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Different types of virtual natural environments enhance subjective vitality through restorativeness☆

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ABSTRACT

The body of evidence supporting the psychological benefits of exposure to virtual nature, such as increased mood and decreased stress, is rapidly growing. However, few studies have explored the potential of virtual nature to boost subjective vitality, defined as a positive feeling of aliveness and energy. In this contribution, we investigate the role of virtual nature in enhancing subjective vitality through restorativeness. In particular, we expand the existing literature by considering different types of natural environments (i.e., a national park, a lacustrine environment, and an arctic environment vs. an urban environment). We designed a randomized between-subject design with a sample of 113 university students (M_{age} = 21.99, SD = 1.82). Participants were exposed to four 360-degree panoramic photos with a virtual reality (VR) head-mounted display. We collected measures of the variables of interest immediately before and after exposure, and a series of control variables (i.e., sociodemographics, individual differences and personal conditions, previous VR experience, frequency of contact with nature, and variables related to participants' experience during VR). We performed a mediation analysis with a multicategorical independent variable (i.e., the experimental condition). Results confirmed our hypotheses, with three significant indirect effects of virtual nature exposure on subjective vitality through restorativeness, one for each natural environment as compared to the urban environment. The wide range of practical implications for different types of psychological interventions as well as future research directions are discussed.

1. Introduction

The benefits of nature experience have been highlighted by hundreds of studies in the academic literature (e.g., Bratman et al., 2019; de Bell et al., 2020; White et al., 2017; Wyles et al., 2017). This research has highlighted a positive association between nature exposure and well-being, demonstrating its pivotal role in promoting individuals' health, positive emotions, restorative states, and decreased levels of stress (e.g., Ballew & Omoto, 2018; Choe et al., 2020; Panno et al., 2017; Tzoulas et al., 2007). In addition to real-life (in situ) experiences, an increasing number of studies have used virtual reality (VR) methods to investigate the specific contribution of exposure to virtual nature to well-being and health (e.g., Browning, Mimnaugh, et al., 2020; Reese et al., 2022; Van Houwelingen-Snippe et al., 2021). Although it is critical for individuals to have access to the benefits of nature in real-life contexts, there are many barriers that prevent this, including built infrastructure (e.g., urban design), financial factors (e.g., expendable income), and individual psychophysical characteristics (e.g., limits in mobility; for an overview see Bratman et al., 2021; see also Browning et al., 2017, 2020; Depledge et al., 2011). Though these challenges must be addressed, there are circumstances in which VR provides an avenue for individuals who do not otherwise have the opportunity for nature experience, and these benefits from virtual contact with nature are important to consider (Berto, 2014).

Examples of these benefits are included in a recent systematic review on the association between virtual immersion in nature and

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psychological outcomes that found a decrease in negative affect to occur consistently after exposure to virtual natural environments (Spano et al., 2022). Furthermore, recent studies have also shown that exposure to virtual natural environments increased positive affect, well-being, and restorativeness, the latter defined as the replenishment of physical and psychological resources exhausted in the continuous efforts to meet daily demands (Berto, 2014; Han, 2018; Mattila et al., 2020; Pasca et al., 2021). In this regard, Schutte et al. (2017) found that restorativeness was higher in a virtual natural vs. a virtual urban environment and that this restorativeness mediated the relationship between exposure to the virtual natural environment and increased positive affect (Schutte et al., 2017).

Nevertheless, despite the abovementioned evidence, little is known about the impacts of exposure to different virtual environments on subjective vitality through restorativeness. Subjective vitality can be defined as a positive experience of aliveness and being full of energy and is an essential component of eudaimonic and psychological well-being (Ryan & Deci, 2000). Given that well-being is a multicomponent and complex phenomenon not ascribed solely to the absence of disease (Bratman et al., 2019; Park et al., 2022), it is essential to delve into the relationship between natural environments and aspects of positive well-being, including benefits that come from virtual reality experiences. Therefore, the present study aimed to cover this gap in scientific literature by investigating the relationship between distinct virtual natural environments and subjective vitality and the underlying processes that help explain this relationship.

1.1. The Effect of VR Nature Exposure on Subjective Vitality Through Restorativeness

VR is an advanced technology based on the simulation of environments accessible through special equipment such as head-mounted displays, allowing individuals to immerse themselves in the created environment (Jayaram et al., 1997; Yu et al., 2018). Interestingly, the positive effect of VR exposure on psychological outcomes such as affect and physiological stress has been shown to be larger than 2D exposure (Je & Lee, 2020; Liszio et al., 2018) due to the greater sense of "experienced presence" attributed to VR vs. 2D images (Yeo et al., 2020). Content in VR can be produced mainly in two ways: The first involves using computer graphics and consists of the reconstruction of the 3D environment through specific programs (and skills). The second involves the use of a 360-degree panorama camera. Although the former provides opportunities for more interactivity, it is costly in terms of time and skills required for its realization. Despite its limited static nature, the 360-degree panorama camera has been shown to result in affective benefits due to the sensation of reality and vividness of the environments presented (Bishop & Rohrmann, 2003; Jacobs, 2004; Yu et al., 2018).

Research on the psychological impacts of VR is growing rapidly. Specifically, VR exposure has been found to be effective in reducing anxiety, depression, and stress levels both in clinical and non-clinical samples (Annerstedt et al., 2013; Bissonnette et al., 2015; Shah et al., 2015). Additionally, other research has shown that VR natural environment exposure significantly increases amusement, creativity, and engagement when compared with VR urban conditions – and in some instances may lead to similar psychological benefits that come from real environmental views, though usually of smaller magnitude (Browning, Shipley, et al., 2020; Chirico & Gaggioli, 2019; Chirico et al., 2018; Yu et al., 2018, 2019; Palanica et al., 2019).

