Comparing Perceived Restorativeness and Stress Reduction in Virtual Reality Environments Using Abstract Fractal Geometries Versus Realistic Natural Landscapes

Diana C. G. Mendes(✉) and Mónica S. Cameirão

Faculdade de Ciências Exatas e da Engenharia & NOVA-LINCS, Universidade da Madeira, and Agência Regional para o Desenvolvimento de Investigação, Tecnologia e Inovação (ARDITI), Funchal, Portugal

diana.mendes@nlincs.uma.pt, monica.cameirao@staff.uma.pt

Abstract. Stress and its related mental conditions are an increasing concern in modern societies. Natural settings have been shown to reduce stress and anxiety levels and help restore lost physical-psychological resources. The Perceptual Fluency Account associates this restorative potential with nature's fractal characteristics, which facilitate their visual processing. While many studies have shown the value of Virtual Reality Nature for stress reduction and even treatment, no study of Virtual Reality fractal abstract worlds for restoration has been found. We question whether an abstract fractal-based environment can have similar restorative effects to a realistic nature-based environment in Virtual Reality. A total of 39 participants took part in two studies. In the first one, two groups (N = 19) of participants performed a collecting task in a fractal- or nature-based environment. The results showed that both environments were perceived as restorative and significantly reduced stress. To infer how the existence of a task modulated the results, in the second study, with 20 participants split into two groups, participants were exposed to the same environments, this time without a task. The results showed that the condition was significantly more restorative for the fractal-based environment when no task was performed. To conclude, fractal-based abstract environments show potential to be used for restoration purposes, but the extent to which having a task influences restorativeness needs further research.

Keywords: Virtual Reality · restoration · abstract fractals

1 Introduction

Stress is the physical and psychological response to demanding circumstances in life that threaten our well-being, and it has been recognized as a major challenge worldwide for workers' health and academic performance [1, 2]. Though generally a part of life, it is directly and/or indirectly linked to mental disorders such as PTSD, acute symptoms of stress/acute stress reaction, depression, and anxiety [3]. Stress-related issues will likely increase as the world population in urban areas increases [3, 4].

J. Abdelnour Nocera et al. (Eds.): INTERACT 2023, LNCS 14145, pp. 3–22, 2023.
https://doi.org/10.1007/978-3-031-42293-5_1

Life in the city is typically tainted with long work hours, mental pressure, and a lack of contact with nature, all associated with reduced levels of happiness and self-satisfaction [5]. Moreover, the characteristic features of urban landscapes (e.g., traffic noise, visual clutter, scarce vegetation) can negatively affect our psychological responses [5, 6]. Au contraire, natural settings (e.g., forests, coasts) have been shown to have very positive psychological effects, reducing stress and anxiety levels and helping to restore or recover the physical and psychological resources lost while adapting to daily demands, a process known as restoration [7, 8].

A few theories have attempted to explain the restorativeness of different environments. The Stress Reduction Theory (SRT) posits that humans subconsciously prefer natural environments as a product of our evolution, feelings of safety and survival that reduce negative thoughts and induce stress recovery [9]. The Attention Restoration Theory (ART) states that urban environments burn out our attention resources for needing constant directed attention, while, the 'soft fascinations' nature provides reduce mental fatigue and stress levels [10]. Other theories associate nature's restorative potential with its mathematical characteristics. The Perceptual Fluency Account (PFA) considers that the fractal characteristics of nature allow us to process it more effectively than human-made non-fractal environments, increasing their healing potential [11]. Fractals are described here as "patterns that repeat at increasingly fine sizes and so create shapes of rich visual complexity" (B. B. Mandelbrot in [12, p. 1]). Studies on fractal art and architecture have shown that they help reduce stress and fatigue and that exposure to abstract non-fractals can have negative effects [12, 13].

Most studies in the field of restorative environments have involved the use of photographs, slides, or videos [14]. Nevertheless, in recent years Virtual Reality (VR) has become a common format for environmental simulations. Some studies using fractals in VR have also shown that they help reduce stress [15, 16]. To the best of our knowledge, no studies have used abstract fractals in a VR setting for restoration purposes. To fill this gap, we conducted two studies to evaluate the restorative potential of abstract fractal landscapes compared to exposure to realistic nature in immersive VR. Both studies explored two base conditions: fractal-abstract and nature-realistic environments. Perceived stress levels and perceived restorativeness of these environments were measured. In the first study, the participants explored the VR environment while collecting crystals. In contrast, in the second study, the participants explored the same environments without crystals to determine to what extent the crystal-collecting task might have influenced the results of our first study. Our results suggested that both environments, with or without a task, significantly reduced perceived stress and showed similar scores of restorativeness.

2 Related Work

2.1 Restorative Features of Nature and Urban Environments

Several studies have shown the restorative potential of nature exposure, even in urban settings [7, 12]. Studies have also suggested features that potentially determine our affective responses to natural environments, such as easily readable spaces with visible pathways, water features, large trees, and sometimes a good balance with man-built elements [6, 7]. Even indoor environments can be restorative as long as there is a greater presence of

trees and forested areas, and indoor views of trees and green landscapes, indoor greenery such as plants and nature walls [5, 6, 12]. The restorative potential of light is also important to remember, as studies suggest that increased sunlight decreases negative affect, tiredness, and psychological distress, and increases cognitive performance and other beneficial effects, as opposed to dark and overcast environments [17].

It has also been suggested that the activities performed in these environments are equally important, especially if the goal is to create a virtual reality nature environment. A revision of the literature suggests that contemplative activities (e.g., mindfulness and interaction with animals) are more restorative than movement-based, cybersickness-inducing activities (e.g., walking) [18]. However, qualitative data from a study on restorative environments in the automotive context suggested that, since urban users are generally disconnected from nature and more accustomed to active relaxing activities (e.g., playing games), these could be more suitable for such users [19].

2.2 Virtual Reality for Restoration

The value of VR nature environments to treat both complicated stress and stress-related clinical mental illnesses like anxiety or depression has also been studied, being considered a viable alternative whenever in-vivo exposure is not possible or not recommended [19–21]. The Virtual Therapeutic Garden reduced depression and stress in a sample of elderly women who had shown no improvement after receiving standard treatment [22]. The Secret Garden, an at-home 10-min exposure to 360º VR video for dealing with the psychological distress associated with the COVID-19 lockdown, resulted in reduced depression and stress symptoms [23]. The Tranquil Cinematic VR, a simulation of natural landscapes through 360º videos deployed on a Head-Mounted Display, led to a significant reduction of subjective stress levels in frontline workers employed by COVID-19 treatment units [24]. Finally, EMMA's World, which uses different natural scenarios to induce and amplify different emotions, helped patients process stressful events in several interventions [25, 26].

2.3 The Restorative Potential of Fractals

Studies have also shown that fractal shapes can provide pleasing experiences due to the effortless attention required [12, 13, 27]. Fractal art and architecture, for instance, have been shown to reduce stress and fatigue compared to chronic exposure to abstract non-fractals, which can have negative effects in the long run [12, 13]. A study devoted to optimizing restoration in a virtual nature environment by emphasizing nature's fractal geometries showed users' preference for a determined dimension of fractals and a trend, with no statistically significant results, for stress recovery after exposure to this optimal fractal dimension [15]. However, up until now, no application of abstract fractal shapes in a VR environment has been found. Animator Julius Horsthuis has created an application in VR as an artwork that shows abstract fractal landscapes in VR as a cinematic experience rather than free exploration. Still, no studies on the effect of this particular experience on people's emotional and psychological well-being have been found [28]. Closer to the use of abstract fractals in VR was the presence of organic abstract art slides

in an immersive virtual environment as a control condition in a study on the restorativeness of natural environments, where it was shown that exposure to these slides also reduced stress [16].

