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Virtual immersion in nature and psychological well-being: A systematic literature review

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ABSTRACT

Immersion in nature provides various psychological benefits to well-being. Recent research examines whether these benefits can be replicated in virtual reality (VR). This study aimed to systematically review the literature on the psychological effects on well-being of virtual immersion in nature. Databases searched included Scopus, EBSCO, Web of Science, Psychnet, and Pubmed with inclusion of peer reviewed articles published in English, between 2015 and 2020 (inclusive to July 2020), in which the research design includes VR-based immersion in nature. A total of 21 quantitative studies were identified. Within these articles, most employed quantitative research methodologies within an experimental design. In regard to psychological well-being, some evidence suggests that virtual immersion in nature significantly decreases negative affect. Conversely, other research found no change or an increase in negative affect. Generally, no significant differences were noted for positive affect. Physiological indicators of stress responses to virtual immersion in nature varied. Overall, research exploring the use of virtual reality immersion in nature is limited and the replication of the potential benefits gained from real immersion in nature is poorly understood. Future research is required to advance understanding and knowledge of the outcomes of virtual immersion in nature on human well-being.

1. Introduction

Research has demonstrated the benefits immersion in natural environments can have on psychological well-being (Cox et al., 2017; Shanahan et al., 2016). For example, Shanahan et al. (2016) ($N = 1538$) found reduced community rates of depression and high blood pressure associated with visits to natural spaces. Whereas, Lee et al. (2011) ($N = 12$) demonstrated that exposure to a forest setting compared to an urban environment significantly increased the intensity of positive mood and decreased negative feelings. Nature immersion benefits have been found to include negative affect and stress reduction, reduced anxiety, increases in positive emotions, attention restoration, increased creativity, and reduced mortality (Cox et al., 2017; Mitchell & Popham, 2008; Vujcic et al., 2017; Wang et al., 2016; Williams et al., 2018).

A key benefit of nature immersion is stress reduction and lower levels of psychological stress (Beil & Hanes, 2013; Ewert et al., 2016). In a small Australian study, Beil and Hanes (2013) used self-report and physiological indicators to examine stress levels when immersed in i) urban and ii) natural environments to reveal immersion in natural settings resulted in a greater reduction in stress. Ewert and Chang (2018) ($N = 105$) reiterated previous studies by demonstrating that lower levels of psychological stress were experienced by those immersed in natural environments than more urbanised environments.

1.1. Theoretical perspectives associated with immersion in nature

Three focal theories have dominated the mechanisms for examining the positive psychological benefits related to nature exposure (VR or real): i) Attention Restoration Theory (ART), ii) Stress Reduction Theory (SRT), and iii) Biophilia Hypothesis (BH).

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Attention Restoration Theory (ART) was used to elucidate the potential cognitive benefits from nature immersion. ART posits that living in built environments leads to fatigue. Urban life is dynamic and may create flight or fight responses, requiring direct attention, while creating distraction, and (over)stimulation from multi-sensory stimuli such as moving objects (e.g., other people, cars), sounds (e.g., car horns, machinery), and perceived threats (e.g., pedestrian crossing, traffic) (Berman et al., 2008). Conversely, spending time in nature reduces stressors through activities aligned with internal motivations, observing captivating stimuli, and experiencing expansive places and spaces (Kaplan, 1995). Additionally, immersion in nature activates the parasympathetic nervous system, stimulating the five sensory systems (Kaplan & Kaplan, 1990) with an increased awareness of the environment amplifying relaxation and attention restoration (Kaplan & Kaplan, 1990). Increases in relaxation can result when attention and concentration are restored by the feeling of calm and engaging components of nature immersion (Ohly et al., 2016).

Several studies identified the processes by which attentional resources can be depleted through competing demands (Kaplan & Berman, 2010). A recent systematic review examined the attention restoration potential of nature immersion (Ohly et al., 2016). The review and meta-analysis included 31 studies and examined the quantity of empirical evidence supporting ART(Ohly et al., 2016). Ohly et al. (2016) reported that for some aspects of attention, there was positive support associated with exposure to nature. However, they noted uncertainty regarding the evidence behind the specific components of attentional processes restored by immersion in nature. Consequently, other theoretical standpoints need to be considered in addition to ART.

Ulrich's Stress Reduction Theory (SRT) focuses on restoration, which pertains to cognitive and behavioural functioning, physiological activity levels, and positive changes in psychological mood states (Ulrich et al., 1991). Similar to ART, this approach has a strong focus on stress reduction facilitated by nature immersion. SRT argues that immersion in nature is restorative, initiates stress recovery, and reduces heightened physiological states. SRT purports restoration is associated with various resources found in natural environments that historically supported humanity's survival and are connected to the elicitation of positive emotions. Natural environments provide qualities such as vegetation, water, richness, spaciousness, and various focal points (Ulrich, 1993). Evolutionary mechanisms may influence the positive emotions, stress reduction, and pleasure of nature immersion (Ulrich et al., 1991). Ulrich (1993) argues that humanity has historically spent most of their time in nature and that, despite modernisation, humans have an inherent love of nature (i.e., biophilia). Consistent with this prominent theory, a systematic review by Shaffee and Shukor (2018) established consistencies between research findings and the claims of the SRT. As with the previous theoretical frameworks, the Biophilia Hypothesis suggests nature immersion generates positive emotions.