Despite the abovementioned evidence, the relationship between exposure to different virtual environments and subjective vitality has been less examined, with a few exceptions (Mattila et al., 2020; see also Bareišytė, 2021). Subjective vitality can be considered to be an aspect of eudaimonic well-being (i.e., related to components such as purpose, meaning, and fulfillment) and is defined as a psychological and physical positive experience of vitality, aliveness, and energy (Bratman et al., 2019; Ryan & Deci, 2001; Ryan & Frederick, 1997; Zelenski & Nisbet, 2014). According to Ryan and Frederick (1997), subjective vitality consists of both trait aspects, related to people's general subjective vitality, as well as state aspects, related to the perception of experienced subjective vitality in that specific moment. Further evidence highlights that subjective vitality acts as a guide in the regulation of purposeful actions and this, in turn, leads to higher levels of well-being and mental health (Ryan & Deci, 2000; Ryan & Frederick, 1997).

Subjective vitality differs from some operationalizations of positive affect insofar as the latter may include high activation (e.g., exhilaration) or low activation (i.e., calmness) concerning the arousal dimension, whereas subjective vitality is specifically associated with high activation of positive emotions that bolster motivational processes to take action. Specifically, this high activation can lead to higher well-being and health benefits, and less vulnerability to illness due to a higher capacity to adopt the necessary coping strategies to deal with stressful conditions (e.g., Cohen et al., 2006; Polk et al., 2005).

The relationship between real-life nature exposure and subjective vitality has been reported by previous studies, showing that the presence of nature in daily life is essential not only to reduce stress levels but represents an important source of revitalization, greater energy, and engagement with the world (e.g., Greenway, 1995; Kaplan & Talbot, 1983; Stilgoe, 2001; Van den Berg et al., 2019). Nonetheless, while researchers have increasingly investigated subjective vitality given its association with a range of beneficial affective outcomes, e.g., reduced stress, improved coping strategies, higher positive and lower negative affect and higher levels of general well-being (Barrett et al., 2004; Bertrams et al., 2020; Dubreuil et al., 2014; Penninx et al., 2000; Swencionis et al., 2013), fewer studies have explored the relationship between nature and subjective vitality using the VR medium. Given the possible positive consequences for human well-being that come from VR (Spano et al., 2022), and the role that subjective vitality plays in well-being overall, it is important to understand the potential impact of exposure to different VR natural environments (vs. virtual urban ones) on subjective vitality specifically.

Additionally, Ryan et al. (2010) highlighted the need to investigate the relationship between natural environments, restorativeness, and subjective vitality. Although both fall under aspects of well-being, they have crucial differences. While restorativeness has often been analyzed in relation to decreased activity and arousal (e.g., relaxation and lower stress levels), subjective vitality is related to increased energy and activity. Therefore, it is worth examining the relationship between these factors and investigating it through distinct virtual natural environments. Here we build on the work of Mattila et al. (2020), which found that both restorativeness and subjective vitality increase after a short break in a VR forest environment and propose a mediation model that explains the mechanism through which subjective vitality is enhanced, hypothesizing that the benefits of virtual nature in enhancing subjective vitality are explained through increased restorativeness that it causes.

According to Stress Reduction Theory (SRT; Ulrich, 1983) and Attention Restoration Theory (ART; Kaplan & Kaplan, 1989), contact with natural (vs. urban) environments is typically more affectively and cognitively restorative. SRT postulates that exposure to nature evokes psychophysiological responses that result in affective benefits, facilitating recovery from stress (Ulrich, 1983). ART focuses on the beneficial role of natural environments in restoring mental fatigue through the engagement of involuntary attention (Kaplan & Kaplan, 1989). These two theories are not mutually exclusive, and both describe important complementary processes involved in restorativeness (Berto, 2014).

Feeling positive, restored and having available mental resources is an important prerequisite for motivation and action initiation (Kruglanski et al., 2012; Shalev, 2016). In support of this reasoning, different studies found restorativeness and subjective vitality to be empirically highly related both in on-site study designs and using VR, using both urban and natural settings and both before and after exposure, with correlations around 0.45 for the Perceived Restorativeness Scale and as high as between 0.70 and 0.90 for the Restorative Outcome Scale (Bielinis et al., 2018; Mattila et al., 2020; Tyrväinen et al., 2014). Following this reasoning, restorativeness coming from the natural environment should contribute to feelings of vitality. Several studies demonstrated that a virtual natural environment enhances restorativeness significantly more than virtual urban settings (Schutte et al., 2017; Tabrizian et al., 2018; Yu et al., 2020) and indoor settings as a control condition (Browning, Mimnaugh, et al., 2020).

Not all natural environments are likely to be equally effective in enhancing subjective vitality through restorativeness (e.g., Shalev, 2016). Previous studies on restorativeness and subjective vitality with VR focused on the effect of virtual landscapes characterized by plants or liquid water (e.g., Mattila et al., 2020; Reese et al., 2021; Schutte et al., 2017). Recently, a type of environment that is receiving growing attention for its potential beneficial effects is a landscape dominated by solid water, including an arctic environment (Li et al., 2022). According to current environmental psychology theory, this environment could be effective in enhancing restorativeness for at least two reasons. First, its potential of inducing fascination has been discussed and documented (Brooke & Williams, 2021; Duffy, 2013; Li et al., 2022). Second, as a usually unfamiliar and extreme environment, in line with ART, it could promote the experience of being away (Li et al., 2022). We believe that insight into the impacts from this kind of environment, considered extreme and difficult to access, acquires new importance with the use of an immersive simulated reality such as VR.

In light of the abovementioned studies, we expected that different immersive natural environments would produce higher subjective vitality through increased restorativeness as compared to an urban environment. As a precedent, environments characterized by plants and those dominated by liquid water proved extensively effective in enhancing restorativeness and subjective vitality in outdoor studies (e.g., Menardo et al., 2021; Ryan et al., 2010). Thus, we sought to corroborate such a link through VR experience. Additionally, few studies have focused on the arctic environment and its effect on positive psychological states (both on-site and through VR; Li et al., 2022). Thus, we tested the effect of this environment on psychological outcomes to fill this gap. We think that the features of the arctic environment (e.g., white, frozen water elements) might support restorativeness.

