were graded "some concerns" for domain 1 (risk of bias arising from the randomization process). Additionally, almost no studies reported the blinding methods used for participants and experimenters. So, for domain 2 (risk of bias due to deviations from the intended interventions), 33 were rated "some concerns". Regarding domain 3 (risk of bias due to missing outcome data), 18 studies provided either all or nearly all data on the outcome of interest and were therefore graded "low risk". As with the observed patterns for domains 1 and 2, most studies did not provide sufficient information about the blinding methods for assessors and relied primarily on subjective measures. For this reason, 31 studies were rated "some concerns" for domain 4 (risk of bias in measurement of the

Table 1
Studies characteristics.

Study (Year)	Theoretical Framework	Study Design	Sample size	Experimental Condition(s) (VN Type)	Control/ Comparison Condition(s)	Exposure Duration	Stress-Inducing Task (Type and Duration)	Psychological Outcomes (Assessment Period)	Psychophysiological Outcomes (Assessment Period)
Abbott & Diaz-Artiles (2022)	Stress Recovery Theory, Attention Restoration Theory	Within	10	VN with olfactory stimuli (CG mixed)	VN without olfactory stimuli	15 min	Yes (Trier Social Stress Test, 8 min)	Affect, Anxiety (Pre- and post-exposure)	No
Alyan et al. (2021)	Stress Recovery Theory	Between	20	High-realism VN (CG green)	Low-realism VN	5 min	Yes (Letter Detection Test, 2 min)	Affect, Depression (Post-exposure only)	Heart rate, Skin conductance (Pre- and post-exposure)
Baktash et al. (2024)	Attention Restoration Theory, Biophilia Hypothesis	Between	36	VN with audio-olfactory stimuli (360 mixed)	VN without audio-olfactory stimuli	8 min	No	Anxiety (Pre- and post-exposure)	No
Browning, Mimnaugh, et al. (2020)	Stress Recovery Theory, Attention Restoration Theory	Between	89	VN (360 mixed)	Real-world nature and non-exposure	6 min	No	Affect (Pre- and post-exposure), Restorativeness (Post-exposure only)	Skin conductance (Pre- and post-exposure)
Browning et al. (2023)	No	Between	40	VN (360 mixed)	Non-exposure	4 min	No	Affect, Anxiety, Depression (Pre- and post-exposure)	No
Chan et al. (2023a, Study 1)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Within	30	VN (CG green)	Virtual urban scenario	5 min	No	Affect (Pre- and post-exposure)	Heart rate, Heart rate variability (Pre- and post-exposure)
Chan et al. (2023b, Study 1)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	71	VN (CG mixed)	Virtual indoor scenario	5 min	No	Affect, Restorativeness (Post-exposure only)	No
Chan et al. (2023b, Study 2)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	79	VN (CG green)	Virtual indoor scenario	5 min	No	Affect (Pre- and post-exposure), Restorativeness (Post-exposure only)	No
Davidov et al. (2023)	Stress Recovery Theory, Attention Restoration Theory	Within	20	VN (360 green)	2D nature and non-exposure	3 to 5 min	No	Affect (Post-exposure only)	No
Frewen et al. (2020, Study 3)	No	Within	48	VN (CG mixed nature)	2D nature and non-exposure (imagining nature)	Unknown	No	Affect (Post-exposure only)	No
Greco et al., 2024	No	Within	26	Walk in VN (360 blue)	Walk in real-world nature	6 min	No	No	Heart rate (Post-exposure only)
Hsieh et al. (2023)	No	Between	45	VN with auditory stimuli (360 mixed)	VN without auditory stimuli	5 min	Yes (Trier Social Stress Test [only arithmetic], 6 min)	Affect, Anxiety (Pre- and post-exposure)	Heart rate, Heart rate variability (Pre- and post-exposure)
Hu et al. (2025)	Biophilia Hypothesis	Between	58	VN plus therapy exercises (CG mixed)	VN-only and therapy exercises-only	30 min	No	Anxiety, Restorativeness (Pre- and post-exposure)	No

(*continued on next page*)

Table 1 (*continued*)

Study (Year)	Theoretical Framework	Study Design	Sample size	Experimental Condition(s) (VN Type)	Control/ Comparison Condition(s)	Exposure Duration	Stress-Inducing Task (Type and Duration)	Psychological Outcomes (Assessment Period)	Psychophysiological Outcomes (Assessment Period)
Jo et al. (2021)	Stress Recovery Theory, Attention Restoration Theory	Between	60	VN (360 green)	2D nature and non-exposure	5 min	No	No	Heart rate variability (Pre- and post-exposure)
Li et al. (2021, Study 2)	Stress Recovery Theory, Attention Restoration Theory	Between	189	Interactive VN (CG mixed)	Virtual urban scenario and non-interactive VN	10 min	No	Affect (Pre- and post-exposure), Restorativeness (Post-exposure only)	No
Manchón & Šimunić (2024)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	64	Interactive VN (CG mixed)	Non-exposure and non-interactive VN	6 min	No	Affect, Stress (Pre- and post-exposure)	No
Masters et al. (2024)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	48	High-realism VN (CG green)	Non-exposure and low-realism VN	10 min	Yes (Arithmetic Task, duration unknown)	Affect, Restorativeness (Pre- and post-exposure)	Heart rate, Blood pressure (Pre- and post-exposure)
Mostajeran et al. (2023)	Stress Recovery Theory, Attention Restoration Theory	Within	27	High-realism VN (CG green)	Low-realism VN	10 min	No	Affect, Stress, Restorativeness (Post-exposure only)	No
Newman et al. (2022, Study 2)	No	Between	120	VN (CG green)	Virtual urban scenario	10 min	Yes (Write about a stressful time, 10 min)	Affect (Pre- and post-exposure)	No
O'Meara et al. (2020)	Stress Recovery Theory, Attention Restoration Theory	Between	40	VN among individuals with higher and lower anxiety levels (360 mixed)	Virtual urban scenario among the same individuals	4 min	No	Affect (Pre- and post-exposure)	No
Poli et al. (2024)	No	Within	31	Cycling in VN (360 mixed)	Cycling in real-world nature and cycling in 2D nature	10 min	No	No	Heart rate (Post-exposure only)
Pratviel et al. (2024)	Attention Restoration Theory	Within	36	VN (CG green) plus heart rate variability biofeedback	Heart rate variability biofeedback-only	5 to 10 min	No	Stress, Anxiety (Pre- and post-exposure)	Heart rate variability (Pre- and post-exposure)
Quirós-Ramírez et al. (2025)	No	Within	59	High-quality VN (360 green)	Low-quality VN	5 min	No	Affect (Pre- and post-exposure)	No
Reece et al. (2022)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	31	VN (360 mixed, + historic street)	2D nature (+ historic street)	6 min	Yes (Watch traffic videos, 90 s)	Stress, Anxiety (Pre- and post-exposure)	No
Romano et al. (2024)	Stress Recovery Theory, Attention Restoration Theory	Between	86	VN (CG white) plus mindfulness	VN-only and virtual urban scenario plus mindfulness	4 min	No	Affect (Pre- and post-exposure), Restorativeness (Post-exposure only)	No
Schutte et al. (2017)	No	Between	26	VN (360 mixed)	Virtual urban scenario	6 min	No	Affect (Pre- and post-exposure), Restorativeness	No

(*continued on next page*)

Table 1 (*continued*)

