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Mattila, Osmo

2020-06

Mattila , O , Korhonen , A , Pöyry , E , Hauru , K , Holopainen , J & Parvinen , P 2020 , ' Restoration in a Virtual Reality Forest Environment ' , Computers in Human Behavior , vol. 107 , no. June , 106295 . https://doi.org/10.1016/j.chb.2020.106295

http://hdl.handle.net/10138/344187
https://doi.org/10.1016/j.chb.2020.106295

Restoration in a Virtual Reality Forest Environment

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Acknowledgments

We thank the Metsämiesten Säätiö Foundation and The Royal Swedish Academy of Agriculture and Forestry (Tandem Forest Values - Value Connect) for funding and anonymous reviewers who provided invaluable advice on how to improve the manuscript.

Abstract

The focus in this research was on the effects of restorative experiences in an immersive virtual reality (VR) forest environment. For five minutes one hundred participants used a VR application depicting a forest via a head-mounted display and headphones. The extent of the restorative effect on the participants was measured in terms of perceived restorative outcomes, vitality, and mood before and after using the VR application. After finding out that using the VR application improved the perceived restoration outcomes, vitality and mood of the participants, the perceived restoration of the VR environment was compared with experiences in physical forests. According to the results, the VR environment was generally perceived as restorative as the physical forest environments, and more fascinating and coherent. The results imply that VR technology could have an effective restorative function during a school or work day when there is no access to highly restorative natural environments. Knowledge about the restorative qualities of physical and virtual natural environments could be applied to develop both the virtual and physical environments that are currently available and where people have access to.

Keywords: Restoration; Virtual reality; Forest; Immersion

1. Introduction and theoretical framework

The high workload and time pressure that characterize many jobs cause depleted attention, stressful short-term experiences (Ilies et al., 2007), and deterioration in well-being over time (de Lange, Taris, Kompier, Houtman, & Bongers, 2003). Similarly, the mental health of students is an increasing concern worldwide, and stress is deemed to be one of the underlying reasons (Bayram & Bilgel, 2008). The harmful effects of stress are likely to cause continuous hindrance unless there are restoration opportunities during the working day (Lee, Sargent, Williams & Williams, 2018; Trougakos & Hideg, 2009).

According to Csikszentmihalyi (2014, p. 3), attention is a process that regulates the admission of various contents into consciousness. Thus, keeping up directed attention is effortful and draining through constant use (Kahneman, 1973). Restoration refers to recovery from both psychological and physiological stress, which can be caused by attentional fatigue (Ulrich, 1983; Ulrich et al., 1991). Voluntary, directed attention requires effort and drains in use but is necessary for maintaining concentration on a task (Kaplan, 1995). Involuntary attention, in turn, is captured effortlessly, and, when engaged, it allows voluntary attention to recover (Kaplan & Kaplan, 1983).

In a literature review by Tzoulas et al., (2007), the benefits of natural environments not only provide various physical and psychological benefits for individuals but also benefit communities more broadly. Environments such as parks and forests provide restorative experiences that improve psychological and physiological health (e.g., Tyrväinen et al., 2014), promote recovery from attentional fatigue (Hartig, Evans, Jamner, Davis, & Gärling, 2003), reduce psychophysiological stress and enhance positive emotional states (Kaplan, 1995; Kaplan & Kaplan, 1989; Ulrich et al., 1991).

Virtual reality (VR) technology can simulate highly realistic environments (Bohil, Alicea & Biocca, 2011). The latest generation of devices offers more pleasant, vivid and immersive experiences, bringing a sense of presence in the virtual world (Waterworth, Waterworth, Riva & Mantovani, 2015). Some scholars propose VR as a mean to enjoy the benefits of restorative environments, and the initial results on people's recovery Annerstedt et al., 2013; Yu, Lee & Luo, 2018) and creativity (Baños et al., 2013; Palanica, Lyons, Cooper, Lee & Fossat, 2019) are promising. The more holistic natures of physical forest experience, including smelling the trees, feeling the wind, touching the ground, and so on, certainly provide features that are not included in the current versions of mainstream commercial VR-devices. However, modelled restorative VR environments have some benefits over the natural ones due to their availability and modifiability, given that the quality of the virtual experience is high enough for restoration.

This paper aimed at validating the restorative effects of a forest environment in VR. This was, firstly, done by measuring the restorative effects of a break that was taken in a VR forest. The previous literature of the restorative effects of breaks in nature was used to qualify the results. Secondly, perceived restoration of the VR forest environment and three physical forest environments were compared to understand in more detail the possible differences in how physical and virtual environments are perceived. The knowledge of the restorative benefits of a simulated natural environment helps designing environments that simultaneously utilize the strengths of the new technology and are based on the extensive knowledge available about restorative natural environments.

1.1 Restoration

Stress Recovery Theory (Ulrich, 1983; Ulrich et al., 1991) and Attention Restoration Theory (ART; Kaplan & Kaplan, 1989; Kaplan, 1995; Kaplan & Berman, 2010) have been dominant approaches to explain restorative experiences. The former has its roots in the evolutionary psychology of human species (Ulrich, 1983; Ulrich et al., 1991) and immediate affective responses to nature. The latter focuses on cognitive benefits that are gained from interaction with natural environments (Kaplan & Berman, 2010; Kaplan & Kaplan, 1989; Kaplan, 1995) with an emphasis on fatiguing directed attention. ART was selected as the theoretical framework of the study as it details the characteristics of restorative natural environments. Restoration is manifested through states such as relaxation, calmness and focus (Hartig et al., 1997; Staats,

Kieviet & Hartig, 2003), as well as through vitality and positive mood states (Bowler, Buyung-Ali, Knight & Pullin, 2010; Hartig, Mang & Evans, 1991; Ryan & Frederick, 1997; Ryan et al., 2010). Environmental psychologists have developed multiple scales to evaluate these restorative outcomes in the context of natural environments, and ART is used to explain these positive changes (Kaplan & Kaplan, 1989). Studies based on ART maintain that restoration happens through restorative experiences in an interaction between a person and the environment. These are comprised four perceived dimensions: coherence, being away, compatibility and fascination (Hartig et al. 1997; Hauru, Lehvävirta, Korpela & Kotze, 2012; Laumann, Gärling & Stormark, 2001).