1.2. The present study

To the best of our knowledge, no previous study has explored the indirect effect of restorativeness of virtual nature on subjective vitality, accounting for varying effects based on different natural conditions, including a virtual arctic environment. To fill the aforementioned literature gaps, the main aim of the present study was to examine the indirect effect of exposure to four different virtual environments on subjective vitality through restorativeness, using 360-degree shots of natural and urban environments. Therefore, the main hypothesis of the current research is that virtual natural environments, namely a national park, a lacustrine environment, and an arctic environment, enhance restorativeness significantly more than the virtual urban environment, and that, in turn, determines greater subjective vitality. The virtual urban environment served as the control condition since, based on the literature, we would expect that it will be less restorative than the other three natural conditions. However, we did not expect a specific size of effects for each natural environment (e.g., a larger effect of the national park in enhancing subjective vitality through restorativeness as compared to the arctic environment) and we therefore comparatively evaluated them in an exploratory way.

To test our hypotheses, we designed a randomized between-subject design with four conditions with a sample of 113 students. We assessed differences between groups with respect to sociodemographic variables of age, gender, marital status, student type, and employment status. We also measured self-reported inclusion of nature in self, as it could interfere with personal reactivity to a natural or urban setting (Schultz, 2002; see also Panno et al., 2020). We also assessed individual levels of perceived stress, as this could influence baseline levels of restorativeness and subjective vitality, and thereby potentially interfere with our inferences regarding potential changes observed in these variables as outcomes (Korpela et al., 2010; Miksza et al., 2021). Based on a recent review (Spano et al., 2022), we controlled for previous VR experience, since the novelty of the medium could affect participants' reactions. We also measured participants' frequency of contact with nature, since it could differently interfere with their preference for natural environments (Alcock et al., 2020).

Additionally, we assessed and controlled for variables related to participants' experience during the VR exposure. In this latter category, we have the attributes of the images shown, namely participants' evaluations of the images. It will serve to understand if, across conditions, the images were comparable in terms of pleasantness, quality, brightness, and familiarity. As perhaps the most important quality of the VR medium (Mostajeran et al., 2021), the sense of presence evoked by the images, namely the psychological experience of being in the virtual environment (Slater & Wilbur, 1997), was measured to check if it was comparable among conditions. Lastly, we also checked if a condition often encountered after the VR experience as motion sickness, namely a state of physical discomfort often characterized by dizziness and nausea resulting from the apparent motion (Gianaros et al., 2001), was comparable among conditions, as this can affect the outcome and experience of VR.

2. Method

2.1. Participants and procedure

To test our hypotheses, we designed a between-subjects design with four conditions. The method applied in the study was approved by the institutional ethics committee of the European University of Rome (prot. n. 11/2021). Before collecting our sample, we made some considerations on the effect sizes expected and the power needed. We considered medium effect sizes for both paths of the mediation (i.e., *a* and *b*). As found by Fritz and MacKinnon (2007, p. 237), to detect medium effect sizes of both paths in a simple mediation at power .80 with the percentile bootstrap method a sample of 78 participants is needed, thus approximately 20 participants for each of the four groups in our case. Nevertheless, small samples tend to overestimate the effect size (Loken & Gelman, 2017) and may not represent a stable estimate for our parameters. Following this reasoning, we decided not to rely solely on the p-value test and collected a larger sample.

The study was conducted in Italy. We collected a sample of 113 social psychology students ($M_{age} = 21.99$, $SD = 1.82$) who agreed to take part in the study voluntarily. Anonymity was assured and participants gave their informed consent. They obtained extra course credit for participating. Of the total sample, 81 (71.7%) were undergraduates while 32 (28.3%) were master's students. Moreover, 90 (79.6%) identified themselves in the female gender, 22 (19.5%) in the male gender, and 1 (0.9%) reported a nonbinary gender. Regarding marital status, 62 (54.9%) were in a relationship but not living together, 50 (44.2%) were single, and 1 (0.9%) was living with the partner. Lastly, 80 (70.8%) were not working while 33 (29.2%) were working students.

To test our hypotheses, participants were randomly assigned to four different conditions based on exposure to different types of environments: (1) an urban environment (urban condition); (2) a national park (park condition); 3) a lacustrine environment (lacustrine condition); and (4) an arctic environment (arctic condition). The environments were shown to participants through 360-degree panoramic photos using a head-mounted display for VR, namely the Oculus Quest 2. The photos were taken by the experimenters in four different settings: a neighborhood of the city of Rome (Italy) with tall buildings and cars; a national park entirely covered with grass, trees, shrubs, and other vegetation and no bodies of water; a lacustrine environment of a national park dominated by liquid water; and an arctic environment characterized by solid water and large areas of permafrost. There were four photos for each setting. To standardize as much as possible the images shown across conditions, for each environment we shot photos of semi-open spaces, avoided capturing other visitors, and chose images with comparable lighting. See https://doi.org/10.17605/osf.io/puhrj for an example of one photo per each environment.

On the basis of previous experiments with VR that were similar to ours (Spano et al., 2022), the time for each photo exposure was established at 1 min per image. Thus, in each condition, participants were exposed to the immersive photos for 4 min in total. The final numbers of participants for each condition were 29 for the urban condition, 29 participants for the park condition, 27 participants for the lacustrine condition, and 28 for the arctic condition.

The opportunity to take part in a study using VR was presented to students during class. Students interested in taking part in the experiment were contacted by phone by research assistants to book an appointment. During the phone call, they were informed about the Covid-19 related procedures to be adopted during the experiment and, importantly, the eligibility criteria. More specifically, the latter corresponded to the conditions in which the use of VR is discouraged (e.g., epilepsy, pacemaker usage).

On their arrival at the laboratory, participants were invited to sign the informed consent in which possible short-term consequences such as dizziness were acknowledged. Then, a first questionnaire was administered with measures of inclusion of nature in self and perceived stress. Students were then invited to wear the VR headset and to stay standing. Participants were invited to wear protective eye masks and a protective cap before putting on the VR headset and were asked to continue to wear surgical masks for the duration of the experiment. They were told that during the viewing of the virtual environments, they could turn their head around to explore the environment but not walk to prevent undesired accidents. The participants were then exposed to the immersive photos of the environments for 4 min. Two research assistants were present in the room for the duration of the VR exposure to assist participants if needed. After this phase, the participant was asked to complete a second questionnaire with our measures of interest (i.e., restorativeness, subjective vitality, and the remaining control variables). See Fig. 1 for a graphical representation of the experimental procedure.