Study (Year)	Theoretical Framework	Study Design	Sample size	Experimental Condition(s) (VN Type)	Control/ Comparison Condition(s)	Exposure Duration	Stress-Inducing Task (Type and Duration)	Psychological Outcomes (Assessment Period)	Psychophysiological Outcomes (Assessment Period)
								(Post-exposure only)	
Shi et al. (2025)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Within	44	VN (CG blue)	Urban VN	7 min	Yes (Arithmetic Task, 3 min)	Affect, Depression, Restorativeness (Post-exposure only)	Heart rate variability (Pre- and post-exposure)
Suseno & Hastjarjo (2023)	No	Between	53	VN plus meditation (CG mixed)	2D nature plus meditation	3 min and 25 s	Yes (Sing-a-Song Stress Test, 1 min and 25 s)	Anxiety (Pre- and post-exposure)	Heart rate, Skin conductance (Pre- and post-exposure)
Ünal et al. (2022, Study 2)	Attention Restoration Theory	Within	26	VN (CG mixed)	Real-world nature and virtual urban scenario	20 min	Yes (Sudoku, 50 min)	Affect, Restorativeness (Post-exposure only)	No
Wang et al. (2022, Study 1)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	20	VN (CG mixed) among individuals with higher levels of anxiety and depression	VN among individuals with lower levels of anxiety and depression	8 to 10 min	No	Anxiety, Depression (Pre- and post-exposure), Restorativeness (Post-exposure only)	No
Wang et al. (2022, Study 2)	Stress Recovery Theory, Attention Restoration Theory, Biophilia Hypothesis	Between	186	Interactive VN (CG mixed)	Virtual urban scenario and non-interactive VN	10 min	No	Anxiety, depression (Pre- and post-exposure), Restorativeness (Post-exposure only)	No
Yin et al. (2022)	Stress Recovery Theory	Between	95	Green VN (360 green)	Virtual indoor scenario and brown VN	10 min	Yes (Trier Social Stress Test, 15 min)	No	Arterial pressure, Salivary biomarkers (Pre- and post-exposure)
Yoon & Jeon (2025)	Stress Recovery Theory, Attention Restoration Theory	Within	42	VN with auditory stimuli (CG green and mixed)	VN without auditory stimuli	3 min	Yes (Arithmetic Task, 3 min)	Restorativeness (Post-exposure only)	Heart rate, Heart rate variability (Pre- and post-exposure)
Yu et al. (2018)	Stress Recovery Theory, Attention Restoration Theory	Within	30	VN (360 mixed)	Virtual urban scenario	9 min and 30 s	Yes (Paced Auditory Serial Addition Test, duration unknown)	Affect, Depression (Pre- and post-exposure)	Heart rate variability, Blood pressure, Salivary biomarkers (Pre- and post-exposure)
Zhang et al. (2023)	Attention Restoration Theory	Between	51	VN (360 green)	Virtual indoor scenario	9 min	Yes (Arithmetic Task, 3 min)	Stress (Pre- and post-exposure)	No

Note. VN = virtual nature. Min = minutes. S = seconds.

outcome). Likewise, almost none of the studies reported a pre-specified analysis plan, resulting in 33 studies being graded "some concerns" for domain 5 (risk of bias in the selection of the reported result). For crossover trials specifically, two studies were rated as "high risk" for domain S (risk of bias arising from period and carryover effects) because the time allowed for carryover effects to dissipate before the next outcome assessment was deemed insufficient (e.g., 10 min). All studies were included, regardless of their final assessment. Therefore, the findings of this systematic review must be considered in light of these limitations.

3.3. Studies' findings

We organized the findings by outcomes, first presenting the psychophysiological outcomes and then the psychological outcomes (see Tables S3 and S4). For each outcome, we begin with findings comparing VN to a control condition (i.e., 2D nature, non-exposure, real-world nature, urban VN, virtual indoor scenario, and virtual urban scenario), followed by findings comparing VN features (i.e., type of VN, level of realism, level of interaction, with audio-olfactory stimuli, with another intervention, and used among university students with varying levels of psychological distress). At the end, we presented findings on indirect effects (i.e., mediation) involving VN.

In addition to reporting the findings of each study, we extracted the magnitude of the effect sizes directly from the included studies whenever available. The magnitude was determined using conventional thresholds, namely: 0.2 (small), 0.5 (medium), and 0.8 (large; Cohen, 1988). However, in several cases, the magnitude could not be

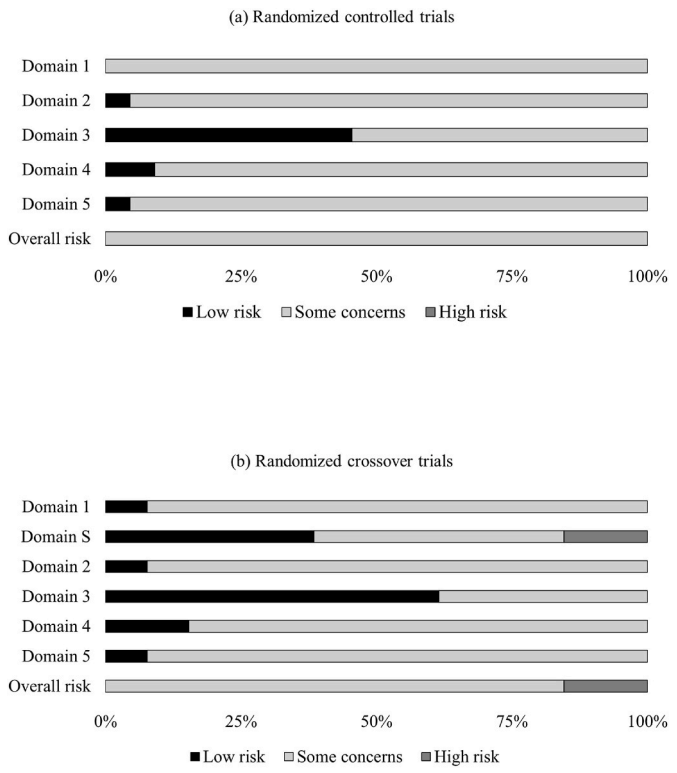


Fig. 2. Risk of bias per type of randomized trials.

determined due to insufficient information, so no effect was reported. Lastly, for all outcomes, we summarize the findings based on the direction of the effects that were most consistent to provide an overview of trends across studies (see Figs. 3 and 4).

3.3.1. Cardiac activity

Thirteen independent studies evaluated heart activity. Of these, 9 focused on heart rate. Compared with real-world nature, walking in VN resulted in a lower heart rate (large effect size, Greco et al., 2024), while cycling in VN led to a higher heart rate (small effect size, Poli et al., 2024). Though in both studies, the difference in maximum heart rate between conditions was non-significant (Greco et al., 2024; Poli et al., 2024). In Chan et al. (2023a, Study 1), only VN had an effect, increasing IBI (which translates into lower heart rate) compared with a virtual urban scenario (medium effect size). Other studies found non-significant differences in heart rate between VN and a virtual urban scenario (Yu et al., 2018), 2D nature (Poli et al., 2024; Suseno & Hastjarjo, 2023), and non-exposure (Masters et al., 2024). Focusing on VN features, Alyan et al. (2021) observed that a higher-realism VN lowered heart rate more than a lower-realism version (medium effect size). In contrast, Masters et al. (2024) reported a non-significant difference between conditions. Likewise, Hsieh et al. (2023) and Yoon and Jeon (2025) found non-significant differences across various levels and types of auditory stimuli in VN.

Seven studies measured heart rate variability. We grouped the metrics into time-domain indices (i.e., RMSSD and SDNN), which quantify the magnitude of variability in cardiac interbeat intervals over time, and frequency-domain indices (i.e., HF, LF, and LF/HF), which describe how heart rate variability power is distributed across oscillatory frequency bands (Laborde et al., 2017).