1.2 Immersion and presence in virtual reality

Immersion and presence are key concepts in VR research. Immersion could be defined as the extent to which computer displays are capable of delivering an inclusive, extensive, all-round and vivid illusion of reality (Slater & Wilbur, 1997). Having compared screen sizes showing natural environments, de Kort, Meijnders, Sponselee and IJsselsteijn (2006) argue that that immersion enhances the restorative potential of a mediated environment. Palanica et al. (2019) also claim that three-dimensional VR technology depicting a natural environment allows a higher level of creative thinking than two-dimensional videos because of its higher immersive capability. Presence, on the other hand, is related to the subjective feeling or the emotion of 'being there' when using an IT system (Biocca & Levy, 1995; Lombard & Ditton, 1997; Slater & Wilbur, 1997). It is assumed that a high sense of presence in a VR system improves task performance, for example, because it helps the user focus and be more involved in the task (Riecke & Schulte-Pelkum, 2015; Smyth, Benyon, McCall, O'Neill & Caroll, 2015).

This research contributes to the understanding of attention restoration and the ability of a VR application to generate restoration by utilizing the visual, spatial and audio characteristics of a forest environment. To find out how restoration states change when people take a break to a VR forest environment, we measured changes in VR users' vitality, mood and restoration outcomes before and after the break. We were also interested in the restoration effects of a VR forest environment compared with various physical forest environments, and therefore we investigated how perceived restorativeness (coherence, being away, compatibility and fascination) differs between a VR forest environment and three kinds of physical (real) natural environments. Next, two research hypotheses are presented.

1.3 Hypotheses

There is plenty of research that shows that spending time in natural versus urban environments enhances restoration. For example, subjective vitality – the positive feeling of aliveness and energy (Ryan & Frederick, 1997, p. 529) – was known to increase as a result of visits to parks and forests (Tyrväinen et al., 2014). Natural environments also strengthen positive and weaken negative mood states (Bowler et al., 2010; Hartig et al., 1991; Tyrväinen et al., 2014). Restoration outcome scale (ROS) reflects relaxation and calmness, attention restoration and clearing one's thoughts (Korpela et al., 2008), and research shows that these outcomes can be gained by a visit to a natural environment (Korpela et al., 2008; Tyrväinen et al., 2014).

Some studies have been able to produce similar results by applying the elements of natural environments to simulated virtual worlds. In a pilot study, Annerstedt et al. (2013) found that using a VR forest application that included the sounds of nature facilitated stress recovery. Yu et al. (2018) found that the level of negative emotions, such as confusion, tension and depression, decreased after the use of a VR application that depicted a natural environment. They also found that peaceful natural environments were more restorative than urban surroundings when being watched as 360-degree videos through VR headsets. Similarly, Baños et al. (2013) found that the general mood and zest for life among cancer patients increased following the use of a VR application depicting urban parks, and there were also signs of decreased sadness. It seems therefore reasonable to believe that a VR forest could have positive effects on restoration. By measuring restoration outcomes with subjective vitality, positive and negative mood states and restoration outcome scale, we hypothesize that:

H1: Positive (negative) restoration outcomes increase (decrease) after taking a break in a VR forest.

Coherence could be described as a person's understanding of a place as a 'whole world in itself' (Hauru et al., 2012; Ivarsson & Hagerhall, 2008). According to Hauru et al. (2012, p. 362), it is 'a perception of the environment being ordered, related and understandable so that it feels possible to step in there and get to know the place'. Although coherent environments tend to be described in physical terms (Hartig, Korpela, Evans, & Gärling, 1997), virtual environments could also create a perception of coherence. VR used with a head-mounted display allows a high level of control of the visual view and of the auditory environment, making it possible to create a coherent experience. On the other hand, the more holistic nature of a physical forest experience is likely to strengthen the sense of coherence. However, we follow the approach that underlines a person's understanding of the coherence of a place (Hauru et al. 2012; Ivarsson & Hagerhall, 2008), which does not require physicality. Thus, virtual environments may even be perceived as more coherent than physical environments because they can be designed not to have any incoherent elements.

Being away refers to the need to get away from everyday life to another environment or situation (Kaplan, 1995). Such a feeling may simply emerge as a result of the physical translocation from one place to another, but it could also occur on the mental level in terms of psychologically escaping one's everyday thoughts (Laumann et al., 2001). Putting on a VR headset facilitates the rapid shift to a new environment (Smyth et

al., 2015) and simultaneously blocks visual and audio connections to one's physical surroundings. Putting on a VR headset brings about a rapid change to the perceptual environment, and the transition is immediate rather than gradual. The high and fast contrast may create a stronger feeling of being away than physical environments.

Compatibility could be referred to the feeling of belonging to a place (Hauru et al., 2012) or congruence with the observer's preferences (Kaplan, 1983). The theme of the virtual world that was used was a natural environment that, according to Kaplan, (1995) tends to be high in compatibility, even among people who are more familiar with urban environments. If the virtual experience is strong enough, awareness of using a technology and simultaneously feeling like being present in the simulated environment may exist together making the experience compatible.

