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Short virtual nature breaks in the office environment can restore stress: An experimental study

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ABSTRACT

Knowledge workers need short breaks during their office hours to relieve stress. We examined the benefits of virtually produced nature environments during afternoon breaks. Knowledge workers (n = 39) visited the Virtual Nature Room a total of nine times. During their 15-min break, the volunteers 1) watched a video (of a forest or water environment) on a TV monitor with related nature sounds, 2) listened to nature sounds (without a video), or 3) as a control condition, sat in the quiet room without audio-visual material. The volunteers responded to the psychological measures, and we measured the heart rate variability during the experiment. All breaks indicated stress reduction in some measures. The video with audio sessions increased the felt restoration more than the audio and the control conditions. The mean heart rate was sensitive to detect slight decrease during video conditions over the control. Some unexpected results such as the decrease of positive emotions and energy level during breaks are discussed.

1. The short virtual breaks for knowledge workers

1.1. The importance of short breaks at the workplace

Knowledge work is becoming a norm in many occupations. It includes planning, engineering, teaching, research, and office assistance work. Knowledge workers primarily produce or work with information, solve demanding problems, and develop new knowledge in the workplace. Such work requires substantial cognitive resources of workers, and they may even ignore their tiredness and need of a work break because of their focus on their tasks (Franklin, Hodas, & Lerman, 2017).

Inadequate stress management leads to reduced work performance, increased risk behavior (e.g., healthcare staff washing their hands less often during long working hours (Dai, Milkman, Hofmann, & Staats, 2015)), and can result in serious health problems such as burnout. However, only a few countries in Europe have data on burnout from representative cross-sectoral studies (Eurofound, 2018). For example, in Finland, 3% of women and 2% of men suffer from severe burnout, and 24% of women and 23% of men suffer from distress at work (Suvisaari et al., 2012). Burnout also affects brain data processing and especially increases the tendency to process negative information (Sokka et al., 2014). The brain requires decent breaks every 2 to 4 h to perform efficiently (Müller, 2003) and to mitigate the risk of stress and burnout (see Lyubykh et al., 2022).

There is no unified definition of a work break. It is usually understood as a shorter or longer interruption of work, taking place during work or after work in different environments (for a review, see Scholz et al., 2019). Restorative environments that not only permit but also promote restoration and stress reduction (Hartig, 2004; Korpela, De Bloom, & Kinnunen, 2015), should be easily accessible during and after the working day to provide environments that would support relaxation and so prevent long-term stress and burnout.

Restorative environments can be defined from two theoretical perspectives. According to the attention restoration theory (ART), cognitive tiredness is a result of directed attentional fatigue, which can be restored in environments that are sufficiently fascinating to catch the attention effortlessly, allow psychological or geographical distance, are sensed as coherent environments, and match personal needs (Kaplan & Kaplan, 1989). The stress recovery theory (SRT) hypothesizes that environments that enhance survival possibilities and feelings of safety affect the

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activity of the parasympathetic branch of the autonomic nervous system, resulting in physiological relaxation, as well as a positive mood change (Ulrich, 1983; Ulrich et al., 1991). Research has shown that outdoor and indoor natural environments especially have these restorative qualities compared to urban environments (Berto, 2014). Environments that allow stress relief and attention restoration are essential for workers with high cognitive demands to avoid chronic stress and burnout and an incapacity to work in the long run.

1.2. The relevance of nature for work stress

Research has shown that visiting nature during or after the working day promotes office worker's restoration and stress alleviation. For example, visiting green urban areas after the working day (compared to an urban center) for 45-min sitting and walking periods positively affected mood and energy levels and enhanced perceived restoration (Tyrväinen et al., 2014), a 15-min sitting and viewing period at the start of these visits decreased blood pressure and heart rate and increased heart rate variability (Lanki et al., 2017). A 15-min intervention for lunch breaks indicated that relaxation exercises indoors, as well as park walks, reduced work stress and tiredness over a 10-day period, yet the effects of park walks were slightly more stable across the study period (deBloom et al., 2017). All the self-reported and physiological stress measures (heart rate and salivary cortisol) showed a positive improvement in the intervention program in which workers visited nature twice a week for 2 h over a three-week period during their working hours for various activities, followed by a stress management discussion with a psychologist (Daniels et al., 2022).

Most of the knowledge work today is done indoors in an urban context in which access to nature is not necessarily available. This is especially true in large urban areas and conglomerates, where urban expansion and densification has led to the construction of green areas and a decreased provision of nature environments (Africa et al., 2014; Tyrväinen, Pauleit, Seeland, & de Vries, 2005). In consequence, people have less opportunity to visit nature in their living and working environments. Because of this, bringing natural elements indoors has become more popular. In office environments, green window views and living plants in the office environment show similar positive effects on attention restoration and stress management compared to visiting nature outdoors (Chang & Chen, 2005). Indoor plants are even associated with reduced sick leave and higher productivity (Bringslimark, Patil, & Hartig, 2008), and only 40 s' view of a green roof compared to a view of concrete improved attentional restoration, measured with the sustained attention to response task (Lee, Williams, Sargent, Williams, & Johnson, 2015). The recent review indicates that viewing different landscapes and objects in photos or videos also aids recovery from physiological stress (rise of parasympathetic nervous activity) (Jo, Song, & Miyazaki, 2019). There is already a long tradition of using photos, slides, and videos in research to indicate human preferences and the wellbeing effects of nature over urban or human-made environments (starting with Kaplan, Kaplan, & Wendt, 1972; Ulrich et al., 1991). The new era of technological development has opened completely new opportunities to create and study virtual restorative environments.

1.3. The possibilities of virtual nature environments for improving wellbeing

Virtual nature environments can be described as a surrogate for real environments in which authentic nature is not easily accessible, and that can be used in various situations that aim to provide similar positive restorative effects to a natural environment (e.g., Nukarinen et al., 2022). There are different techniques, methods, and levels of realism in creating virtual nature environments. Showing photographs and/or videos has been the most typical way to study human response and the restorative potential of various environments (e.g., Pilotti, Klein, Golem, Piepenbrink, & Kaplan, 2014; Van den Berg, Jorgensen, & Wilson, 2014). Moreover, different types of visualization media have been extensively used in landscape and environmental planning research, mainly to study people's valuations of the visual quality of landscapes, forest management preferences, or outdoor recreation environments (e.g., Karjalainen & Tyrväinen, 2002; Lindquist, Lange, & Kang, 2016; Tyrväinen, Silvennoinen, & Kolehmainen, 2003).