Starting with time-domain indices, Jo et al. (2021) observed that VN led to higher RMSDD and SDNN than non-exposure (effect sizes not reported). However, the differences between VN and 2D nature for both indices were non-significant (Jo et al., 2021). Meanwhile, in Shi et al. (2025), VN resulted in lower SDNN than in one urban VN scenario (i.e., coastal walkway; effect size not reported). The other comparisons were non-significant (Shi et al., 2025). For RMSSD, the differences between VN and a virtual urban scenario (Chan et al., 2023a [Study 1]), and between VN and urban VN scenarios (Shi et al., 2025), were non-significant. Regarding distinct features of VN, studies found non-significant differences between auditory stimuli in VN for SDNN (Hsieh et al., 2023; Yoon & Jeon, 2025), and between VN plus biofeedback and biofeedback-only for RMSSD (Pratviel et al., 2024).

Among the frequency-domain indices, Jo et al. (2021) observed that VN resulted in higher HF than 2D nature and non-exposure (effect sizes not reported), but the difference between conditions for LF was non-significant. Other studies also showed non-significant differences between VN and a virtual urban scenario for HF and LF/HF (Yu et al., 2018), and between VN and urban VN scenarios for LF/HF (Shi et al., 2025). As for auditory stimuli, Hsieh et al. (2023) showed that VN with higher sounds reduced LF and LF/HF compared with lower sounds (large effect sizes) and no sounds (medium effect sizes). However, studies found non-significant differences between auditory stimuli for LF (Yoon & Jeon, 2025) and for HF (Hsieh et al., 2023; Yoon & Jeon, 2025).

Three studies measured blood and arterial pressure. All studies found non-significant differences between VN and a virtual urban scenario (Yu et al., 2018) and between VN and non-exposure (Masters et al., 2024) for blood pressure, as well as between VN and a virtual indoor scenario for mean arterial pressure (Yin et al., 2022). Regarding the level of realism, Masters et al. (2024) found a non-significant difference between high-realism and lower-realism VN for blood pressure.

In general, VN decreased heart rate more than virtual urban scenarios in half of the findings (see Fig. 3a), which aligns with greater physiological relaxation (e.g., Shao et al., 2024). For heart rate variability, VN had a greater effect on RMSSD/SDNN and HF but not on LF and LF/HF (see Fig. 3d and e). Specifically, VN increased RMSSD/SDNN and HF more than non-exposure, and HF more than 2D nature across all findings (see Fig. 3b and c), indicating higher physiological relaxation (e.g., Hannon et al., 2025). Regarding VN features, higher-realism VN had an effect on lowering heart rate, while VN combined with auditory stimuli had effects on lowering LF and LF/HF. For blood/arterial pressure, the findings show that VN produced effects similar to control conditions (see Fig. 3f).

3.3.2. Electrodermal activity

Three independent studies evaluated skin conductance. Browning, Mimnaugh, et al. (2020) found that VN resulted in higher skin conductance levels than non-exposure (effect size not reported), but showed a non-significant difference from real-world nature. Suseno and Hastjarjo (2023) reported a non-significant difference between VN and 2D nature during exposure. However, VN showed a delayed effect, increasing skin conductance after exposure (effect size not specified, Suseno & Hastjarjo, 2023). Regarding VN realism, Alyan et al. (2021) showed that a higher-realism VN led to lower skin conductance levels than a lower-realism version (large effect size).

Overall, VN increased skin conductance more than non-exposure and 2D nature in at least half of the findings (Fig. 3g), which is less indicative of physiological relaxation (e.g., Scavone et al., 2020). Concerning VN realism, higher-realism VN decreased skin conductance more.

3.3.3. Endocrine activity

Two independent studies examined salivary biomarkers. Yu et al. (2018) found a non-significant difference in salivary α-amylase between VN and a virtual urban scenario. Meanwhile, Yin et al. (2022) reported that brown VN (i.e., desert) reduced salivary cortisol more than a virtual indoor scenario (effect size not reported). Nevertheless, the differences between brown and green VN, as well as between green VN and a virtual indoor scenario, were non-significant.

In general, VN decreased salivary biomarkers more than a virtual indoor scenario (see Fig. 3h), aligning with greater physiological

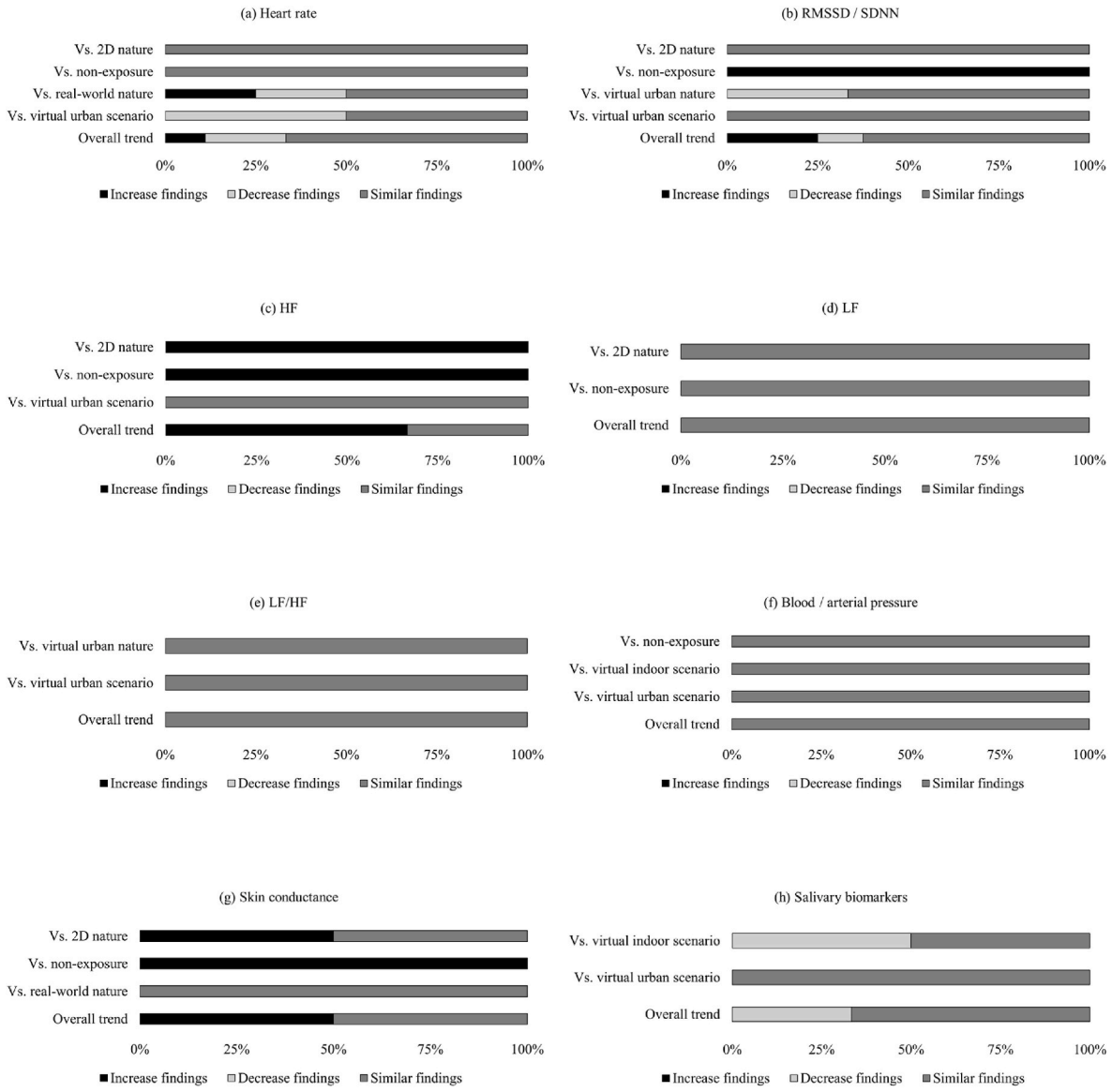


Fig. 3. Trend Analyses of Psychophysiological Outcomes

Note. **Increase findings** indicate that the reference condition showed a significantly greater increase in the outcome than the control condition. **Decrease findings** indicate that the reference condition showed a significantly greater decrease in the outcome than the control condition. **Similar findings** indicate that there were no significant differences between the reference and control conditions for the outcome.

relaxation (e.g., Robinson et al., 2023).