We used one item to verify participants' attention. Following Oppenheimer et al. (2009), we asked participants "*This question is to check the attention of the respondent, if you are attentive please answer 4*". The question was located approximately in the middle of the second (and longer) questionnaire. None of the participants failed the check, suggesting that participants were attentive during the completion of the questionnaire.

2.2. Measures

In the first, pre-exposure questionnaire, we measured two control variables related to individual differences and personal conditions (inclusion of nature in self and perceived stress), while in the post-exposure questionnaire, we measured both our dependent variables (i.e., restorativeness and subjective vitality) and other control variables. These included sociodemographic variables (i.e., age, gender, marital status, student type, and employment status), previous VR experience, variables related to participants' frequency of contact with nature (frequency of visits to natural environments and archeological parks, duration of the visits, frequency of sports in a natural environment such as water sports, mountain sports, and snow skiing), and variables related to participants' experience during the VR exposure (attributes of the images shown, sense of presence, and motion sickness).

2.2.1. Dependent variables

Restorativeness. To measure restorativeness, we selected seven items from the short version of the Perceived Restorativeness Scale (PRS-11) in its Italian version (Pasini et al., 2009, 2014), adapted to specifically refer to the 360-degree photos shown through the VR headset. In particular, two items were chosen from the subscale fascination (e.g., "*The place shown in the pictures is fascinating*"), two from the subscale being away ("*To stop thinking about the things that I must get done I would like to go to in the place shown in the pictures*"), two from the subscale coherence (e.g., "*In places like those shown in the pictures everything seems to have its proper place*"), and one from the subscale scope (e.g., "*In places like those shown in the pictures there are few boundaries to limit my possibility for moving about").* The response scale ranged from 1 (*not at all*) to 5 (*very much*). We used the total score (Pasini et al., 2009). Cronbach's alpha was .88.

Subjective Vitality. To measure subjective vitality, we used the subjective vitality scale in its state version (Bostic et al., 2000; Ryan & Frederick, 1997). The items were translated into Italian using a back-translation method. The scale is composed of seven items, of which one (item 2) is reverse-coded. An example of an item is "*At this moment, I feel alive and vital".* The response scale ranged from 1 (*not true at all*) to 7 (*very true*). Cronbach's alpha was .81.

2.2.2. Control variables

Sociodemographic Variables. We collected information on age, gender (woman, man, nonbinary), marital status (single, married or in a civil partnership, living with the partner, in a relationship but not living together, divorced or separated, widow/widower), student type (undergraduate, master's student), and employment status (i.e., we asked whether they worked while studying: yes, no. There were no differences

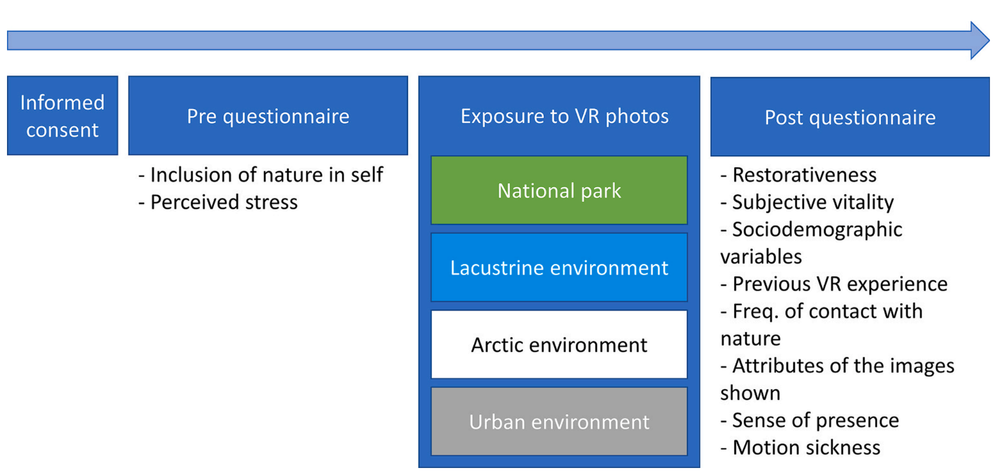

Fig. 1. Graphical representation of the experimental procedure.

in the study program between working and nonworking students).

Inclusion of Nature in Self. We measured the inclusion of nature in self in the pre-exposure questionnaire to control for differences between the four groups. To assess this construct, we used the one-item graphical measure by Schultz (2002). The item is "*Below, please choose the picture that best describes your relationship with the natural environment. How interconnected are you with nature?*" and the seven possible responses, each one constituted by two circles representing respectively nature and the self. The possible responses range from 1 to 7, namely from the first possible answer in which the two circles are independent (i.e., not overlapping at all), to the seventh, in which the two circles are perfectly overlapping.

Perceived Stress. We measured perceived stress in the pre-exposure questionnaire to control for differences between the four conditions. Four items of the original Perceived Stress Scale (PSS: Cohen et al., 1983) in its Italian version (Fossati, 2010) were chosen. This scale assesses the extent to which the respondent perceived stress in the previous month. An example of an item is "*In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?*". Responses ranged from 0 (*never*) to 4 (*very often*). Cronbach's alpha was .80.

Previous VR Experience. Previous VR experience may affect psychological outcomes. Following the methods of prior studies we therefore asked participants about their previous VR experience using one item (Browning, Mimnaugh, et al., 2020; Chirico & Gaggioli, 2019; Liszio et al., 2018; Mattila et al., 2020; Rockstroh et al., 2019; Yeo et al., 2020), which consisted of the following question "*Is this your first time experimenting with immersive VR (with a headset or goggles)?*" with as possible answers "*yes*" and "*no*".