This has led us to question the following: First, would an abstract VR environment based on fractal shapes have restorative effects? We hypothesized that an abstract VR environment using fractal shapes would reduce perceived stress and be considered restorative. Second, does the fact of having a specific activity to perform in the environment influence the results obtained? Based on the literature, we hypothesize that having a task will increase the perceived restorativeness and bring greater levels of perceived stress relief.

3 Study 1. Fractal Abstract Environments for Restoration

This study aims to determine whether a VR environment based on abstract-fractal shapes and geometries reduces perceived stress and is perceived as restorative. It aims to answer our first research question: does an abstract VR environment based on fractal shapes have restorative effects?

3.1 Methods

Experimental Design. This was an independent sample experiment, and the independent variable was the virtual environment the participants were exposed to in two conditions: 1) VR abstract-fractal or 2) VR realistic-nature. There were two dependent variables: perceived levels of stress and perceived restorativeness.

Experimental Environments. The environments have been developed using Unity 3D and were deployed in a high-end Head-Mounted Display (HMD), the Oculus Quest 2. The abstract-fractal setting had an irregular terrain similar to clouds, with abstract shapes and particle systems with fractal characteristics (Fig. 1). The realistic-nature setting depicted a forest-like environment, with spacious paths and areas with trees, bushes, and irregular terrain (Fig. 2). As sound and light have proven to influence stress reduction and perceived restorativeness, both environments had the same daytime cloudless sky and no background music or sound. Despite navigation not being the focus of this study, both environments were characterized by interconnected paths distributed in about 4 Km^2 of virtual terrain, and had some 'built' elements that could work as landmarks (Fig. 1a, 1b and 1c; and 2a and 2b), and their high ground was made non-teleportable to make them as realistic as possible and to avoid reaching its limits. The environments' paths were teleportation areas that the participant used to move around with a pointer (Fig. 1c and 2c), and magic interaction was used (a virtual pointer) to grab objects (Fig. 2d). Some interactable objects were included in both scenes, but to a limited extent (Fig. 1e and 2e). Both environments had crystals instantiated at random points of the terrain (Fig. 1d and 2d), and both groups were assigned to collect these crystals while exploring the environment.

Measures. A demographics questionnaire was used to obtain information about the participant's age, gender, whether they consider themselves a city or country person,

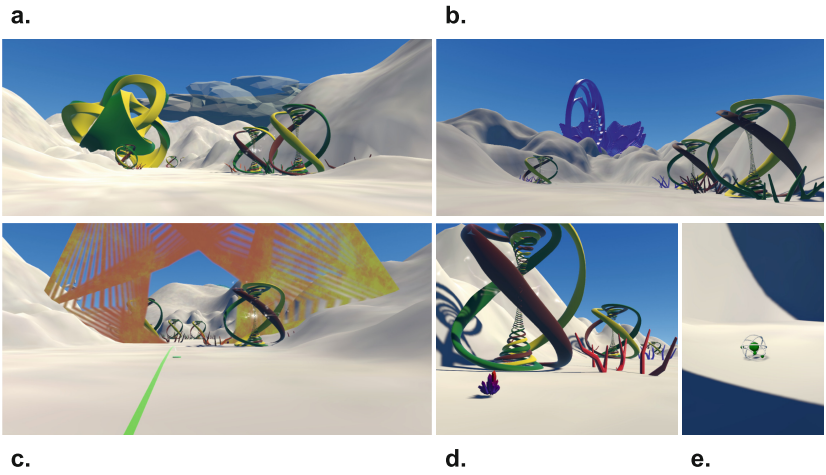

Fig. 1. Fractal-Abstract virtual environment.

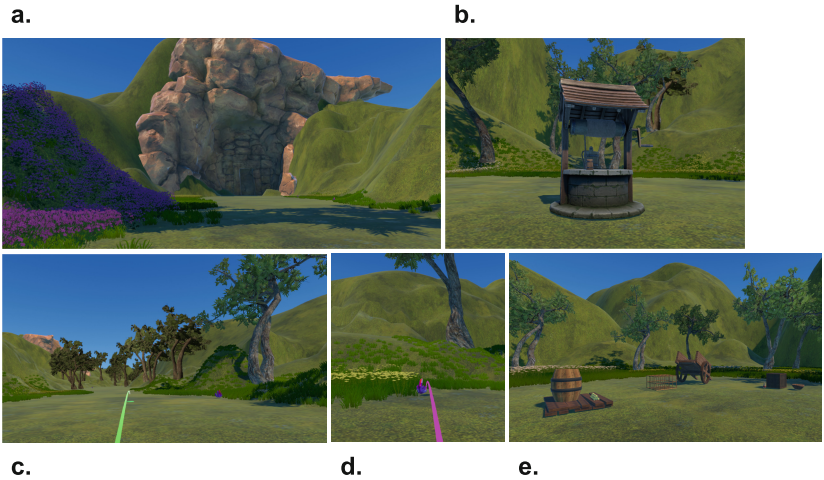

Fig. 2. Nature-Realistic virtual environment.

previous experience with VR using HMDs, and previous video gameplay experience. This was to keep track of possible confounding variables such as their place identity ('dimensions of self that define the individual's personal identity in relation to the physical environment' (Proshansky, 1978, as cited in [29]) and gaming influence.

The Stress Numerical Rating Scale-11 (SNRS-11) was used before and after the experiment to measure stress levels. This test consists of numbers equally spaced across the page from 0 to 10, asking the participants, "On a scale of 0 to 10, with 0 being no stress and 10 being the worst stress possible, what number best describes your level of stress right now?", with participants circling the number that corresponds to their current level of stress [30]. Despite the existence of other more popular and validated subjective

stress scales, such as the Perceived Stress Scale (PSS) [31], these are lengthy and assess past stress to estimate current stress, making them not only prone to retrospective bias but also not perfectly suitable for measuring context-dependent stress [30]. The SNRS-11 has shown moderate to strong construct validity and moderate concurrent validity and has shown to be a promising measure for the efficient assessment of current stress.

The extent to which the participants perceived these environments as restorative was measured with the Perceived Restorativeness Scale (PRS) after the experiment. This self-response instrument comprises 26 items that evaluate the four restoration factors proposed by the Attention Restoration Theory (ART): Being away, Fascination, Extent, and Compatibility [10]. It uses a 7-point Likert scale (0: Not at all - 6: Completely) with a maximum possible score of 156 points. It has been frequently used for evaluating restorativeness levels of places and has been reported to have substantial validity and sensitivity to differences between different sites [32].

A section of open questions was added to collect qualitative data on the most and least preferred features of these two environments; it is composed of two questions: What features of this environment did you prefer the most? and What features of this environment did you prefer the least?