3.3.4. *Affective states*

Twenty-one independent studies assessed affect, with 10 employing a version of the Positive and Negative Affect Schedule (Watson et al., 1988).

Seven studies compared VN to a virtual urban scenario. The studies showed that VN increased vigor (large effect size, Yu et al., 2018), serenity (medium effect size, Newman et al., 2022 [Study 2]), and pleasure (large effect size, Ünal et al., 2022 [Study 2]) compared to a virtual urban scenario. In contrast, Schutte et al. (2017) and Chan et al. (2023a, Study 1) found that only the virtual urban scenario had an effect, decreasing positive affect (large effect sizes). Li et al. (2021, Study 2), Newman et al. (2022, Study 2), and O'Meara et al. (2020) observed non-significant differences between conditions. Moreover, O'Meara et al. (2020) also observed a non-significant three-way interaction effect for positive affect involving time, type of virtual scenario, and baseline levels of anxiety. Meanwhile, studies showed that VN decreased negative affect (effect size not reported, Chan et al., 2023a [Study 1]), confusion, fatigue, anger-hostility, and tension (large effect sizes, Yu et al., 2018) compared to a virtual urban scenario. Conversely, Schutte et al. (2017), O'Meara et al. (2020), Li et al. (2021, Study 2), and Newman et al. (2022, Study 2) reported non-significant differences between conditions. However, O'Meara et al. (2020) found that VN reduced negative affect more, but only among university students with higher baseline levels of anxiety (large effect size). In addition, one study compared VN with urban VN. Shi et al. (2025) reported non-significant differences in vigor across conditions. Regarding negative affect, the authors observed that VN decreased anger and confusion, but increased total mood disturbance more than some urban VN scenarios (e.g., coastal walkway; effect sizes not reported). For tension and fatigue, the differences across conditions were non-significant (Shi et al., 2025).

Six studies contrasted VN with other exposure levels. Studies showed that VN elicited higher positive affect than 2D nature and imagining nature (large effect sizes, Frewen et al., 2020), as well as greater positive affect (effect size not reported, Masters et al., 2024) and happiness (large

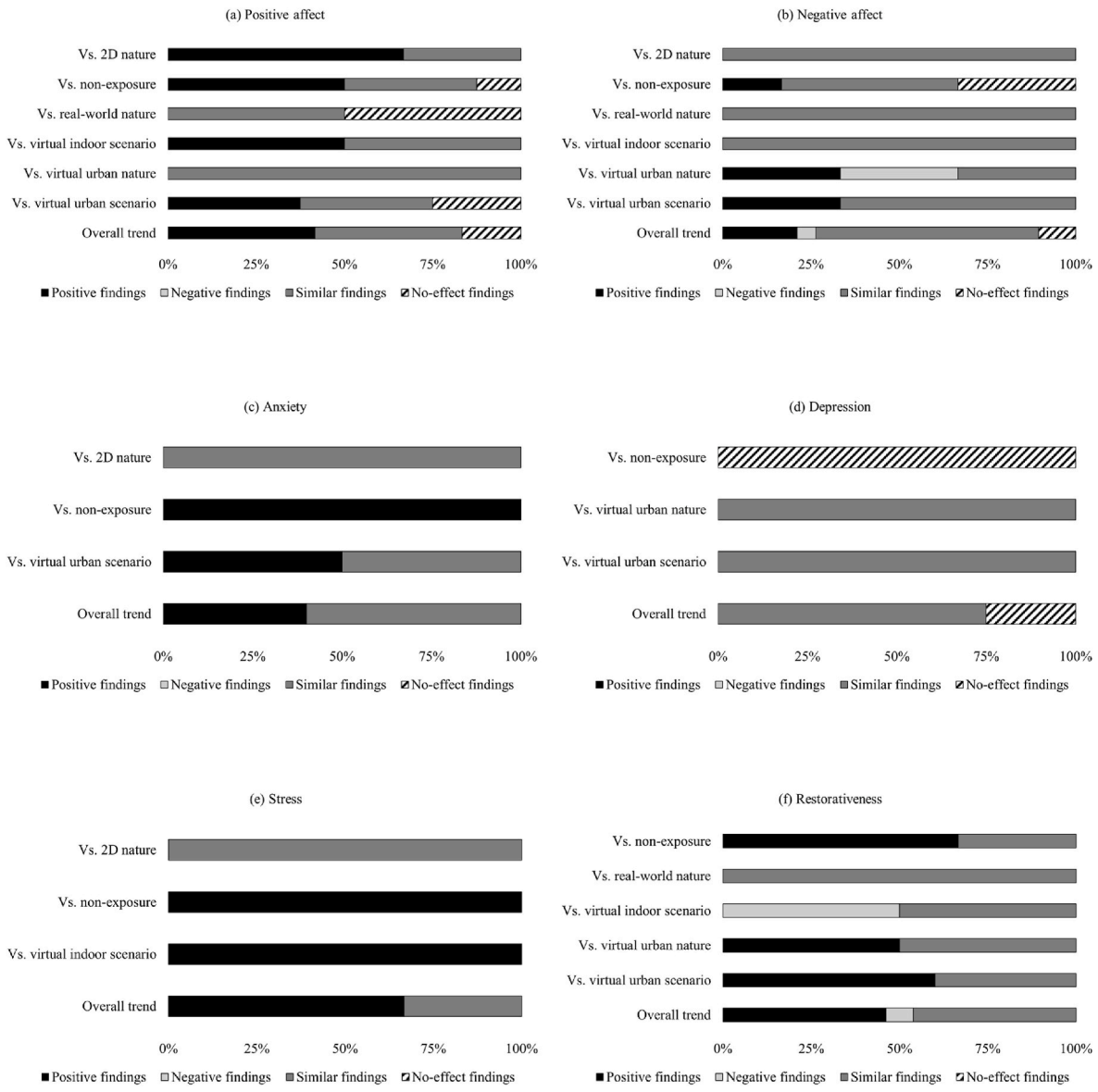


Fig. 4. Trend Analyses of Psychological Outcomes

Note. **Positive findings** indicate that the reference condition produced a significantly more favorable outcome than the control condition. **Negative findings** indicate that the reference condition produced a significantly less favorable outcome than the control condition. **Similar findings** indicate that there were no significant differences between the reference and control conditions for the outcome. **No-effect findings** indicate that the reference condition did not show a significant pre-post change, irrespective of whether the control condition exhibited a significant improvement or decline on the outcome.

effect size, Manchón & Šimunić, 2024) than non-exposure. However, in Masters et al. (2024), the difference between lower-realism VN and non-exposure was non-significant. Additionally, Davidov et al. (2023) reported that, in men, VN led to higher arousal than 2D nature and non-exposure, and higher dominance than non-exposure (effect sizes not reported). In women, VN resulted in increased arousal and dominance compared with non-exposure (effect sizes not reported, Davidov et al., 2023). Differently, Browning, Mimnaugh, et al. (2020) observed that only non-exposure had an effect, decreasing positive affect (effect size not reported). Other studies found non-significant differences across conditions for valence (Davidov et al., 2023), energy, and calmness (Manchón & Šimunić, 2024). Additionally, Manchón and Šimunić (2024) showed that VN reduced tenseness (large effect size), while non-exposure increased sadness (large effect size). For negative affect, studies reported non-significant differences between VN and 2D nature, imagining nature (Frewen et al., 2020, Study 3), and non-exposure (Browning, Mimnaugh, et al., 2020; Masters et al., 2024). Regarding Browning et al. (2023), the authors observed a non-significant change in rumination over time in either VN or non-exposure.

