Empirical Article

A short simulated nature experience as an effective way to promote restoration from work-related stress

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Spending time in nature, and even watching images or videos of nature, has positive effects on one's mental state. However, cognitively stressful work is often performed indoors, in offices that lack easy access to nature during breaks. In this study, we investigated whether watching a 5-min audiovisual video that describes a first-person perspective walk on a forest path could help to restore one's mental state after cognitive stress. Participants were asked to perform cognitive stressor tasks, after which they were shown either a nature walk video or a control video. Subjective restoration was measured using self-reports before and after the videos, while electrodermal activity (EDA) and electroencephalography (EEG) were measured during the video-watching session. The results showed that experiencing the nature walk video enhanced subjective restoration more than watching the control video. Arousal of the autonomic nervous system, measured using EDA, decreased more during the nature walk video than during the control video. Additionally, activity in the EEG's upper theta band (6–8 Hz) and lower alpha band (8–10 Hz) increased during the nature walk video, suggesting that it induced a relaxed state of mind. Interestingly, the participants' connection with nature moderated the effects of the nature video. The subjective and physiological measures both suggest that watching a short, simulated nature walk may be beneficial in relaxing the mind and restoring one's mental state after cognitive stress.

Key words: Nature exposure, EDA, EEG, restoration, stress.

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INTRODUCTION

A large body of experimental studies has shown that exposure to nature or natural stimuli, such as nature images or videos, increases positive mood and relaxation while reducing stress and anxiety (Berto, 2005; Corazon, Sidenius, Poulsen, Gramkow & Stigsdotter, 2019; Shuda, Bougoulias & Kass, 2020). These effects have been explained from a psycho-evolutionary perspective, assuming that humans have adapted during evolution to living in natural environments and that current urban environments do not match such adaptation. The negative affective states evoked in urban environments are replaced by automatic activation of positive ones during exposure to natural stimuli (Stress Reduction Theory [SRT]; Ulrich, 1981; Ulrich, Simons, Losito, Fiorito, Miles & Zelson, 1991), or restoration occurs because natural stimuli capture bottom-up attention and allow directed-attention mechanisms to replenish (Attention Restoration Theory [ART]; Kaplan, 1995; Kaplan & Kaplan, 1989). Rapid urbanization (Leeson, 2018) affects mental health through social, economic, and environmental factors (Ventriglio, Torales, Castaldelli-Maia, De Berardis & Bhugra, 2021), and access to nature and its positive psychological effects becomes less accessible to many people. At the same time, digital technology and the services built on it form an increasingly central part of everyday activities and work. Professionals who do not work physically, such as office workers, researchers, programmers, and students, perform work that is relatively complex and may be cognitively stressful. This raises the need to develop solutions to reduce cognitive stress during workdays.

Taking breaks is an obvious way to prevent cognitive stress and promote restoration and relaxation during work or study days. It has been shown that a walk outdoors during a lunch break can promote restorative experiences for office workers (Johnsen, Brown & Rydstedt, 2022). A recent meta-analysis (Grassini, 2022) suggests that a walk in nature, compared with other environments, promotes mental well-being and reduces anxiety and depression. Even a 10-min nature walk may have positive psychological effects (Mayer, Frantz, Bruehlman-Senecal & Dolliver, 2009). However, not all people have easy access to nature. Information workers in urban environments typically work inside offices and cannot take short nature walks during working hours. In such cases, a short, simulated nature walk during breaks may be a promising alternative. For example, Brancato, Van Hedger, Berman, and Van Hedger (2022) found in an online study that a simulated 15-min walk through a pine forest was capable of increasing self-reported psychological well-being and raising feelings of restorativeness. In a study using a large (55-inch) TV screen, a 15-min video displaying a first-person simulated walk in a forest raised self-reported mood and restoration (Bielinis, Simkin, Puttonen & Tyrväinen, 2020).

The major theories explaining the restorative effects of nature exposure, SRT (Ulrich, 1981; Ulrich *et al.*, 1991) and ART (Kaplan, 1995; Kaplan & Kaplan, 1989), predict that a simulated nature walk might enhance restoration. These theories do not provide strict timelines for how quickly these effects can be observed. SRT assumes that exposure to natural stimuli elicits immediate positive emotions that counteract the negative ones and thus reduce stress. While the positive emotions are evoked immediately according to SRT, it does not specify how long exposure is needed for the positive emotions to reduce stress. Similarly, ART posits that exposure to nature helps in recovering from attentional fatigue, offering a release from the demands of focused attention that deplete cognitive resources, but it does not specify any amount of time for these restorative effects to occur. As the previous studies (Bielinis *et al.*, 2020; Brancato *et al.*, 2022) suggest, a 15-min simulated nature walk may be sufficient for the restorative effects to emerge. This study examines whether even a shorter, 5-min simulated nature walk video experience can have restorative effects after cognitive stress. A short, immersive simulated nature experience would be a beneficial tool to be used for restoration, for example, by workers who do not have access to real nature during working hours.

The restorative effects of the simulated nature walk were measured with a self-reported scale (Restorative Outcome Scale, Korpela, Ylén, Tyrväinen & Silvennoinen, 2008, 2010) and physiological measures. Self-reported restorative effects of watching nature have shown robust effects in meta-analysis, but the results with physiological measures have been inconsistent (Kondo, Jacoby & South, 2018). One limitation of studies using only subjective self-report scales is that such measures may be biased and subject to demand characteristics, favoring nature due to the "nature-positive bias" (Corazon *et al.*, 2019). To avoid this bias, we measured the effects of a simulated nature walk not only with subjective self-reports but also with physiological measures such as electrodermal activity (EDA) and electroencephalography (EEG), which are less susceptible to demand characteristics.

EDA is controlled by the sympathetic nervous system and is a widely used indicator of the activity of the autonomic nervous system (ANS), correlating with emotional arousal and attention. Thus, EDA can be used to measure physiological recovery after a cognitively loading task or stressful experience (Frumkin, Bratman, Breslow, *et al.*, 2017). Previous studies have revealed reduced EDA in response to exposure to natural stimuli (Alvarsson, Wiens & Nilsson, 2010; Elsadek, Liu & Lian, 2019; Hedblom, Gunnarsson, Iravani, *et al.*, 2019), but a reduction in skin conductance is not necessarily observed if no stressor task is performed prior to exposure (Browning, Mimnaugh, van Riper, Laurent & LaValle, 2020; Grassini, Segurini & Koivisto, 2022; Koivisto, Jalava, Kuusisto, Railo & Grassini, 2022). Here, we used cognitive stressor tasks to induce cognitive load and expected that skin conductance responses would be reduced during the virtual nature experience as the sympathetic nervous system recovers from cognitive stress.