Sample. In this study, the inclusion criteria included being over 18 years old and fluent or having intermediate knowledge of English. A convenience sample comprising 21 higher-education students and academic workers participated. However, data from 2 participants in the Fractal-Abstract group were not considered for analysis as technical issues occurred between the first SNRS-11 and exposure to the virtual environment. The first 20 participants were randomly allocated to the two groups using Random.org (https://www.random.org/). Since the invalid results from two participants belonging to the fractal-based group caused an imbalance in the number of participants per group (10 in the nature-based group and 8 in the fractal-based group), the last volunteer participant was allocated to the fractal-based group. They were finally distributed into two groups: 9 (47.4%) in the Fractal-Abstract group and 10 (52.6%) in the Nature-Realistic group.

Experimental Procedure. The experiment took place at the ARDITI facilities, Tecnopolo, Funchal-Madeira. The participants were invited to participate face-to-face by the main researcher and by email. Before the experiment started, the participants were told that the study was about restorative environments: landscapes that increase positive affect and reduce mental fatigue. They were informed about every step and task of the study, were warned about the possibility of dizziness and eyesores immediately after exposure, and were reminded that, as volunteers, they could quit the experiment at any moment. After clarifying any doubts, they signed an Informed Consent. They then completed the demographics questionnaire and did the stress-inducing writing task immediately after. For this task, the participants were asked to recall their most stressful situation within the last six months; whenever they failed to recall such event within the specified timeframe, this was extended to the most recent they could remember. They were informed they had 5 min to write while listening to audio in their headphones (the type of sounds was not specified) and that they could take home or dispose of this text. The headphones would play loud construction site sounds while they wrote. After this, the participants completed the SNRS-11. Once complete, the participants put on the HMD already set up for a stationary area and practiced moving and interacting with the

environment using the handheld controllers. When participants felt comfortable using the technology, they were given 10 min to explore the environment and collect the crystals they could find to complete the experimental condition. Once the virtual exploration was complete, the participants filled in the SNRS-11 and the PRS. Immediately after, the participants were exposed to a funny video and were offered chocolate to counteract any possible negative effects of the experience. In the end, we debriefed the participants on the ultimate goal of the study and took notes of their feedback.

Statistical Analyses. Because of the ordinal nature of the data, nonparametric tests were used. Specifically, we used the Wilcoxon match-paired signed-rank test to examine differences in perceived stress before and after exposure to the virtual environment within each group; and the Mann-Whitney U test for between-group comparisons. The threshold for statistical significance was set at 5% ($\alpha = 0.05$). The analyses were conducted in SPSS, version 28.0 [33]. Post-hoc power analyses were carried out using the G*Power software, version 3.1.9.7 [34].

3.2 Results

Demographic Data. The final sample comprised 19 people aged between 20 and 52 years (63.2%, n = 12 male). The participants were distributed evenly in terms of age, with the Fractal-Abstract group having an average age of 31 (SD = 8.0) and the Nature-Realistic group having an average of 30.1 (SD = 8.5). However, females were underrepresented, with most in both groups being men (55.6%, n = 5 of the Fractal-Abstract group and 70.0%, n = 7 of the Nature-Realistic group). Regarding place identity, 66.7% (n = 6) of participants in the Fractal-Abstract group considered themselves country people and 60.0% (n = 6) in the Nature-Realistic one identified themselves as city people. All participants (100%, n = 19) had experience playing video games. Most participants in both groups (77.8%, n = 7 Fractal-Abstract; 90%, n = 9 Nature-Realistic) had previous experience with virtual reality using HMDs.

Perceived Stress. The perceived stress levels between groups before exposure to the experimental environments did not differ significantly, with U = 53.500, p = 0.497 (two-tailed test), a small effect size of r = 0.162, and a post hoc achieved power of 0.112. Comparing perceived stress before and after exposure for each group, reported stress levels from the group exposed to the Fractal-Abstract environment were significantly lower after exposure to the virtual environment, T = 0.000, p = 0.0035 (one-tailed test), with a large effect size of r = 0.893, and a post hoc achieved power of 0.997 (Fig. 3). Reported stress levels from the group exposed to the Nature-Realistic environment were also significantly lower after exposure to the virtual environment, T = 1.000, p = 0.008 (one-tailed test), resulting in a large effect size of r = 0.760, and a post hoc achieved power of 0.964 (Fig. 3). Finally, when comparing between groups, the levels of reported stress reduction between those exposed to the Fractal-Abstract environment did not differ significantly from those exposed to the Nature-Realistic environment, U = 44.000, p = 0.484 (one-tailed test), with a small effect size of r = 0.019, and a post hoc achieved power of 0.060 (Table 1).

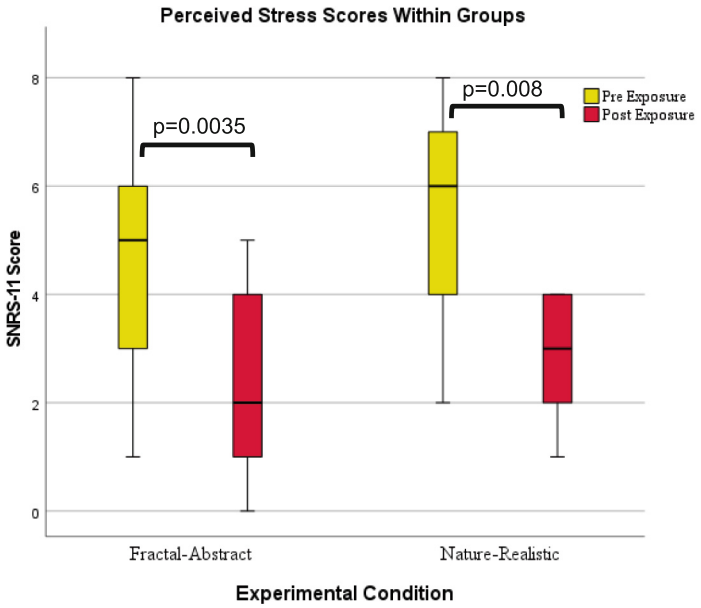

Fig. 3. Boxplot of differences in perceived stress scores before and after exposure to the Nature-Realistic and Fractal-Abstract environments.

Perceived Restorativeness. The levels of perceived restorativeness of those exposed to the Fractal-Abstract environment and the Nature-Realistic environment respectively did not differ significantly, U = 49.500, p = 0.360 (one-tailed test), with a small effect size of r = 0.084, and a post hoc achieved power of 0.057 (Table 1).

Table 1. Comparison of Experimental Environments With-Task.

	Nature-Realistic	Fractal-Abstract	*p-value*
SNRS-11 pre	6 (4)	5 (4)	$p = 0.497^2$, $r = 0.162$
SNRS-11 post	3 (2)	2 (4)	–
p-value	$\mathbf{p = 0.008^1, r = 0.760}$	$\mathbf{p = 0.004^1, r = 0.893}$	
Stress reduction	−3 (5)	−2 (3)	$p = 0.484^2$, $r = 0.019$
PRS	93.5 (44)	95 (31)	$p = 0.360^2$, $r = 0.084$

Central tendency and dispersion presented as Median (IQR).
[1] P-value results of Wilcoxon signed ranks tests.
[2] P-value results of Mann-Whitney tests.