Research using virtual nature environments to study stress reduction and mental relaxation remains limited. In the study by Van den Berg et al. (2015), the responses of the autonomic nervous system were studied in students' viewing of photos of green and built environments in a laboratory setting. The results indicated an increase in respiratory sinus arrhythmia (RSA) after viewing green scenes (a marker of parasympathetic activity), but no difference in marker of sympathetic activity (pre-ejection period (PEP)). The results indicated the dominant role of the parasympathetic nervous system in the restorative effects of viewing a green space. A decrease in blood pressure and heart rate after presenting different virtual environments such as forests, blue spaces, or even busy urban areas presented through VR technology (e.g., Yu, Lee, & Luo, 2018) has also been found.

Most studies report positive changes in the self-reported measures of affect, attention restoration, and stress relief in virtual nature environment conditions. For example, Browning, Mimnaugh, Van Riper, Laurent, and LaValle (2020) found that a forest environment video presented through VR glasses effected a positive change in mood state compared to an indoor environment. Mattila et al. (2020) also found an increase in positive and decrease in negative emotions and an increase in perceived restoration after watching a forest video. A decrease in negative emotions in virtual nature environments has also been shown by other studies, e.g., Chirico and Gaggioli (2019) and Gao, Zhang, Zhu, Gao, and Qiu (2019). Hence, Pilotti et al. (2014) found that there was no difference in the self-reported emotional state measure between nature or busy urban street videos watched after a working day, but the nature video had a positive effect on memory.

Today, it is suggested that virtual nature solutions that combine visual and auditory stimuli create immersive nature experiences that best affect wellbeing outcomes (Litleskare, MacIntyre, & Calogiuri, 2020). Annerstedt et al. (2013) presented young male participants with virtual nature environments with and without exposure to sounds of nature after the virtual stress test situation. The results showed that only virtual nature combined with nature sounds activated the parasympathetic nervous system. Yet soundscapes and olfactory stimuli have rarely been included in studies, even though they significantly contribute to nature experiences. In a study conducted in the UK, the soundscape of nature (birdsong) was perceived as more pleasant than the sounds of the urban environment (Ratcliffe, Gatersleben, & Sowden, 2018). Moreover, senses can have a different relative importance in the formation of the nature experience. For some individuals, olfactory and auditory experiences may facilitate more stress reduction than visual stimuli (Hedblom et al., 2019).

The wellbeing effects of virtual nature have been studied in practical situations, such as nursing environments, dental practices, and various therapeutic environments (e.g., Reynolds, Rodiek, Lininger, & Mcculley, 2018; Tanja-Dijkstra et al., 2017; White et al., 2018). Viewing nature on a large screen and listening to nature sounds could also be utilized quite easily in healthcare centers, doctors' waiting rooms, and other places where people need the opportunity to calm down.

1.4. The current study

The few available research results show that the positive effects of actual nature are greater than virtually mediated nature (Browning et al., 2020; Kjellgren & Buhrkall, 2010). There are still not enough studies about the effects of nature-based interventions for employees' wellbeing (see Gritzka, MacIntyre, Dörfel, Baker-Blanc, & Calogiuri, 2020 for a review), but time constraints during the working day and the limited access to nature indicates an even greater need to study the possibilities of modern technologies to create restorative environments in work places that are, preferably easy to build, multifunctional, and accessible to all.

Although virtual nature environments have been shown to have similar positive effects on humans to real nature (e.g., Van den Berg et al., 2015), further research is needed. In this study, we were interested in achieving a more coherent understanding of the effects of virtual nature environments on stress relief and relaxation in a working environment.

Our main objective was to study the (self-reported and physiological) effects of a virtual nature environment used during short breaks in a real-life working place relaxation room on stress recovery. We chose to present virtual nature using a TV monitor and surround sound system, as this equipment is easy to use and accessible in many workplaces. The key research questions were the following: Does a virtual nature (VN) break have additional restorative and stress relieving effects during the working day compared with control condition? What effects do the visual and auditory elements of VN have on the overall experience? The final exploratory question was: Does the content of the video with corresponding sound (forest or water) have different effects on stress recovery?

The research hypotheses were:

Hypothesis 1. A short break during the workday leads to psychological and physiological signs of recovery from self-reported stress and the regulation of the physiological state. Positive emotions, perceived restoration, and feelings of energy increase, and negative emotions and anxiety decrease after rest compared to the start of the experiment. During rest, the parasympathetic nervous system is more active than during work.

Hypothesis 2. An experimental condition with video and sound of nature is the most effective setting for stress recovery than other conditions.

Hypothesis 3. The sound condition is less effective for stress recovery than the video and sound condition and more effective than the control condition (silence).

2. Method

2.1. Participants

A total of 39 healthy, full-time employed participants, of which 21 were women, volunteered to participate in the study. The selected participants were knowledge workers whose workplace was within a short walking distance of the experiment's location. The exclusion criteria for participation were a medication affecting the central nervous system, continuous medication for cardiac diseases, asthma, hypertension, or a severe neurological condition (including clinical depression), as well as hearing loss.

Several recruitment methods were used, such as sending invitation letters through the employer's email lists, using information stands in entrance halls and corridors, and organizing recruitment days next to the workplace's canteens. Most of the recruited participants had permission from their employer to visit the experiment during their working hours.

Participants were informed that they should avoid alcohol consumption 24h and all caffeinated drinks 3h before each experimental session, as well as heavy physical exercise. As we recruited healthy participants, the subjective health status, subjective physical fitness, and subjective quality of life were mostly evaluated as very good or rather good (76.9%, 64.1%, and 64.1% respectively). Almost all the participants had a university degree, and most worked in a senior position. Some participants' work was in some way related to nature research. The participants were relatively active in outdoor recreation. During the summer (April–September), 81.2%, and during the winter (October–March), 59% of the participants visited nature at least weekly. On average, the participants were satisfied with their work, but most also evaluated their work as stressful and involving the pressure of incomplete work. Their weekly working hours were heavy (44.2 h) (one participant whose working hours were 11 per week was deleted from this calculation, because being not a full-time employee). The participants' background information and work and health status are presented in Supplementary Materials A, Tables S1 and S2.

2.2. Study design and procedures

The experiment was conducted in accordance with the principles of the Declaration of Helsinki. The ethical review statement for this study was given by the Ethical Review Board in the Humanities and Social and Behavioural Sciences at the University of Helsinki. Before the experiment, the participants were informed about the course of the study, their rights, and the goals of the experiment. All the participants gave their written informed consent. The experiment was carried out in the office environment between September 2017 and March 2018. The experimental room was set up in the Otaniemi campus area in Espoo, Finland, which hosts various departments of Aalto University, state research offices, and private companies.