The brain's activity in different frequency bands, measured with EEG, has been used to examine brain functional dynamics related to restoration and relaxation. Of the frequency bands (delta: 0.5–4 Hz; theta: 4–8 Hz; alpha: 8–13 Hz; beta: 13–30 Hz; and gamma: >30 Hz), the activity in the alpha band has been studied most frequently as it is related to a relaxed state of mind. The alpha waves are produced from postsynaptic potentials in a neural network associated with alertness and attention (Sadaghiani, Scheeringa, Lehongre, Morillon, Giraud & Kleinschmidt, 2010), involving the thalamus, dorsal anterior cingulate, anterior insula, and anterior prefrontal cortex. Previous studies have revealed that nature exposure with static pictures or video clips increases alpha activity (Sahni & Kumar, 2021; Ulrich, 1981), most clearly in the lower alpha band (Grassini *et al.*, 2019, 2022), confirming that simulated nature experiences produce a relaxed state of mind. In addition, viewing nature videos (Grassini *et al.*, 2022; Sahni & Kumar, 2021) or attributing a stimulus to nature (Koivisto *et al.*, 2022) have been reported to increase the theta power along with the alpha power. This pattern is similar to that observed during mindfulness (Lomas, Ivtzan & Fu, 2015) and meditation (Aftanas & Golocheikine, 2001; Lagopoulos, Xu, Rasmussen, *et al.*, 2009), suggesting that it is related to a relaxed yet alert state of mind.

Based on previous research (Grassini *et al.*, 2019, 2022; Koivisto *et al.*, 2022), we expected to observe greater band power in the upper theta band (6–8 Hz) and lower alpha band (8–10 Hz) during the nature walk condition compared with the control condition. We also predicted a reduction in skin conductance responses during the nature walk, indicating that the sympathetic nervous system recovers from cognitive stress (Frumkin *et al.*, 2017). Additionally, we explored whether participants in general benefit from nature exposure, or whether the potential restorative effects of nature exposure depend on individual factors, such as nature connectedness (Mayer *et al.*, 2009; Tam, 2013). Nature connectedness refers to how strongly individuals feel connected to the natural world and how strongly they include nature as part of their identity. It may mediate or moderate the effects of nature exposure on psychological well-being and emotions (Mayer *et al.*, 2009; McMahan, Estes, Murfin & Bryan, 2018; Pensini, Horn & Caltabiano, 2016). Thus, we expected that the stronger the nature connectedness, the greater the restorative effects of the simulated nature walk would be.

METHODS

Participants

This study involved 30 participants (11 females, 19 males). One of the participants withdrew from the study and was replaced with a new one. The average age of participants was 26 years, ranging from 18 to 38 years. They were volunteers recruited from the students and staff of Turku University of Applied Sciences. Because our statistical analyses used linear mixed effect models, the power calculations should ideally have been done with power simulations, but because of a lack of suitable previous or pilot data, we estimated the sample size prior to participant recruitment with G*Power simply by calculating the sample size needed for detecting partial eta squared effect sizes of 0.03–0.06 (smallish to medium size) in a 2 × 5 design, using a repeated-measures F-test with 80% power, an alpha level of 0.05, and high correlation (r = 0.7) between repeated measures. This procedure can give a ballpark estimate of the required sample size based on fixed effects, but its main limitation is that it does not consider the random effects that mixed-effects models handle. The sample size (n = 30) was expected to be sufficient for 80% power to detect smallish to medium effect size with an alpha level of 0.05, even in the case that a few participants' data would need to be rejected due to artifacts in the physiological data. The participants gave informed written consent before the study started. The study was conducted according to the Declaration of Helsinki and accepted by the Ethics Committee of Turku University of Applied Sciences. We confirm that we report all measures, all conditions, data exclusions, and how we determined the sample size. The datasets and R-scripts for statistical analyses are available at OSF.io: https://osf.io/4e7ds/.

Videos

The independent variable that was manipulated within participants was the type of video (nature walk vs. control). The simulated nature walk video was selected from the KorpiForRest pool of Korpi Moment nature experiences (https://vimeo.com/user125185467). The duration of the simulated nature walk was 5 min, and it was recorded in the Kytäjä-Usmi outdoor recreation area in Hyvinkää, Finland, during a summer day (Fig. 1). The video moves forward using a first-person perspective along the forest path, stopping a couple of times to look at the landscape. The soundscape was based on natural sounds recorded on the same site and thus aims for the most authentic experience possible. The video began with a so-called breathing exercise: The participants were asked to breathe calmly to the rhythm of the moving circle in the picture for 30 s. The video in the control condition was constructed from weather forecast videos and lasted for 5 min. The control video did not contain any nature elements, and any additional information banners were removed from it. We used watching weather forecasts as the control condition because it was associated with relatively neutral content and passive activity that resembles casual activities such as watching TV or video clips from the Internet, activities that information workers or students may perform during work or study breaks.

Stressor tasks

Digit span backward (DSP). The participants were presented with 10 series of digits, one at a time, through headphones in increasing length from three digits to seven digits. The task was to repeat each series backward, from the end to the beginning. The presentation speed was one digit per second. At the end of each series, a number pad appeared on the computer screen, and the answer was given by clicking the numbers in the numeric pad with the computer mouse. After the answer, the number pad disappeared, and the next series was presented through the headphones. The task started with two trials of three digits, followed by two trials of four digits, and so on until the longest two series contained seven digits; thus, the task became progressively more and more demanding. Normally functioning young or middle-aged adults can repeat backward about four or five digits correctly (Gregoire & Van der Linden, 1997), so the last trials (seven digits) should be cognitively very loading. Although digit span has also been used with varying results as an outcome measure in studies on nature exposure, in the present study, this task served only as a stressor task, and the performance results were not stored (observing differences between nature and control conditions probably requires exposure to real outdoor environments and a larger sample of participants; see Ohly, White, Wheeler, *et al.*, 2016).

Equations. The equation task was a 3-min speeded mental arithmetic task (similar to that of Alvarsson *et al.*, 2010). The participants were presented with equations visually (e.g., 45 – 12 = 33), and their task was to decide within 3 s whether each equation was correct or false. The responses were given with the left and right buttons of the computer mouse. After each equation, feedback was presented on the screen: "correct," "false," or "too late" (if the response was given after more than 3 s). The equations involved addition, subtraction, division, or multiplication tasks. Half of them were correct and half incorrect. Participants saw their overall performance (percent correct) continuously updated and displayed in the upper part of the screen.

Subjective self-report scales

The Restoration Outcome Scale (ROS; Korpela *et al.*, 2008, 2010) measured restorative experiences with six items. Three of the items reflected relaxation and calmness, one item reflected attention restoration, and two items reflected clearing one's thoughts. The participants were asked to rate how much they agreed with each item's statement about their feelings at the moment on a scale from 1 (*not at all*) to 7 (*totally*), so that the summary score could vary between 6 and 42. Cronbach's alpha for the ROS in the present data was 0.92 (calculated from the first pre-exposure ROS before the first video exposure). When the ROS was filled out after the videos (post-exposure ROS), there was an additional statement, "I experienced the [video] break as relaxing," which was rated using the same scale as the actual ROS items.