Fascination could be described as an attribute of an environment that captures involuntary attention and allows neural inhibitory mechanisms to recover (Kaplan, 1995). It may be experienced in natural environments as aesthetic pleasure or as peaceful feelings (Herzog, Black, Fountaine, & Knotts, 1997; Herzog, Maguire, & Nebel 2003), and it is required to direct an observer's attention automatically, without effort (Hauru et al., 2012). In typical VR devices, head-mounted displays and earphones disconnect the user from the physical reality. Furthermore, a VR experience can engender a strong sense of immersion, aesthetic pleasure and peaceful feelings (Gromala, Tong, Choo, Karamnejad & Shaw, 2015), all of which relate to so-called soft fascination (Herzog et al., 1997; Herzog et al. 2003). It could also be assumed that VR technology, which is still relatively new and unfamiliar to many, increases fascination with the environment.

By measuring the restorativeness of an environment in terms of perceived coherence, being away, compatibility and fascination we hypothesize that:

H2: A VR forest is perceived as restorative as a physical forest.

2. Material and methods

2.1 Participants

One hundred people participated in the study by using a VR forest application. The data were collected in Helsinki, Finland. The participants were randomly sampled at the test site and they did not have previous information about the test. All the tests were conducted during office hours between 9 am and 4 pm. Age was coded into two categories: younger than 35-years-old (67 percent) and 35 and older (33 percent) to enable comparisons with the data collected by Hauru et al. (2012). Females comprised 44 percent of the participants, 54 percent were male and two percent other. In terms of occupation, 61 percent were students,

37 percent were working and two percent were doing something else. Less than half of the participants (44 percent) used VR technology for the first time, whereas 56 percent had used it previously.

Complementing the information obtained from the VR application users, we used data collected by Hauru et al. (2012) to compare perceived restorativeness of the VR forest environment with the perceived restorativeness of physical forests in Helsinki, Finland. Hauru et al. (2012) studied three kinds of urban forest environments: 1) a forest environment (a closed forest view without any visual connection to the urban elements), 2) a semi-urban forest environment (at the edge of a forest where the view of urban elements was semi-closed by trees and vegetation), and 3) an urban forest environment (at the edge of a forest where the view of urban elements was open and unobstructed). These environments represent different qualities of restorative natural environment that people in urban areas have an easy access to. The data collected by Hauru et al. (2012) consisted of 132 surveys completed by 66 respondents. In this data, 37 percent were younger than 35 years and 64 percent were 35 or older. Females comprised 59 percent of the participants and males 41 percent. Thus, the Hauru et al. (2012) sample consisted of older people and of more females than the sample of the VR study.

2.2 Study design

The VR application was designed to be as detailed as possible, and it used the same plant species that are common in the area where the research took place. It depicted a 'closed view' of a forest, meaning that there were not any urban elements at sight (Hauru et al., 2012). The modeled objects moved slightly replicating wind, and small details such as butterflies made the environment more vivid. The application was developed by 3D-modelling professionals using a game engine (Unreal Engine), and the environment was experienced via a head-mounted display (HTC Vive) and with headphones. Reflecting the work of Aletta, Oberman and Kang (2018), a soundscape consisting of a mix of ambient sounds such as wind and birds singing was also part of the experience. The setup consisted of an area of six square meters that enabled movement physically and simultaneously in the modeled VR environment. That usage area was surrounded by a forest environment that stretched as far as the user was able to see (Figure 1).

Figure 1. Screenshot of the virtual reality forest

The research setup was pre-tested multiple times by asking random passersby to test the setup. Two of the authors observed the pre-tests and discussed the experience with the users after having tested the application. The first batch of users tested the setup standing, which was noticed to result in exploring the surroundings instead of relaxing. The second batch of users was asked to sit on an office chair while using the application without any time limit. Based on the observations, this setup helped the users to calm down. Most usually, after four to six minutes, the users started to activate and get restless. Some for example started to try if there was anything to further to do or find in the virtual environment. Based on the pre-tests, a treatment of five minutes of using the VR application was selected because the aim of the study was to allow the participants to relax.

The participants were tested individually in a calm office space. Before the VR experience, they answered survey questions concerning their background and their current vitality, mood and restoration states. They were then asked to sit on an office chair and a researcher helped them to put on the VR devices. They were told that they could rotate freely in the VR environment, and that the researcher would tap them on the shoulder when the test was over. After the test, the respondents again answered questions about their vitality, mood and restoration state, as well as about the perceived restorativeness of the VR forest environment. The VR study was performed in accordance with the university code of conduct for empirical research. All participants filled a form of consent for the study.

2.3 Measures

Apart from the background questions (gender, age, occupation, and VR usage experience), all the survey items were measured on a Likert-type seven-point scale (‘How well do the following statements describe your feelings right now?’, 1 = strongly disagree, 7 = strongly agree). The following scales were used to

evaluate the outcomes of the VR experience by presenting them to the participants beforehand and afterwards: Ryan and Frederick's (1997) Subjective Vitality Scale (SVS), Watson, Clark and Tellegen's (1988) Positive and Negative Affect Scale (PANAS), and Korpela et al.'s (2008) Restoration Outcome Scale (ROS).

3. Results

The internal consistency of the scales was determined by means of Cronbach's alpha tests, which indicated good validity: Cronbach's alpha for SVS was .92, for PANAS positive .90, for PANAS negative .88, and for ROS .87 before the treatment (Table 1). SVS, PANAS positive, and ROS were positively correlated with each other and PANAS negative was negatively correlated with the other constructs before and after using VR ($p < .01$, Table 2). Multicollinearity was tested by comparing all constructs before using VR. No problems arose as Tolerance varied between .33 and .69 (threshold > .10) and the VIF between 1.48 and 3.06 (threshold < 10) (Hair et al., 1998).