The study included nine experimental sessions, which each followed the course shown in Fig. 1. The first participants arrived at 12:30pm at the earliest and the last at 3:30pm at the latest. For each participant the nine separate sessions were conducted in the afternoons approximately at the same time of day to avoid variation in the alertness or behavior of HRV. The participants visited each experimental condition at least once on separate days, nine times in total during their normal working day. The participant chose the experimental dates according to their preference remembering there should be at least one day between experimental dates. The number of participants was optimized based on the maximal number of measurements for each experimental condition in the experimental room during the available period. We used randomized block design, which secured measures from all experimental conditions despite possible interruptions. Based on our expert evaluations, the optimal number of participants was 40 (9 x 40 = 360 measurements).

At the beginning of each visit, a two electrode HRV device capable of recording R-R intervals of electrocardiogram (ECG) (Bodyguard 2.0, Firstbeat Technologies, Finland) was attached to the participant's chest – one electrode on the right under the collarbone and the other on the left of the body on the rib cage. The participant was then guided to an open office space to sit by the desk opposite the researcher. The participant first filled in a questionnaire about the current status of experiences of stress, general health, outdoor activities, etc. Thereafter, during the next 15 min, the participant was instructed to work normally without speaking, using either a mobile device or computer or read or write according to their preference. On the first occasion (sometimes also part of the second), the participant also completed a background questionnaire during a 15-min work period and continued with their own work if completing the questionnaire took less than 15 min. The 15 min working period was used for HRV calculations.

The work period was followed by a 15-min break in the virtual environment room. The participant sat in an armchair and was instructed to feel comfortable and to keep eyes open during the experiment (HRV reading changes when closing eyes). No other instructions were given.

In the experimental room, one of the three conditions (within a randomized block design) was presented: a+b) full virtual environment with video and sounds; c) only an audio environment; d) a neutral room with no sounds or video presented (control setting). Each of the three conditions was run three times for each participant, equating to up to nine visits. The participant was unaware beforehand which type of break was coming each time. After the 15-min virtual environment break in the experimental room, the participant responded to the second set of questionnaires. The HRV device was removed after the participants had

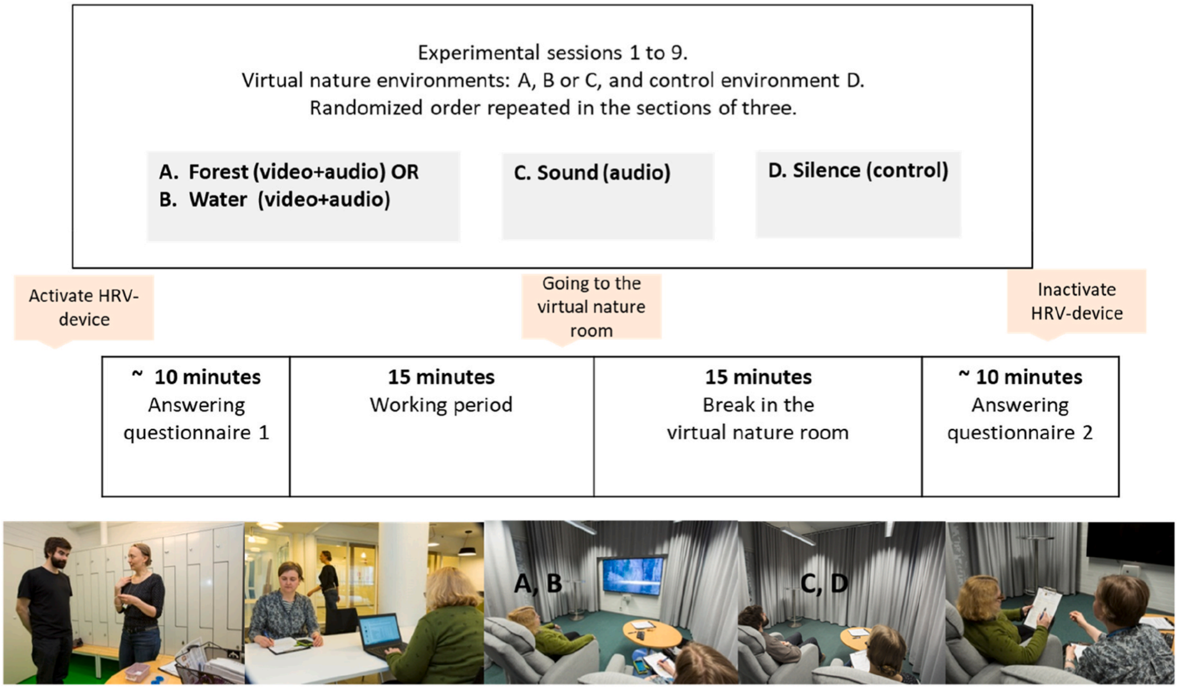

Fig. 1. The experimental plan.
Note. The photos are illustrative; those shown are not actual participants.

filled in the questionnaire. One visit took approximately 45–50 min, during which the participant was always with the researcher. The presence of the researcher ensured that the technology would work, and that the participant would not close their eyes during the physiological measures.

2.3. *The Virtual Nature Room and its materials*

The Virtual Nature Room was a separate 16 m^2 room equipped with a Samsung 75" screen, a JBL surround sound system, and adjustable lights. The TV screen was covered by curtains when it was not being used. Neutral light gray colors were used in the room's interior decoration to minimize its effects on stress recovery during the experiment (see Fig. 1 and S1 (Supplementary Materials A)) and the short video examples (https://www.youtube.com/watch?v=uQFMTSMf_UE; https://www.youtube.com/watch?v=oMw-vJeRv94).

Two different audio-visual materials and one audio material without a video were used in the experiment. Sitting in a silent room without audio-visual material was used as a control condition. The used material was chosen from the archives of the DocArt company, which specializes in the production of nature documentaries. The presented material was designed with the research group and the company. Before the final experiment, the material was tested with five independent evaluators, and the material was improved based on their comments. The film material was of high quality and precision and had been shot using professional-level equipment typically used in producing nature documentaries.

All the material used in the study was familiar to the participants, as it represented Finnish nature. There were two different videos, one representing mostly forested environments (forest video, FV) and the other representing water-based environments (water video, WV). The videos included both urban and rural landscapes, and in addition to the scenery, the videos showed some wild mammals and birds, as well as a few outdoor visitors from a remote distance. The videos presented both broader landscape views and close-ups focusing on various elements of nature, such as plants, the flow of water, and the fall of leaves or snowflakes. The video's rhythm mimicked a conventional observation of natural environments: first viewing landscapes at a general level, then refining the view of the details of the landscape. Most of the FV scenes were from mature or old forests representing both coniferous and deciduous forests, shot in both protected areas and commercial forests. The video focusing on water-based environments represented views from the shore areas to different waterbodies: lakes, rivers, and the sea. The scenes' atmosphere varied from calm lake landscapes and the flowing water to large thundering waves on the seafront. In both videos, the natural landscapes shown progressed through fall and winter to spring and summer, following the annual change of seasons. The third environment in the Virtual Nature Room included only nature sounds from the videos.