Two studies compared VN with real-world nature. Browning, Mimnaugh, et al. (2020) reported that only real-world nature had an effect, increasing positive affect (effect size not reported). However, Ünal et al. (2022, Study 2) showed a non-significant difference in pleasure between conditions. As for negative affect, Browning, Mimnaugh, et al. (2020) also found a non-significant difference between conditions.

Two studies contrasted VN with a virtual indoor scenario (i.e., a museum). In Study 1, Chan et al. (2023b) revealed that VN elicited higher positive affect than a virtual indoor scenario (medium effect size). In Study 2, the authors found a non-significant difference between conditions. This pattern was also observed for negative affect in both studies (Chan et al., 2023b [Study 1]; Chan et al., 2023b [Study 2]).

Five studies evaluated VN realism levels. Mostajeran et al. (2023) showed that a higher-realism VN increased positive affect more than a

lower-realism version (large effect size). In contrast, Quirós-Ramírez et al. (2025, Study 2) found that viewing VN on a higher-quality VR device reduced positive affect, while using a lower-quality device increased it (effect size not reported). Other studies, however, reported non-significant differences between higher- and lower-realism VN for positive affect (Masters et al., 2024; Newman et al., 2022 [Study 2]), and for serenity (Newman et al., 2022 [Study 2]), and vigor (Alyan et al., 2021). Meanwhile, Alyan et al. (2021) observed that a higher-realism VN decreased total mood disturbance and confusion more than a lower-realism version (large effect sizes). In contrast, all studies showed non-significant differences between the conditions for negative affect (Masters et al., 2024; Mostajeran et al., 2023; Newman et al., 2022 [Study 2]; Quirós-Ramírez et al., 2025 [Study 2]), and for tension, anger, and fatigue (Alyan et al., 2021).

Two studies assessed VN interaction levels. Both found non-significant differences between interactive and non-interactive VN for positive affect (Li et al., 2021 [Study 2]), and for happiness, energy, and calmness (Manchón & Šimunić, 2024). Differently, Manchón and Šimunić (2024) reported that only interactive VN affected tenseness, reducing it (large effect size). Concerning negative affect (Li et al., 2021 [Study 2]) and sadness (Manchón & Šimunić, 2024), the studies found non-significant differences between conditions.

Two studies examined the effects of audio-olfactory stimuli in VN. Hsieh et al. (2023) showed that VN with lower sounds, compared with higher sounds and no sounds, decreased arousal (large effect sizes) and increased pleasure (medium and large effect sizes, respectively). Meanwhile, Abbott and Diaz-Artiles (2022) reported a non-significant change in positive affect over time in either VN combined with olfactory stimuli or VN-only. As for negative affect, the authors found that only VN combined with olfactory stimuli led to a reduction (effect size not reported, Abbott & Diaz-Artiles, 2022).

Overall, VN increased positive affect more than 2D nature, non-exposure, and virtual indoor scenarios in at least half of the findings (see Fig. 4a). Among VN features, higher-realism VN and VN combined with auditory stimuli had effects on increasing positive affect. For negative affect, most findings indicate that VN produced effects similar to those in control conditions (see Fig. 4b). Additionally, higher-realism VN, interactive VN, VN combined with olfactory stimuli, and VN used among university students with higher psychological distress decreased negative affect more.

3.3.5. *Psychological distress*

Ten independent studies assessed anxiety, 8 of which used a version of the State-Trait Anxiety Inventory (Spielberger et al., 1983). Similarly, 6 studies evaluated depression, with 3 using a subscale of the Profile of Mood States (McNair et al., 1971), and 5 studies assessed stress, with 2 using a version of the Perceived Stress Scale (Cohen & Williamson, 1988).

Four studies compared VN with other exposure levels. Some of the studies found that VN decreased worry, panic (effect size not reported, Browning et al., 2023), and stress (large effect size, Manchón & Šimunić, 2024) in comparison with non-exposure. Conversely, other studies found non-significant differences between VN and 2D nature for state anxiety (Reece et al., 2022 [1]; Suseno & Hastjarjo, 2023) and for stress (Reece et al., 2022). In Browning et al. (2023), the authors observed a non-significant change in depressive symptoms over time in either the VN or non-exposure.

Two studies contrasted VN with a virtual urban scenario. Wang et al. (2022, Study 2) found that certain types of VN (e.g., fishing) decreased state anxiety compared to a virtual urban scenario (effect size not reported). At the same time, the comparisons with other types (e.g., watering) were non-significant. Regarding depression levels, Yu et al. (2018) and Wang et al. (2022, Study 2) showed non-significant differences between conditions. Additionally, one study contrasting VN to urban VN scenarios found a non-significant difference in depression levels across conditions (Shi et al., 2025). Another study comparing VN with a virtual indoor scenario showed that only VN had an effect on stress, reducing it (medium effect size, Zhang et al., 2023).

Three studies investigated the effects of audio-olfactory stimuli in VN. In Abbott and Diaz-Artiles (2022), only VN combined with olfactory stimuli lowered state anxiety (effect size not reported). Other studies found non-significant differences in state anxiety across different levels of auditory stimuli (Hsieh et al., 2023) and audio-olfactory stimuli (Baktash et al., 2024).

Two studies examined the realism levels in VN, and both showed that higher-realism VN resulted in lower stress (small effect size, Mostajeran et al., 2023) and lower depressive mood (large effect size, Alyan et al., 2021) compared with a lower-realism version.

Two studies assessed the interaction levels in VN. Manchón and Šimunić (2024) found that interactive VN lowered stress more than a non-interactive version (large effect size). Contrarily, in Wang et al. (2022, Study 2), non-interactive VN decreased state anxiety more than one type of interactive VN (i.e., watering; effect size not reported). The other interactive comparisons (e.g., fishing) were non-significant. Moreover, the authors also found a non-significant difference across conditions in depression levels (Wang et al., 2022 [Study 2]).

Two studies investigated the effects of adding an intervention to VN. Pratviel et al. (2024) found non-significant differences between VN plus biofeedback and biofeedback-only for state anxiety and stress. In Hu et al. (2025), the authors observed a non-significant change in social anxiety over time across conditions (i.e., VN plus therapy, VN-only, or therapy-only). In addition, two studies evaluated the effects of VN on university students with varying baseline levels of psychological distress. The studies found that VN reduced state anxiety, stress (Pratviel et al., 2024), and depression levels (Wang et al., 2022 [Study 1]), but only among those with higher anxiety and/or depression levels (effect sizes not reported). Inversely, Wang et al., 2022 found that VN increased state anxiety, but only among university students with lower levels (effect size not reported). Furthermore, the authors reported a non-significant change in trait anxiety over time in either condition (Wang et al., 2022 [Study 1]).

In general, VN had a greater effect on anxiety and stress but not on depression (see Fig. 4d). Specifically, VN reduced anxiety more than non-exposure and virtual urban scenarios in at least half of the findings (see Fig. 4c). Regarding stress, VN decreased it more than non-exposure and virtual indoor scenarios across all findings (see Fig. 4e). Concerning VN features, VN combined with olfactory stimuli lowered anxiety more, while higher-realism VN was more effective in reducing depression and stress. Non-interactive VN reduced anxiety more, whereas interactive VN lowered stress more. Moreover, VN was more effective at improving all three outcomes among university students with higher levels of psychological distress.