The Biophilia Hypothesis (BH) proposes humans are innately drawn to nature and, when immersed in nature, experience positive emotions (Kellert & Wilson, 1995). Humans have lived in forest environments and thus are neurologically wired to thrive in nature (Kahn, 1997). Nature is not only a resource for survival but an important stimulus to human emotional, cognitive, and spiritual growth. BH posits these are the reasons nature immersion supports mental health and reduces stress (Beatley, 2009). Conversely, negative mental health outcomes may result from being deprived of immersion in nature.

While the benefits of nature immersion are well-established, increasing urbanisation means many individuals have limited access to natural environments. Further, physical and/or cognitive challenges (e.g., dementia, physical disability, and frailty) limit accessibility (Gladwell et al., 2013; Zhang et al., 2017). Accordingly, with rapid technological advancements and innovation have created avenues to replicate immersive nature experience. This begs the question, *does immersion in virtual nature result in positive benefits to psychological well-being*?

Notably, two recent reviews (Browning et al. 2020, 2021) explored nature immersion using simulated and virtual nature's effect on cognitive performance, mood, and health. A systematic review of 175 experiments within 148 research papers, predominantly with student samples, found nature simulations can lead to positive outcomes. Specifically, 100 experiments demonstrated mood improvements and 50 experiments were associated with improved cognition or attention, perceived restoration, reductions in stress, and increased pain tolerance (Browning et al., 2021). This review was not limited to VR as it included photographs, slideshows, and videos displayed on a range of devices, such as head-mounted displays, computer, projector, and television screens. A related meta-analysis was conducted on nature's effect on mood through either natural settings or via virtual simulation (Browning, Mimnaugh, et al., 2020). Six studies revealed that nature settings improved mood more than simulated nature settings, whereas, both settings reduced negative affect. However, the review had a limited number of studies and again, simulations included viewing nature on a computer or television screen, as well as, using head-mounted displays (Browning, Mimnaugh, et al., 2020). Therefore, further research and reviews focused specifically on virtual immersion in nature are required.

A growing body of literature examining virtual reality (VR) as a proxy for real immersion in nature (Berto, 2014) reveals exposure to videos depicting natural scenery, significantly improved restoration and stress recovery, in comparison to urban scenes (Wang et al., 2016). Concerns have also been shared about the potential negative effects of using VR technology, such as cybersickness and eyestrain (White et al., 2018). This systematic review aims to elucidate on the psychological well-being effects of virtual immersion in nature by collation, assessing, and analysing to reveal opportunities associated with the psychological benefits of virtual immersion in nature.

2. Methods

2.1. Eligibility criteria

This systematic review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). Methodological decisions were based on the Population, Intervention, Comparisons, and Outcomes (PICO) framework to inform inclusion/exclusion criteria. The primary objective of this review was to assess the effects of immersive VR in nature for psychological well-being. Due to the limited studies to date and the potential utility of VR, both clinical and non-clinical populations were included. The intervention used had to include immersive VR (see below) with a comparison or control group used to assess the impact on psychological well-being. Studies identified as meeting inclusion criteria as stated above, were then graded using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach generating a quality rating for each article (Guyatt et al., 2011). Additional inclusion/exclusion criteria were peer-reviewed journal articles published in English between January 2015 and July 2020. Consequently, discussion articles, case reports, and grey literature were excluded from the review. Studies examining clinical and non-clinical samples were included, provided participants were adults 18 years of age or older. The studies had to include virtual immersion in nature and have a measure of psychological well-being. In setting the context, three aspects are delineated: i) nature, ii) VR and iii) well-being.

Nature was defined as any natural, non-built environment with natural environments (including natural landscapes and vegetation) being referred to as green spaces and natural environments dominated by water bodies, referred to as blue spaces. Various definitions for VR exist. VR has been used to reference the hardware used (e.g., head-mounted displays) or the virtual content depicted (e.g., computer-generated environment; Bryant et al., 2020). Here, VR is defined as a human-computer interaction mediated through head-mounted gear or Cave Automatic Virtual Environment (CAVE system), displaying both captured media (e.g., video of a forest) and computer-generated environments (Bryant et al., 2020). VR, in this context, does not contain digital elements such as Augmented Reality (AR) or Mixed Reality (MR).

Well-being includes measures of emotional, psychological, and cognitive aspects of a person's life and uses Linton et al.'s (2016) account of mental well-being; that states that psychological well-being includes an individual's experience of happiness and thoughts and feelings regarding the quality of their life. This is the perspective taken in this review.

2.2. Information sources and search strategy

Literature was identified by searching within the following databases: Scopus, EBSCO, Web of Science, Psychnet, and Pubmed. The searches were completed by two of the researchers (SL & JA) independent from each other. Keyword combinations are provided in Table 1.