Each environmental clip lasted 15 min. In the audio-visual material, the scenes were on average a half minute long, and the audio material was 7.5 min from the FV sound and 7.5 half minutes from the WV sound.

Based on the decibel measurements, during the audio material, the sound average was 44.8 dB, during the forest video 40.1 dB, during the water video 41.4 dB and during the silence 34.4 dB. The strength of the sound was purposely higher during the audio material based on the pilot testing and sound expertise.

2.4. *Measures of this study and data pre-processing*

2.4.1. *Psychological measures*

During the experiment, we used several psychological scales to measure the participants' self-reported restoration, vitality, and mood – all these measures are related to stress relief and attention restoration and were previously used in similar studies (Annerstedt et al., 2013; Tyrväinen et al., 2014). Participants were asked to complete the scales before (Time 1) and after each experimental session (Time 2). All the before-after measures used in this experiment are reported here.

We used the Restorative Outcome Scale (ROS) (Korpela, Ylén, Tyrväinen, & Silvennoinen, 2008; cf. Hartig, Lindblom, & Ovefelt, 1998; Staats, Kieviet, & Hartig, 2003) to measure restorative experiences (Kaplan & Kaplan, 1989). The ROS scale has six items, of which three reflect relaxation and calmness ("I feel restored and relaxed," "I feel calm," "I have enthusiasm and energy for my everyday routines"), one reflects attention restoration ("I feel focused and alert"), and two reflect clearing one's thoughts ("I can forget everyday worries," "My thoughts are clear").

The Positive and Negative Affect Scale (PANAS) (Watson, Clark, & Tellegen, 1988) measured the self-reported mood. We calculated the PANAS Pos, from ten items indicating positive affect, a high energy level, full concentration, and pleasurable engagement, and the PANAS Neg. from ten items, indicating negative affect, distress, and a variety of aversive mood states.

Four items measured the self-reported perceptions of having energy and feelings of being alive ("I feel alive and vital," "I have energy and spirit," "I look forward to each new day," and "I do not feel very energetic" (reverse) from the Subjective Vitality Scale (Ryan & Frederick, 1997). We calculated the summated indexes based on the ROS and SVS items.

We measured all these scales using Likert scales from 1 (not at all) to 7 (completely).

The anxiety felt was measured with the six-item scale from Marteau and Bekker's (1992) anxiety measure, which has previously been used in Finnish population studies (e.g., Konttinen, Haukkala, & Uutela, 2008) and describes irritability and feeling tense on a scale of 1 (does not describe at all) to 4 (describes very well).

Baseline work stress on the experimental day was measured by a single-item measure ("In your opinion, how stressful has been your current working day" based on Elo, Leppänen, & Jahkola, 2003; Gilbert & Kelloway, 2014) once at the start of each experimental visit using a 5-point Likert scale from 1 – "not at all stressful," to 5 – "very stressful."

2.4.2. Physiological measures

Before the statistical analysis (see section 2.5), HRV-related analysis was conducted using the statistical software R (version 3.4.3, RStudio version 1.1.423; R Core Team, 2014) and a colibri package (Henelius, 2014). With prior analysis, the artifacts were detected and removed using the method of Xu and Schuckers (2001). A visual inspection of the cleaned data was performed. The dataset was segmented into 5-min segments using an overlap of 75%, which is a common practice in HRV analysis. From the segments, we analyzed the same HRV metrics used previously in the related studies (Lanki et al., 2017). Time domain measures included mean heart rate (mean HR), standard deviation of normal-to-normal RR intervals (SDNN), and root-mean square of successive RR interval differences (RMSSD). The following measures were analyzed from the frequency domain: power at low (LF, 0.04–0.15 Hz) and high frequencies (HF, 0.15–0.4 Hz), as well as their normalized values, LF.nu and HF.nu. In total, seven HRV metrics were analyzed.

2.5. Statistical analysis

The study design was a nine-visit repeated measurement structure, in which there were two measurement timepoints within each visit, Time 1 = "before" and Time 2 = "after" of each psychological variable, and Time 1 = "work" and Time 2 = "break" for physiological measures. The model structure was:

Response variable = Intercept + Environment(F) + Time(F) + Environment × Time(F) + Sex(F) + Covariates(F) + Visit(F) + Visit lag(R) + Time(visit)(R).

In the formula, F stands for fixed effect, and R for R-side random effect. The covariates for all models were age and work stress.

The distributions of all psychological variable values were symmetrical, and no transformation was applied to any of these variables. A general linear mixed model was fitted using normal distribution (identity link) (Stroup, 2013). The distribution of all HRV variable values was positively skewed, and a log transformation was therefore applied to the data. The estimated means, differences, and endpoints of the confidence intervals were converted to the original data scale using the exponential function. A Kenward-Roger approximation was used to analyze degrees of freedom. Statistical tests were based on predefined comparisons according to study hypothesis, and no multiplicity adjustments were made. The model fit was checked from the shape of Pearson residuals and from the observed vs. predicted plots. The modeling was performed by the GLIMMIX procedure of the SAS/STAT software (version 9.4, SAS Institute, 2018).

All the statistical comparisons were made for a one-sided hypothesis based on research hypothesis, except for the comparison between water and forest videos with the corresponding sounds (see Tables SB1 and SB2, Supplemental B).

During the study planning phase, the sample size estimation was based on the researcher's expert opinion and the available financial resources. After the study, the retrospective estimation of adequate sample size and power calculations confirmed that the study design was sufficiently powerful to detect even a small effect measured by Cohen's d (Cohen, 1988). A detailed description of statistical analyses, power and effect size calculations, and retrospective estimation of adequate sample size is given in Supplementary Materials B, Statistical analyses.

3. Results

3.1. Results from the psychological measures

We tested the differences between the types of virtual environments related to stress relief and restoration. The descriptive statistics, including means and standard deviations of all measures before and after the experiment, are presented in Supplementary Materials A, Table S3, and correlations in Table S4.

We did not find the effect of sex, visit, and age in the models, except for PANAS Neg. with a small effect of age. Because there was no interaction between control variables and treatment effects, the effect is constant and affects the interpretation of treatment effects in the same way. The work stress was statistically significant in all models: the effects for ROS, PANAS Pos., and SVS were negative, and PANAS Neg. and Anxiety were positive, indicating that high levels of work stress are associated with lower psychological wellbeing.

Except for the ROS, in all other psychological measures, the main effect of Time (before-after the experiment) was statistically significant (PANAS Pos. t = -6.781, p < .0001, Cohen's d = 0.365; PANAS Neg. t = -12.781, p < .0001, Cohen's d = 0.686; SVS t = -6.006, p < .0001, Cohen's d = 0.322; Anxiety t = -11.298, p < .0001, Cohen's d = 0.607), and in PANAS Neg., the main effect of the environment was also statistically significant (see Table 1 and Fig. 2).