3.3.6. *Restorative outcomes*

Fourteen studies assessed restorativeness, with 7 employing a version of the Perceived Restorativeness Scale (Hartig et al., 1997).

Five studies contrasted VN to a virtual urban scenario. Some studies showed that VN increased restorativeness (large effect sizes, Romano et al., 2024; Schutte et al., 2017; Ünal et al., 2022 [Study 2]), fascination, novelty, escape, and coherence (large effect sizes, Ünal et al., 2022 [Study 2]) more than a virtual urban scenario. Opposingly, Li et al., 2021 and Wang et al. (2022, Study 2) reported non-significant differences between conditions. In addition, one study compared VN with urban VN. Shi et al. (2025) found that VN increased restorativeness, being away, and compatibility more than one type of urban VN (i.e., coastal plaza; effect sizes not reported). The differences between conditions for fascination and extent were non-significant.

Two studies compared VN with a virtual indoor scenario (i.e., a

[1] This result should be regarded carefully, as both conditions involved a brief exposure to a historic street scenario in addition to the nature scenario.

museum). In Study 1, Chan et al. (2023b) found a non-significant difference between conditions. However, in Study 2, the virtual indoor scenario led to higher restorativeness (medium effect size, Chan et al., 2023b).

Two studies contrasted VN with non-exposure, and both reported that VN was associated with increased restorativeness (effect sizes not reported, Browning, Mimnaugh, et al., 2020; Masters et al., 2024). Nevertheless, in Masters et al. (2024), the difference between lower-realism VN and non-exposure was non-significant.

One study contrasted VN with real-world nature. Ünal et al. (2022, Study 2) reported non-significant differences between conditions for restorativeness, fascination, novelty, escape, and coherence.

Two studies examined realism levels in VN. Compared with lower-realism, higher-realism VN increased restorativeness (effect size not reported, Masters et al., 2024; large effect size, Mostajeran et al., 2023), as well as being away (large effect size), compatibility (large effect size), coherence (small effect size), and fascination (large effect size, Mostajeran et al., 2023). Yet the difference between conditions for scope was non-significant (Mostajeran et al., 2023).

Two studies assessed VN interaction levels, and both showed non-significant differences between interactive and non-interactive VN regarding restorativeness, being away, fascination, compatibility, and extent (Li et al., 2021 [Study 2]; Wang et al., 2022 [Study 2]).

Two studies explored the effects of adding an intervention to VN. In Romano et al. (2024), VN plus mindfulness increased restorativeness more than VN-only (large effect size). In contrast, Hu et al. (2025) observed a non-significant difference among VN plus therapy, VN-only, and therapy-only. Additionally, one study examined the effects of VN on university students with varying baseline levels of psychological distress. Wang et al. (2022, Study 1) reported a non-significant difference in restorativeness between those with lower and higher levels of anxiety and depression.

One study investigated the effects of auditory stimuli and found that VN combined with auditory stimuli resulted in higher restorativeness (effect size not reported, Yoon & Jeon, 2025). However, the differences across stimulus types (i.e., water, insects, and/or bird sounds) were non-significant (Yoon & Jeon, 2025).

Overall, VN increased restorativeness more than non-exposure, virtual urban scenarios, and urban VN in at least half of the findings (see Fig. 4f). As for VN features, higher-realism VN, VN combined with auditory stimuli, and VN combined with mindfulness increased restorativeness more.

3.3.7. Indirect effects

Five independent studies examined mediation effects involving VN. Chan et al. (2023a, Study 1) found that nature connectedness mediated the relationship between VN (compared with a virtual urban scenario) and negative affect, but not positive affect. The opposite pattern was observed in Chan et al. (2023b, Study 1 and Study 2) when VN was compared with a virtual indoor scenario. Additionally, Schutte et al. (2017) and Romano et al. (2024) found that restorativeness mediated the relationship between VN (versus a virtual urban scenario) and positive affect and the state of awe, respectively.

In sum, some findings show that VN increased connectedness to nature, which in turn reduced negative affect and increased positive affect. Similarly, it increased restorativeness, thereby enhancing positive affect, including the state of awe.

4. Discussion

University students' poor mental health and well-being are a growing concern, with profound implications for their personal development and future professional lives (Bantjes et al., 2022; Sheldon et al., 2021). Exposure to VN has the potential to help during intense academic periods by mimicking some of the benefits of being in contact with real-world nature. To date, only one synthesis has centered on this population (Hubbard et al., 2025), despite their distinct needs and experiences. Our systematic review aimed to examine the effects of immersive VN on university students' psychophysiological and psychological well-being outcomes compared with a control condition. Additionally, we aimed to identify which features of immersive VN have the greatest influence on these outcomes. Despite the mixed pattern of findings, overall, VN positively impacted university students by promoting physiological relaxation (with stronger evidence for improved cardiac and endocrine activity) and psychological well-being (with clearer evidence for higher positive affect and restorativeness, and lower anxiety and stress) in comparison to a control condition. Although fewer studies examined the mechanisms of mediation, nature connectedness and restorativeness were found to mediate effects on affect. Regarding VN features, the findings were most consistent for higher-realism VN and VN combined with audio-olfactory stimuli.

4.1. Findings' summary

The observed mixed findings are consistent with those from similar reviews of the general population (e.g., Frost et al., 2022; Spano et al., 2023). Our trend analyses indicate that the findings were often similar between VN and a control condition across nearly all outcomes. However, some findings support using VN to promote university students' well-being. The benefits were more pronounced for psychological outcomes (see Fig. 4) than for psychophysiological outcomes (see Fig. 3).

VN increased restorativeness and decreased state anxiety, while, to a lesser extent, also increasing positive affect and decreasing negative affect in comparison to virtual urban scenarios. Additionally, it promoted physiological relaxation, lowering the heart rate. When compared to virtual indoor scenarios, VN reduced stress, increased positive affect, and promoted physiological relaxation, with lower levels of salivary biomarkers. These findings align with the Attention Restoration (Kaplan & Kaplan, 1989) and Stress Reduction (Ulrich, 1983) theories, which propose that nature is more restorative and has a greater positive impact on emotional experience than human-made environments. Simultaneously, the findings challenge the central role attributed to nature in these theories by showing comparable effects across virtual scenarios. Furthermore, one study found that VN was less restorative than a virtual indoor scenario, specifically an art museum (Chan et al., 2023b [Study 2]). One possible explanation is that, although these are human-made environments, they may still possess restorative qualities. For example, an art museum might evoke fascination, immersion, and a sense of being away, much like nature, due to its aesthetic appeal. In another study, where the virtual indoor scenario was a workplace, arguably more neutral and typical for university students, VN reduced stress more effectively (Zhang et al., 2023). Concerning virtual urban environments, some studies used scenarios with little or no human or traffic activity (e.g., Li et al., 2021), providing a quieter and possibly more enjoyable experience than real-world urban environments. Moreover, some scenarios included natural elements (e.g., trees; Wang et al., 2022 [Study 2]) that could have acted as confounders by drawing sufficient attention to produce a restorative effect.

In comparison to non-exposure, VN decreased state anxiety and stress, increased restorativeness and positive affect, while only slightly reducing negative affect. It also promoted physiological relaxation, with higher RMSSD, SDNN, and HF. In contrast, fewer findings showed non-significant differences between conditions. Here, we use "non-exposure" as an overarching concept, as the studies gave different instructions to the university students in these conditions. For example, Masters et al. (2024) instructed them to close their eyes and do nothing, while Manchón and Šimunić (2024) asked them to stare at a virtual white wall. Regardless, a common aspect across studies is the lack of stimuli for a specific period, which might have compelled university students to take a break from academic tasks, thereby providing some emotional relief. It is also possible that during this interval, they engaged in mental processes (e.g., mindfulness) that improved their emotional state.