4 Study 2. Virtual Environments with or without Task

In the previous study, we observed that exposure to the fractal-based abstract VR environment significantly reduced perceived stress levels, the same as the nature-based environment, and that it was perceived as restorative. With this second study, we wanted to analyze to what extent the above results might have been influenced by the fact of having a specific task to perform inside the virtual environment. Basically, it is aimed at answering our second research question: does the fact of having a specific activity to perform in the environment influence the results obtained?

4.1 Methods

Experimental Design. As in the first study, this was a between-group experiment. The independent variable was the virtual environment the participants were exposed to, and it had two levels: 1) Fractal-Abstract Without-Task, and 2) Nature-Realistic Without-Task. The same two dependent variables were recorded: perceived levels of stress and perceived restorativeness.

Experimental Environments. The experimental environments were the same as in the previous study, with the difference that no crystals were instantiated at random points. Hence, participants were not instructed to collect anything but rather explore the environment freely. The few other interactable objects were kept in both scenes but remained to a limited extent (Fig. 1e and 2e).

Measures. We used the same measures as in the previous study: a demographics questionnaire to obtain information about the participant's age, gender, whether they consider themselves a city or country person, previous experience with VR using HMDs, and previous video gameplay experience; the SNRS-11 to measure stress levels at the moment [31]; the PRS to measure to what extent the participants perceive these environments as restorative [33]; and an open questions section to collect qualitative data on the most and least preferred features of these two environments.

Experimental Procedure. The experiment occurred at the exact location as the previous study, and they were also randomly allocated to two groups using Random.org (https://www.random.org/). All participants were sent the same invitation as in Study 1 by e-mail. However, we specified we were looking for volunteers to extend the study, so those who had already participated understood they were not applicable. The steps and tasks of the session were the same as in the previous study: they were introduced to the study, completed a demographic questionnaire, did a 5-min stress-inducing writing task, completed the SNRS-11 questionnaire, went through a 10-min environment exploration, completed the SNRS-11 and PRS questionnaires, and watched a funny video. All materials used for the stress-inducing writing task and funny videos were the same as in Study 1.

Sample. Inclusion criteria included being over 18 years old and fluent or having intermediate knowledge of English. A convenience sample of 21 higher-education students and workers was recruited. Data from 1 participant from the Fractal-Abstract Without-Task group were not considered for analysis as technical issues occurred between the first

SNRS-11 and exposure to the VR environment. They were distributed into two groups: 10 (50%) in the Fractal-Abstract Without-Task and 10 (50%) in the Nature-Realistic Without-Task group.

4.2 Results

Demographic Data. The final sample was composed of 20 people aged 22–47 years old (65%, n = 13 female). The participants were distributed evenly in terms of age, with an average age of 29.50 (SD = 8.8) in the Fractal-Abstract Without-Task group and of 29.40 (SD = 5) in the Nature-Realistic Without-Task group. Regarding sex, the participants were evenly distributed (50/50%) in the Nature-Realistic Without-Task group but not in the Fractal-Abstract Without-Task group, where the majority were female (80%, n = 8). Regarding place identity, in both the Fractal-Abstract Without-Task and the Nature-Realistic Without-Task group, 70% (n = 7) of the participants identified themselves as city people. All participants (100%, n = 20) had experience playing video games, most participants in the Nature-Realistic With-out-Task group (80%, n = 8) had previous experience with VR using HMDs, while most of the Fractal-Abstract Without-Task group (60%, n = 6) did not.

Comparison Between Nature-Realistic and Fractal-Abstract Without-Task Conditions

Perceived Stress. The perceived stress levels between groups before exposure to the experimental Without-Task environments did not differ significantly, with U = 66.000, p = 0.247 (two-tailed test), a medium effect size of r = 0.278, and a post hoc achieved power of 0.084. When comparing the perceived stress before and after exposure for each group, we observed that the reported stress levels of the Fractal-Abstract Without-Task group were significantly lower after exposure to the VR environment, T = 0.000, p = 0.0025 (one-tailed test), with a large effect of r = 0.888, and a post hoc achieved power of 1.00. Reported stress levels provided by the Nature-Realistic Without-Task group were significantly lower after exposure to the VR environment, T = 8.000, p = 0.023 (one-tailed test), a large effect size of r = 0.630, and a post hoc achieved power of 0.993 (Fig. 4). When comparing stress reduction after exposure from groups, the levels of reported stress reduction from the Fractal-Abstract Without-Task group did not differ significantly from the Nature-Realistic Without-Task group, U = 66.000, p = 0.123 (one-tailed test), with a medium effect size of r = 0.273, and a post hoc achieved power of 0.492 (Table 2).

Perceived Restorativeness. The levels of perceived restorativeness reported by the participants in the Fractal-Abstract Without-Task and the Nature-Realistic Without-Task group did not differ significantly, U = 30.000, p = 0.0715 (one-tailed test), with a medium effect size of r = 0.338, and a post hoc achieved power of 0.432 (Table 2).

Comparison Between Nature-Realistic With-Task and Without-Task conditions

Perceived Stress. The perceived stress levels before exposure to the experimental environments between the Nature-Realistic With-Task group (Mdn = 6, IQR = 4) and the

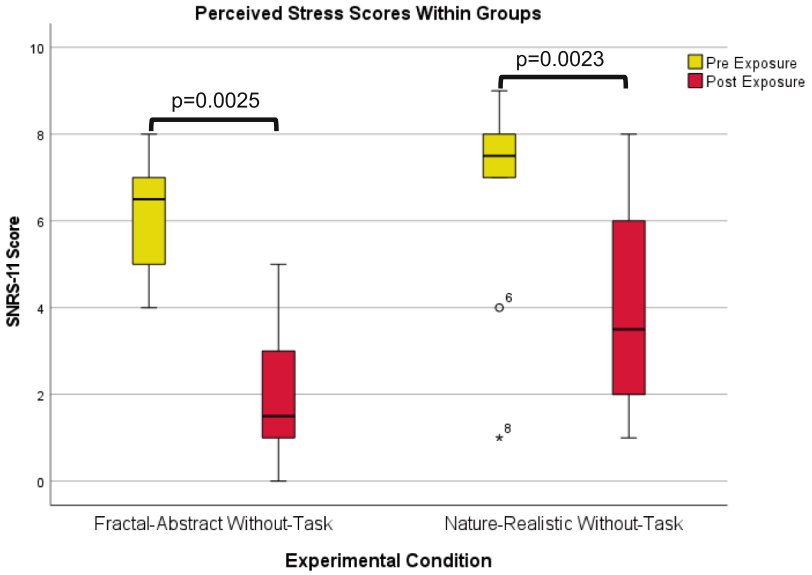

Fig. 4. Boxplot of differences in perceived stress scores before and after exposure to the Nature-Realistic and Fractal-Abstract Without-Task environments.

Table 2. Comparison of Experimental Environments Without-Task.