The interaction between the type of environment and the time (before-after) was significant only in the ROS and PANAS Pos. models (see Table 1 and Fig. 3).

In the ROS, nature videos with a sound condition had more restorative impacts compared to a nature sound condition alone (A + B vs. C (t = 1.932, p = .0271, Cohen's d = 0.104)) and compared to a silence condition (A + B) vs. D (t = 4.063, p < .0001, Cohen's d = 0.218). Forest and water environments separately, and a sound environment, all had a more restorative effect than silence (A vs. D (t = 3.413, p = .0004, Cohen's d = 0.183)), B vs. D (t = 3.221, p = .0007, Cohen's d = 0.173), C vs. D (t = 2.130, p = .0169, Cohen's d = 0.114)) respectively. In addition, the forest video with sound had a more restorative effect than a nature sound environment (t = 1.669, p = .0480, Cohen's d = 0.090). There was no statistically significant difference between the forest and water environment conditions (A vs. B (t = 0.150, p = .8810)).

In the experiment, participants experienced less positive feelings after the experiment than at the start of the experiment (the main effect of Time was statistically significant). In PANAS Pos., positive emotions decreased more during the silence condition than in the nature video environments (A + B) vs. D (t = 3.417, p = .0004, Cohen's d = 0.184) and between the nature videos and nature sound environments (A + B vs. C (t = 1.914, p = .0282, Cohen's d = 0.103). Nature videos separately differed from the silence condition (A vs. D (t = 2.353, p = .0096, Cohen's d = 0.127; B vs. D (t = 3.227, p = .0007, Cohen's d = 0.174)). In

Table 1
Main effects and interactions of all psychological models (degrees of freedom, F-test and level of significance).

Measure	Effect	*df*	*DenDF*	*F*	*p*
ROS	Env.	3	259.3	1.294	.277
	Time	1	347.0	.558	.456
	Env.*Time	3	347.0	5.515	.001
	Sex	1	35.9	1.379	.248
	Age	1	35.8	.261	.613
	Work stress	1	319.2	70.839	.000
	Visit	8	242.2	1.393	.200
PANAS Pos	Env.	3	260.2	1.643	.180
	Time	1	347.0	46.055	.000
	Env.*Time	3	347.0	4.170	.006
	Sex	1	36.1	.964	.333
	Age	1	36.1	.215	.646
	Work stress	1	314.9	24.653	.000
	Visit	8	240.4	1.557	.139
PANAS Neg	Env.	3	269.1	2.926	.034
	Time	1	347.0	162.166	.000
	Env.*Time	3	347.0	.133	.940
	Sex	1	35.6	.333	.568
	Age	1	35.6	4.195	.048
	Work stress	1	326.2	124.774	.000
	Visit	8	249.5	.789	.613
SVS	Env.	3	270.6	1.898	.130
	Time	1	347.0	36.074	.000
	Env.*Time	3	347.0	1.749	.157
	Sex	1	35.8	.004	.951
	Age	1	35.8	.001	.978
	Work stress	1	323.0	17.109	.000
	Visit	8	250.1	1.430	.184
Anxiety	Env.	3	259.6	1.869	.135
	Time	1	347.0	128.148	.000
	Env.*Time	3	347.0	1.947	.122
	Sex	1	34.6	4.763	.036
	Age	1	34.5	.266	.609
	Work stress	1	326.3	116.821	.000
	Visit	8	239.9	1.892	.062

Note. ROS – Restoration Outcome Scale; PANAS Pos. – Positive Emotions; PANAS Neg. – Negative Emotions; SVS – Subjective Vitality Scale; Env. – environmental condition during the experiment; Work stress – subjective work stress level before the experiment; Visit – number of visits.

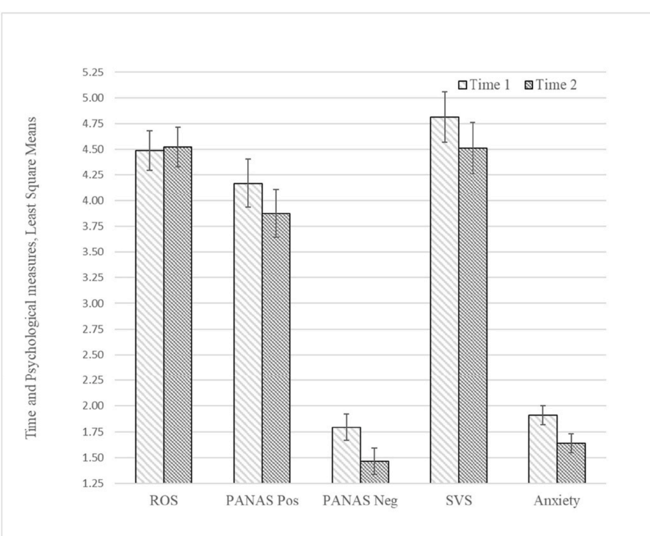

Fig. 2. Main effects of time (before experiment (Time1) and after break periods (Time 2)) on psychological measures (mean and 95% confidence intervals). The effect of Time is significant for all variables except for ROS.

addition, during the water video and not during the forest video, positive emotions diminished statistically significantly less than in the sound condition (B vs. C, $t = 2.003$, $p = .0230$, Cohen's $d = 0.108$).

For all model estimates, changes in the psychological measures before the work and after the break periods and covariate estimates, see Tables S5–S9; for random effect parameters, model residual check, and models without covariates, see Tables S10–S15 (Supplemental A). The predicted effects of time, and time and type of environment interactions, are described in Supplementary B in Tables SB1. The effects of time and experimental conditions are presented in detail in Table S8 (Supplemental A). A complete overview of the psychological results is presented in Table S29 (Supplemental A).

3.2. The HRV measures

Of the 39 participants, two were deleted from the physiological dataset due to inappropriate medication. Of the 37 whole sets, 4 sessions out of 330 (1.2%) from different participants were partly omitted due to technical difficulties.

Descriptive statistics and correlations of HRV parameters are presented in Supplementary Materials A, Tables S16 and S17. In the models we did not find the effect of sex, visit, work stress and age, except for SDNN and LF with a small effect of age.

The interaction between the type of environment and time (work break) was significant only in the mean HR model (see Table 2 and Fig. 5), and in other physiological measures, only the main effects (working period vs. break period) were significant.