The Extended Inclusion of Nature in Self (EINS) scale (Martin & Czellar, 2016) measured self–nature connectedness. It consisted of four pictorial items (overlap, size, distance, and centrality), each with seven alternatives (min = 1, max = 7). The overlap item consisted of two circles. The overlap of the two circles varied between the seven alternatives from none to full. The alternatives in the size item consisted of seven circles symbolizing nature; their sizes varied. The distance item included two bars, one representing self and the other representing nature; the distance between the bars varied across the alternatives. The centrality item included a circle and a cross (representing nature and center), with the distance between the centers of the circle and cross varying between alternatives. For each item, the participants selected the alternative that best described their relationship with the natural environment. The summary score could vary between 4 and 28. Cronbach's alpha for the EINS in the present data was 0.72.

Experimental design and procedure

The experiment was run using a within-subjects design so that each participant took part both in the nature walk video exposure condition and

Fig. 1. The virtual nature experience was recorded at Kytäjä-Usmi nature trail near the city of Hyvinkää, Finland.

in the control video exposure condition. For simplicity, hereafter we refer to the exposure conditions as the nature and control conditions, respectively. The order of the conditions was counterbalanced across the participants: Half of them performed the nature condition first, followed by the control condition, whereas half performed the conditions in the opposite order.

After a 2-min quiet baseline period, during which the participants sat silently, the experimental conditions (i.e., nature and control) consisted of the following sequence of events: (1) stressor tasks (digit span backward and arithmetic equations), (2) measurement of restorative experiences (pre-exposure ROS), (3) watching the 5-min video, and (4) measurement of restorative experiences (post-exposure ROS). After both conditions were completed, a questionnaire measuring self–nature connectedness (EINS) was filled in.

After setting up the EDA and EEG electrodes, the experiment began with the baseline measurement. The participants were asked to sit silently and to avoid unnecessary movements for 2 min. The baseline measurement was followed by the stressor tasks. First, the participants performed the digit span backward task, which started with easy trials and became progressively more loading. After this task, the speeded equation stressor task was performed, followed by filling in the ROS scale (pre-exposure ROS). The participants were asked to respond to each item in the ROS according to their current feelings. After responding, the first 5-min video (either nature or control) was presented. After the video, the ROS scale was filled in again (post-exposure ROS). Then the same sequence of tasks, beginning from the stressor tasks, was completed with the exception that the participants who had seen the nature video saw the control video, and vice versa. The EINS scale was filled in at the end of the testing session. The whole session took about 35 min to complete.

A laptop computer (Hewlett Packard Zbook 17 G6) with iMotions 9.2 (iMotions A/S, Copenhagen, Denmark) software was used for presenting the stimuli and recording the responses. All the videos and psychological scales, as well as the task instructions, were presented on a large 65-inch TV (Samsung HG65EJ690UB) from a viewing distance of about 2 m. The resolution of the videos was 1920 × 1080 pixels. The auditory stimuli were presented through two Genelec 8040A speakers that were placed on both sides of the TV.

EDA recording and analysis

Electrodermal activity (EDA) was recorded using Shimmer3 GSR+ (Shimmer) with a 128 Hz sampling rate. The electrodes were placed on the top surfaces of the forefinger and middle finger of the non-dominant hand. The data was processed using Ledalab 3.4.9 software (Benedek & Kaernbach, 2010), running under MATLAB (v. R2021b; The MathWorks, Inc., Natick, MA, USA). Continuous Decomposition Analysis (CDA) was performed on the activity during the 5-min video conditions (nature, control). CDA decomposes the skin conductance data into slowly varying tonic activity (skin conductance level; SCL) and fast varying phasic activity (skin conductance response; SCR) (Benedek & Kaernbach, 2010). SCL is influenced by the overall activation of the sympathetic nervous system, and it represents the baseline level of sympathetic nervous system activity. SCL may be influenced, for example, by participants' fatigue or boredom, which may be a problem in within-subject experiments (such as the present one), in which every participant takes part in all the exposure conditions. This may cause a slow increase in the SCL throughout the test session. In contrast, SCRs are faster peaks measured over the SCL with a duration of only a few seconds; they are always measured in relation to the activity level immediately prior to and after them. SCRs can be elicited either by specific events or spontaneously. As SCRs are less influenced than SCL by the slow changes of the overall activity level across the conditions, we considered SCRs to be a more suitable measure of electrodermal activity in the present within-subjects experiment.

The EDA data was downsampled to 16 Hz and divided into 1-min periods; also, the mean activity during the baseline and equation tasks was analyzed to verify that the stressor tasks increased the skin conductance responses. A significant phasic peak (SCR) was detected if a local maximum had a difference of ≥0.01 μS from its preceding or following local minimum (Benedek & Kaernbach, 2010). The resulting independent variables were the number of skin conductance responses (nSCR) and the amplitude (μS) of SCRs; the higher the number or the amplitude of SCRs, the more arousal (i.e., stress in the present context) they indicate. The results of one of the participants had to be removed from the analyses, because the EDA responses were extremely low (no SCRs were detected, and the global EDA was below 0.2 μS). Square root transformations of the nSCR scores and log transformations of SCR amplitudes were used in the statistical analyses. The final sample in the EDA analyses consisted of data from 29 participants.

EEG recording and analysis

Electroencephalographic activity was measured using Nic 2.0 (Neuroelectronics)/iMotions 9.1 software and an Enobio8 amplifier (Neuroelectronics) with a 500 Hz sampling rate. Six scalp electrodes (F3, F4, C3, C4, P3, P4) were placed according to the 10–10 electrode system using a cap with NG Geltrode (Neuroelectronics) gel electrodes with Signa Gel (Parker). The signal was referenced online to the left ear. For artifact detection and correction, eye movements and blinks were recorded using two additional Ambu Blue Sensor M-OO-S electrodes (Ambu electrodes) placed about 2 cm to the right of the right eye and about 2 cm below it.

The EEG data was processed offline using the EEGLAB (v. 2021.1; Delorme & Makeig, 2004), running under MATLAB (v. R2021; The MathWorks, Inc., Natick, MA, USA). Data was downsampled to 256 Hz and high pass filtered at 1 Hz and low pass filtered at 40 Hz. Bad data periods were corrected with Artifact Subspace Reconstruction with a burst criterion of 20. Bad channels were interpolated using spherical interpolation. At this phase, the data from four participants had to be rejected from the analyses because they had in all the channels strong amplitude peaks that could not be removed or corrected (independent component analysis could not be done due to the small number of electrodes). In the next phase, the data recorded during the video exposures were divided into nature and control epochs, which both were further divided into five 1-min segments. The power of the lower alpha band (8–10 Hz) and upper theta band (6–8 Hz) in each of the segments was calculated with fast Fourier transform (FFT) performed on Hamming windows of 2 s with 50% overlap. Darbeliai plugin (Baranauskas, 2019) was used to calculate the absolute power (mean power in the six scalp electrodes). Log-transformed values were used in the statistical analyses.

Statistical analyses

The results were analyzed with R statistical software 3.5.0 (R Core Team, 2018), using the lme4 package (Bates, Mächler, Bolker & Walker, 2015) and lmerTest (Kuznetsova, Brockhoff & Christensen, 2017). The results were visually illustrated with the ggplot2 (Wickham, 2016) and sjPlot 2.4.1 (Lüdecke, 2019) packages.