	Nature-Realistic	Fractal-Abstract	*p-value*
SNRS-11 pre	7.5 (2)	6.5 (2)	$p = 0.247^2$, $r = 0.278$
SNRS-11 post	3.5 (4)	1.5 (3)	–
p-value	$\mathbf{p = 0.023^1, r = 0.630}$	$\mathbf{p = 0.003^1, r = 0.888}$	
Stress reduction	−3 (5)	−5 (5)	$p = 0.123^2$, $r = 0.273$
PRS	92 (39)	114 (32)	$p = 0.072^2$, $r = 0.338$

Central tendency and dispersion presented as Median (IQR).
[1] P-value results of Wilcoxon signed ranks tests.
[2] P-value results of Mann-Whitney tests.

Nature-Realistic Without-Task group (Mdn = 7.5, IQR = 2) did not differ significantly, with U = 74.500, p = 0.063 (two-tailed test), and a medium-to-large effect of r = 0.422, and a post hoc achieved power of 0.335. After exposure, the levels of reported stress reduction by the Nature-Realistic With-Task group (Mdn = −3, IQR = 5) did not differ significantly from the Nature-Realistic Without-Task group (Mdn = −3, IQR = 5), with U = 46.500, p = 0.398 (one-tailed test), with a small effect of r = 0.059, and a post hoc achieved power of 0.073 (Tables 1 and 2).

Perceived Restorativeness. The levels of perceived restorativeness of the Nature-Realistic With-Task (Mdn = 93.5, IQR = 44) and the Nature-Realistic Without-Task

groups (Mdn = 92, IQR = 39) did not differ significantly, U = 48.000, p = 0.456 (one-tailed test), with a small effect size of r = 0.033, and a post hoc achieved power of 0.078 (Tables 1 and 2).

Comparison Fractal-Abstract With-Task and Without-Task Conditions

Perceived Stress. The perceived stress levels before exposure to the experimental environments between the Fractal-Abstract With-Task group (Mdn = 5, IQR = 4) and the Fractal-Abstract Without-Task group (Mdn = 6.50, IQR = 2) did not differ significantly, with U = 64.500, p = 0.113 (two-tailed test), and a medium effect size of r = 0.370, and a post hoc achieved power of 0.607. Regarding stress reduction, the levels of reported stress reduction by the Fractal-Abstract With-Task group (Mdn = −2, IQR = 3) were significantly lower than the Fractal-Abstract Without-Task group Mdn = −5, IQR = 5), U = 24.500, p = 0.048 (one-tailed test), with a medium effect size of r = 0.389, and a post hoc achieved power of 0.764 (Fig. 5) (Tables 1 and 2).

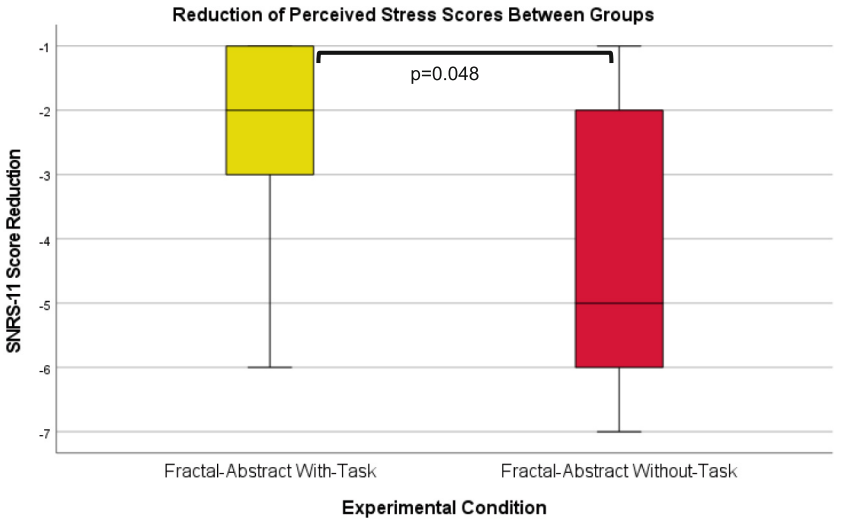

Fig. 5. Boxplot of differences in perceived stress reduction between the Fractal-Abstract With-task and Without-Task conditions.

Perceived Restorativeness. The levels of perceived restorativeness of those exposed to the Fractal-Abstract With-Task environment (Mdn = 95, IQR = 31) were significantly lower than participants in the Fractal-Abstract Without-Task environment (Mdn = 114, IQR = 32), U = 66.500, p = 0.040 (one-tailed test), with a medium-to-large effect size of r = 0.403, and a post hoc achieved power of 0.577 (Fig. 6) (Tables 1 and 2).

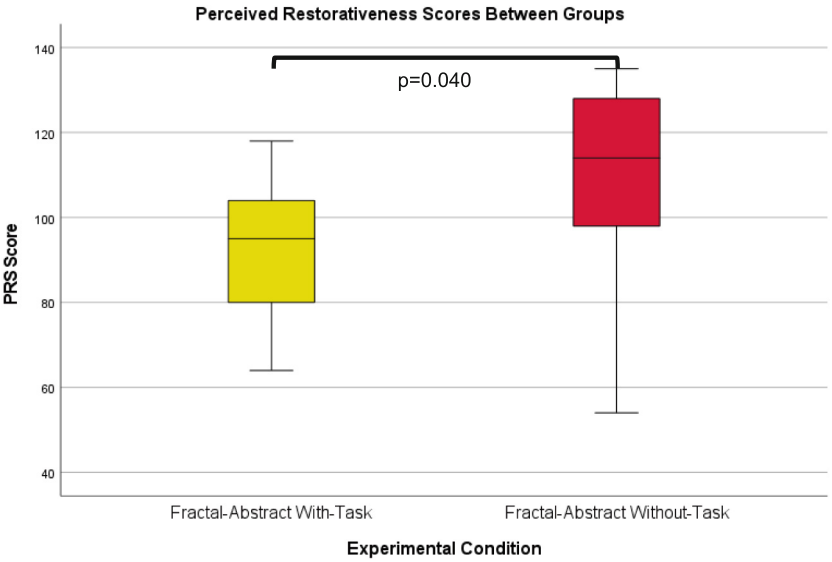

Fig. 6. Boxplot of differences in perceived restorativeness between the Fractal-Abstract With-Task and Without-Task conditions.

5 Discussion

Extensive literature has provided evidence of how beneficial exposure to natural environments is, whether in the real world, through two-dimensional images, or computer-based immersive and non-immersive representations. Exposure to nature has proven to reduce stress and negative affect, increase positive affect, and even reduce symptoms of mental health illnesses like depression. This has translated into several applications using natural landscapes in virtual environments for different purposes, from stress reduction for individuals with limited access to real nature, to supporting treatment for those who have not responded satisfactorily to conventional psychotherapy. However, the number of applications using natural landscapes for restoration purposes also shows the very limited exploration of the restorative potential abstract virtual environments may have. Considering this, we wished to contribute to the literature aimed at designing restorative virtual environments by comparing an abstract world of fractal geometries with a more traditional natural realistic landscape in terms of their potential to reduce stress and their perceived restorativeness.

5.1 Abstract Fractal Environments for Restoration

In our first study, we hypothesized that a fictional VR environment using fractal shapes would help reduce self-reported stress and be perceived as restorative. Our results show a statistically significant perceived stress reduction after exposure to the Fractal-Abstract environment, which supports our main hypothesis. Regarding their perceived restorativeness, the Fractal-Abstract and the Nature-Realistic environments showed no significant differences. Our results suggest that virtual environments based on abstract fractal

shapes can spark interest and comfort individuals, reducing perceived stress almost as much as virtual nature. Fractal abstract environments stay caught up in terms of perceived restorativeness, being perceived as nearly as restorative as a realistic natural environment.