Table 1. Measurement scales for subjective vitality, mood and perceived restoration outcomes

	Before using VR (N = 100)			**After using VR (N = 100)**		
	M	*SD*	*Cronbach α*	*M*	*SD*	*Cronbach α*
Subjective Vitality Scale (SVS) (Ryan & Frederick, 1997)	4.65	1.17	0.92	5.32	0.89	0.87
I feel alive and vital	4.80	1.30		5.55	0.94	
I don't feel very energetic (reversed)	4.56	1.52		5.21	1.44	
I feel so alive I just want to burst	4.75	1.43		5.25	1.02	
I look forward to each new day	5.08	1.30		5.59	1.08	
I feel alert and awake	4.36	1.38		5.29	1.14	
I feel energized	4.36	1.43		4.99	1.18	
Positive Affect Schedule (PANAS) (Watson et al., 1988). I feel…	4.80	1.00	0.90	5.14	0.89	0.90
Enthusiastic	5.00	1.56		4.89	1.53	
Interested	5.53	1.09		5.59	0.95	
Strong	4.70	1.23		5.15	1.13	
Excited	5.02	1.30		5.23	1.14	
Proud	4.28	1.44		4.50	1.53	
Attentive	4.48	1.43		5.07	1.17	
Inspired	4.53	1.49		5.46	1.10	
Determined	4.78	1.34		5.24	1.03	
Alert	4.61	1.35		5.06	1.36	
Active	4.94	1.33		5.20	1.25	
Negative Affect Schedule (PANAS) (Watson et al., 1988). I feel…	2.23	0.96	0.88	1.60	0.64	0.88
Distressed	2.26	1.28		1.59	0.94	
Upset	1.62	1.15		1.34	0.69	
Guilty	2.18	1.61		1.66	1.08	

Scared	1.80	1.21		1.41	0.87	
Hostile	1.62	0.97		1.26	0.58	
Irritable	2.53	1.49		1.58	0.93	
Ashamed	1.90	1.28		1.44	0.91	
Nervous	2.71	1.62		1.88	1.12	
Jittery	3.12	1.59		2.15	1.18	
Afraid	2.72	1.56		1.85	1.10	
Restoration Outcome Scale (ROS) (Korpela et al., 2008)	4.20	1.11	0.87	5.22	0.97	0.88
I feel restored and relaxed	3.84	1.48		5.56	1.10	
I feel calm	4.64	1.38		5.66	1.13	
I have enthusiasm and energy for my everyday routines	4.49	1.36		5.12	1.20	
I feel focused and alert	4.35	1.33		5.07	1.40	
I can forget everyday worries	3.51	1.63		4.65	1.67	
My thoughts are clear	4.48	1.40		5.27	1.12	

*Notes: * Item translations same as in Tyrväinen et al. (2014)*

Table 2. Correlation matrix for subjective vitality, mood and perceived restoration outcomes

Correlations		Before using VR				After using VR			
		SVS	PANAS pos	PANAS neg	ROS	SVS	PANAS pos	PANAS neg	ROS
Before using VR	SVS	1	.78	-.56	.72	.61	.59	-.33	.41
	PANAS pos		1	-.44	.75	.62	.72	-.28	.42
	PANAS neg			1	-.57	-.33	-.27	.73	-.40
	ROS				1	.58	.63	-.41	.60
After using VR	SVS					1	.84	-.39	.71
	PANAS pos						1	-.28	.67
	PANAS neg							1	-.53
	ROS								1

Notes: All correlations signficant at $p < .01$

Hartig et al.'s (1997) Perceived Restorativeness Scale (PRS) was used to evaluate the participants' perceptions of the restoration of the VR forest environment. The Cronbach's alphas of the four dimensions of this scale were consistent with those reported in previous studies (e.g., Hartig et al., 1997; Hauru et al., 2012), as follows: coherence = .76, being away = .77, compatibility = .89, and fascination = .89. Table 3 presents the item and construct means and standard deviations of the four dimensions for both the VR forest environment and the physical forest environments of Hauru et al. (2012). Coherence, being away, compatibility and fascination were positively correlated with each other ($p < .01$, Table 4) but multicollinearity tests did not raise concerns as Tolerance varied between .26 and .77 and VIF between 1.31 and 3.89.

Table 3. Measurement scales for restorative experiences

Perceived Restorativeness (Hartig et al., 1997) (PRS)**	**VR forest environment (N = 100)**		**Physical forest environments**						**Cron bach α**
			Forest environment* (N = 48)		**Semi-urban environment * (N = 39)**		**Urban environment* (N = 45)**		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Coherence (all items reversed)	5.90	0.90	5.48	1.23	4.76	1.47	4.61	1.3	0.764
There is a great deal of distraction	6.07	1.31	5.17	1.86	4.41	1.74	4.49	1.85	
It is a confusing place	5.27	1.54	5.75	1.48	5.13	1.91	4.84	1.83	
There is too much going on	5.98	1.19	5.10	1.80	4.54	1.71	4.13	1.75	
It is chaotic here	6.26	1.00	5.90	1.56	4.95	1.92	4.98	1.57	
Being away	5.66	1.04	5.47	1.21	4.63	1.5	3.89	1.79	0.77
Being here suits my personality	5.72	1.21	5.58	1.30	4.85	1.57	4.16	1.88	
Spending time here gives me a good break from my day-to-day routine	5.60	1.19	5.35	1.54	4.41	1.79	3.62	2.06	
Compatibility	4.98	1.23	4.88	1.34	4.14	1.42	3.54	1.56	0.89
I could find many ways to enjoy myself in a place like this	5.28	1.47	4.83	1.63	4.23	1.60	3.87	1.71	
I have a sense that I belong here	4.90	1.52	4.92	1.58	4.08	1.68	3.71	1.89	
I have a sense of oneness with this setting	4.81	1.51	4.67	1.62	3.95	1.54	3.24	1.73	
I can do things I like here	4.92	1.51	5.10	1.55	4.31	1.61	3.36	1.75	
Fascination	5.64	0.86	4.83	0.98	4.12	1.14	3.63	1.33	0.89
My attention is drawn to many interesting things	5.99	0.88	5.06	1.38	4.77	1.58	4.33	1.55	
It is an escape experience	5.55	1.20	5.19	1.47	4.33	1.74	3.67	1.87	
The setting has fascinating qualities	5.62	1.03	4.98	1.10	3.95	1.56	3.76	1.71	
I want to explore the area	5.97	0.99	4.52	1.37	4.03	1.68	3.44	1.67	
I would like to get to know this place better	5.58	1.46	4.38	1.55	4.03	1.58	3.51	1.63	
I'd like to spend more time looking at the surroundings	5.14	1.52	4.83	1.40	3.59	1.52	3.09	1.56	