First, the summary scores of ROS were analyzed with a linear mixed-effect model including Time (pre-exposure vs. post-exposure ROS), Condition (nature vs. control), and their interaction as fixed effects and random intercept for participants as a random effect. The same random effect structure was used consistently in all other analyses reported below as all the models converged with it.

In the analyses of EDA, we first compared the number of SCRs (nSCR/min) and the SCR amplitudes between baseline and equation tasks with a linear mixed-effect model including Condition as a fixed effect (baseline vs. equation task before nature condition vs. equation task before control condition). The effects of nature vs. control video exposure on nSCR and SCR amplitudes were analyzed as a function of time. For the EDA (and EEG analyses), we divided the 5-min exposure duration in both conditions into five 1-min periods to track the time course of the effects. We hypothesized that the restorative effects of video exposure would take some time to develop, with differences between the nature walk and control video conditions emerging toward the end of the exposure. Plotting the results as a function of time (from the 1st to 5th minute) suggested that the EDA responses in both outcome measures may have followed a curvilinear function. Therefore, we ran 2nd order polynomial linear mixed-effect models on the results. Condition (nature vs. control), Time (5), and their interactions served as the fixed effects. For both the number of SCRs and their amplitude, the Akaike information criterion (AIC) values suggested that the 2nd order (quadratic) model fit the data better than the 1st order linear model, so the results of the 2nd order models will be reported.

The effects of the video exposure condition (nature vs. control) on EEG, recorded during the viewing of the videos, were analyzed using the same procedure as the EDA data. The AIC values suggested that the 1st order linear model fit the data better than the 2nd order or 3rd order models, in both the upper theta and lower alpha bands. However, plotting the results as a function of time suggested that the function was not completely linear, but theta activity and lower alpha activity especially in the nature condition seemed to decrease during the 4th minute and then increase during the 5th minute. Therefore, the models were run also with Time as a factor (i.e., a categorical variable).

RESULTS

Restoration outcome scale (ROS)

In the nature condition, the mean pre-exposure ROS score was 25.7 ($SD = 7.7$) and the post-exposure ROS score was 27.5 ($SD = 7.5$). In the control condition, the mean pre- and post-exposure scores were 26.7 ($SD = 8.4$) and 25.1 ($SD = 8.2$), respectively. The first linear mixed-effect model compared pre-exposure ROS and post-exposure ROS scores in the nature and control conditions. Figure 2 shows the modeled results. The summary ROS scores in the nature and control conditions did not differ statistically significantly in the pre-ROS, $B = 1.067$, $SE = 0.824$, 95% confidence interval (CI) [−0.537 to 2.671], $df = 87$, $t = 1.30$, $p = 0.199$. In the nature condition, the ROS score was higher in the post-ROS than in the pre-exposure ROS, as suggested by the statistically significant effect of Time, $B = 1.867$, $SE = 0.824$, 95% CI [0.263 to 3.471], $df = 87$, $t = 2.267$, $p = 0.026$. Most important, the increase of ROS scores was statistically significantly higher in the nature condition than in the control condition (Condition[control]:Time[post]: $B = -3.500$, $SE = 1.165$, 95% CI [−5.768 to −1.232], $df = 87$, $t = -3.005$, $p = 0.003$).

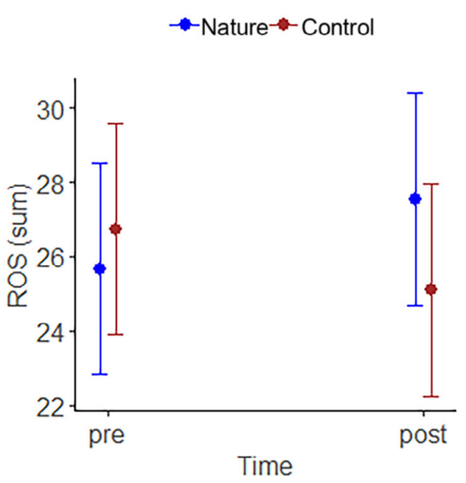

Fig. 2. Modeled summary scores of the Restoration Outcome Scale (ROS) before (pre) and after (post) the nature and control video exposure. Error bars represent 95% confidence intervals.

As a response to the question about how relaxing the participants found the video break to be, they rated it on a scale from 1 to 9 that the nature video ($M = 4.97$, $SD = 1.61$) was more relaxing than the control video ($M = 3.77$, $SD = 1.70$), $B = -1.200$, $SE = 0.419$, 95% CI [−2.031 to −0.369], $df = 29$, $t = -2.863$, $p = 0.008$.

Electrodermal activity (EDA)

To verify that the stressor tasks induced stress, operationalized as skin conductance responses, the activity during the baseline was compared with that during the equation task administered before the nature and control conditions (Fig. 3). The number of skin conductance responses (nSCR, square root transformed) was higher in the equation task conducted before the nature condition ($M = 22.9$, $SD = 14.1$), $B = 0.740$, $SE = 0.222$, 95% CI [0.305 to 1.175], $df = 56$, $t = 3.330$, $p = 0.002$, and before the control condition ($M = 23.1$, $SD = 13.9$), $B = 0.735$, $SE = 0.222$, $df = 56$, $t = 3.308$, $p = 0.002$, as compared with that in the baseline ($M = 17.2$, $SD = 13.9$). Similarly, the amplitude (log-transformed) was higher before the nature condition ($M = 0.13$, $SD = 0.13$), $B = 0.593$, $SE = 0.157$, 95% CI [0.285 to 0.901], $df = 56$, $t = 3.768$, $p < 0.001$, and the control condition ($M = 0.12$, $SD = 0.13$), $B = 0.545$, $SE = 0.157$, 95% CI [0.237 to 0.853], $df = 56$, $t = 3.463$, $p = 0.001$, as compared with that in the baseline ($M = 0.08$, $SD = 0.09$).

The observed number of skin conductance responses (average number per minute) and their amplitudes during the nature and control conditions as a function of Time and Condition are presented in Table 1 and illustrated in Fig. 4. For the number of SCRs in the nature condition, there was a quadratic trend, $B = 4.314$, $SE = 1.922$, 95% CI [1.351 to 6.645], $df = 256$, $t = 2.245$, $p = 0.026$, and the trend in the control condition did not differ from that in the nature condition, $B = -0.787$, $SE = 1.922$, 95% CI [−4.530 to 2.957], $df = 256$, $t = -0.409$, $p = 0.683$. Thus, the number of SCRs first decreased and then stayed constant. However, the 1st order (linear) trend interacted with Condition, $B = 4.3142$, $SE = 1.9215$, 95% CI [−9.766 to −4.472], $df = 256$, $t = 2.245$, $p = 0.026$, suggesting that decrease of SCRs was larger in the nature condition. To study in more detail the difference in the shape of the curves between the conditions, we modeled the early time period (from the 1st to 3rd minute) and late time period (from the 3rd to 5th minute) separately. The conditions did not differ in the early period, $B = -0.057$, $SE = 0.150$, 95% CI [−0.351 to 0.237], $df = 142$, $t = -0.379$, $p = 0.706$. However, in the late period, the control condition elicited more SCRs than the nature condition, $B = 0.329$, $SE = 0.144$, $df = 142$, $t = 2.281$, $p = 0.024$.