2.3. Study records and data items

Collectively, all search results were downloaded and to increase consistency and confirmation, each researcher, using a full list each, removed duplicates. The resulting list was compared and consolidated into one main list. Ordering alphabetically, the list of articles was divided into two sets (A-L, and M-Z). Two investigators (SL & JA) to independently review by title, abstract and full-text. Reasons for exclusion of articles at the full-text screening stage was in accordance with the PICO framework and predominantly due to "VR" not meeting the pre-established definition (e.g., non-immersive computer screen) or article type (e.g., a discussion rather than a research article). At a full-text level, article eligibility was collaboratively resolved. A database of information, based on the data extracted from each article included sample characteristics, type of control used, type of intervention, measures used, and type of VR equipment utilised. The review process outlined focused on four stages: Identification ($n = 2,056$), screening ($n = 954$), eligibility ($n = 32$), and included articles ($n = 21$) (Fig. 1).

This review's primary aim was to ascertain the measured psychological benefits from participants' virtual immersion in nature from quantitative and qualitative studies. Secondary outcomes include other measures such as non- or indirectly related psychological well-being (e.g., blood pressure and heart rate) included in the studies. Quality was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system, which generates a quality rating for each article (Guyatt et al., 2011). The quality of data extracted from the articles was assessed for consistency, precision, publication bias, risk of bias, and directedness. A systematic narrative synthesis of findings was completed to illustrate the findings and key characteristics of the studies included (Table 2; Fig. 2; Fig. 3).

3. Results

The sample consisted of 21 peer-reviewed research studies that collectively included a total of 1301 participants. Studies were mostly European ($n = 8$), Asian ($n = 5$), and North American ($n = 4$) followed by Australian ($n = 3$) and Lebanese ($n = 1$). Six (29%) of the 21 studies

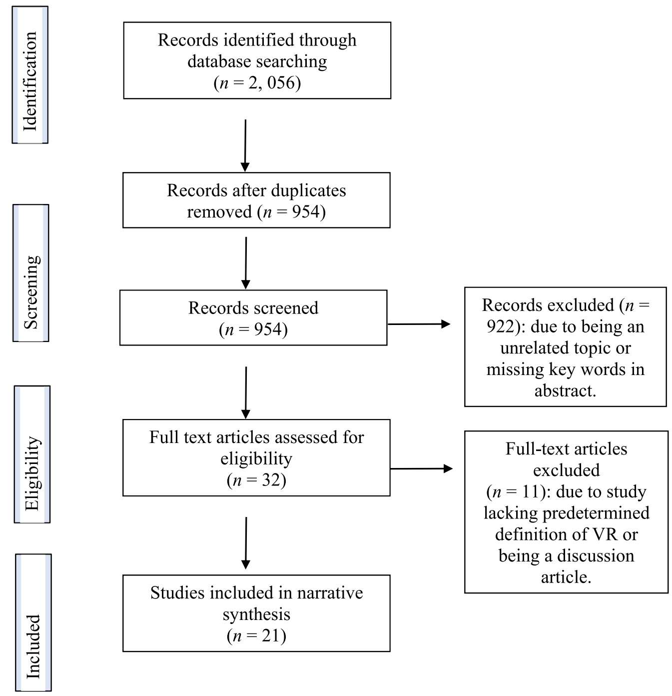

Fig. 1. Flow diagram of data identification, screening, eligibility, and inclusion process.

Table 2
Theories used to guide the research.

Theory/Framework	No. Studies	Research
Attention Restoration Theory	11	Anderson et al. (2017); Blum et al. (2019); Browning, Mimnaugh, et al. (2020); Calogiuri et al. (2018); Gao et al. (2019); Gerber et al. (2019); Hedblom et al. (2019); Liszio et al. (2018); Mattila et al. (2020); Tabrizian et al. (2018); Yu et al. (2018)
Prospect Refuge Theory	1	Tabrizian et al. (2018)
Scanning for Threats Theory	1	Browning, Mimnaugh, et al. (2020)
Stress Recovery Theory	3	Gerber et al. (2019); Mattila et al. (2020); Yu et al. (2018)
Stress Reduction Theory	3	Browning, Mimnaugh, et al. (2020); Gao et al. (2019); Wang et al. (2020)
Theory of Stress Relief	1	Wang, Shi, et al. (2019)
Vagal Tank Theory	1	Blum et al. (2019)
Theory not stated	8	Appel et al. (2020); Chirico and Gaggioli (2019); Frewen et al. (2020); Ganry et al. (2018); Lakhani et al. (2020); Schebella et al. (2019); Schutte et al. (2017); Wang, Tsai, et al. (2019)

Note. Multiple theories were found within some individual studies.

evaluated clinical populations with participants meeting probable diagnostic criteria for dementia, generalised anxiety disorder, post-traumatic stress disorder, or depression. All studies used adult populations ranging from 18 to 90 years of age with approximately equal numbers of female and male participants. However, it is noted that one study did not report participants mean age or sex. Sample sizes ranged from 18 to 154 participants, with one-third of all studies ($n = 7$; 33%) comprised predominantly of student populations.