*Notes: * Data received from Hauru et al. (2012), ** Item translations same as in Hauru et al. (2012)*

Table 4. Correlation matrix for perceived coherence, being away, compatibility and fascination

Correlations	Coherence	Being away	Compatibility	Fascination
Coherence	1	.50	.46	.46
Being away		1	.82	.81
Compatibility			1	.80
Fascination				1

Notes: All correlations significant at p < .01

The analysis consists of two parts. First, one-way repeated-measures MANOVA was used to analyze the effect of VR forest environment on the participants' vitality, mood, and restoration outcomes. Second, MANOVAs were used to analyze the mean differences between how restorative the VR forest environment and the three kinds of physical forest environments were perceived.

3.1 Restoration outcomes after visiting a VR forest environment

A repeated-measures MANOVA with time (before and after using the VR application) as the independent variable (within-subject factor) and SVS, PANAS pos, PANAS neg and ROS as dependent variables was first performed. The results indicate that time provided a good explanation for the variability of the model ($F(4, 86) = 33{,}37$, $p < .001$; Wilk's $\Lambda = 0.39$, $\eta_p^2 = .61$). Increased effects were found in all of the positive states (SVS: $F(1, 89) = 45.18$, $p < .001$, $\eta_p^2 = .34$; PANAS pos: $F(1, 89) = 21.57$, $p < .001$, $\eta_p^2 = .20$; ROS: $F(1, 89) = 109{,}77$, $p < .001$, $\eta_p^2 = .55$) and a decreased effect in PANAS neg ($F(1, 89) = 80.90$, $p < .001$, $\eta_p^2 = .48$). Hypothesis 1 is therefore supported. Figure 2 presents the means of the dependent variables before and after using the VR application.

Additionally, a repeated-measures MANOVA was conducted by using time as a within-subject factor and background variables (age, gender, occupation and previous VR experience) as between-subject factors. As main effects, there were no statistically significant differences between subjects for age, ($F(4, 85) = 0.87$, $p = .49$), gender ($F(4, 83) = 0.84$, $p = .50$), occupation ($F(8, 168) = 1.04$, $p = .41$) and previous VR experience ($F(4, 85) = 0.22$, $p = .93$). The only statistically significant interaction effect of background variables and time was with previous VR experience ($F(4, 85) = 3.28$, $p = 0.02$). However, adding previous VR experience decreased the explanation power of the model ($\eta_p^2 = .13$) compared with the previously mentioned model without the between-subject variables.