For SCR amplitudes, there was a quadratic trend in the nature condition, $B = 3.728$, $SE = 0.863$, 95% CI [2.047 to 5.409], $df = 256$, $t = 4.321$, $p < 0.001$, showing that the SCR amplitudes first decreased as a function of time and then stayed constant. The results in the control condition did not differ from those in the nature condition in the quadratic trend, $B = -1.350$, $SE = 1.220$, 95% CI [−3.727 to 1.028], $df = 256$, $t = -1.106$, $p = 0.270$. The 1st order polynomial Time by Condition interaction was statistically significant, $B = 3.495$, $SE = 1.220$, 95% CI [1.118 to 5.873], $df = 256$, $t = 2.865$, $p = 0.005$, suggesting that the linear

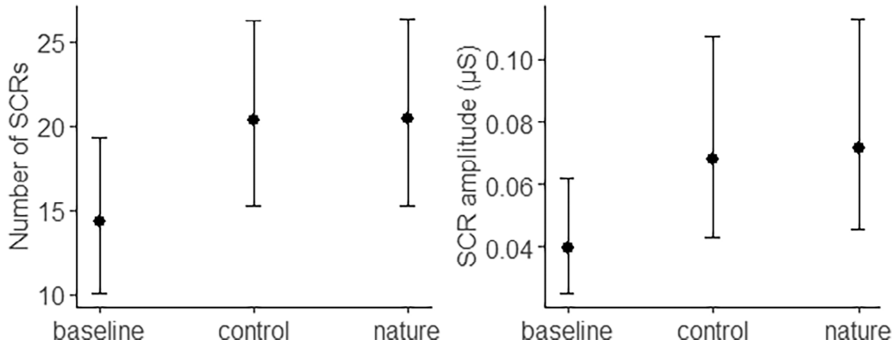

Fig. 3. Modeled median number of skin conductance responses per minute (left) and their amplitude (right) during the baseline and the stressor (equation) task before control and nature conditions. Sqrt- and log-transformed responses have been back-transformed to the original scale. Error bars represent 95% confidence intervals.

Table 1. *Means and standard deviations for the number of SCRs (n = 29), SCR amplitude (n = 29), upper theta band power (n = 26), and lower alpha band power (n = 26)*

		Number of SCR		SCR amplitude		Theta power		Alpha power	
Condition	Time (min)	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	1	20.62	18.06	0.10	0.13	4.41	1.5	3.4	1.23
	2	17.21	18.47	0.07	0.09	4.54	2.72	3.44	1.48
	3	17.86	17.91	0.08	0.12	4.53	2.36	3.57	1.66
	4	17.28	18.84	0.08	0.10	4.16	2.17	3.48	1.48
	5	17.79	16.35	0.10	0.16	4.67	2.57	3.37	1.18
Nature	1	21.97	15.94	0.13	0.14	4.09	1.51	3.32	1.33
	2	17.10	15.89	0.08	0.11	4.68	2.99	3.76	2.02
	3	15.86	17.72	0.08	0.11	4.7	2.78	3.76	1.89
	4	14.52	17.12	0.08	0.14	4.39	2.02	3.44	1.41
	5	15.38	16.01	0.09	0.13	5.72	4.71	4.13	1.97

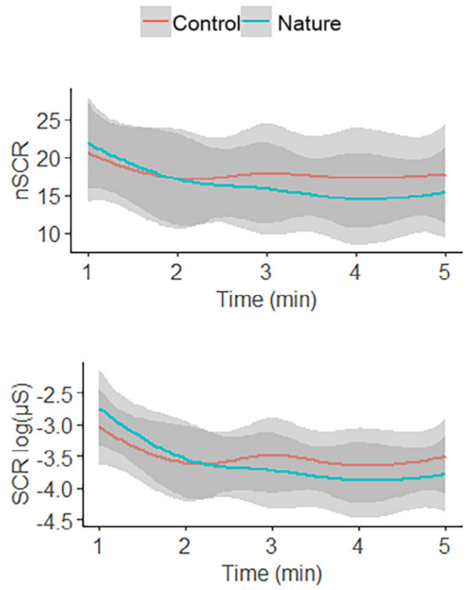

Fig. 4. The observed number of skin conductance responses (nSCRs; upper panel) and their amplitudes (lower panel) from the 1st minute to the 5th minute during the nature and control conditions. The shaded areas represent 95% confidence intervals.

decrease of amplitudes was steeper in the nature condition than in the control condition. To reveal where the difference in the number of SCR amplitude occurred between the conditions, we modeled the early time period (from the 1st to 3rd minute) and late time period (from the 3rd to 5th minute) separately. The difference between conditions was not statistically significant in the early period, $B = -0.040$, $SE = 0.092$, 95% CI [−0.220 to 0.141], $df = 142$, $t = -0.431$, $p = 0.6670$. In the late period, the SCR amplitudes were larger in the control than in the nature condition, $B = 0.252$, $SE = 0.090$, 95% CI [0.077 to 0.427], $df = 142$, $t = 2.805$, $p = 0.006$.

EEG

Figure 5 plots the spectral power in the nature condition (upper panel) and in the control condition (lower panel) as a function of the time period. Visual inspection of the upper panel suggests that there were power differences between the time periods in the nature condition in the upper theta band and in the lower alpha band (i.e., between 6 and 10 Hz), with the power being the highest during the last (5th) minute of exposure. The results in the control condition (lower panel) did not show any similar pattern. Thus, it seems that the changes in the brain's electrophysiological