The work periods differed significantly from the short breaks. Following our hypothesis, the results indicate more physiological signs of recovery during breaks (Table 2 and Table S21 supplemental). This is shown as significantly higher values in RMSSD ($t = 13.459$, $p < .0001$, Cohen's $d = 0.787$), SDNN ($t = 9.906$, $p < .0001$, Cohen's $d = 0.549$), HF ($t = 15.996$, $p < .0001$, Cohen's $d = 0.887$), and HF.nu ($t = 14.795$, $p < .0001$, Cohen's $d = 0.820$), and lower in mean HR ($t = -33.871$, $p < .0001$, Cohen's $d = 1.885$), and LF.nu ($t = -13.639$, $p < .0001$, Cohen's $d = 0.755$) during the break period. In contrast, the low-frequency LF behaved in the opposite way to our hypothesis and was higher during the break period; however, the effect was small ($t = 3.039$, $p = .001$, Cohen's $d = 0.168$). The significant differences are presented in Fig. 4 and in Table S21 (Supplemental A).

Mean HR showed a statistically significant interaction effect of work and break periods on virtual environment settings. There was a statistically significant difference between nature videos and the silence condition, in which mean HR was lower during the break in the nature videos condition ($t = -3.084$, $p = .001$, Cohen's $d = 0.172$). The difference between nature videos and the sound condition was not statistically significant ($t = -1.647$, $p = .0503$). Mean HR was lower during the break in the water condition than during silence ($t = -3.200$, $p = .001$, Cohen's $d = 0.178$) and the sound condition ($t = -2.041$, p = .021, Cohen's $d = 0.114$). Mean HR was also lower during the forest condition than during silence ($t = -1.819$, $p = .035$, Cohen's $d = 0.101$) However, all these effects were very small.

For all the HRV model estimates, changes during the work and break periods and covariate estimates, see Tables S18–S22; for random effect parameters, model residual check, and models without covariates, see Tables S23–S29 (Supplemental A). The predicted effects of time, and time and type of environment interactions, are described in Supplementary B in Table SB2. The effects of time and experimental conditions are presented in detail in Table S21 (Supplemental A). A complete overview of the HRV results is presented in Table S30 (Supplemental A).

4. Discussion

Although the number of studies about the effects of virtual nature has grown, most of the studies are conducted in the laboratory setting and are performed among the student population. The virtual restorative

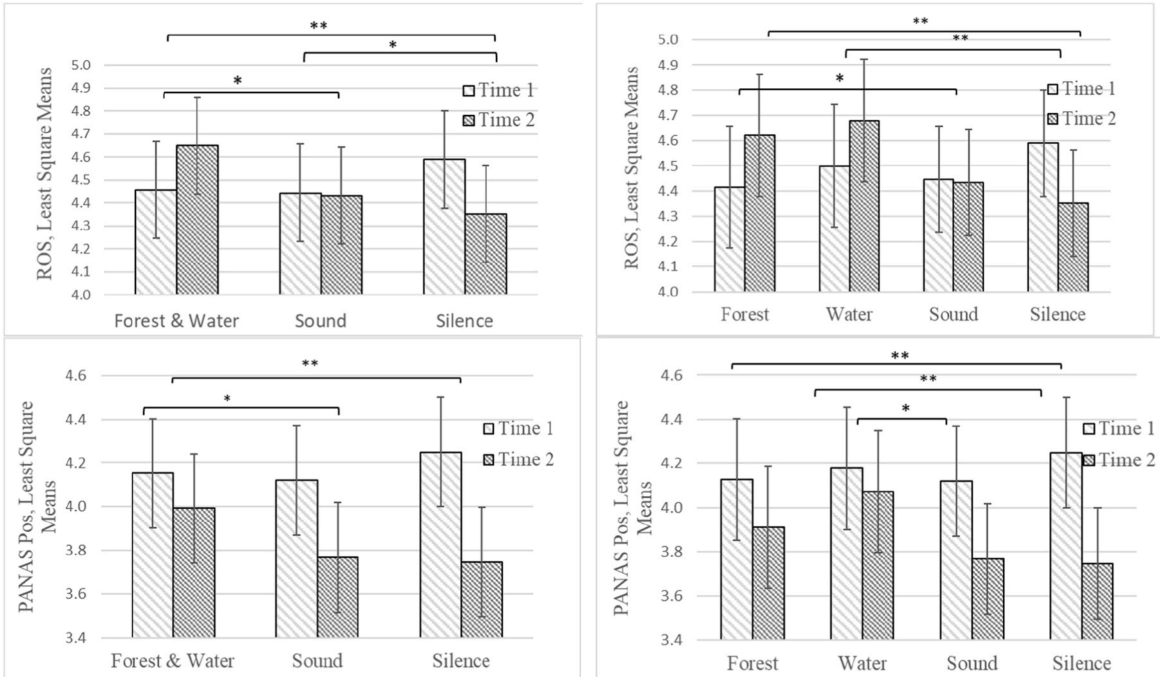

Fig. 3. The environment types and measurement time (before experiment (Time1) and after break periods (Time 2)) interaction graphs with mean values and 95% confidence intervals of the Restoration Outcome Scale (ROS) and Positive Affect subscale (PANAS Pos), where the forest and water video conditions are pictured together (left side) and then separately (right side). The connection lines above the bars describe statistically significant differences among predefined contrast comparisons, ***p <.01, *p <.05.*

environments have great potential to support human wellbeing, stress reduction, and relaxation (e.g., Browning et al., 2020; Mattila et al., 2020) and the best way to study this potential is in the environments where people live and work.

In this study, healthy full-time knowledge workers visited the Virtual Nature Room, a room intended for employee restoration with or without virtual material, nine times during their afternoon breaks. Based on the earlier studies (e.g. Annerstedt et al., 2013), we hypothesized that all the breaks, including control (silence) have stress relieving effects, but based on the condition with video and sound is the most effective, and the silence condition the least effective for stress recovery. We also had an exploratory question if the content of the video (forest or water) had different effects on stress recovery.

Overall, the measurements and the experimental plan used were also able to capture the small changes between the break options.

We found differences between the before and after measures. Confirming Hypothesis 1, the reduction of negative emotions and anxiety, and the increase of parasympathetic nervous activity indicated relaxation after breaks. However, the alert state and positive emotions were also lower after the experiment compared to the initial situation.

The results showing decreasing energy level and positive emotions were contrary to our hypothesis. One reason for the lower energy level might be the short duration of the break and that the increase in enthusiasm may take longer time. In the experiments with a real nature, the changes of mood towards more positive direction and the raise of energy level seem to be especially evident (e.g., Pasanen, Johnson, Lee, & Korpela, 2018; Tyrväinen et al., 2014), but not that clear when comparing virtual nature to real outdoor experience, and even a decrease of positive mood has been found (e.g., Calogiuri et al., 2018). In this study, lower energy level and positive mood, as well as anxiety and negative mood after the experiment appears to be associated with relaxation and calming down, which is also supported by the physiological results of this study. To study the mood changes in different types of virtual nature content and technological solutions, deserves definitely more attention in future studies.