Frequency of Contact with Nature. A set of questions asking the frequency of contact with different types of natural environments. We asked about the frequency of visits to natural environments with one question, namely "*How often do you visit nature parks, snowy mountain parks, lakes, and other natural environments?*", the frequency of visits to archeological sites, namely "*How often do you visit archeological sites or parks?*" and the frequency of involvement in different kinds of outdoor sports during the year, namely water sports, mountain sports, and snow skiing. The possible responses for this set of questions were: 1 (*at least once a day*), 2 (*several times a week*), 3 (*once a week*), 4 (*once a month*), 5 (*once every two months*), and 6 (*once every three or more months*). Lastly, one question asked about the duration of the visits to natural environments, namely "*How long does your visit to nature parks, snow-capped mountain parks, lakes, and other natural environments usually last?*" with the possible answers: 1 (*15 min or less*), 2 (*30 min*), 3 (*an hour*), 4 (*2 h*), 5 (*a few hours*), and 6 (*days*).

Attributes of the Images Shown. To control for possible effects related to the attributes of the images, we asked participants to evaluate them. We asked about the pleasantness of the images "*To what extent did you like the images shown?*" from 1 (*not at all*) to 10 (*very much*), the quality of the images shown "*How would you rate the quality of the images shown?*" from 1 (*very bad quality*) to 10 (*excellent quality*), the brightness of the images "*How would you rate the brightness of the images shown?*" from 1 (*very bad brightness*) to 10 (*excellent brightness*), the familiarity of the images "*How familiar are you with the place you saw in the pictures?*" from 1 (*not at all familiar*) to 10 (*extremely familiar*).

Sense of Presence. The sense of presence that comes as a result of the immersive nature of the VR experience can distinguish it from 2D stimuli. Previous work has found that the level of experienced presence impacts the positive outcomes of exposure to a virtual environment (Li et al., 2021; Yeo et al., 2020). We measured the sense of presence and subjective immersion using the Igroup Presence Questionnaire (IPQ; Schubert et al., 2001). The items were translated into Italian using a back-translation method. The original measure is a 14-item questionnaire (four subscales: general presence, spatial presence, involvement, and experienced realism, see the complete list of items at http://www.igroup.org/pq/ipq/download.php) that assesses the sense of presence experienced in a computer-generated environment. Since we used 360-degree photos of real natural environments, we adapted the questions to refer to our specific case. For the same reason, we excluded the last two items which refer to how real the computer-generated world seemed. In this study, we used the total score. Cronbach's alpha was .81.

Motion Sickness. Motion sickness can frequently occur after the usage of a VR headset and can affect the VR experience (Liszio & Masuch, 2019; Mostajeran et al., 2021; O'meara et al., 2020; Reese et al., 2021). To control for potential influence of this on our outcomes, we assessed the motion sickness experienced by participants using the Motion Sickness Assessment Questionnaire (MSAQ; Gianaros et al., 2001). It is composed of 16 items, divided into four different clusters of symptomatology resulting from the VR usage, namely gastrointestinal, central, peripheral, and sopite-related. The items were translated into Italian using a back-translation method. In this study, we used the total score computed as suggested by Gianaros et al. (2001). Cronbach's alpha was .88.

3. Results

3.1. Preliminary analysis

First, we checked whether the distribution of the participants was even across conditions in terms of our control variables. A series of chi squares tests confirmed that the distribution of participants was balanced for gender χ^2 (6, 113) = 4.154, p = .656, marital status χ^2 (6, 113) = 4.130, p = .659, student type χ^2 (3, 113) = 7.126, p = .068, and employment status χ^2 (3, 113) = 1.203, p = .752. A one-way analysis of variance (ANOVA) also confirmed that participants were evenly distributed by age F (3, 107) = 1.421, p = .241, η_p^2 = .038. Inclusion of nature in self was not significantly different between conditions F (3, 109) = 0.980, p = .405, η_p^2 = .026 and neither was perceived stress F (3, 109) = 1.000, p = .396, η_p^2 = .027. We performed a chi square test to determine whether the proportion of participants with previous VR experience was equal among the four conditions. The results confirmed that this proportion also did not differ by condition χ^2 (3, 113) = 1.535, p = .674.

Our next step was to check if participants' frequency of contact with natural environments was distributed evenly between conditions. To do so, we performed a series of one-way ANOVAs in which we found that the distribution did not differ for the frequency of visit F (3, 109) = 1.486, p = .222, η_p^2 = .039, duration of the visit F (3, 109) = 1.305, p = .276, η_p^2 = .035, frequency of visit to archeological parks F (3, 109) = 0.148, p = .931, η_p^2 = .004, frequency of water sports F (3, 109) = 0.792, p = .501, η_p^2 = .021, frequency of mountain sports F (3, 109) = 0.327, p = .806, η_p^2 = .009, and frequency of snow skiing F (3, 109) = 1.172, p = .324, η_p^2 = .031.

These preliminary analyses confirmed that participants were balanced across conditions on relevant sociodemographic variables, inclusion of nature in self, perceived stress in the last month, previous VR experience, and the frequency of contact with natural environments.

Next, we proceeded to check if participants' experiences during the VR exposure were different by condition. To this end, we performed a series of one-way ANOVAs with each of the attributes of the images shown as the dependent variable, applying Tukey's post-hoc test. Results the pleasantness of the images showed that it differed by condition F (3, 109) = 12.733, $p < .001$, η_p^2 = .260. Tukey's post-hoc test attested that the pleasantness of the urban environment was significantly lower than that of the park (p = .045), the lacustrine environment (p = .047), and the arctic environment ($p < .001$). Interestingly, the pleasantness of the arctic environment was higher than that of the park (p = .003), and the lacustrine environment (p = .005). Lastly, the pleasantness of the park and the lacustrine environment did not differ significantly (p = 1.000). Since pleasantness showed different means across conditions, it was included as a covariate in a separate model when testing our hypotheses.