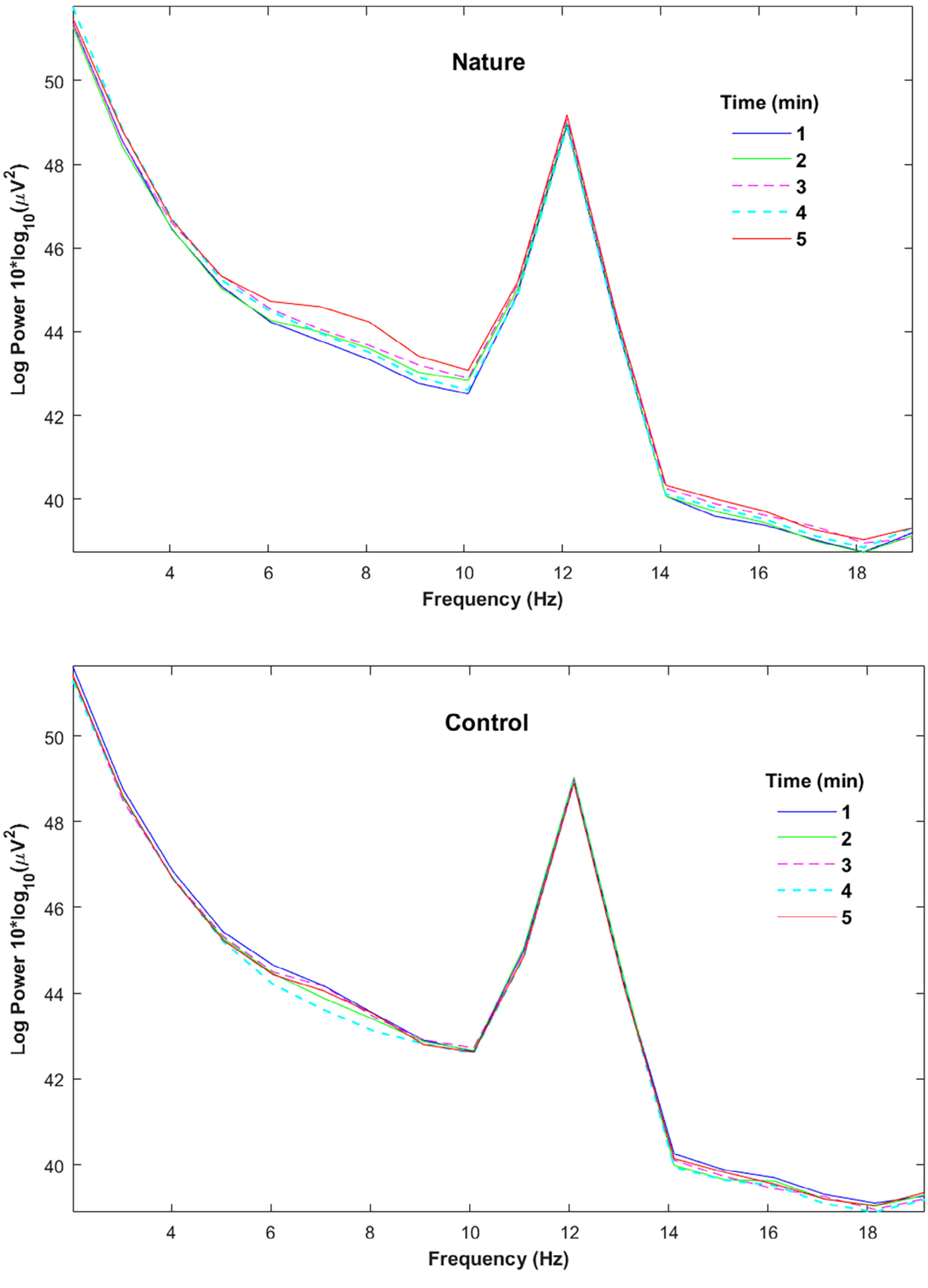

Fig. 5. Average spectral power in the nature condition (upper panel) and control condition (lower panel) from the 1st to the 5th minute during the video exposure.

activity during watching the nature video occurred in the frequency bands where they were expected based on the previous studies that tested specifically the upper theta and lower alpha bands during nature exposure (Grassini *et al.*, 2019, 2022; Koivisto *et al.*, 2022). Next, we tested whether or not the differences in band power were statistically significant between the nature and control conditions.

Figure 6 plots the observed power in the upper theta band and lower alpha band as a function of Time and Condition. The 1st order polynomial (linear) model fit the data better than the 2nd and 3rd order models in both frequency bands. For the upper theta band, the 1st order model suggested a linear increase of theta power as a function of time in the nature condition, B = 0.900, SE = 0.272, 95% CI [0.368 to 1.431], df = 231,

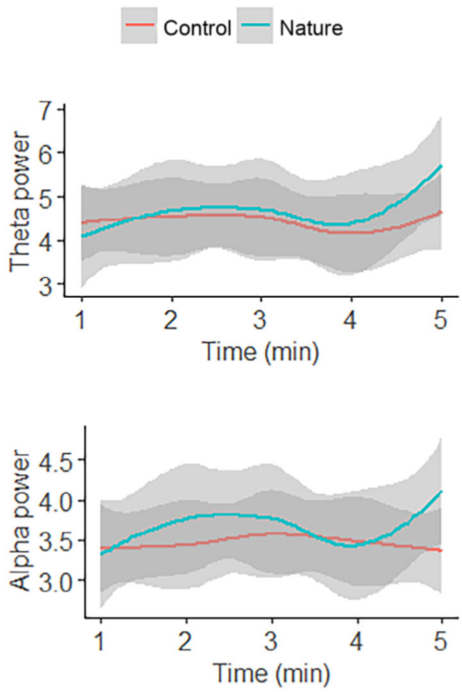

Fig. 6. Observed band power in the upper theta band (upper panel) and lower alpha band (lower panel) as a function of time. The shaded areas represent 95% confidence intervals.

$t = 3.313$, $p = 0.001$. This increase was stronger in the nature condition than in the control condition, as suggested by the Time × Condition interaction, $B = -1.019$, $SE = 0.384$, 95% CI [−1.770 to −0.268], $df = 231$, $t = -2.654$, $p = 0.009$. However, because the results in the 4th minute seem to deviate from the linear relationship (Fig. 6 suggests a decrease of power in both conditions), we analyzed the upper theta activity also by scoring Time as a factor (i.e., a categorical variable). The Time × Condition interaction was statistically significant in the 4th minute, $B = -0.148$, $SE = 0.075$, 95% CI [−0.292 to −0.004], $df = 255$, $t = -1.978$, $p = 0.049$, and in the 5th minute, $B = -0.192$, $SE = 0.075$, 95% CI [−0.336 to −0.048], $df = 255$, $t = -2.572$, $p = 0.011$, confirming that the upper theta activity differed between the conditions in the last minutes of the video exposure.

For the lower alpha band, the linear trend was statistically significant in the nature condition, $B = 0.727$, $SE = 0.254$, 95% CI [0.230 to 1.225], $df = 231$, $t = 2.858$, $p = 0.005$. In addition, the Time by Condition interaction was statistically significant, $B = -0.788$, $SE = 0.360$, 95% CI [−1.492 to −0.084], $df = 231$, $t = -2.190$, $p = 0.030$. These results suggest that alpha power increased as a function of time more in the nature condition than in the control condition. However, closer inspection of Fig. 6 (lower panel) suggests that the increase of power was not strictly linear, but the results in the 4th minute seemed to deviate from the linear trend. Therefore, we scored Time as a factor (i.e., a categorical variable) and ran a linear mixed-effect model with both Time and Condition as factors. It revealed Time × Condition interactions only in the 5th minute, $B = -0.191$, $SE = 0.070$, 95% CI [−0.321 to −0.042], $df = 225$, $t = -2.717$, $p = 0.007$, suggesting that in the last minute of the videos, alpha power was higher in the nature than in the control condition, $t(225) = 3.14$, $p = 0.002$.