Our results seem to support that the mathematical features of nature might influence our physio-psychological well-being more than we think. A review on the subject suggested that, despite being widely believed that the "mysterious vitalistic qualities of the natural scenes" [35, p. 16] are the key to restoration (which has resulted in most restorative environments being mostly realistic representations of nature), positive responses to nature are triggered much more by their fractal shapes than by an accurate representation. A study by Valtchanov et al. comparing free exploration in virtual nature against the visualization of slides presenting organic abstract paintings corroborated that exposure to a computer-generated natural environment leads to an increase in positive affect [16]. However, it also showed that exposure to the abstract-art slideshow had similar effects [16].

The question remains about whether exposure to the studied environments would really differ from relaxing by, for instance, simple exposure to a white empty virtual room. Few studies have been devoted to studying the effect of exposure to an empty environment. However, a study by Browning et al. compared 6 min of sitting and 6 min of walking in a real outdoor natural location, a VR 360ª video captured at the same location, and a control condition where the participants were indoors and instructed to sit in front of a blank white wall [36]. Their main results corroborated that Virtual and outdoor nature led to higher levels of positive affect when compared to the control condition, even though the control condition led to small reductions both in negative and positive affect [36]. Considering this, it is possible that a comparison between our experimental environments and an empty white virtual space would have resulted in the Nature-Realistic and Fractal-Abstract landscapes performing best.

5.2 The Weight of a Task in Virtual Reality-Based Restoration

In our second study, we compared the same opposite environments used in our first study (Fractal-Abstract and Nature-Realistic), but this time without any task to perform. When comparing both environments in the absence of a task, the results were similar to those obtained when the environments had a task: both the Fractal-Abstract and Nature-Realistic Without-Task conditions showed significant reductions of perceived stress when comparing data before and after exposure, and the difference between these two conditions was not significant. Nevertheless, it was still possible that exposure to one environment with a task could be more restorative than exploring the same environment without a task.

To understand if having a specific task to perform influenced the perceived stress reduction and their restorativeness, we compared both environments used in Study 1, where the user had a task to perform (here referred to as With-Task conditions) with their task-less counterparts from Study 2 (here referred to as Without-Task conditions). We hypothesized that having a task would increase the perceived restorativeness and bring greater levels of perceived stress relief. However, our results were unexpected. On the one hand, the Nature-Realistic environment did not obtain significant differences

when comparing the With-Task and Without-Task conditions regarding perceived stress reduction or restorativeness. On the other hand, with the Fractal-Abstract environment, when comparing the With-task and Without-Task conditions, significant differences were obtained in both measures. Regardless, the reductions recorded did not go in the expected direction. Instead, they suggested that the Fractal-Abstract environment was more effective in its Without-Task condition. Overall, there is no evidence to suggest that having the crystal-collecting task heavily influenced the results obtained from Study 1.

It is always possible that different activities result in different outcomes. Some authors have considered contemplative activities, such as meditation, more restorative than those requiring movement (e.g., walking or tennis). In contrast, others suggest that active activities, such as playing a game, are more restorative for users who live in a city environment [18, 19]. In our study, we selected the crystal collection activity as we considered it neutral, neither very active nor passive. Therefore, we cannot reject the possibility that our second hypothesis could have proven correct if the activity performed had been meditation or playing a game.

We could also question how different our results could have been had the participants not moved or done anything at all. A study by Rupp et al. compared the effect of a passive break, a relaxation activity, and a casual video game on affect and stress [37]. It showed that, even though all conditions led to some affective restoration, no improvements in positive affect were visible and cognitive resources were still being depleted while the participants were sitting quietly in their thoughts in the passive break condition [37]. We believe that, even though our participants would have obtained some benefit from being exposed to a natural or fractal-based environment while doing nothing, stress recovery would have been reduced.

5.3 Other Modulating Factors

When analyzing the profile of the participants of our studies, some factors could have modulated the results. The participants' age might have determined to some extent the effect of these environments on their perceived stress. A systematic review and meta-analysis suggested that older samples exposed to natural settings had more positive emotions and less negative emotions than when exposed to urban or built environments, so it might not be farfetched to think that the effect these environments had on the current sample are different from those we could have obtained from a majority of participants in, for instance, their 50s or 70s [38].

Their gender could have also influenced perceived stress reduction. Studies have suggested that males demonstrate more stress recovery when cortisol levels are measured than when self-reported [39, 40], and that women are more likely to create stronger associations between greenery and positive health in comparison [41]. Therefore, stress recovery reported in our studies, especially in groups composed of a majority of male participants, could be lower than what their actual physiological state demonstrates.

Another factor could have been environmental preference. Some studies suggest that even though congruence between preference and the type of environment exposed to does not always result in higher perceived restorativeness, it does have some effect in some cases [29]. For instance, most participants exposed to the Nature-Realistic group in

both studies were city people. One could argue that city people would be more receptive to abstraction or less naturalistic shapes, so we cannot reject the possibility that had this group been exposed to the Fractal-Abstract environment instead, perceived stress reduction and perceived restorative potential levels could have been higher.

Personality is another important factor, as the 'Big Five' personality traits have been associated with tendencies to choose specific coping styles [42, 43]. A study performed with incarcerated men in Poland suggested that extraversion, openness to experience, consciousness and agreeableness were associated with task-oriented coping strategies [43]. In contrast, men high in neuroticism tended to choose emotion-oriented coping strategies. In other words, it is possible that participants with high extraversion benefited more from having a task to perform in the virtual world than those with high neuroticism, who would have most likely benefited more from emotional support instead.

Exposure time could have also influenced perceived stress reduction. Suppakittpaisarn et al. [44] studied the effect of duration of exposure to virtual natural landscapes in stress recovery, and they concluded that 5 min of exposure was more stress-reducing than 1 or 15 min [44]. Therefore, we cannot reject the possibility that, had our participants been exposed to 5 or 15 min in our environments, stress reduction scores would have been lower or greater.

5.4 Practical Implications and Future Work

We believe this research adds further evidence to a corpus showing the potential of using Virtual Reality to promote mental health in a society that is more and more prone to suffering stress-related morbidities. Immersive Virtual Environments cannot fully imitate real exposure to nature and its inherent fractal geometries. However, we believe that the main contribution of this study lies in adding to a small corpus devoted to studying the potential of fractal geometry in virtual reality environments. Even though fractals and biophilic designs have been widely studied in art and architecture, much more exploration is needed within the vast possibilities of Virtual Reality through Head-Mounted Displays or KAVE systems. Our work will hopefully inspire future interactive media designers for well-being to diverge from the highly established realistic nature pattern and explore the possibilities of using abstract and otherworldly landscapes in their proposals.

