
Physiological and Psychological Restoration in Matched Real and Virtual Natural Environments

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Abstract

We present a study comparing physiological and psychological restoration in matched real and virtual natural environments. Participants ($n=24$) experienced a real forest, or one of two audiovisual virtual forests wearing a head-mounted display: a 3D forest or a 360-degree video. The results showed that some of the benefits of the real forest could also be obtained using virtual equivalents. Furthermore, we found the 3D forest to be emotionally more restorative than the 360-degree video forest. The findings can be used in creating restorative virtual environments for people who are unable to visit real natural environments.

Author Keywords

Restoration; virtual natural environment; virtual reality; head-mounted display.

CCS Concepts

•Human-centered computing → Empirical studies in HCI; Virtual reality;

Introduction

The stress-reducing or restorative benefits of being in real natural environments, such as forests, are well documented by research in environmental psychology [11, 14]. However, many people are not able to obtain these benefits because the distance to the natural space is too far, say for

city dwellers, or perhaps an individual has mobility issues that make access to the natural space difficult. A potential alternative is to use virtual natural environments that can be accessed, for example, by using head-mounted displays capable of producing immersive experiences.

Even though there are plenty of virtual forests available for download that claim to offer 'relaxation' [15, 17, 18], it is not known how effective they are in practice. We believe that it is important to understand the relationship between psychophysiological restoration in the real and the virtual environment to be able to assess the potential of virtual nature. The question this investigation seeks to answer is what proportion of the benefits from a real natural environment could be obtained from a virtual equivalent of the same environment. Further, we seek to answer whether a 3D model of the space or a 360-degree video would be more suitable for presenting a virtual natural environment. We had no prior hypothesis in support of either approach.

In the remainder of this paper, we first present previous work in this field. We then introduce our experiment and report the results. Finally, we discuss our findings and present the main conclusions.

Previous Work

Spending time in virtual environments with natural elements has been shown to produce physiological restorative benefits, in terms of reduced heart rate [2, 7, 19, 22], blood pressure [7, 22], skin conductance [1, 20, 19], and psychological benefits in terms of improved mood [1, 12, 19, 22]. In these experiments, participants experienced virtual environments through head-mounted displays that showed audiovisual presentations of natural environments. Some restoration studies with head-mounted displays have also shown negative effects, such as worsened mood and fa-

tigue [3], and inhibition of physiological restoration [10]. VR sickness could be one important contributor to this.

Currently, there seem to be only a few studies that have directly compared real nature with virtual nature. Television screens [13, 9, 16] were used in three studies as a presentation device, while two studies [3, 21] used head-mounted displays. In each study, the real nature condition was found to be physiologically and psychologically restorative, and in none of the cases was virtual nature more restorative than real nature. Evidence of positive physiological restoration in the virtual nature conditions was found in 3 studies, with no evidence in the other two. Evidence of positive psychological restoration was found in 3 studies, but negative changes in this were found in the other two. The real nature condition was physiologically more restorative than the virtual condition nature in 3 of the 5 cases and psychologically more restorative in 4 of the 5 cases.

Furthermore, four studies in virtual environments [2, 7, 19, 22] showed an average of a 4.9 % reduction in heart rate. Two studies [20, 10] demonstrated a similar trend without statistical significance. Thus, a lowered heart rate could be one common indicator of a restorative VR environment. Blood pressure and skin conductance are other possible metrics that could show benefits. Concerning heart rate variability, excluding one study [1], there is not evidence for restorative benefits of VR. Regarding psychological metrics, four studies [1, 12, 19, 22] that measured mood reported improved moods for participants using the VR systems.

The current paper adds to this existing knowledge by making two novel contributions. First, we compare physiological, affective, and cognitive parameters in seated restoration in a real forest and a virtual representation of the same place. Second, we compare the restorative benefits of 3D and 360-degree video environments.



Figure 1: In the real location (top), the participant sat on the front chair with measuring device on rear chair. The VR 3D (middle) and VR 360 video (bottom) conditions mimicked the real location.

Methods

Participants

A total of 24 volunteers took part in the experiment. They were all students and staff at Tampere University of Applied Sciences and Tampere University. There were 13 females and 11 males (mean age 26, range 20-39 years).

Experimental Design

We anticipated that an order effect would be very likely if the same person was exposed to the same environment on three separate occasions (1 real and 2 VR) as the intention was that the participant would remain seated in the same location throughout each 10 minute exposure period. Consequently, we chose a between-participants design. The participants were randomly allocated to 1 of the 3 groups so that they experienced only one of the environments.