The ratings of the quality of the images differed significantly between conditions F (3, 109) = 3.871, p = .011, η_p^2 = .096. Tukey's post-hoc test showed that the quality of the urban environment did not differ significantly from that of the park (p = .983) and the lacustrine environment (p = .981), but it was significantly lower than that of the arctic environment (p = .036). The quality of the park did not differ from that of the lacustrine (p = .881) and the arctic environment (p = .088). The quality of the lacustrine environment was significantly lower than that of the arctic environment (p = .014). As for pleasantness, the quality of the images differed across conditions, and it will be taken into account in a separate model when testing our hypotheses.

The brightness of the images did not differ significantly between conditions F (3, 109) = 1.501, p = .218, η_p^2 = .040. The familiarity of the images differed significantly between conditions F (3, 109) = 13.763, p < .001, η_p^2 = .275. The familiarity of the urban environment was higher than that of the park (p < .001), the lacustrine (p < .001), and the arctic (p < .001) environment. The familiarity of the other environments was not significantly different, in particular, the familiarity of the park did not differ from the lacustrine environment (p = .924) and that of the arctic environment (p = .237). The familiarity of the lacustrine environment did not differ from that of the arctic environment (p = .603). As with pleasantness and the quality of the images, familiarity was taken into account in a separate model when testing our hypotheses.

Next, we ran a one-way ANOVA to establish if the photos shown in the different conditions elicited different levels of sense of presence. The results showed that the sense of presence evoked in the different conditions was comparable F (3, 109) = 2.00, p = .118, η_p^2 = .052. Moreover, results of an additional one-way ANOVA suggested that participants reported comparable levels of motion sickness across conditions F (3, 109) = 1.028, p = .383, η_p^2 = .028.

In sum, as expected, pleasantness was higher for the arctic condition and lower for the urban condition, while familiarity followed the opposite trend, with higher familiarity for the urban condition and lower for the arctic condition. In the urban and lacustrine conditions, the quality of the images was perceived as lower than that of the arctic condition. Lastly, brightness did not differ by condition. Both sense of presence and motion sickness were not different by condition, suggesting that the groups were comparable in these two aspects.

3.2. Mediation analysis

To test our hypotheses, we conducted a mediation analysis with observed variables using the IBM SPSS macro PROCESS 3.3 version (Hayes, 2018). We included the condition (a multicategorical variable with four indicators) as the predictor, the restorativeness of the environments as the mediator, and the subjective vitality as the outcome. Consistent with the indications by Hayes and Preacher (2014) for the case of mediation analysis with a multicategorical independent variable, PROCESS coded the condition variable treating each group as an indicator or a dummy variable. The park condition, the lacustrine condition, and the arctic condition were thus coded as dummy variables with a value of 1 if a case was in the relative condition and 0 if otherwise. We set the urban condition, the control group in our design, as the reference group. In this way, the urban condition received a code of 0 on the park condition, the lacustrine condition, and the arctic condition (see Table 1).

Table 1
The indicator coding system used for the multicategorical independent variable "condition".

	Urban condition (control)	Park condition	Lacustrine condition	Arctic condition
Park condition	0	1	0	0
Lacustrine condition	0	0	1	0
Arctic condition	0	0	0	1

Because of our coding system, the estimated indirect effects in the model refer to the differences in the means between each predictor and the references group (the urban condition) on the outcome, while the direct effects correspond to the adjusted or expected mean differences in the analysis of covariance (ANCOVA) between each predictor and the reference group on the outcome controlling for the mediator (Hayes & Preacher, 2014). Lastly, the total effects correspond to the observed differences between the two group means (i.e., predictor and reference group) on the outcome (i.e., subjective vitality in our case, Hayes & Preacher, 2014). Therefore, the total, indirect, and direct effects are then called *relative* effects because they depend on the coding system chosen (Hayes & Preacher, 2014) .[1] Thus, in this case, standardized effects may not be more meaningful than unstandardized ones (see Hayes & Preacher, 2014, p. 461). To estimate the indirect effects, a bootstrapping procedure with 5000 bootstrap samples is used in PROCESS to estimate 95% (percentile bootstrap) confidence intervals (see Hayes, 2018). According to Preacher and Hayes (2008), confidence intervals that do not include zeros provide evidence of significant indirect effects.

Results of the mediation model are reported in Fig. 2. In the first step, the three dummy variables corresponding to respectively the park condition, the lacustrine condition, and the arctic condition were posed as predictors of restorativeness. Results of this first model explained a significant portion of the variance of the outcome R^2 = 0.40, F = 24.03, p < .001. In particular, all effects were positive and significant (see Fig. 2, paths a_1, a_2, *and* a_3), attesting that all the natural conditions were significantly more effective than the urban condition in enhancing restorativeness. This result (i.e., path a_3) represents a novel aspect, with respect to previous studies, because it points out the positive and significant effect of the arctic condition on restorativeness as compared with the urban condition.

In the second step, the three dummy variables corresponding to the three natural conditions and restorativeness were included as predictors, while subjective vitality was considered as the outcome. Findings showed that the second model too explained a significant portion of the variance of the outcome R^2 = 0.27, F = 10.07, p < .001. Here, the effect of restorativeness was positive and significant over and beyond the effect of the conditions, attesting that restorativeness enhanced subjective vitality (path b).

All the relative indirect effects of the natural conditions on subjective vitality through restorativeness were positive and significant. Specifically, the relative indirect effect for the park condition was 0.78, BootSE = 0.22, [95% BootCI = 0.38, 1.25], for the lacustrine condition was 0.87, BootSE = 0.21, [95% BootCI = 0.49, 1.30], and for the arctic condition was 1.10, BootSE = 0.23, [95% BootCI = 0.66, 1.56], while the partially standardized indirect effect for the park condition was 0.74, BootSE = 0.20, [95% BootCI = 0.38, 1.16], for the lacustrine condition was 0.84, BootSE = 0.19, [95% BootCI = 0.48, 1.22], and for the arctic condition was 1.05, BootSE = 0.20, [95% BootCI = 0.66, 1.46]. These results indicate that all the natural conditions were significantly more effective than the urban condition in enhancing subjective vitality

[1] Hayes and other scholars (e.g., MacKinnon et al., 2000) recommend that "researchers do not require a significant total effect before proceeding with tests of indirect effects. (...) A failure to test for indirect effects in the absence of a total effect can lead to you missing some potentially interesting, important, or useful mechanisms by which X exerts some kind of effect on Y" (Hayes, 2009, pp. 414-415).