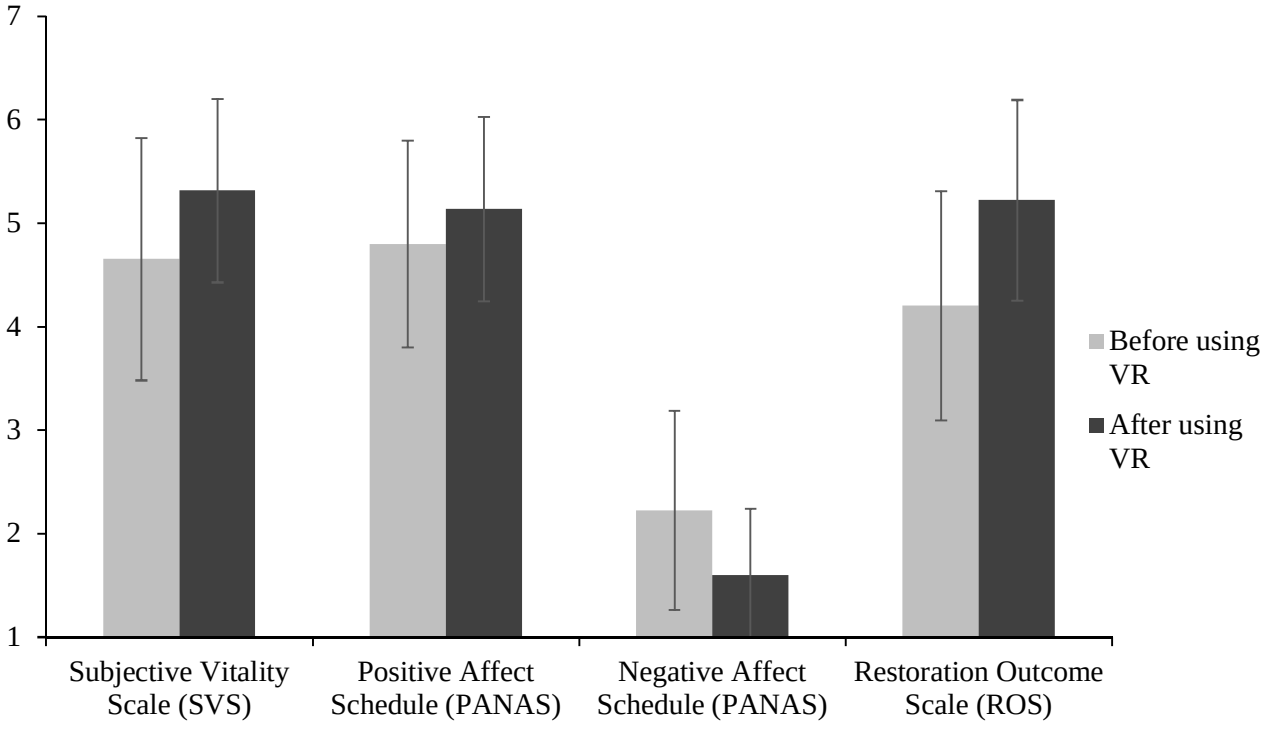

Figure 2. Means of subjective vitality, positive and negative affects, and restoration outcomes before and after using the VR application

3.2 Perceived restoration of VR and physical forest environments

Participants who used the VR application were younger and they were more often male than the participants who visited the physical forests. To see whether the differently sampled groups could be compared, the means of perceived restoration (coherence, being away, compatibility and fascination) of the different forest environments were compared across different age groups (< 35, ≥ 35) and genders (males, females). Among those who used the VR application, a MANOVA showed no statistically significant differences with regards to age ($F(4, 93) = 2.22$, $p = .07$, Wilk's $\Lambda = .91$ $\eta_p^2 = .09$) or gender ($F(4, 91) = .37$, $p = .83$, Wilk's $\Lambda = .98$ $\eta_p^2 = .02$). Similarly, among those who visited one of the three physical forest environments, a MANOVA did not reveal any statistically significant differences based on age (urban forest environment: $F(4, 40) = 0.32$, $p = .87$; semi-urban forest environment: $F(4, 34) = .36$, $p = .83$; forest environment: $F(4, 43) = .19$, $p = .94$) or gender (urban forest environment: $F(4, 40) = .16$, $p = .96$; semi-urban forest environment: $F(4, 34) = .79$, $p = .54$; forest environment: $F(4, 43) = .14$, $p = .97$). With regard to the VR group, it was also found that perceived restorativeness did not depend on previous VR experience ($F(4, 93) = 1.51$, $p = .15$, Wilk's $\Lambda = .97$ $\eta_p^2 = .06$). Perceived restorativeness was however found to depend on occupation ($F(4, 91) = 3.70$, $p < .001$, Wilk's $\Lambda = .86$ $\eta_p^2 = .14$); Students ($M = 5.77$, $SD = .82$) found the VR forest more fascinating than those who were working ($M = 5.41$, $SD = 0.86$) ($F(1, 94) = 4.16$, $p = .04$, $\eta_p^2 = .04$).

Figure 3 presents the means of perceived restoration. We used MANOVA to find out if perceived restoration differed in the various forest environments, and the analysis suggests that it did ($F(12, 590.29) = 14.84$, $p < .001$; Wilk's $\Lambda = .50$, $\eta_p^2 = .21$). A comparison of the mean differences revealed that the VR forest environment was perceived more restorative than the urban forest environment in terms of all the subscales (coherence: $F(1, 141) = 47.05$, $p < .001$, $\eta_p^2 = .25$; being away: $F(1, 141) = 55.17$, $p < .001$, $\eta_p^2 = .28$; compatibility: $F(1, 141) = 34.71$, $p < .001$, $\eta_p^2 = .20$; fascination: $F(1, 141) = 116.57$, $p < .001$, $\eta_p^2 = .45$). The VR forest environment was also perceived more restorative than the semi-urban forest environment (coherence: $F(1, 135) = 30.54$, $p < .001$, $\eta_p^2 = .19$; being away: $F(1, 135) = 20.96$, $p < .001$, $\eta_p^2 = .13$; compatibility: $F(1, 135) = 11.55$, $p < .001$, $\eta_p^2 = .08$; fascination $F(1, 135) = 71.44$, $p < .001$, $\eta_p^2 = .35$). When comparing the VR forest environment and the forest environment (closed view), the VR forest was perceived more coherent ($F(1, 144) = 5.50$, $p < .05$, $\eta_p^2 = .04$) and fascinating ($F(1, 144) = 25.99$, $p < .001$, $\eta_p^2 = .15$), but the difference was not significant for the perception of being away ($F(1, 144) = 0.96$, $p = .33$, $\eta_p^2 = .01$) or compatibility ($F(1, 144) = .16$, $p = .70$, $\eta_p^2 = .001$). In other words, the VR forest environment was perceived more coherent and fascinating than any of the three physical forest environments and more

compatible and more like ‘being away’ than the semi-urban and urban forest environments. Hypothesis 2 is thus supported for most parts.

To test the results also with samples that were more balanced in terms of age, a random subsample was taken among the ones who visited VR forest. This meant including all of the participants who were 35 years or older and taking a random sample of 19 from the participants in the age group of younger than 35. In line with the previous results, this model indicated that the differences in perceived restoration depended on the forest environment one visited (VR, or one of the physical forests) ($F(12, 465.94) = 9.01$, $p < .001$, Wilk’s $\Lambda = .58$, $\eta_p^2 = .17$) but not on age ($F(4, 178) = 0.43$, $p = .79$, Wilk’s $\Lambda = .99$, $\eta_p^2 = .01$). The results of pairwise comparisons were also parallel with the results of the complete dataset.