In line with Hypothesis 2, watching the forest and water landscape videos with accompanying sounds best promoted recovery from work-related stress shown by increased felt restoration and decreased mean heart rate. These results are in line with previous research findings dealing with virtual nature (Annerstedt et al., 2013; Yu, Lee, & Luo, 2018). Perceived restoration has been found to verify differences between environments well also in previous field experiments (e.g., Tyrväinen et al., 2014). In this study, the forest and water environment videos with accompanying sounds were experienced as more restorative than the sound alone condition, as well as the silence condition after the experiment.

The other measure that detected differences in breaks was the positive emotions subscale from the PANAS positive and negative affects scale. Interestingly, the positive emotions diminished during all breaks, which was an unexpected result (we expected an increase in positive emotions). The diminishment of positive emotions may indicate the calming of an emotional state. On the other hand, positive emotions diminished less during video and sound in the forest and water conditions than in the sound alone and silence conditions. It may be that visual stimulation maintained the state of positive emotions more, as many of these emotions indicate an active and energetic mood. The mean heart rate during experiment supported the relaxation as it was lower during video break conditions compared to silence conditions however with a very small effect size. The mean heart rate was also slightly lower in the water video condition than in the audio and silence conditions.

No differences were found after resting in different break settings based on the measure energy and vitality (SVS), anxiety, and negative affects (PANAS Neg.).

There was also some support for Hypothesis 3, as there were significant differences between the nature sound alone and other break environments. The restorative and stress reducing effects were higher in the silence condition but smaller in nature video conditions in some measures. It therefore seems that a multisensory experience (video with sound) reduces stress better than presenting visual or audio material

Table 2
Main effects and interactions of all physiological models (degrees of freedom, F-test and level of significance).

Measure	Effect	*df*	*DenDF*	*F*	*p*
meanHR	Env.	3	229.06	3.514	.016
	Time	1	322.98	1147.273	.000
	Env.*Time	3	322.97	3.629	.013
	Sex	1	33.93	1.288	.264
	Age	1	33.92	1.151	.291
	Work stress	1	276.15	.181	.671
	Visit	8	212.14	.873	.540
RMSSD	Env.	3	250.74	2.399	.068
	Time	1	324.95	181.156	.000
	Env.*Time	3	324.93	1.753	.156
	Sex	1	33.92	.007	.933
	Age	1	33.91	2.492	.124
	Work stress	1	284.61	.920	.338
	Visit	8	228.52	.662	.724
SDNN	Env.	3	244.81	.986	.400
	Time	1	325.91	98.125	.000
	Env.*Time	3	325.88	.411	.745
	Sex	1	33.85	2.058	.161
	Age	1	33.84	6.869	.013
	Work stress	1	281.53	1.138	.287
	Visit	8	226.94	.657	.729
HF	Env.	3	250.11	2.504	.060
	Time	1	325.36	255.862	.000
	Env.*Time	3	325.34	.961	.411
	Sex	1	33.87	.036	.851
	Age	1	33.86	3.938	.055
	Work stress	1	283.18	.588	.444
	Visit	8	228.99	.594	.782
LF	Env.	3	243.24	1.751	.157
	Time	1	326.19	9.237	.003
	Env.*Time	3	326.15	.113	.953
	Sex	1	33.96	1.993	.167
	Age	1	33.95	7.790	.009
	Work stress	1	276.85	.002	.964
	Visit	8	227.24	.450	.889
HF.nu	Env.	3	257.86	3.652	.013
	Time	1	325.75	218.892	.000
	Env.*Time	3	325.72	1.714	.164
	Sex	1	33.89	4.286	.046
	Age	1	33.89	.002	.969
	Work stress	1	289.47	.274	.601
	Visit	8	236.32	.837	.570
LF.nu	Env.	3	253.70	4.943	.002
	Time	1	326.13	186.022	.000
	Env.*Time	3	326.10	1.193	.312
	Sex	1	33.80	2.213	.146
	Age	1	33.79	.034	.855
	Work stress	1	294.98	1.868	.173
	Visit	8	226.40	.649	.736

Note. Env. – environmental condition at the experiment; Work stress – subjective work stress level before the experiment; Visit – number of visits.

alone (e.g., Annerstedt et al., 2013).

4.1. Limitations of this study

The current study has some potential limitations. First, the conditions for the successful measurements may affect the results. For example, the partially reduced arousal after the experiment may also be due to the experimental plan, in which the subjects had to keep their eyes open because of the physiological heart rate variability measure. The instruction to keep the eyes open may have prevented relaxation, at least for some subjects.

Second, in our experimental plan, we did not have measures throughout the visiting period. We therefore did not know if there were any short- or long-time changes in relaxation and work quality when employees returned to their own workplace.

Third, the material used in the Virtual Nature Room was not shot exclusively for this study, and there were some limitations to making the final choices of video clips to be used in this experiment. This may explain the slightly different results between the forest and water environments. The forest video included less movement than the water video. In the forest video, there were moving branches, birds flying, and animals moving, but no constant movement (e.g., a stormy landscape) as in some of the water video clips (a stormy sea or a foaming waterfall).

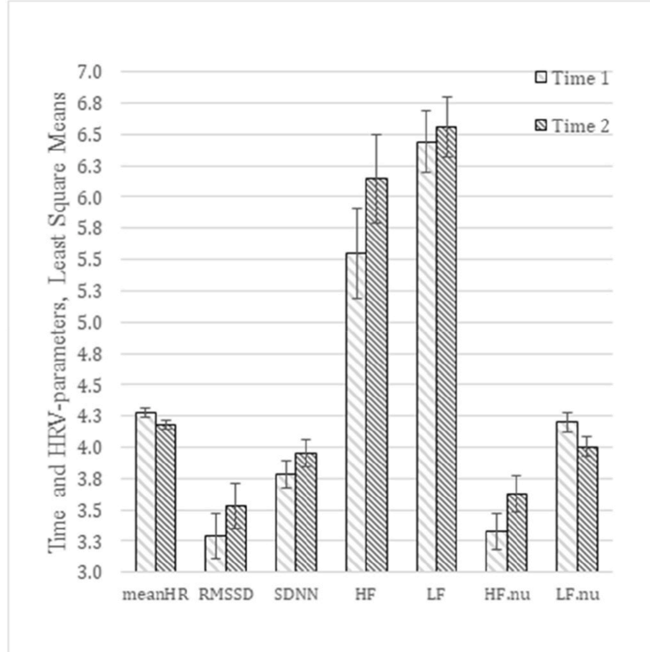

Fig. 4. Main effects of time (during work (Time1) and break periods (Time2)) on HRV measures (mean and 95% confidence intervals). The effect of Time is significant for all variables.