Our studies provided answers to our main questions. However, it has also generated further questions. Would our results be significantly different if we had used repeated measures? We believe that carrying out similar studies, but this time exposing participants to both types of environments would complement this research well. In these studies, we did not include soundscape because of the strong restorative effect it has been reported to have, and we focused on the visual aspect. However, it would be interesting to see the degree of stress reduction and perceived restorativeness after exposure to these environments while listening to their respective soundscape: nature sounds, relaxing music, others. We were able to see that, in our case, having a collection task did not influence our environments' potential for restoration significantly. However, similar studies comparing experimental environments with highly active against highly passive tasks (e.g., Nature-Realistic playing golf vs. mindfulness exercises) are needed, especially for designing virtual reality environments for mental health purposes.

It has also been argued that people tend to feel more comfortable with fractal images of nature than non-fractal abstract shapes, and that built elements lacking fractals might cause virtual strain and hence negative physiological effects [12, 13]. Previous studies have suggested that Euclidean shapes have low restorative potential and even increase stress [45]. So, would an immersive VR environment that uses non-fractal or Euclidean geometrical shapes to imitate elements of nature have or not restorative potential? After all, one of our experimental environments is fractal-based but not necessarily free of Euclidean geometries. An area of research that also deserves attention is the potential that abstract environments have for increasing the feeling of 'being away' from our world that immersive VR already offers. It would be interesting to study, regardless of being restorative or not, the level of presence and place illusion [46, p. 3551] felt in a realistic VR environment compared to an abstract environment absent of or with minimal references to reality.

5.5 Limitations

Regarding the limitations of our study, our sample size was small (39 participants, split into 4 different groups), so these results are not generalizable. Furthermore, these environments were tested in a sample mostly of young adults, so we cannot be sure that the benefits of abstract fractal environments would apply to older audiences. This study was also limited to self-reporting measuring tools, which can always be subjected to the influence of cognitive and contextual differences. Data obtained would be better compared, complemented, and corroborated by physiological data such as the participant's heart rate. Moreover, we must remember that the PRS has had different versions and modifications in time, is not completely independent from personal and contextual attributes, and is not specially prepared for VR environments. This means our scores may not consider aspects and features exclusive to the VR realm.

6 Conclusions

We can conclude that exposure to both fractal-abstract and natural-realistic environments seems to be effective for stress reduction and restorativeness, regardless of having a task or not. Hence, the fact of having a task might not be a determinant factor of a VR environment's restorative potential. However, it is important to highlight that this does not mean that those users who explored the environments with no tasks assigned would not have preferred or had had a more enjoyable experience if they had been given any activity to perform. A task might not be essential for restoration in a specially-designed environment, but an appropriate task can always improve the experience and make it more meaningful or memorable.

Acknowledgements. This work was supported by the Fundação para a Ciência e Tecnologia through the scholarship UI/BD/151404/2021, the AViR project (EXPL/CCI-INF/0298/2021) and NOVA LINCS (UIDB/04516/2020), and by MACbioIDi2 (INTERREG program MAC2/1.1b/352).

References

1. Leka, S., Cox, T., Griffiths, A.: Work organization & stress: systematic problem approaches for employers, managers and trade union representatives. In: Protecting workers' health series, no. 3. Geneva, Switzerland: World Health Organization (2003). https://apps.who.int/iris/bitstream/handle/10665/42625/9241590475.pdf
2. Teixeira, R.J., Brandão, T., Dores, A.R.: Academic stress, coping, emotion regulation, affect and psychosomatic symptoms in higher education. Curr. Psychol. 1 (2021). https://doi.org/10.1007/s12144-020-01304-z
3. World Health Organization. Guidelines for the Management of Conditions Specifically Related to Stress, pp. 1–273. WHO, Geneva, Geneva (2013)
4. Abdullah, S.S.S., Rambli, D.R.A., Sulaiman, S., Alyan, E., Merienne, F., Diyana, N.: The impact of virtual nature therapy on stress responses: a systematic qualitative review. Forests **12**(12), 1–19 (2021). https://doi.org/10.3390/f12121776
5. Lederbogen, F., et al.: City living and urban upbringing affect neural social stress processing in humans. Nature **474**, 498–501 (2011). https://doi.org/10.1038/nature10190
6. Ulrich, R.S.: Human responses to vegetation and landscapes. Landsc. Urban Plan. **13**, 29–44 (1986). https://doi.org/10.1016/0169-2046(86)90005-8
7. Weinreb, A.R., Rofè, Y.: Mapping feeling: an approach to the study of emotional response to the built environment and landscape. J. Arch. Plan. Res. **30**(2), 127–145 (2013)
8. Simkin, J., Ojala, A., Tyrväinen, L.: Restorative effects of mature and young commercial forests, pristine old-growth forest and urban recreation forest - a field experiment. Urban Forest. Urban Green. **48**, 1–12 (2020). https://doi.org/10.1016/j.ufug.2019.126567
9. Ulrich, R.S., Simons, R.F., Losito, B.D., Fiorito, E., Miles, M.A., Zelson, M.: Stress recovery during exposure to natural and urban environments. J. Environ. Psychol. **11**(3), 201–230 (1991). https://doi.org/10.1016/S0272-4944(05)80184-7
10. Kaplan, S.: The restorative benefits of nature: toward and integrative framework. J. Environ. Psychol. **15**, 169–182 (1995)
11. Joye, Y., van den Berg, A.: Is love for green in our genes? a critical analysis of evolutionary assumptions in restorative environments research. Urban Fores. Urban Green. **10**(4), 261–268 (2011). https://doi.org/10.1016/j.ufug.2011.07.004
12. Taylor, R.P.: The potential of biophilic designs to promote health and performance: a review of experiments and applications. Sustainability **13**(2), 1–25 (2021). https://doi.org/10.3390/su13020823
13. Wise, J.A., Taylor, R.P.: Fractal design strategies for enhancement of knowledge work environments. In: Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting, vol. 46, no. 9, pp. 854–858 (2002). https://doi.org/10.1177/154193120204600905
14. Stone, R., Small, C., Knight, J., Qian, C., Shingari, V.: Virtual natural environments for restoration and rehabilitation in healthcare. In: Ma, M., Jain, L.C., Anderson, P. (eds.) Virtual, Augmented Reality and Serious Games for Healthcare 1. ISRL, vol. 68, pp. 497–521. Springer, Heidelberg (2014). https://doi.org/10.1007/978-3-642-54816-1_24
15. van Almkerk, M., Huisman, G.: Virtual nature environments based on fractal geometry for optimizing restorative effects. In: Proceedings of British HCI 2018, pp. 1–11. BCS Learning and Development Ltd., Belfast, UK (2018). https://doi.org/10.14236/ewic/HCI2018.55
16. Valtchanov, D., Barton, K.R., Ellard, C.: Restorative effects of virtual nature settings. Cyberpsychol. Behav. Soc. Netw. **13**(5), 503–512 (2010). https://doi.org/10.1089=cyber.2009.0308
17. Beute, F., de Kort, Y.A.W.: Let the Sun Shine! measuring explicit and implicit preference for environments differing in naturalness, weather type and brightness. J. Environ. Psychol. **36**, 162–178 (2013). https://doi.org/10.1016/j.jenvp.2013.07.016