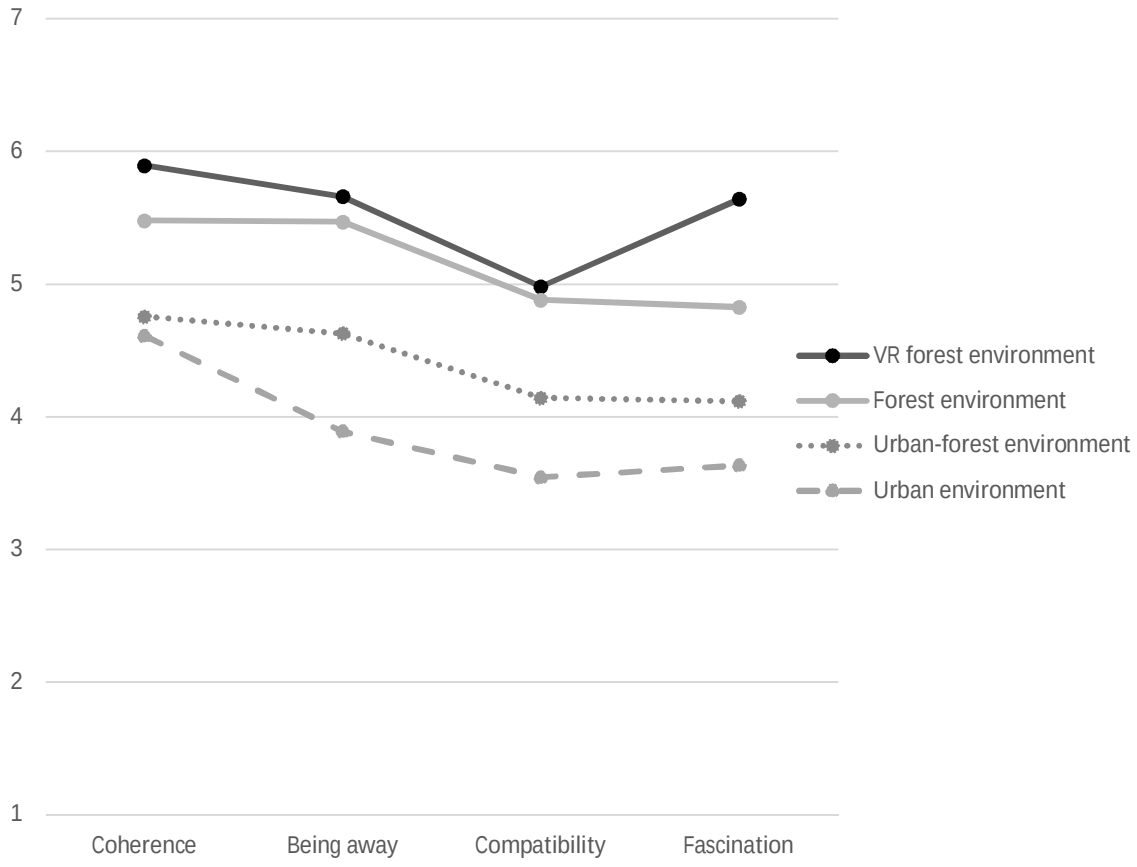

Figure 3. Means of perceived coherence, being away, compatibility and fascination in different kinds of forest environments

4. Discussion and conclusions

4.1 Positive restoration outcomes

According to the results, a short break in a VR forest environment brought about a significant improvement in vitality, mood, and perceived restoration outcomes (relaxation and calmness, attention restoration, and clearing one's thoughts) among the participants. Tyrväinen et al. (2014) suggest that a stay in a natural environment of longer than 15 minutes is needed to enhance subjective vitality. Our findings imply that a stay of just five minutes in a restorative VR forest environment can result in significant enhancement in subjective vitality but also in mood and restorative outcomes. Putting on a VR headset may provide such a high contrast to the physical environment in an office that restoration occurs faster.

The similarities in the research setup, the survey questions and scales make it possible to make some comparisons of the current results to those of Tyrväinen et al. (2014), who used the same measures of perceived stress relief among people after visiting a physical forest. Thus, even though the differences cannot be statistically tested, comparisons of the magnitudes of the changes imply that the positive changes in vitality, mood and restoration outcomes were at least as positive if not more positive after visiting a VR forest environment than visiting a physical forest environment.

According to the literature, an immersive information system enables the user to feel present (Biocca & Levy, 1995; Lombard & Ditton, 1997), and when one feels present one is unaware of any mediating technology and is free to become immersed in the content (Lombard & Ditton, 1997). Our results, in line with those reported by Smyth et al. (2015), show that current VR devices can immediately create the illusion of being transported into a virtual world beyond the headset, which consequently facilitates presence in a restorative natural environment with the consequent psychological benefits. It has been reported in previous research based on fairly similar technology that virtual natural environments may enhance stress recovery and relaxation (Annerstedt et al., 2013; Baños et al., 2013), as well as increase levels of vigor and decrease levels of negative emotions (Yu et al., 2018): the present study extends these findings. The positive effects of carefully designed digital tools on people's wellbeing have also been shown in other contexts such as with digital meditation applications (Bostock, Crosswell, Prather & Steptoe, 2019).

4.2 A VR forest as a restorative environment

Our results show that a VR forest environment was perceived more coherent and fascinating, and as compatible and capable of creating a feeling of 'being away' as a physical forest environment with no urban elements. Further, perceived restoration was higher on all the four dimensions when comparing the VR forest environment with physical forests that include urban elements (c.f. Hauru et al., 2012). The close scrutiny of the features of a VR forest environment enables us to interpret the results. First, it lacks some sensory stimuli compared with physical forests, such as tactile and olfactory features (e.g., wind, feeling the ground, scents). VR devices are designed to obstruct external sensory stimuli, which enables immersion and thus concentration on the content of the application immediately after putting the headset on. This lack of

disturbing elements and the controlled setup may well have influenced the perceptions of coherence and the feelings of being away in the VR environment. Furthermore, the results suggest that the feeling of being away does not require translocation, as also implied in earlier research (Laumann et al., 2001).