Interestingly, one study showed that VN increased skin conductance levels more than non-exposure (Browning, Mimnaugh, et al., 2020), which generally indicates less physiological relaxation. Instead, the authors propose that this reflected the increase in positive affect, indicating a state of positive arousal rather than stress (Browning, Mimnaugh, et al., 2020).

When VN was compared with other types of nature, the findings mostly showed similar effects. Nature itself appears to have a strong positive impact, regardless of how university students experience it. This was most pronounced when compared with real-world nature, further supporting the use of VN when access to real-world nature is somewhat limited. Nevertheless, real-world nature remains preferable, as it provides a more holistic and richer sensory experience that goes beyond what has been observed in VN so far. In fact, some studies still demonstrated that real-world nature had a more positive effect on students' well-being (e.g., increased positive affect [Browning, Mimnaugh, et al., 2020] and decreased heart rate [Poli et al., 2024]). Notably, one study found that VN lowered heart rate more effectively (Greco et al., 2024), although the variation between studies in heart rate may be related to the activity performed during VN exposure (walking versus cycling). Meanwhile, in comparison to 2D nature, VN increased positive affect and physiological relaxation more, with a higher HF. Certain VR-related aspects might help explain these findings. If university students have little to no prior experience with VR, participating in these studies might be an entirely new way of exposure. Thus, it is reasonable to assume that the novelty could help improve their emotional state, especially if there are no negative side effects (e.g., cybersickness). However, based on previous research, VN is more likely to have produced higher levels of immersion (Bolouki et al., 2024) because it surrounds the user with a wider field of view and improves depth perception, unlike a 2D display. Consequently, increased immersion is associated with greater presence, or a "sense of being there" (e.g., Cummings and Bailenson, 2016), consistent with the Attention Restoration Theory (Kaplan & Kaplan, 1989), which states that for an environment to have a positive, restorative effect, it must provide a "sense of being away" from the current situation. One study reported that VN increased skin conductance levels more than 2D nature (Suseno & Hastjarjo, 2023), though, as previously suggested, this could be an indicator of positive arousal. Another study found that, in some comparisons, VN increased restorativeness and decreased negative affect more than urban VN. In others, urban VN reduced negative affect and increased physiological relaxation (i.e., higher SDNN) more effectively (Shi et al., 2025), which contradicts the existing literature (e.g., McAllister et al., 2017). The authors suggest that elements in urban VN, such as water, greenery, and human-made structures, may have created a smoother, more coherent visual experience and greater spatial consistency (Shi et al., 2025).

Considering the small number of studies focused on different VN features, the findings are quite limited, and several indicate similar effects (see Tables S4 and S5). Nevertheless, some evidence showed that a higher level of realism in VN increased positive affect, restorativeness, and physiological relaxation (i.e., lower heart rate and skin conductance levels), and decreased depressive mood, negative affect, and stress. This finding is consistent with Bolouki et al. (2024). Similarly, combining VN with audio-olfactory stimuli increased positive affect, restorativeness, and physiological relaxation (with lower LF and LF/HF), and decreased negative affect and state anxiety. These features are likely to provide a more realistic experience, better aligning with expectations for contact with real-world nature. As a result, they can increase fascination (e.g., Mostajeran et al., 2023) and immersion (e.g., Hsieh et al., 2023), ultimately enhancing the effectiveness of VN. In contrast, one study found that viewing VN on a lower-quality VR device increased positive affect more (Quirós-Ramírez et al., 2025), but it is unclear why this result was observed. Findings regarding the level of interaction were more mixed. Interactive VN reduced negative affect and stress, whereas non-interactive had a greater effect on reducing state anxiety. Some authors (e.g., Manchón & Šimunić, 2024) point to personal preferences. For instance, some university students might prefer a less interactive (and possibly less overwhelming) experience, while others might find it boring. In addition, VN was particularly effective for university students with higher levels of psychological distress, reducing negative affect, state anxiety, depression, and stress. This may be because these students have a greater need to relieve their symptoms. Combining VN with mindfulness also increased restorativeness. Together, these findings suggest, albeit modestly, that VN might be beneficial at a (sub)clinical level as well.

These findings must be interpreted with caution, given that almost all studies were rated as having some concerning risk of bias. This was mainly because the studies did not provide sufficient information about the methodological techniques and decisions applied.

4.2. Research gaps and future studies

4.2.1. Conceptual

Two major conceptual gaps became apparent during data synthesis. The first one concerns the theoretical support underpinning the included studies. Not all studies cite a theoretical framework, and even those that do often fail to clearly establish a relationship between the framework and the research aims. As a result, this can compromise core aspects of a study, such as hypothesis formulation and interpretation of findings. In addition, few studies delineate the implications of their results for theory development, thereby limiting their potential contribution to the broader theoretical debate on this research topic. Moreover, the most cited theories were Attention Restoration (Kaplan & Kaplan, 1989) and Stress Reduction (Ulrich, 1983). Despite being developed four decades ago, these theories are still widely regarded as the primary explanatory frameworks for human-nature interaction. However, more recent literature has challenged this notion, with several authors arguing that these theories do not fully capture the complexity of the interaction. For example, Joye et al. (2024) identified several unaddressed limitations, including theoretical underdevelopment (e.g., poorly defined key concepts), untested key assumptions (e.g., which environments are most restorative), and a lack of integration between the emotional and cognitive aspects of restoration. Additionally, the authors highlighted that both theories have a limited explanatory range (Joye et al., 2024), which reduces the explanatory power of the studies. For this reason, emerging literature has begun to update and/or propose extended versions of previous frameworks (e.g., adding a social component; Hartig, 2021), develop new frameworks (e.g., the Conditioned Restoration Theory; Egner et al., 2020), and explore the role of other psychological processes (e.g., emotion regulation; Vitale & Bonaiuto, 2024) in an attempt to explain the unaccounted positive effects of nature. The distinction between restoration (i.e., after resources are depleted) and instoration (i.e., before resources are depleted; Hartig, 2007) may also be an important factor that is often overlooked. We argue that these principles should be equally applied to VN research.

Another related concern is that although the literature on VN most often cites these two explanatory theories, their application remains limited. It is reasonable to posit that restorativeness serves as a mediator, explaining how exposure to VN leads to cognitive and emotional improvements. However, most studies only evaluate restorativeness as a final outcome, without testing whether these processes mediate the relationship between VN exposure and the observed psychophysiological or psychological outcomes. This theoretical gap makes it difficult to understand the underlying processes behind the restorative benefits of VN. Future studies need to investigate these theories more systematically to improve the understanding of these processes.

The second gap concerns how psychological outcomes were conceptualized and operationalized in the included studies. A considerable number of studies included in this systematic review did not provide a clear or operational definition of the outcomes. This limitation is particularly evident in the human–nature interaction research topic, which is inherently interdisciplinary. In fact, the same outcome can be

defined in different ways, depending on factors such as the study area and the supporting theories. For example, affect is an overarching concept that can be viewed as encompassing emotions, mood, and other affective states that persist over time (Gross, 2015). Therefore, it is important to provide a precise definition to ensure accurate interpretation, as well as consistency and comparability across studies.