Methodological approaches were primarily quantitative, with three (14%) studies conducting a mixed-methods analysis. The majority of studies used a pre-test, post-test, comparative experimental design, with

Table 1
Key word combinations used (adapted for each database).

Title must include	Virtual
Abstract must include	natur* OR wilderness OR park* OR marine OR biosphere* OR "open space*" OR "green space" OR greenspace OR wood* OR bush OR forest OR countryside OR outdoor* OR sea OR ocean
Abstract must include	psychological OR emotion* OR mood OR eudemonic OR hedonic OR cogniti* OR mental OR behavio* OR attention OR neuro* OR well-being OR "well being" OR wellbeing

Note. Search terms were combined into one search.

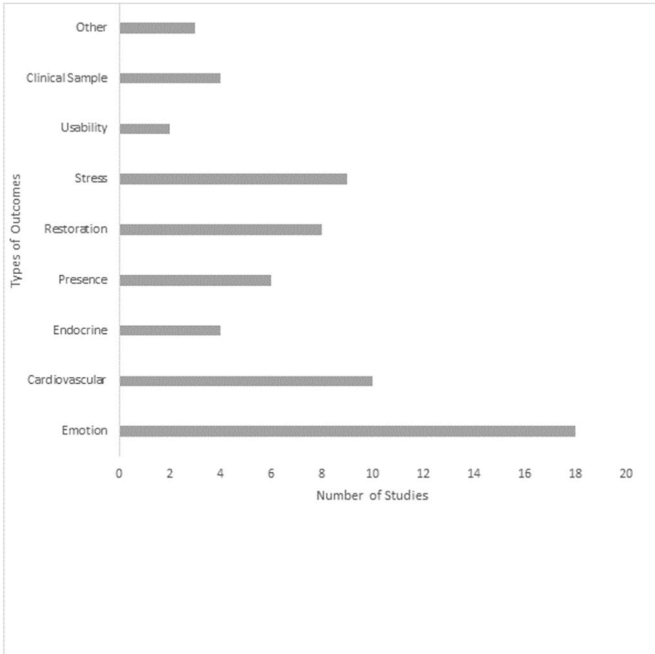

Fig. 2. The Number of Studies by Type of Outcome.
Note. Multiple types of outcomes were found within individual studies ($N = 21$). Categories were measured once within each study. *Emotions* included subjective self-report measures based on positive and negative affect; and mood. *Cardiovascular* included heart rate variability, blood pressure, respiration rate, and the perceived exertion scale. *Stress* included; galvanic skin response and electrodermal activity. *Endocrine* included measurements of salivary cortisol. *Presence* included subjective self-report measures such as the Presence Scale and the Modified Reality Judgement and Presence Questionnaire. *Other* included satisfaction with VR, biodiversity perceptions, and perceptions of safety.

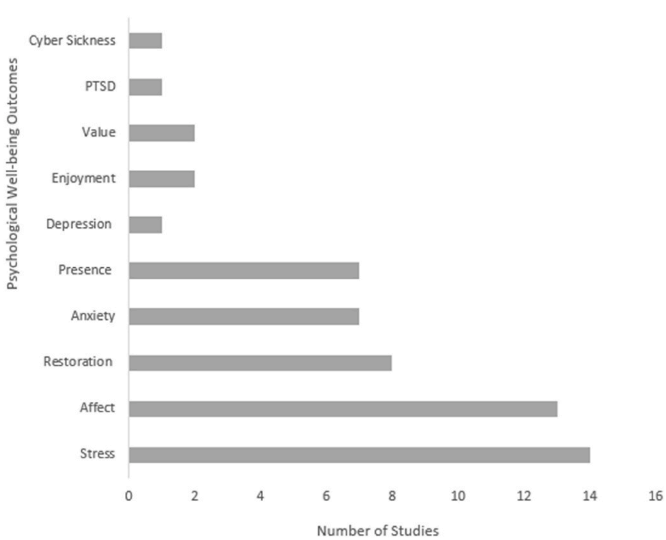

Fig. 3. The Number of Studies that Measured Psychological Well-Being Outcomes by Type (N = 21).
Note. Multiple types of psychological well-being outcomes were found within individual studies. Categories were measured once within each study.

only 14% ($n = 3$) of studies including a control group. All but one study used a cross-sectional design. The one remaining study used an across-time design, implemented over three consecutive days. Data collection occurred pre-and post-intervention, with a follow up at one-week post-intervention.

VR was both broadly operationalised, and conceptualised. Studies operationalised nature using two and three dimensional 260° and 360° panoramic photos, while others used video footage viewed through a head-mounted display (HMD). A further two studies utilised a CAVE system. A CAVE system is a projection based virtual reality environment where images are projected on to a large screen or multiple screens on surrounding walls. The conceptualisation of nature was similarly diverse, requiring categorisation for clarity based on dominant setting characteristics such as urban, green, or blue space. Guidelines for conducting research are shown in Table 2 below.