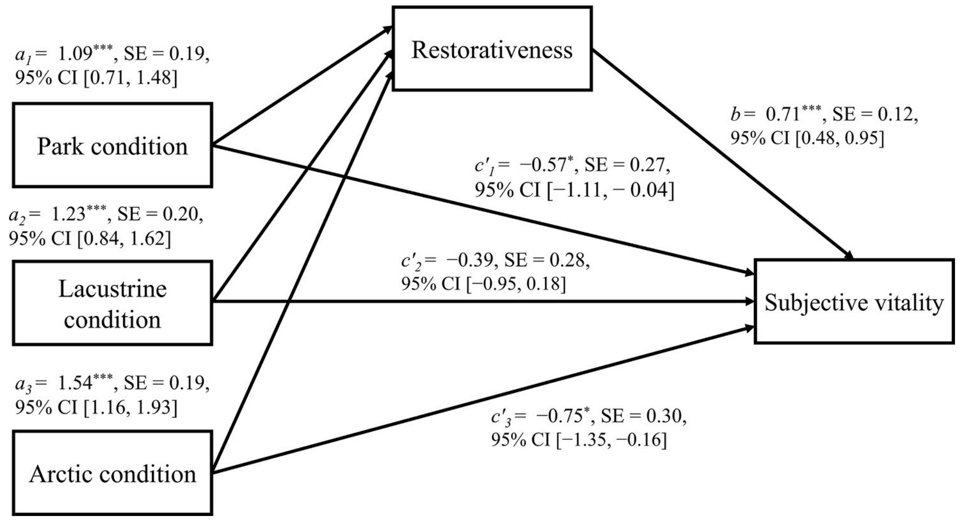

Fig. 2. Graphical representation of the results of the mediation model
Note. Because of our coding system, paths *a* and *c'* are to be considered as the differences in the means between each natural environment condition and the urban condition. All estimates correspond to unstandardized effects. $^{***}p < .001$, $^{*}p < .05$.

through restorativeness.[2]

The relative effects of the natural conditions moved from being positive in the first step to becoming negative in the second step (see Fig. 2). Moreover, the magnitudes of the direct effects resulted larger than those of the total effects (the total effects are all nondifferent from zero), and the relative direct effects and the relative indirect effects are of opposite sign (the former are negative while the latter are positive). All these specific peculiarities of our model suggest that we are dealing with an inconsistent mediation pattern and that restorativeness acts as a suppressor variable (MacKinnon et al., 2000). When included in a relationship between a predictor (or predictors, such as in our case) and an outcome variable, a suppressor variable has the capability of increasing the magnitude of the relationship observed (MacKinnon et al., 2000). Taken together, the obtained results point out that the natural conditions, as compared to the urban one, enhance restorativeness, which in turn, increases subjective vitality.

Mean restorativeness scores were as follows: for the urban condition M = 2,50 (SD = 0.93), for the park condition M = 3.60 (SD = 0.81), for the lacustrine condition M = 3.73 (SD = 0.67), and for the arctic condition M = 4.05 (SD = 0.41). Means of subjective vitality were as follows: for the urban condition M = 3.85 (SD = 1.13), for the park condition M = 4.05 (SD = 1.13), for the lacustrine condition M = 4.33 (SD = 1.04), and for the arctic condition M = 4.19 (SD = 0.84).

4. Discussion

This study was aimed at investigating the indirect effect of exposure to virtual natural environments on subjective vitality through restorativeness. To this aim, we conducted an experimental study testing a mediation model, which includes exposure to virtual natural environments – compared to a virtual urban environment – as the independent variable, the restorativeness of these environments as the mediator, and subjective vitality as the dependent variable. The findings confirmed our hypotheses. Indeed, we found that the distinct virtual natural environments, namely a natural park, a lacustrine environment, and an arctic environment enhance restorativeness, which in turn, increases subjective vitality. Importantly, all three natural environments were more effective than the urban environment in increasing subjective vitality through restorativeness.

Our findings build on work by Ryan et al. (2010) and Mattila et al. (2020) by relating restorativeness and subjective vitality through a mediational model. Specifically, while previous findings demonstrated that virtual natural environments promote recovery from stress and well-being separately (Reese et al., 2021; Schutte et al., 2017), we found that the positive, energetic, and intrinsic motivational aspect of well-being (i.e., subjective vitality) experienced after exposure to natural virtual environments was mediated by experienced restorativeness (Kaplan & Kaplan, 1989; Kruglanski et al., 2012; Ulrich, 1983).

Available physical and psychological energy represents an essential prerequisite for subjective vitality (Dagar et al., 2022; Ryan & Frederick, 1997). Our results help to explain the processes underlying the relationship between virtual natural environments and well-being. Previous findings support the notion that both arctic and antarctic experiences improve positive emotion and well-being over time, but there is a lack of empirical evidence for other health benefits (Kjærgaard, Leon, Venables, & Fink, 2013; Zimmeret al., 2013). Given the fact that these environments tend to be extremely difficult to access, opportunities to experience improved subjective vitality from just 4 min of virtual exposure to them support the use of VR nature as a time and cost-efficient resource.