In addition, the psychological outcomes were thought to operate at the same level. However, there are conceptual distinctions to consider, such as the longevity of the outcome (i.e., state or momentary versus trait or long-lasting). For instance, the studies were less clear about this distinction for the stress and depression outcomes. Since exposure to VN was tendentially brief and limited to a single session, we did not expect it to be sufficient to affect trait dimensions or long-lasting conditions. This is because a more structured and ongoing intervention is typically necessary to modify them, often through strategies that promote cognitive reappraisal of the underlying causes (e.g., cognitive-behavioral therapy; Kaczkurkin & Foa, 2015). Accordingly, the included studies found no effects in trait anxiety (Wang et al., 2022, Study 1) and social anxiety (Hu et al., 2025), regardless of the condition. Contrarily, we expected the positive effects of VN to be more consistent across different state dimensions and momentary conditions, as interventions targeting these dimensions mainly focus on reducing arousal through buffering strategies (e.g., distraction), similar to VN. Yet, as discussed above, the findings are mixed, and the type of control condition appears to account for much of the observed patterns. Nevertheless, it is important to note that VN may indirectly affect trait dimensions, as reduced arousal can help restore the cognitive resources needed for reappraisal (e.g., Mostajeran et al., 2023).

In conclusion, the current state of the art and existing theories need to evolve to assess better whether and how using VN is most beneficial for university students. Moving forward, research should focus on filling these conceptual gaps by grounding its aims in stronger, more comprehensive theoretical frameworks and by defining its outcomes of interest (especially psychological ones) with greater clarity and precision.

4.2.2. Methodological

Research on VN is relatively new and fast-paced, not only because VR devices undergo continuous upgrades and improvements, but also because many VN scenarios (with different features) are being developed and studied simultaneously. Therefore, it is not surprising that this systematic review revealed substantial heterogeneity across several methodological aspects among the included studies. For example, even after restricting to immersive VN scenario studies only, the studies are still not fully comparable. First, differences in format (e.g., CG versus 360°) and type (e.g., green versus blue) are very likely, as seen in real-world nature. For example, an international study of more than 16.000 people across 18 countries found more consistent mental health benefits from green nature than from blue nature (White et al., 2021). Second, there are many ways to be exposed to VN. While some studies asked university students only to observe the scenario, others asked them to explore or even interact with it. Third, the duration and, to a lesser extent, the number of exposures were often different. However, almost no studies have focused specifically on these comparisons for this group. It is reasonable to think that these different features might also help explain some of the observed findings. As a result, uncertainty remains about the optimal type of exposure for university students.

Other methodological aspects also raise questions. First, the same control condition was employed in fewer than one-third of the studies, and virtual urban scenarios were the most common. However, a comparison with virtual indoor scenarios might be more adequate for university students, as they spend a significant amount of time in these spaces studying or working on their academic tasks. Yet only four studies employed this comparison, and two of them involved an art museum, which proved to be quite restorative (Chan et al., 2023b [Study 2]). Furthermore, few studies have compared different features within VN scenarios (e.g., realism and interaction level), despite the aforementioned pattern. Second, studies rarely used the same self-report measures. For instance, affect and restorativeness were the most highly assessed outcomes, yet only nearly half of the studies used the same measure. Also, anxiety, depression, and stress are largely understudied. Another concern is that the measures used to assess depression and stress might not have accurately captured the complexity of these outcomes. More studies using validated measures for these constructs are necessary to establish stronger connections. Among the psychophysiological measures, electrodermal and endocrine activity were significantly less explored than cardiac activity, but mostly for heart rate. There was considerably more variation among the indices evaluated for heart rate variability. Nevertheless, all psychophysiological measures remain understudied. Future studies should aim to combine self-report measures with psychophysiological indices, as the latter can be difficult to interpret in VR settings. Although the goal is often to promote relaxation, VR immersion can also elicit positive arousal (e.g., Browning, Mimnaugh, et al., 2020), which may act as a confounder. Third, most studies did not include a stress-induction task, and some showed a reduced effect of it (e.g., Suseno & Hastjarjo, 2023). In this population, inducing stress can be particularly important to simulate periods when the academic calendar includes significant deadlines and key evaluations. This is even more important when data is collected during periods of lower academic pressure.

Synthesizing the evidence also helped identify additional research limitations that should be considered in future studies. First, more than half of the studies included small samples, and several did not calculate sample size a priori, which can limit statistical power. An effort must be made to recruit a sample size appropriate for the study's objectives. Still, the reported effect sizes tended to be large.

Second, about half of the studies included in this systematic review considered that the samples being composed solely of university students was a limitation. University students are often considered a convenience sample because they tend to be readily accessible and in good health. However, this assumption can be harmful, as the literature has shown declines in their mental health (e.g., Auerbach et al., 2018). More so, some studies did not report carrying out a pre-assessment of participants' health. For this reason, studies should focus on the specific challenges, needs, and experiences of university students as a group of interest.

Third, Asia has emerged as the most common publication continent, but when combined with Europe and North America, these account for more than half of the studies. These three continents include several countries with a high level of education, which may introduce geographical and cultural bias into the results. Thus, there is a need for a more comprehensive examination of cultural and geographical differences.

Fourth, the studies did not provide sufficient information about their methodological and analytical decisions, as determined during quality assessment. We also observed a lack of information regarding other aspects, for example, the pre-processing methods for raw psychophysiological data. This, in turn, limits the ability to replicate studies or determine the best research methods within this topic. Aligned with this, some studies reported statistical data poorly and failed to provide raw data for means, standard deviations, and/or effect sizes. This makes it challenging to accurately assess the true magnitude and significance of the study's findings.

Together, these substantial methodological variations make it difficult to compare, synthesize, and generalize the findings. At this stage, there is a pressing need for additional studies, including replication studies, to confirm or clarify these results. It is also crucial that the methodology used evolves to provide more robust evidence of the benefits of VN for university students, especially when compared with different control conditions. A valuable contribution to the literature and to future interventions would be to produce more comparable evidence to support meta-analyses.

4.3. Review strengths and limitations

The decision to include only studies with at least one immersive VN condition and one control or comparison condition is a methodological strength. Another key strength is its detailed trend analysis, which considers not only the outcomes of interest but also comparisons between VN and all control conditions. Moreover, the entire review process was thoroughly documented, ensuring transparency and reproducibility.

Nevertheless, some limitations must be considered. In the search strategy, requiring the title to include "Virtual OR VR" may not have been fully comprehensive, as some studies use alternative keywords such as "immersive". No manual searches were conducted, and no gray or non-English literature was included, which may introduce a potential publication bias. Additionally, some studies included quantitative data on VR variables (e.g., presence, cybersickness) and qualitative data on user experience that were not included in this systematic review but could have provided valuable insights and explanations, especially concerning the similar findings across virtual scenarios.

5. Conclusion

This review systematically explored how immersive VN affects university students' mental health and well-being compared with a control condition. Most studies focused on direct psychophysiological and psychological outcomes, yielding mixed findings. Still, several findings indicated a positive effect of VN. For psychophysiological outcomes, the benefits were more consistent for cardiac and endocrine activity. Regarding psychological outcomes, there is a trend toward improvements in positive affect, anxiety, stress, and restorativeness. A few studies found that nature connectedness and restorativeness mediated effects on affect. In contrast, findings were less consistent across electrodermal activity, negative affect, and depression, underscoring the need for further research. Nonetheless, these findings suggest that immersive VN may benefit university students under specific conditions. It can provide immediate, temporary relief by offering a brief, relaxing break, helping students return to demanding academic tasks with a more positive outlook. However, because the theoretical foundations are still limited and methodological approaches vary widely, establishing optimal practices for implementing VN as an intervention for this population remains challenging. Future studies are needed to identify the conditions under which these benefits are most pronounced.

CRediT authorship contribution statement

Rita Moura: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Sílvia Luís:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Cristina Camilo:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Eliana Portugal:** Writing – review & editing, Investigation, Formal analysis.

Ethical approval

This work did not require ethical approval because it only involved a review of existing published literature.

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Declaration of interest

None.

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Appendix A. Supplementary data

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