18. Nukarinen, T., et al.: Measures and modalities in restorative virtual natural environments: an integrative narrative review. Comput. Hum. Behav. **126**, 1–14 (2022). https://doi.org/10.1016/j.chb.2021.107008
19. Li, J., Ma, Y., Li, P., Butz, A.: A journey through nature: exploring virtual restorative environments as a means to relax in confined spaces. Presented at the Creativity and Cognition (C&C 2021), pp. 1–9. Virtual Event, Italy, Virtual Event, Italy, ACM, New York, NY, USA (2021). https://doi.org/10.1145/3450741.3465248
20. White, M.P., et al.: A prescription for 'nature' - the potential of using virtual nature in therapeutics. Neuropsychiatr. Dis. Treat. **14**, 3001–3013 (2018). https://doi.org/10.2147/NDT.S179038
21. Yu, C.-P., Lee, H.-Y., Luo, X.-Y.: The effect of virtual reality forest and urban environments on physiological and psychological responses. Urban Forestry Urban Green. **35**, 106–114 (2018). https://doi.org/10.1016/j.ufug.2018.08.013
22. Szczepanska-Gieracha, J., Cieslik, B., Serweta, A., Klajs, K.: Virtual therapeutic garden: a promising method supporting the treatment of depressive symptoms in late-life: a randomized pilot study. J. Clin. Med. **10**, 1–13 (2021). https://doi.org/10.3390/jcm10091942
23. Riva, G., et al.: A virtual reality-based self-help intervention for dealing with the psychological distress associated with the COVID-19 lockdown: an effectiveness study with a two-week follow-up. Int. J. Environ. Res. Public Health **18**(8188), 1–19 (2021). https://doi.org/10.3390/ijerph18158188
24. Beverly, E., et al.: A tranquil virtual reality experience to reduce subjective stress among COVID-19 frontline healthcare workers. PLoS ONE **17**(2), 1–13 (2022). https://doi.org/10.1371/journal.pone.0262703
25. Guillén, V., Baños, R.M., Botella, C.: Users' opinion about a virtual reality system as an adjunct to psychological treatment for stress-related disorders: a quantitative and qualitative mixed-methods study. Front. Psychol. **9** (2018). https://doi.org/10.3389/fpsyg.2018.01038
26. Botella, C., Osma, J., Palacios, A.G., Guillén, V., Baños, R.M.: Treatment of complicated grief using virtual reality: a case report. Death Stud. **32**(7), 674–692 (2008). https://doi.org/10.1080/07481180802231319
27. Juliani, A.W., Bies, A.J., Boydston, C.R., Taylor, R.P., Sereno, M.E.: Navigating performance in virtual environments varies with fractal dimension of landscape. J. Environ. Psychol. **47**, 155–165 (2016). https://doi.org/10.1016/j.jenvp.2016.05.011
28. Hayden, S.: Pioneering Fractal Artist Julius Horsthuis is Returning to VR with a New Album Soon. Road to VR (2022). https://www.roadtovr.com/quest-fractal-art-recombination-horsthuis/. Accessed 20 Aug 2022
29. Wilkie, S., Stavridou, A.: Influence of environmental preference and environment type congruence on judgments of restoration potential. Urban Forest. Urban Green. **12**(2), 163–170 (2013). https://doi.org/10.1016/j.ufug.2013.01.004
30. Karvounides, D., Simpson, P.M., Davies, H.H., Khan, K.A., Weisman, S.J., Hainsworth, K.R.: Three studies supporting the initial validation of the stress numerical rating Scale-11 (Stress NRS-11): a single item measure of momentary stress for adolescents and adults. Pediatric Dimen. **1**(4), 105–109 (2016). https://doi.org/10.15761/PD.1000124
31. Cohen, S., Kamarck, T., Merlmelstein, R.: A global measure of perceived stress. J. Health Soc. Behav. **24**(4), 385–396 (1983). https://doi.org/10.2307/2136404
32. Hartig, T., Korpela, K., Evans, G.W., Gärling, T.: A measure of restorative quality in environments. SHPR **14**(4), 175–194 (1997). https://doi.org/10.1080/02815739708730435
33. IBM Corp. IBM SPSS Statistics for Windows. IBM Corp, Armonk, NY (2021)
34. Faul, F.: G*Power. Universität Düsseldorf, Düsseldorf, Germany (2020)
35. Salingaros, N.A.: A 26. Fractal Art and Architecture Reduce Physiological Stress. Unified Architectural Theory: Form, Language, Complexity: A Companion to Christopher Alexander's The Phenomenon of Life-The Nature of Order, vol. Book 1, pp. 11–28 (2017)

36. Browning, M.H.E., Mimnaugh, K.J., van Riper, C.J., Laurent, H.K., LaValle, S.M.: Can simulated nature support mental health? comparing short, single-doses of 360-degree nature videos in virtual reality with the outdoors. Front. Psychol. **10**, 1–14 (2020). https://doi.org/10.3389/fpsyg.2019.02667
37. Rupp, M.A., Sweetman, R., Sosa, A.E., Smither, J.A., McConnell, D.S.: Searching for affective and cognitive restoration: examining the restorative effects of casual video game play. Hum. Factor J. Hum. Fact. Ergon. Soc. **59**(1), 1–12 (2017). https://doi.org/10.1177/0018720817715360
38. Yao, W., Chen, F., Wang, S., Zhang, X.: Impact of exposure to natural and built environments on positive and negative affect: a systematic review. Front. Public Health **9**, 1–13 (2021). https://doi.org/10.3389/fpubh.2021.758457
39. Jiang, B., Li, D., Larsen, L., Sullivan, W.C.: A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. Environ. Behav. (2014). https://doi.org/10.1177/0013916514552321
40. Jiang, B., Chang, C.-Y., Sullivan, W.C.: A dose of nature: tree cover, stress reduction, and gender differences. Landsc. Urban Plan. **132**, 26–36 (2014). https://doi.org/10.1016/j.landurbplan.2014.08.005
41. Sillman, D., Rigolon, A., Browning, m.H.E.M., (Violet) Yoon, H., McAnirlin, O.: Do sex and gender modify the association between green space and physical health? a systematic review. Environ. Res. **209**, 112869 1–13 (2022). https://doi.org/10.1016/j.envres.2022.112869
42. Baumgartner, J.N., Schneider, T.R.: Personality and stress. In: Zeigler-Hill, V., Shackelford, T.K. (eds.) Encyclopedia of Personality and Individual Differences, Springer Reference, pp. 3699–3704. Springer, Switzerland (2020). https://doi.org/10.1007/978-3-319-24612-3
43. Leszco, M., Iwanski, R., Jarzebinska, A.: the relationship between personality traits and coping styles among first-time and recurrent prisoners in Poland. Front. Psychol. **10**(2969), 1–8 (2020). https://doi.org/10.3389/fpsyg.2019.02969
44. Suppakittpalsarn, P., et al.: Duration of virtual exposure to built and natural landscapes impact self-reported stress recovery: evidence from three countries. Landscape Ecol. Eng. **19**, 95–105 (2023). https://doi.org/10.1007/s11355-022-00523-9
45. Trombin, R.: Working with Fractals: A Resource for Practitioners of Biophilic Design. Terrapin Bright Green, New York (2020). https://www.terrapinbrightgreen.com/report/biophilia-fractals-toolkit/
46. Slater, M.: Place illusion and plausibility can lead to realistic behavior in immersive virtual environments. Phil. Trans. R. Soci. B **364**(1535), 3549–3557 (2009). https://doi.org/10.1098/rstb.2009.0138