Within the 21 studies, seven theoretical frameworks were identified; however, eight studies (38%) did not provide a theoretical framework. Approximately half ($n = 11$; 52%) of the studies were posited within Attention Restoration Theory. The most frequently measured outcomes related to emotion, stress, and cardiovascular or endocrine function (as an indication of stress or relaxation). Outcome measurement tools used as a guide to the effectiveness of nature replicated in VR on psychological well-being (Fig. 2).

Psychological well-being outcomes were most frequently related to stress, affect (emotion), restoration, anxiety, and presence. Also, safety, depression and PTSD, resulting in ten subcategories (see Fig. 3). Other outcome categories such as useability, although relevant to VR were not the focus of this review.

Statistically significant relationships between VR immersion and psychological well-being variables were examined within the final sample. Of the 21 studies, all but one found a statistically significant relationship between nature exposure through VR immersion and psychological well-being, as shown in the summary of findings in Table 3. Appel et al. (2020), who did not find a significant relationship, did report several positive changes in mean scores following treatment intervention, however, reported means and standard deviations were insufficient to infer a statistically significant difference between pre and post-test results.

Nature immersion replicated in VR resulted in positive affect, albeit limited and varied. For example, a statistically significant increase in vigour and self-esteem was associated with simulated forest environments compared to simulated urban environments (Yu et al., 2018). The type of nature environment replicated in virtual space, may significantly impact positive or negative affect (Wang, Shi, et al., 2019). For instance, nature environments shown in VR, that contained wooden structures such as a pavillion (as a representation of a refuge and social space) significantly increased positive affect. Tabrizian et al. (2018) found the association between enclosed nature environments replicated in VR (inferring refuge) and increased restoration could be explained (was mediated) by perceptions of safety, allowing participants to be present. This is consistent with Stress Reduction Theory (Ulrich, 1993) that suggests that an individual's perception of reward (i.e., non-threatening) or danger (i.e., threating) can influence a participant's experience. For example, in the immersive underwater VR intervention, some participants reported feeling fearful, instead of relaxed, due to the potential for encountering threat (Liszio et al., 2018).

Preference for scenes in nature contributed to psychological well-being in the four studies that examined this construct. Preferred nature scene influenced a greater decrease in negative affect (Anderson et al., 2017) and increased positive affect (Gao et al., 2019). This was evident in the thematic analysis as participants expressed their desire for preferred nature scenes (Appel et al., 2020), with preferred scene accounting for a 9% ($N = 89$) variance in restorativeness (Browning, Mimnaugh, et al., 2020). These results are consistent with ART (Kaplan, 1995), where the relationship between positive affect and nature immersion replicated in VR can be explained by an increase in perceived restorativeness (Schutte et al., 2017; Wang et al., 2020) associated with satisfaction (Wang et al., 2020). Concerning negative affect, one-third of studies ($N = 7$; 33%) reported a significant reduction in negative affect, while eight (38%) reported either no change or an increase in negative affect related to nature immersion replicated in VR.

Table 3
Summary of findings for the studies included in the systematic review.

Study	Random allocation to group	Clinical population	Sample size N	Age	Nature	Significant outcomes by type	Measure of effect size	Quality
Anderson et al. (2017)	No		18	32 ± 12	Blue Space Natural Green Space	Positive affect Stress		* Very Low
2020	No	Cognitive Impairment	66	81 ± 11	Blue Space Natural Green Space			* Very Low
	Yes		60	34 ± 9	Blue space with man-made features	Stress Anxiety		**** High
Browning, Mimnaugh, et al. (2020)	Yes		89	20 ± 1	Natural Green Space	Positive affect Stress Restoration		**** High
Calogiuri et al. (2018)	Yes		26	26 ± 8	Urban green space + exercise	Affect Presence	*r*	*** Moderate
Chirico and Gaggioli (2019)	Yes		50	23 ± 3	Green space with water	Negative affect		*** Moderate
Frewen et al. (2020)	Yes	27% scored above PTSD cut-off	48 (n = 12)	Student sample	Natural green space	Positive affect PTSD	$d > 0.80$	**** High
Ganry et al. (2018)	No	Preoperative anxiety	20	57	Natural Blue space	Stress		** Low
Gao et al. (2019)	Yes		120	21 ± 2	Natural green space Green space with water	Negative affect Positive affect Restoration	η^2	**** High
Gerber et al. (2019)	Yes		45	59 ± 16	Natural green space Natural blue space	Stress		* Very Low
Hedblom et al. (2019)	Yes		154	28	Green space + Auditory & Olfactory stimuli	Pleasantness (predicted stress)	β	** Low
Lakhani et al. (2020)	Yes	Spinal Cord Injury	24	52 ± 21	Natural Blue Space Underwater immersion Underwater immersion with man-made features	Depression scores PHQ – 8 Positive affect	$d > 0.80$	**** High
Liszio et al. (2018)	No		62	23 ± 5	Underwater immersion	Affect Anxiety Stress Presence	Partial η^2	* Very Low
Mattila et al. (2020)	No		100	67% < 35 33% ≥ 35	Natural green space Urban green space	Restoration	Partial η^2	** Low
Schebella et al. (2019)	No		52		Natural green space Green space + Auditory & Olfactory stimuli	Affect Anxiety Stress		* Very Low
Schutte et al. (2017)	Yes		26	34 ± 13	Natural green space	Positive affect Restoration	Partial η^2	**** High
Tabrizian et al. (2018)	No		87	20 ± 3	Urban green space	Restoration	Partial η^2	*** Moderate
Wang et al. (2020)	Yes	Generalised Anxiety Disorder	77	50–75	Urban green space	Stress Restoration Affect	Partial η^2	**** High
Wang, Tsai, et al. (2019)	Yes	Generalised Anxiety Disorder	60	50–75	Urban green space	Stress		*** Moderate
Wang, Shi, et al. (2019)	Yes		96	24 ± 5	Natural green space Green space with man-made features (chairs) Green space with water	Affect Stress		** Low
Yu et al. (2018)	Yes		30	20–35	Natural green space Green space with water	Affect Stress	Partial η^2	*** Moderate