To the best of our knowledge, these results from our mediational model and the use of four distinct virtual environments represent a set of novel findings. First, as far as we know, this study is the first to investigate the underlying mechanisms of the effect of exposure to different virtual natural environments (i.e., a natural park, a lacustrine environment, and an arctic environment vs. an urban environment) on subjective vitality through restorativeness. Since the field of study on the benefits of virtual nature is new and is showing an impressive increasing number of studies (see Spano et al., 2022 for a review), we believe that it is helpful to increase insight into mechanisms and dynamics underlying the beneficial effects of VR on psychological outcomes. Second, to the best of our knowledge, the current research is the first study to investigate the restorative effects of an arctic environment using real 360-degree photos. Third, our findings were significant after controlling for a high number of potential confounding variables. Fourth, unlike cross-sectional mediation models, we were able to use a controlled environmental intervention and include the direction of the relationship

[2] We further tested a model including pleasantness, the quality of the images, and familiarity as covariates. The results of interest remained substantially unchanged except for the direct effects that in this case were all nonsignificant. Regarding the effects of the covariates, in the first model with restorativeness as the outcome, the only significant effect among the three was that of pleasantness (b = 0.24, SE = 0.03, p < .001). On the contrary, in the second model, all the effects of the covariates were nonsignificant.

(i.e., causality) between exposure to the type of environment and the dependent outcomes.

This study is not free of limitations. First, the possibility of a self-selection bias in our sample should be considered (Harber et al., 2003). We tested our model on a sample of young social psychology students. Given the potential individual-level characteristics of this population (Rasoal et al., 2012), we acknowledge results may differ from those of other student samples. Although we do not have specific a priori reasoning for why these effects would be different in other nonstudent samples (e.g., adults and workers), these results should be replicated in these populations to increase their generalizability.

Second, although we believe that our methodological approach was able to control for a number of potential confounding variables, further research should take into account the effect of other possible relevant variables not included in our study, such as landscape preference. Third, future studies could replicate our findings with an additional control condition, namely a group that is exposed to 2D rather than VR photos to assess the added value of VR exposure in this case. Fourth, we used 360-degree photos of the environments and did not employ audio. In particular, multisensory experiences including auditory and olfactory stimuli have been proven to be related to the sense of presence, enhancing VR benefits (Schebella et al., 2019). Nevertheless, sounds made by other visitors may negatively affect the experience (Jo & Jeon, 2020). Future studies should consider replicating our study using videos and other stimuli apart from visual ones to investigate the effect of such experiences. Fifth, future studies could consider additional types of urban environments not included in our studies, such as urban parks and forests, botanical gardens, and shopping malls.

Lastly, studies on the role of virtual nature in well-being, including this one, in most cases, use very limited exposure to nature (i.e., few minutes) and observe immediate effects on individuals' health (Spano et al., 2022). Future studies are needed to establish the optimal duration of a single session and consider the possible added value of interventions based on repeated exposure (e.g., every day for a certain amount of time; Browning et al., 2023). Importantly, future efforts should be focused on clarifying the length of the positive effect observed on vitality after exposure to virtual nature. Indeed, although our study suggests that state vitality is enhanced immediately after exposure, we do not know how long this effect lasts. It is reasonable to expect that brief exposure determines brief changes; nevertheless, further studies are needed to quantify the length of the benefits and determine how to prolong them.

4.1. Practical implications

We believe that a primary strength of these results lies in the broad range of implications they have for both practical purposes and future research designs, especially for the role of virtual nature in psychological interventions. One of the possible applications of the findings is using virtual nature exposure to sustain the role of subjective vitality in the promotion of healthy lifestyles (Shalev, 2016). Indeed, higher levels of subjective vitality could be important in sustaining health behaviors such as smoking abstinence (Niemiec et al., 2010). A previous study highlighted how pictures of a landscape with water are more effective than those of a desert in enhancing subjective vitality, which, in turn, increases confidence in changing negative habits (Shalev, 2016). Our study suggests that VR images of a park, a lacustrine, and an arctic environment may also be effective in similar ways.

Another field of possible application of these findings is the clinical setting. For instance, as part of an individual's motivation and internal attribution of control, it has been proposed that subjective vitality is a desirable outcome of psychotherapy (Ryan & Deci, 2008). Thus, an intervention based on virtual nature that can increase subjective vitality may be complementary to psychotherapeutic and counseling programs in those cases in which patients cannot access outdoor nature (e.g., prison settings, hospitals). New frontiers of VR for psychological interventions have been explored due to restrictions from the Covid-19 pandemic (Hatta et al., 2022). Several studies identified the role of subjective vitality in sustaining adjustment during home confinement (e.g., Arslan et al., 2022; Teran-Escobar et al., 202). In this sense, exposure to virtual nature to enhance subjective vitality when access to nature may be impeded, such as during lockdowns and individual quarantines, could be important in coping with these stressful situations (Arslan et al., 2022) and could contribute to sustaining motivation for engaging in a healthy lifestyle (Teran-Escobar et al., 2021).

The use of VR to increase subjective vitality may become an important aid for both the patients and all healthcare providers as it could promote greater compliance, especially in long-term care and bedridden patients. Lastly, the use of virtual nature could be useful to sustain students and workers' vitality in their working environments. The adoption of VR for improving subjective vitality in the short term for those who cannot access nature (e.g., individuals with severe allergies) during certain conditions (e.g., pollen season) could be beneficial for reducing stress, enhancing engagement and performance, and dealing with overwhelming demands (Bakker & Demerouti, 2007; Fiorilli et al., 2017).

5. Conclusion

In conclusion, these findings demonstrated that different virtual natural environments are effective in enhancing subjective vitality through restorativeness. Researchers and practitioners should not consider virtual nature as a substitute for access to presence in nature in real life. It is overly reductive to think that virtual photos and experiences are comparable to multi-sensory and deep experiences in nature, which consist of sounds, lights, movements, and a huge variety of interactions with local elements, as well as deep personal connections and relationships with the natural world. However, our results do suggest potential for VR nature as an option that could be considered in cases in which access to nature is limited or impossible, while solutions to those barriers are simultaneously developed.

Author contributions

AT and AP contributed to the conceptualization of the study and designed the experiment; AT wrote the original manuscript, organized the data, and performed the statistical analysis; LR wrote the original manuscript; AP and GAC acquired the resources for the research stimuli; GC and RR collected the arctic material; AP was the project administrator and acquired the necessary fundings; GNB and AP contributed to the manuscript revision; AP supervised. All authors read and approved the submitted version.

Declaration of competing interest

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