Nature connectedness

Finally, we explored whether nature connectedness (EINS) would predict the differences between the nature and control conditions. We repeated the models on ROS, EDA, and EEG, which were described above, with the addition that centered EINS scores (a continuous variable) with their interactions were included as fixed effects. Here we report only the statistically significant interactions including EINS (centered summary score) as a variable (Fig. 7 presents the modeled results).

The analysis of the ROS scores (Fig. 7, upper panel) revealed two interactions involving EINS. First, the higher the EINS score, the larger was the increase of post-exposure ROS scores in relation to the pre-exposure ROS in the nature condition, $B = 1.200$, $SE = 0.792$, 95% CI [0.481 to 3.512], $df = 84$, $t = 2.521$, $p = 0.014$. Second, the higher the EINS score, the larger was the difference between the nature and control conditions in the post-exposure ROS, as compared with that in the pre-exposure ROS, $B = -3.013$, $SE = 1.120$, 95% CI [−5.157 to −0.870], $df = 84$, $t = -2.690$, $p = 0.009$.

For SCR amplitudes (Fig. 7, lower panel), the interaction between Condition and EINS was significant, $B = 0.166$, $SE = 0.071$, 95% CI [0.028 to 0.304], $df = 251$, $t = 2.322$, $p = 0.021$. This finding suggests that the higher the EINS score, the larger was the amplitude difference between the nature and control conditions. In other words, especially the participants with higher than average nature connection tended to respond with lower SCR amplitude to the nature video than to the control video, whereas the participants with low nature connectedness showed little difference in their responses to the two types of videos.

For the number of SCRs, the results resembled those of SCR amplitudes, but the only effect approaching statistical significance was the interaction between Condition and EINS, $B = 0.204$, $SE = 0.113$, 95% CI [−0.014 to 0.421], $df = 251$, $t = 1.807$, $p = 0.072$.

Analysis of the upper theta power and the lower alpha power did not detect any statistically significant interactions including EINS and Condition as fixed effects ($p > 0.24$ in polynomial or linear models). One should note that the EEG analyses were based on a smaller sample size ($n = 26$) than the analyses of ROS ($n = 30$) and SCR ($n = 29$).

DISCUSSION

The effects of a short, 5-min simulated nature walk on cognitive stress restoration were tested in this study. Our hypothesis was that this nature walk would lead to increased self-reported restoration, decreased sympathetic nervous system activity measured through SCRs, and increased brain activity in the theta and alpha frequencies, indicating a relaxed state of mind. All of our hypotheses were supported, as self-reported restoration was higher after the simulated nature walk than before it, and this effect was different from that in the control condition. Additionally, the number and amplitude of SCRs decreased more

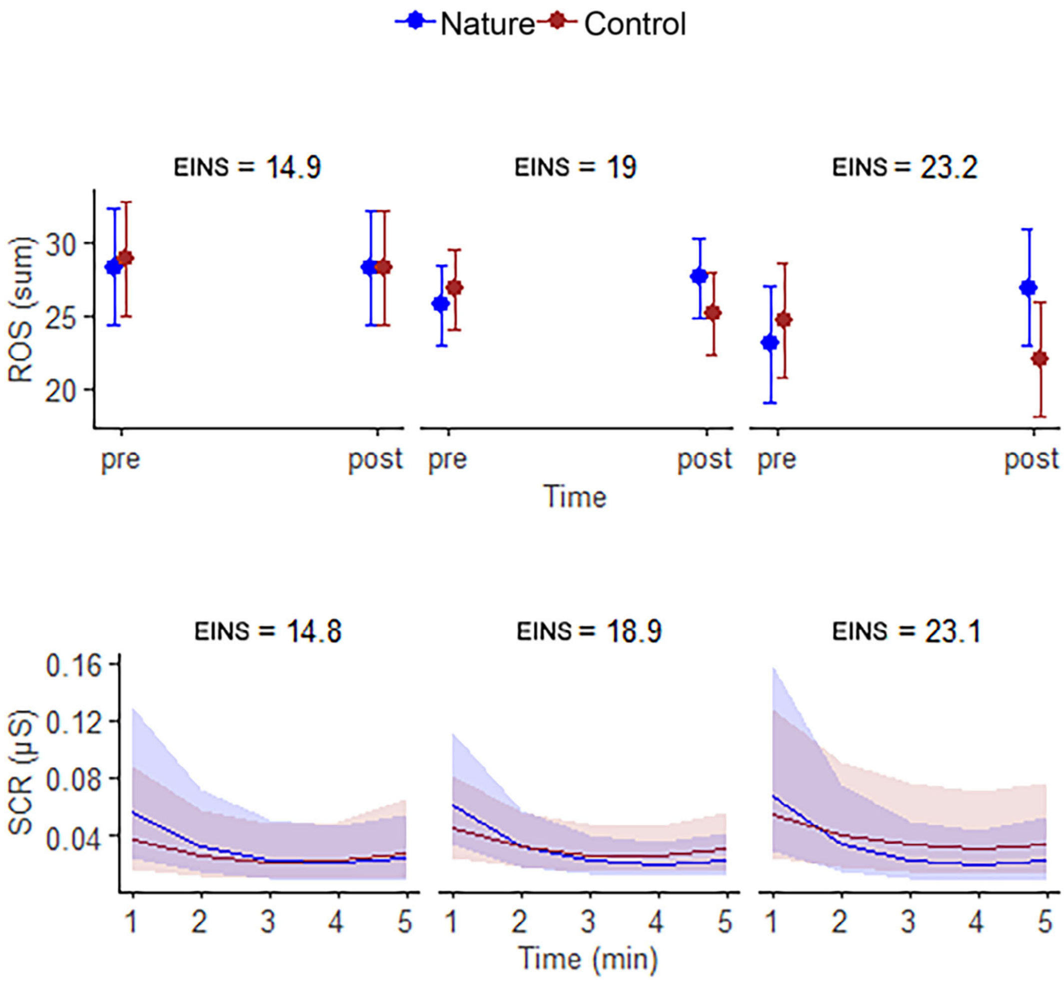

Fig. 7. Nature connectedness (EINS) and the exposure condition (nature vs. control) as predictors of the ROS summary score (upper panel) and the amplitudes of skin conductance responses (SCR, lower panel). The panels in the center show the modeled results for the centered mean of EINS score, whereas the left and right panels display the results when the EINS score was 1 *SD* lower or 1 *SD* higher than the mean, respectively. The error bars and shaded areas represent 95% confidence intervals.

during the simulated nature walk than during the control condition, and upper theta and lower alpha activity increased during the simulated nature walk more than during the control condition. Thus, the present study supports, with both subjective and objective physiological measurements, the idea that a relatively short simulated nature experience (for example, during work breaks) is a useful way to temporarily relax and promote restoration from cognitively demanding tasks.