Note. Some sources operationalised nature in multiple ways. Urban green space includes neighbourhood parks, woods, forests, and rivers. Natural blue space includes beaches. Black stone beach with glacier, rocky shore. Natural green space includes countryside scenery, dense pine forests, open field. Green space with water includes lakes, rivers, ponds, waterfalls. * indicates Very Low Quality, ** indicates Low Quality, *** indicates Moderate Quality, **** indicates High Quality in accordance with GRADE guidelines (Grading of Recommendations Assessment, Development and Evaluation).

Variability in the operationalisation of nature was evident in all 21 studies. Subsequently, VR-related nature was categorised into three broad types: green spaces, urban spaces, and blue spaces. However, to avoid potential confounding of results, further subcategories for clarity were added and included exercise or olfactory stimuli (Table 4).

Most studies operationalised nature using natural green space; however, included several nature typologies due to between-group comparative experimental study design. From these studies, it was determined that nature settings replicated in VR that were rich in biodiversity were found to decrease tension, confusion, and negative affect (Wang, Shi, et al., 2019).

Studies using physiological measures such as endocrine results as indicators of stress or relaxation demonstrated mixed results. In six out of the ten studies that examined the impact of nature replicated in VR on stress reduction, significant decreases in galvanic skin response (GSR), salivary cortisol, respiration rates, heart rate variability, and blood pressure were found. This is consistent with the Biophilia Hypothesis (Beatley, 2009), wherein, humans are thought to have positive emotional experiences in nature, as nature is a symbol of resources and survival, leading to decreased physiological stress. Conversely, in eight of the same ten studies, results varied from significant (increases in GSR and salivary cortisol) to non-significant (GSR, heart rate variability, and alpha brain wave activity), rendering these findings inconclusive.

In clinical populations, positive outcomes were evidenced for anxiety

Table 4
Operationalisation of nature in virtual reality studies.

Nature	Immersive virtual reality*	No. of Studies	Studies reporting no significant result	Studies reporting both significant and non-significant results
Urban green space	HMD Cave	2		Hedblom et al. (2019); Tabrizian et al. (2018)
Urban green space + exercise	HMD Cave	1 2		Calogiuri et al. (2018); Wang et al. (2020); Wang, Tsai, et al. (2019)
Natural green space (no man-made features)	HMD Cave	10	Appel et al. (2020)	Anderson et al. (2017); Browning, Mimnaugh, et al. (2020); Frewen et al. (2020); Gao et al. (2019); Gerber et al. (2019); Lakhani et al. (2020); Mattila et al. (2020); Schebella et al. (2019); Wang, Tsai, et al. (2019)
Green space with man-made features (chairs)	HMD Cave	2		Mattila et al. (2020); Wang, Shi, et al. (2019)
Green space with water	HMD Cave	6		Chirico and Gaggioli (2019); Gao et al. (2019); Lakhani et al. (2020); Schutte et al. (2017); Wang, Shi, et al. (2019); Yu et al. (2018)
Green space + Auditory & Olfactory stimuli	HMD Cave	2		Hedblom et al. (2019); Schebella et al. (2019)
Natural blue space (no man-made features)	HMD Cave	5	Appel et al. (2020)	Anderson et al. (2017); Ganry et al. (2018); Gerber et al. (2019); Lakhani et al. (2020)
Natural blue space with man-made features	HMD Cave	1		Blum et al. (2019)
Underwater immersion with man-made features (wreck)	HMD Cave	1		Lakhani et al. (2020)
Underwater immersion	HMD Cave	2		Lakhani et al. (2020); Liszio et al. (2018)