Real and Virtual Environments

The real natural environment was a forest on the edge of a lake near to the University of Applied Sciences in Tampere, Finland (see Figure 1). Two virtual versions of the location were created. One was a 3D model rendered within Unity. Several custom tools and a pipeline for foliage placement and terrain data conversion were developed to automate the process. However, the assets in the direct vicinity of the test location were placed manually to produce a high level of correspondence between the real and virtual location. The second virtual version was a 360-degree video shot in the physical location. An audio soundscape was produced with recordings made at the physical location. This soundscape was used in the VR 3D condition and the VR 360 video condition.

Measures

The physiological parameters studied were heart rate (HR), heart rate variability (HRV), and electrodermal activity (EDA).

The aggregated data for each from the first 60 seconds and the final 60 seconds of the treatment were used as the measures. The Mindmedia NeXus-10 neuro- and biofeedback system was used to collect this data. The psychological parameters were working memory capacity, summed ratings of negative affect, and summed ratings of positive affect. Data on these were collected immediately before and after the treatment.

Positive and negative affect were scored with the PANAS-scale [4]. The working memory test consisted of reading sequences of random digits to a participant and after each asking the participant to repeat the sequence. The sequence length increased by one each time until the participant made two consecutive errors. The sum of the correctly recalled sequences was taken as the score. These measures were taken immediately before and after the treatment, and the treatment score was taken as the difference between the pre- and post-treatment measures. All physiological and psychological measures were made by the same person for all participants. All questionnaires and tests were conducted in Finnish.

Procedure

The participants were told that some would sit in real nature and some in virtual nature. They could look in different directions in real and virtual nature while being seated. Details of the measurements to be taken were included in a consent form that those who wished to participate filled in before the experiment. Participants received a movie ticket in return for their time.

For the real condition, individual participants met one of the researchers at the edge of the forest, and then both walked to the test location, which took about 7 to 8 minutes. Participants were asked to sit in the chair for approximately 10 minutes to allow their heart rate to return to the resting

heart rate after the walk. During this time, they completed a demographic data collection questionnaire, followed by the pre-treatment working memory test and the positive and negative affect questionnaire. Then the measuring equipment was introduced, and the electrodes were fitted. Participants were asked to sit quietly for the duration of the treatment period of 10 minutes. After this, the electrodes were removed, and the participants were asked to fill in again the positive and negative affect questionnaire and complete the working memory test. Finally, the researcher walked with the participant back to edge of the forest.

For the two VR conditions, the procedure was similar but not identical. The tests took place in two sound-proof rooms, one on each university campus. The mean temperature was approximately 20-22 °C, but the temperature variation was larger outdoors (from 18 to 26 °C). Once the participants entered the room, the procedure was the same as with the real nature condition. After the pre-treatment tests were completed, participants put on an HTC Vive headset. This was removed at the end of the period, and before the post-trial measurements began.

Data Analysis

Because the between-participants design introduces the normal variation between participants in the analysis, we chose to study the extent of the changes within individuals. The observed data was the difference between the early period (first 60 seconds) and late period (last 60 seconds) in-trial measures for the physiological variables, and between the pre- and post- measures for the psychological variables. For calculating HRV and EDA data, we used MATLAB extensions HRVAS and LEDALAB. For each measure, we took the median of the differences within a group (real, VR 3D model, and VR 360-video), and then compared the three groups in pairs. For each pair, we used the

<i>Measure</i>	Median difference		
	<i>Real</i>	<i>VR 3D</i>	<i>VR 360</i>
HRV	6.15 (8)	-8.9 (8)	-10.85 (8)
HR (BPM)	-4.9 (8)	2.3 (8)	0.5 (8)
EDA	-0.24 (8)	-1.34 (7)	-0.61 (8)

Table 1: Medians of observed end trial - start trial differences in physiological measures (and number of observations).

absolute difference between the medians as the observed statistic.

To test for the statistical significance of the differences, we used permutation tests [8, 6] that do not depend on as many assumptions on the sample distribution as some other tests, such as t-test and ANOVA [5]. Individual difference data for a pair of groups were first pooled. Then two random samples of the same size were created from the pool by sampling without replacement, and the absolute difference of the medians of these was calculated and saved. This was repeated 10000 times. We were interested in the number of times this process produced a value as great or greater than the observed statistic.