Fourth, we did not study stress relief based on individual differences and nature preferences. People may be differently sensitive to different environments. For example, in real environments, people's recovery from stress depends on their orientation towards urban or nature environments (Ojala, Korpela, Tyrväinen, Tiittanen, & Lanki, 2019), or people who are more stressed gain more from nature walks (Pasanen, Johnson, & Korpela, 2018). Moreover, preferences for and the suitability of virtual nature environments may also differ between individuals due to personal characteristics, previous nature experiences and expectations. In addition, the technological solutions and the content and quality of the presented video and sound material also defined the strength and effects of the nature experiences during the experiment. For example, viewing still images of different landscape types in Taiwan had different effects on brain region activity (measured by fMRI). The water and urban environment were the extremes. The water landscape was the most restorative, and the forest and mountain images were in the middle, based on their restorative effects (Tang et al., 2017). In the study by Yeo et al. (2020), positive affect was higher in the computer-generated condition with hand-held controller compared to TV screen video experience. With more advanced technologies such as creating larger immersive nature spaces with high quality projectors generating 360-degree environments, the use of augmented reality and/or the more suitable content of the nature videos meeting individual preferences and present needs may have an even stronger effect on the measured outcomes such as restoration.

Although the number of participants in this study was only 39, the study design with repeated measures (9 visits) resulted to high power (repeatability) to detect even small effects measured by Cohen's *d*. However, the replication of this study is important. The results with power higher than 0.90 should be replicable with identical study design and sample size (persons and repeated measures). The results with

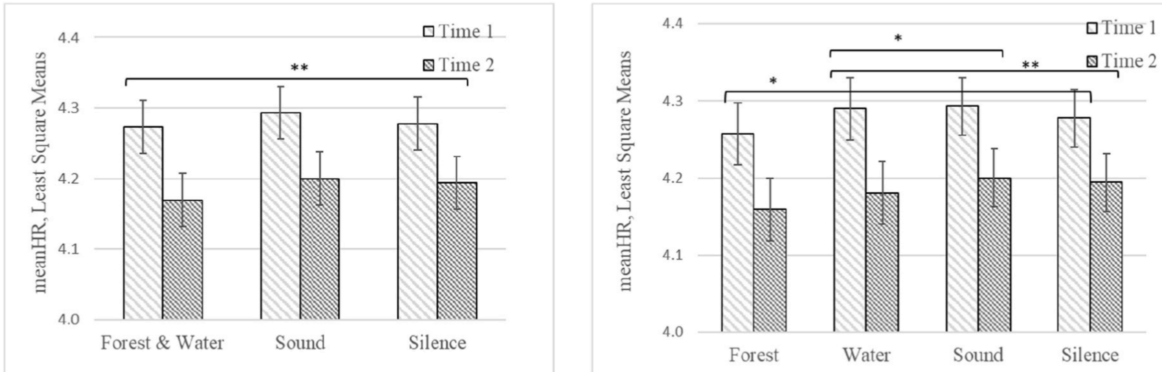

Fig. 5. The environment types and measurement times (during work (Time 1) and break periods (Time2)) interaction graphs with mean values and 95% confidence intervals of the mean HR where the forest and water video conditions are pictured together (left side) and separately (right side). The connection lines above the bars describe statistically significant difference among predefined contrast comparisons, $**p < .01$, $*p < .05$.

smaller power would need higher sample size given the effect truly exists.

4.2. Future perspectives

The current trend in the interior design of office workspaces is to reorganize the use of space more efficiently and save costs. This has led to a situation in which employees work close to each other, with less personal space and less frequent access, for example, to restorative window views. During Covid-19 pandemic, the number of employees suffering from fatigue and exhaustion has even increased (e.g., Magnavita, Soave, & Antonelli, 2021), the demands for restorative spaces in the work environments have therefore also increased. This experiment's outcome suggests that virtual nature environments can provide an innovative stress relief and restoration method during short breaks in places where people work (offices, homes, etc.), where nature is not easily accessible. Workers need regular breaks during the working day, but the options for breaks need to be easily accessible because of time constraints. Enhancing the recovery during the normal 15-min coffee or lunch breaks may therefore be an optimal method to help short-term recovery, which will result in greater resilience and better long-term recovery and stress management.

Our original plan was to make a follow-up study and to monitor the use of the Virtual Nature Room after the experimental period, but the relocation of the Virtual Nature Room made this plan impossible. We therefore could monitor the use of the Virtual Nature Room for only a short period. Although there were few users, the employees gave positive feedback and reported satisfaction with this environment. They had used the visual and auditory material during breaks, and some also used it in the background during their work. The long-term effects of such recreational rooms are a promising future study topic.

This study's experimental room was equipped with a somewhat inexpensive and simple technique. Currently, advanced technologies allow the creation of immersive nature environments indoors, and a virtual natural environment in the workplace could therefore also be an economically feasible way to improve office working conditions in the future. For example, the space for relaxation can be created in a coffee or meeting room, and it can be used for multiple purposes. The nature sounds could be used in the background while working, while having a meeting, and the room could be used alone or with a group. Ideally, the employee should be able to regulate the time, as well as the content of their break in the virtual nature space.

The research area is still in its infancy, suggesting an untapped potential in places other than work environments such as schools and the healthcare and social sectors. Accessing nature can sometimes be time-consuming and difficult, especially for individuals with physical disabilities.

A virtual nature environment could also be a retreat for workspaces with noise and visual disadvantages, such as factory environments, but this needs further study.

Moreover, visiting nature environments is typically associated with feelings of "being away" from everyday struggles and positive emotional reactions and stress reduction. A visit to a virtual nature room may mimic an ordinary recreational visit to nature, and lead the person away from working life stress and help them redirect their attention. Moreover, technological development and digitalization have opened cost-effective new ways to simulate the nature environment and create nature experiences indoors. Virtual nature solutions may therefore have a positive impact on society and real nature environments by helping urbanized people maintain connectedness with nature, psychologically reconnect with the natural world, and in the best case, even boost their interest in visiting nature (e.g., Litleskare et al., 2020).

In the future, it would be interesting to study the different content and methods of presentations of virtual nature in different environments and working contexts. It would also be interesting to explore the possibilities of virtual nature as a source of not only relaxation, but work creativity, inspiration, and enthusiasm. More information is also needed on how we can meet the needs of different individuals.

Credit authorship contribution statement

Ann Ojala: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - original draft, Visualization, Project administration, Funding acquisition. Marjo Neuvonen: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - original draft, Visualization, Funding acquisition. Mika Kurkilahti: Methodology, Formal analysis, Writing - original draft. Marianne Leinikka: Methodology, Formal analysis. Minna Huotilainen: Conceptualization, Methodology, Writing – Reviewing and Editing. Liisa Tyrväinen: Conceptualization, Methodology, Visualization, Writing – Reviewing and Editing, Project administration, Funding acquisition.

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Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2022.101909.

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