Note. *HMD indicates head-mounted display. Some studies operationalised nature in multiple ways. Urban green space includes neighbourhood parks, woods, forests, and rivers. Natural blue space includes beaches. Black stone beach with glacier, rocky shore. Natural green space includes countryside scenery, dense pine forests, open field. Green space with water includes lakes, rivers, ponds, waterfalls. Auditory and olfactory stimuli include birdsong, the smell of grass and fir.

and post-traumatic stress disorder post-exposure to nature replicated in VR. However, for spinal cord injury participants with depressive symptomology and cognitive and/or physically impaired populations, no significant differences were found. Interestingly, despite the high comorbidity rate of anxiety with depression, only one of the 21 studies examined clinical depression in this systematic review (Lakhani et al., 2020). In response to nature replicated in VR, an initial improvement of depressive symptoms in spinal cord injury patients was evidenced but not maintained past the one-week post-test (Lakhani et al., 2020). Mean depression scores, however, decreased over the one-week. While not a statistically significant difference, these results suggest that improvements may be possible over time.

4. Discussion

This systematic review explored VR immersive nature experiences and psychological well-being. Over half of the studies included for review were based on ART (Kaplan, 1995), reiterating that restoration through nature is achieved through concentration, mental fatigue recovery, soft fascination or interest, and reflection. According to ART (Kaplan, 1995), nature exposure will not result in restoration if the situation is distracting, requires sustained directed attention, or there is a perceived sense of danger.

The results of this systematic review are consistent with ART (Kaplan, 1995); and Browning et al.(2020) observation that there is a trend in the literature for decreased negative affect (restoration and mental fatigue recovery) after exposure to nature replicated in VR but no increase in positive affect. Out of 21 studies, one-third ($N = 7$; 33%) reported a significant reduction in negative affect, while eight (38%) reported either no change or an increase in negative mood in response to exposure to nature replicated in VR. This may be related to cyber/motion sickness, gait instability and frustration regarding useability, with time lag movement between VR and reality (Anderson et al., 2017; Calogiuri et al., 2018). This highlights the potential value of utilising CAVE systems, which may have an advantage over head-mounted displays for reducing anxiety, cybersickness, useability, exercise and gait stability, and feasibility. For example, participants expressed frustration with difficulties, such as maintaining balance (caused by incongruence between vestibular biofeedback and image oscillations) and feasibility issues using HMD for prescription lens wearers potentially interfering with presence. Positive correlations were demonstrated between presence and restorativeness with high ratings of movement lag and cyber sickness impacting perceived presence (Calogiuri et al., 2018).

In some instances, the operationalisation of nature exposure replicated in VR may potentially increase rather than decrease negative affect. In the study by Liszio et al. (2018), ten participants in the VR condition were excluded due to abnormally high (greater than one standard deviation above the mean) cortisol levels at baseline. This study involved underwater immersion, with several participants reporting feeling afraid (Liszio et al., 2018). Threat anticipation was hypothesised to impact restoration consistent with ART (Kaplan, 1995) potentially increasing negative affect (Tabrizian et al., 2018). While for other participants, significantly higher immersion predicted low anxiety (Liszio et al., 2018). Tabrizian et al. (2018) examined enclosed nature environments replicated in VR and restorativeness and found that perceptions of safety mediated the relationship. However, Lakhani et al. (2020) found that underwater immersion replicated in VR improved relaxation and positive affect immediately following VR exposure. This potentially highlights the importance of incorporating participants preference for nature scene to achieve successful outcomes. However, it is important to note that the positive effects were immediate but were not maintained over a two-week period (Lakhani et al., 2020).

Similar results were found for objective physiological indicators of stress and self-reported subjective measures indicating a disparity between physiological stress and perceived stress, providing limited associations. Browning, Mimnaugh, et al. (2020) found higher GSR levels were significantly correlated with positive affect, and significant increases in GSR were demonstrated in both nature replicated in VR and nature intervention. It is possible that what Browning, Mimnaugh, et al. (2020) and others evidenced is symptomatic of physiological arousal through overstimulation. Therefore, an increased GSR may represent physiological arousal that could be positive (concentration, fascination, and interest) or negative (over-stimulation and cybersickness) dependent on individual perception. In Wang, Tsai, et al. (2019) study, GSR was significantly lower in the intervention group than the comparison group although, no significant difference in heart rate variability between groups was demonstrated. Further, Hedblom et al. (2019) found no significant relationship between GSR and perceived stress.

Where the purpose of nature immersion replicated in VR is to assist clinical populations, then VR may be suitable as a therapeutic intervention. In the six clinical populations included in this review, significant positive outcomes were evidenced for anxiety and post-traumatic stress disorder following exposure to nature replicated in VR. This result is hardly surprising given its demonstrated effectiveness in clinically related populations such as specific phobias (White et al., 2018). However, no significant outcomes were evidenced for depression (Lakhani et al., 2020). As mentioned previously, Browning, Mimnaugh, et al. (2020) found that positive baseline affect accounted for 61% of the variance in positive affect results, following nature exposure replicated in VR. In spinal cord injury patients, depression initially decreased in response to nature replicated in VR, but these results were not sustained one-week post-test (Lakhani et al., 2020). It is possible that given their lower positive affect baseline in comparison to non-clinical populations, nature replicated in VR will have the desired therapeutic benefits for depression. However, it may need to be implemented more frequently or over a longer period of time.