Time had an effect on the physiological measures, as the effects of the simulated nature exposure took some time to develop. The SCRs started to decrease in both conditions similarly during the first few minutes of the exposure, but the decrease was stronger in the nature walk condition, and the differences between conditions emerged after 3 min. The time course for EEG was less clear, as in the 4th minute there seemed to be a decrease in both theta and alpha activity specifically in the nature condition, and then the activity in both bands increased again in the 5th minute. Although the statistical analyses indicated a significant linear interaction between time and exposure condition, the time course of the band power increase did not look linear in the nature walk condition. A possible explanation for the 4th minute's power decrease may be that during the 4th minute of the nature walk, the camera stopped for a longer time than usual during the video and presented a static view toward a lake, while the soundscape was at the same time dominated by the sound of a cuckoo. However, it is not possible to reach any firm conclusions about the source of the decrease based on the present design, and it also remains unclear why the studied frequency bands showed a decrease rather than an increase in power. In any case, the results suggest that the physiological effects of viewing the nature walk occur within 3 to 5 min after the onset of exposure.

Previous studies have reported increased alpha activity during nature exposure (Chang, Hammitt, Chen, Machnik & Su, 2008; Ulrich, 1981), but they have not tried to distinguish between lower and upper alpha activity. The finding that specifically the lower alpha band shows increased power during the nature condition in this study replicates the finding of Grassini *et al*. (2022), who observed power increase in the lower alpha band during viewing of nature videos for 12 min, as compared with viewing urban or neutral videos. In an earlier study, Grassini *et al*. (2019) found increased lower alpha activity, but not higher alpha activity, during watching photos depicting natural environments, as compared with watching urban photos. In addition, an ambiguous sound (pink noise), whose source was attributed to nature, increased lower but not higher alpha band power in relation to attributing the source of the sound to industry (Koivisto *et al*., 2022).

The results of the present study revealed that simulated nature walks not only enhanced relaxation and lower alpha activation but also increased the upper theta power. Similar findings were reported by Sahni and Kumar (2021) and Grassini *et al*. (2022), who found that watching nature videos increased both alpha and theta power. Moreover, relaxation techniques such as mindfulness (Lomas *et al*., 2015) and meditation (Aftanas & Golocheikine, 2001; Lagopoulos *et al*., 2009) have been found to increase alpha and theta power, indicating a relaxed and positive emotional state. Thus, virtual nature experiences and watching nature in general appear to produce a similar state of relaxation and alertness observed during mindfulness or meditation.

Additionally, we investigated whether an individual's nature connectedness (EINS) was related to the restoration experienced. Our findings showed that nature connectedness moderated self-reported restoration (ROS), with higher connectedness resulting in more restoration compared with the control condition. Similarly, the activity of the sympathetic nervous system during a simulated nature walk decreased more in highly connected participants than in those who were weakly connected. However, nature connection did not moderate the effects observed in the EEG's theta and alpha bands. These moderation results should be considered preliminary due to the small sample size, because reliable detection of correlative relationships usually requires a relatively large sample.

One strength of the study is that it avoided the "nature-positive bias" by using a combination of self-reports and two types of physiological measurements. Although some of the effects were only slightly below the threshold of statistical significance, the results from all the outcome measures (ROS, EDA, EEG) converge on the same conclusion, suggesting that a short virtual nature experience can aid in reducing stress and easing the mind. In this study, the positive effects of a virtual nature experience were observed using a two-dimensional audiovisual setup. Although three-dimensional virtual natural environments are more immersive (Slater & Wilbur, 1997), two-dimensional virtual nature experiences (e.g., on large TV or computer screens) are currently a viable alternative (Yeo, White, Alcock, *et al*., 2020) due to the limited availability of virtual reality devices and the virtual reality–associated symptoms (such as nausea, dizziness, or loss of balance) in some individuals.

A limitation of the current study is that only one example of nature videos was used. Previous work using self-reports suggests that there may be differences in the restorative effects between different subtypes of natural (or urban) environments (Brancato *et al*., 2022). In addition, the differences in restoration observed between nature and control conditions may depend on the type of the control condition. Here we used forecast videos as a control, which was thought to be a "neutral" and equally passive condition in comparison with the nature condition video. It was considered to be a better choice than an urban walk video, as urban exposure might have induced negative feelings (Brancato *et al*., 2022). In any case, we observed in the nature walk condition that its effects evolved as a function of time between the pre- and post-exposure tests, as indicated by the increase in the subjective ROS score and alpha and theta power and in a decrease of skin conductance responses, which did not happen in the control condition. Another limitation in our design was the lack of cognitive outcome measures. Therefore, it is not clear whether the subjective and physiological restoration from cognitive stress was accompanied also with improvement in cognitive performance. The effect sizes in cognitive performance measures, such as the digits span backward, are typically small (Ohly *et al*., 2016), and hence the experiments aiming to show that viewing nature improves performance require a large sample of participants and perhaps also exposure to real nature. Thus, the laboratory experiments using virtual nature typically may be underpowered to detect the effects in performance due to relatively small sample size, short exposure duration, and lack of immersion comparable to that in real nature. In the present study, the digit span backward could have been used as a performance measure, but it served only as a stressor task and its results were not recorded.

The nature video began with a half-minute breathing exercise, posing a potential confounding factor between the nature and control conditions. It remains challenging to definitively isolate its effects on the outcomes, leaving uncertainty about which elements in the nature video drove the observed differences between the conditions. Initial physiological data from the 1st minute of exposure did not present any evidence favoring the nature condition over the control. In fact, the average number and amplitudes of skin conductance responses (SCR) were marginally higher in the nature condition, though not to a statistically significant extent. This observation does not support the hypothesis that the breathing exercise alone accounted for the reduced physiological stress or arousal in the nature condition compared with the control condition, a disparity that manifested only after 3 to 5 min of exposure. Furthermore, the observation that the disparity in restorative effects between the nature and control conditions, as measured by self-ratings and SCR, was most pronounced among participants with above-average nature connectedness implies that the natural elements in the nature condition contributed to the differences observed. Had the breathing exercise been the sole influencer, one might expect participants with lower nature connectedness to exhibit a similar level of restoration. Nonetheless, the videos differed in numerous aspects, as do the potential activities workers may undertake during work breaks. Our primary objective was to evaluate the effectiveness of the short virtual nature walk video as a restorative break option during work hours.

In conclusion, this study provides converging evidence from self-reports as well as measurements of autonomic nervous activity and brain activity supporting the use of simulated nature experiences for stress reduction in office workers or students who engage in cognitively demanding work. This implies that office workers or students who are doing cognitively loading work could reduce their stress with the aid of relatively short audiovisual nature experiences. Such experiences could be used individually with digital devices or in break rooms equipped with audiovisual facilities at offices and schools to provide a relaxing pause during stressful days.

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CONFLICT OF INTEREST

Mikko Pohjola is one of the founders of Korpi Solutions Oy, which is the company that owns and develops Korpi(r) Moments and Korpi(r) ForRest stress management software.

ETHICS APPROVAL

The study was conducted according to the Declaration of Helsinki and accepted by the Ethics Committee of Turku University of Applied Sciences.

PARTICIPANT CONSENT STATEMENT

The participants gave informed written consent before the study started.

DATA AVAILABILITY STATEMENT

The datasets and statistical analysis scripts are available at OSF.io: https://osf.io/4e7ds/.

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