Even people who are strongly connected to urban environments tend to seek restoration in natural areas such as forests and scenic landscapes (Korpela et al., 2008). It was therefore surprising that the VR forest environment was perceived as more compatible than the urban and semi-urban forest environments. It could be that such urban forest environments are *too* ordinary to offer oneness and enjoyment (Hauru et al., 2012). A simulated forest that people have not seen before but which resembles a familiar forest landscape they like might even be better in creating the perception of compatibility.

The VR forest environment was consistently perceived as more fascinating than any of the physical environments, which was not surprising given that it was specifically developed to be aesthetically attractive, immersive and peaceful - qualities often referred to as reflecting soft fascination (Herzog et al., 1997; Herzog et al., 2003). The sound of birds singing and the steady and moderately varying forest view could well have fostered the perception that there was something going on behind the visible landscape, thus increasing the level of fascination. According to Hauru et al. (2012), it is more difficult to find similar aesthetic and pleasurable experiences in urban forest environments in particular. Finally, it could be that 'ordinary' physical forests are generally perceived as less fascinating than a new and technologically exciting VR forest environment.

The perceived restoration of the VR or physical forest environment did not depend on the person's age or gender. Further, the perceived restoration of the VR forest environment did not depend on the user's previous experience with VR technology suggesting that the perceptions were not merely a sign of technology enthusiasm or novelty effect. The VR forest was however perceived more fascinating among students versus those who were working, possibly implying that students are more curious of virtual worlds than those in the workforce.

4.3 Limitations and future research

The study has some limitations that need to be addressed. First, the participants' experience in the VR forest environment was studied using only one kind of environment: different kinds of VR forest environments may have produced different results, and the way the environment was experienced (for five minutes, sitting down and looking around) may have been influential. The way that the VR experience was built was determined based on pre-tests, which may have resulted in a setup that made overly sure the participants relaxed instead of activating, and did not get bored or frustrated with the experience. Future research could test different kinds of VR environments and other ways of using the application to see if the results remain.

Furthermore, we did not consider the long-term effects of using the application: each participant only used it once. According to Korpela et al. (2008), the length of the stay and the frequency of visiting one's favorite place are positively related to restorative experiences. More research is needed to study the effects of frequent visits to restorative VR environments. Another interesting research avenue concerns personal modifications of VR environments: there are numerous studies on people's favorite places, and it could be that the observed benefits of the VR forest could be even more substantial if the personal preferences of the users were considered.

Second, we considered only self-reported survey answers as indicators of vitality, mood and restoration, which has its limitations. However, these survey items are commonly used in research on restorative experiences and they allowed us to make comparisons with previous research results. Previous research suggests that virtual natural environments could also have positive physiological effects (Annerstedt et al., 2013; Yu et al., 2018), but the current study cannot make such conclusions. Moreover, we studied people who took a break during their studying or working day but we do not know what effects such breaks have on performance, albeit a positive relationship could be inferred from earlier research (Lee et al., 2018).

Third, even though we were able to compare the effect of visiting a VR forest and visiting a physical forest, there are limitations. The participants of two studies (the current one and Hauru et al., 2012) were different and had somewhat different socio-demographic backgrounds, and hence the results should be interpreted with care. Further, we do not claim that visits to VR forests should replace visits to physical forests. Our results simply imply that when it is not possible to visit a physical forest or other natural environment, VR technology could serve a restorative purpose. However, given the lack of similar comparisons, we believe that our study makes a valuable contribution to existing knowledge and encourages future research on VR technology as a restorative mechanism.

4.4 Practical implications

According to our results, taking a break in a VR forest environment can be a restorative experience. This is particularly important for people who do not have easy access to physical forests or other natural environments. The reported improvements in vitality, mood and restoration outcomes make VR technology attractive, particularly for use during a study or work day: significant improvements can be achieved quickly without leaving the office. It is acknowledged that the quality of the software and hardware needs to be high enough to create such benefits, and that knowledge about restorative environments and landscape planning is required for designing the applications.

Our findings also imply that VR applications could be used to plan and test the appearance and perceptions of physical environments and their effects on the people in them, even if only virtually. VR technologies

have potential in testing and assessing various environments quickly and effectively (e.g., Tabrizian, Baran, Smith & Meentemeyer, 2018), and recent innovations in content production (c.f. Tussyadiah, Wang, Jung & tom Dieck, 2018) make it easier for landscape architects and urban planners to test increasingly realistic plans in VR before the building process starts. Our study suggests that also the softer restorative qualities that are needed in environments designed for relaxation, peacefulness and even creativity and enjoyment can be tested in the same way. Thus the design and testing of restorative qualities in various public, private and commercial spaces can be informed by our research.

Finally, even though we do not suggest that VR technology could or should substitute physical experiences of nature, we believe it opens up possibilities for new groups of people to enjoy similar benefits. Providing positive and memorable experiences may make it possible to connect people with nature and real environments. According to Tussyadiah et al.'s (2018) study on VR tourism, the heightened feeling of 'being there' resulted in a stronger liking of and preference for the destination. It is not desirable for people endlessly to increase their traveling, but VR technology could offer experiences of various places and natural habitats on a sustainable basis (Dewailly, 1999). Indeed, VR-based traveling and adventure applications have become available to the masses during the past few years, and the present study attests to the user value of such applications when used appropriately.

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