Interestingly, this was also the only study that did not use a cross-sectional design, implementing the intervention over three consecutive days. Browning, Mimnaugh, et al. (2020) examined dose-response and found no significant interaction between those participants with previous VR experience and those without in regard to affect. However, consistent with other therapeutic interventions for depression, it is unlikely that a significant improvement would be evidenced after three consecutive days of treatment. This may be due to the time required for re-establishing lost neurological connections (Kahn, 1997) and aligns with the Biophilia Hypothesis (Kellert & Wilson, 1995).

4.1. Strengths & limitations

The application of VR research to clinical populations has already been established for pain management, phobias, eating disorders, and rehabilitation, and as a relaxation tool for inpatients (White et al., 2018). For example, for patients undergoing palliative care in public health settings, nature replicated in VR is highly desirable in terms of ease of use and cost-efficiency. Nature exposure has long been established as a protective factor for mental health and well-being, evidenced to boost immunity (Cox et al., 2017). Further research into the impact of biodiversity and preferred environs to achieve maximum restoration effects would facilitate this process. In addition, these findings could be applied to rural and remote settings, aged care, education, and submariners who spend extended periods at sea. Particularly relevant is the current impact of the COVID-19 pandemic and its subsequent bearing on mental health due to restrictions being placed on peoples movement for extended periods. An unexpected positive finding of exposure to nature replicated in VR was discovered in an aged care setting when participants became engaged in a discussion over their VR experience (Appel et al., 2020).

VR is a rapidly evolving technology, and, as a result, variability in the tools and technology used was apparent. These varied from 260° to 360° photos and images to the use of videos. Further, we did not include studies that utilised augmented or mixed reality, or grey literature, which may have contributed further to the understanding of immersion in nature exclusive of in vivo settings. In addition, psychological well-being is a profoundly heterogeneous term with different criteria forming multiple definitions with outcomes dependent on scales used and constructs measured. The experimental study designs were mainly cross-sectional, with only three studies including a control group to determine the true effect of nature exposure replicated in VR. Results using physiological indicators of stress were inconsistent; therefore, scales with evidence of good reliability (reported as Cronbach's alpha) and validity are essential but were frequently excluded. Sample sizes were often small, with insufficient statistical power and diversity to ascertain any true effect. While there were few clinical samples, a potential limitation with these studies may be that participants' state of health might have influenced the perception of their well-being. Of note, student samples with limited generalizability as a non-representative population were not frequent. The reporting of effect sizes was generally omitted and should incorporate baseline effect sizes to allow for comparisons and extend the usefulness of research.

4.2. Future research

Nature replicated in VR may potentially increase psychological well-being, but the effective operationalisation of restoration remains unidentified. Widening future research parameters to focus on increased perceived restorativeness in conjunction with the key elements of VR, such as presence and immersion, may provide an answer (Schutte et al., 2017; Wang et al., 2020). Engagement with beauty significantly predicted increased positive affect in nature replicated in VR (Browning, Mimnaugh, et al., 2020). Incorporating preference for nature scene, combined with personality traits (Litleskare et al., 2020), and connectedness to nature may allow research to extend on ART (Kaplan, 1995). Most studies were conducted using HMD; however, CAVE systems' practicality requires further examination due to its potential ability to overcome issues related to cybersickness, green exercise, and feasibility for prescription lens wearers. HMD also calls into question the suitability of experimenters, training, and qualifications or use of a treatment manual.

The results of any study can only be judged based on previous research to allow for a synthesis of results. A failure to pre-register studies and limited documenting of intention to treat numbers creates the illusion of the perfect study, blurring the boundaries of treatment integrity. For nature exposure replicated in VR to have any pragmatic application beyond a novel relaxation method, more longitudinal studies are needed, particularly regarding clinical populations. Despite depression's high comorbidity rates with anxiety, anxiety-related disorders and stress reduction have dominated the research literature on nature replicated in VR to date. Research examining the short, medium, and long-term effects of treatment for anxiety, depression, or simply the quality of life outcomes for participants using nature replicated in VR would help gain a further understanding of how VR impacts individuals behaviour over time. However, longitudinal research examining the mental health consequences of using such technology requires further exploration.

5. Conclusion

There is a vast amount of creativity and innovation in developing and adapting VR for psychological well-being, but this aspect also limits its use. As technology rapidly evolves, making comparisons between research studies has proved challenging. Concerns that nature replicated in VR will replace nature are likely unfounded. Similar to social media, technology is yet to replicate the benefits derived from human contact or natural environments that lead to relaxation and reflection, enhanced restoration and psychological well-being. Nature replicated in VR should instead be viewed as an extension of nature, for which target populations retain a reduced but beneficial effect, rendering continued research a worthwhile pursuit in this area.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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