Results

Physiological Measures

Table 1 shows the medians of differences between the end of the trial and the beginning, so a positive value indicates an increase in the measure throughout the trial. Heart rate variability (HRV/RMSSD) increased over the trial in the real condition but decreased in both VR conditions. Heart rate in beats per minute decreased in the real condition but increased or changed very little in the VR conditions. The skin conductance decreased in all conditions. We exam-

	Between group comparisons		
	Real vs VR 3D	Real vs VR 360	VR 3D vs VR 360
HRV	15.05	17	1.95
p(Ho)	0.05	0.02	0.92
HR (BPM)	7.2	5.4	1.8
p(Ho)	0.02	0.01	0.43
EDA	1.11	0.37	0.74
p(Ho)	0.06	0.29	0.70

Table 2: Physiological measure comparisons between groups in terms of absolute differences between medians.

ined the probabilities that differences between the groups have occurred by chance using the resampling approach described above.

Table 2 shows that for the measures of HRV and of HR, there was a significant difference between the real and the 2 virtual conditions, but not between the 2 virtual conditions. Thus, the real nature condition had higher HRV values and lower heart rate values than either of exposure to virtual nature. For the EDA comparisons, there were no significant differences between groups, although the difference between the real condition and the VR 3D was close to significance at $p = 0.06$.

Psychological Measures

If attention restoration had taken place, we would expect an increase in working memory capacity (+ median). Also, if the affective state had been restored, we would expect a decrease in rating of negative affect (- median) and an

Measure	Median difference		
	Real	VR 3D	VR 360
Working Memory	0 (8)	2 (8)	1.5 (8)
Negative Affect	-4.5 (8)	-4.5 (8)	-1.5 (8)
Positive Affect	-1 (8)	0 (8)	-4 (8)

Table 3: Medians of observed end trial - start trial differences in psychological measures (and number of observations).

increase in rating of positive affect (+ median). Table 3 suggests that the virtual conditions produced an increase in working memory while the real condition did not. All conditions produced a decrease in negative affect, while the real and VR 360 conditions produced a decrease in positive affect.

Table 4 shows that the differences in changes in working memory capacity between the virtual conditions and the real condition were not significant. The real condition produced a significantly greater decrease in negative affect than the VR 360 condition. There was however no significant difference between the VR conditions in spite of the observed differences between the medians. There were no significant differences between the groups in terms of changes in positive affect.

Discussion

We have investigated physiological, cognitive, and affective parameters to quantify the restorative benefits of spending time in a virtual representation of a real forest compared with those obtained from the actual forest. The results for HRV and HR showed that the real condition was significantly more restorative from the virtual counterparts, but the two virtual conditions did not differ. EDA decreased in

	Between group comparisons		
	<i>Real vs VR 3D</i>	<i>Real vs VR 360</i>	<i>VR 3D vs VR 360</i>
Working Memory p(Ho)	2 0.15	1.5 0.20	0.5 1
Negative Affect p(Ho)	0 1	3 0.03	3 0.19
Positive Affect p(Ho)	1 0.97	3 0.37	4 0.37

Table 4: Psychological measures comparisons between groups in terms of absolute differences between medians.

all conditions but less in the real condition than in the virtual conditions. Overall, the data suggested an increased parasympathetic activity ("rest and digest") for the real condition and a decreased activity for the VR conditions. Furthermore, all conditions decreased sympathetic nervous system activity ("fight or flight" response) to some extent.

In terms of emotion, negative affect was reduced in all conditions. The real and the VR 360 condition differed significantly, while the real and VR 3D condition did not. The data showed reduced positive affect for the VR 360 condition. Some participants said they disliked the experience of hovering above the ground in VR 360, a limitation of 360 technology, which could explain the negative effect. Cognitive performance, as measured by working memory, may have improved in the virtual condition but not in the real condition. A possible explanation for this, and the lack of positive restoration evidenced by EDA in the real condition, is that the walk to the test site in the real forest was restorative

in itself. If so, the participants would be partly restored by the time the test began. In summary, the findings of measured psychological factors are less clear than the findings of physiological measures. Previous work has also resulted in mixed findings.

The first limitation of this study was the number of participants (8) in each condition, which was a result of the time available for the study. The second limitation was that we only assessed convergent thinking. To give a more comprehensive picture of restoration, measuring divergent thinking (i.e., associative, creative information processing) would also be useful.

Conclusions

While the real forest was more restorative than the virtual forests, some benefits could still be obtained using head-mounted displays. This is a promising finding since the number of people unable to visit natural environments increases due to urbanization. At the same time, head-mounted displays and other technologies capable of creating immersive experiences become more affordable and popular. Furthermore, we found that the 3D model of a forest was emotionally more restorative than the 360-degree video. For the future, we plan broader comparative studies of real and virtual natural environments that take additional aspects such as multisensory stimulation of restoration into account.

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