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Psychophysiological recovery from viewing nature and urban settings: A multisite replication

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ABSTRACT

The idea that merely viewing nature can promote stress recovery has profound societal implications, driving the use of nature imagery in the design of environments where access to real nature is limited. Scientific support for this concept originates from a pioneering study by Ulrich et al. (1991), which demonstrated superior psycho-physiological stress recovery during exposure to nature videos compared to urban videos. Despite its influence, this foundational study has never been systematically replicated. To address this gap, ten research teams across the Netherlands, Belgium, the UK, Sweden, and the USA collaborated on a multisite replication. A final sample of 959 participants (49% women, 51% men, mean age 22 years) were exposed to a 10-minute stressful video followed by viewing a video one of six environments: natural settings (forest or stream), urban pedestrian areas (quiet or busy), or urban traffic areas (quiet or busy). Affective states (ZIPERS; Zuckerman, 1977) were measured at baseline, post-stressor, and post-environmental video, while sympathetic (SRC, PEP) and parasympathetic (RMSSD, RSA) responses were continuously recorded using the VU-AMS device. Results partially confirmed the original findings that psychological recovery was greater for the natural conditions. For physiological measures, only parasympathetic responses showed consistency with the original study in promoting greater initial recovery. Unexpected differences were observed between the two nature videos, potentially due to the loud noise of fast-streaming water in one video. In general, this multisite experiment supports the psychological relevance of nature imagery for stress recovery, while highlighting important nuances in physiological responses.

1. Introduction

A visit to nature is widely recognized as a way to relieve stress. Perhaps more counterintuitively, research suggests that even simply viewing nature imagery can already support recovery. One of the earliest and most influential controlled experiments to demonstrate this effect was conducted by Ulrich et al. (1991) who showed that viewing videos of natural, compared to urban, settings promotes recovery from

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psychological and physiological stress. Subsequent research has built on these findings, indicating powerful mood enhancing and stress-relieving impacts of viewing nature imagery (De Kort et al., 2006; Laumann et al., 2003; Staats et al., 1997; Van den Berg et al., 2003). More recently, a growing body of work has examined the stress-relieving benefits of actively engaging with real nature through nature-based interventions (e.g., Silva et al., 2024) and hands-on, active sensory engagement with wildlife for both children and adults (Richardson et al., 2022; Wyles et al., 2019). While important, these advances risk diverting attention from the practical health applications of simulated nature as a valuable tool for promoting well-being and relieving stress in environments with limited access to real nature, including institutional settings (hospitals, nursing homes, prisons, schools), public areas (train stations, airports), work environments (offices, distribution centers), and commercial spaces (restaurants, shopping malls) (Gillis & Gatersleben, 2015; Nadkarni et al., 2017; Pati et al., 2016).

Given the considerable impacts of Ulrich et al. (1991), it is timely to revisit the empirical robustness of the original study. In early stages of a research field, when the number of empirical studies is still limited and systematic replication is uncommon, knowledge development necessarily relies more heavily on findings from individual studies. In such contexts, conclusions are more vulnerable to limitations in fidelity and robustness that may only become apparent as the evidence base expands. This vulnerability is further amplified by factors such as publication bias favoring confirmatory results. Replication is therefore particularly important in the present case because (a) the original study was published in the early years of research on nature and health, (b) has been highly influential but never directly replicated, (c) later studies have reported variable results, particularly for physiological measures, and (d) technological advances since the publication of the study allow for more precise measurement.

The original study was conducted in the late 1980s and some materials are no longer available, which means an exact replication was not possible. Our aim was therefore a high-fidelity replication that adhered as closely as possible to the original design while updating stimuli and physiological measures to modern standards (Ioannidis, 2005). In light of the above concerns, testing the robustness of original research through independent replication is crucial. One of the most effective approaches is a multisite replication, where several research teams repeat the procedures of an original study as closely as possible with a new sample to determine whether similar results can be obtained (Hagger et al., 2016; Klein et al., 2014). In this article, we report a multisite study that was designed to replicate Ulrich et al.'s (1991) influential findings.

1.1. *Restorative effects of viewing nature imagery: the Ulrich et al. (1991) study*

One of the reasons why Ulrich et al.'s (1991) paper has been highly impactful is that it not only provided an empirical study of stress-relieving effects of nature imagery, but also a theoretical account of how these effects may come about. Building on earlier ideas on aesthetically pleasing nature (Ulrich, 1983, 1986), the authors presented Stress Reduction Theory (SRT), which, along with Attention Restoration Theory (Kaplan & Kaplan, 1989), continues to be a leading framework in research and practice on the health benefits of nature (Bornioli & Subiza-Pérez, 2023; White et al., 2023). SRT proposes an evolutionary basis for humans' positive responses to natural environments (cf. Joye & Van den Berg, 2011). Familiar, safe, and resource-abundant natural settings provided survival benefits for pre-human ancestors, leading to a predisposition to favor such environments. In contrast, human-made environments were uncommon in evolutionary history, and no similar predisposition is thought to have evolved.

Ulrich et al. (1991) further introduced experimental methods that were advances at the time to examine the stress-reducing effects of nature. In the original experiment, 120 healthy participants underwent a stress induction, which consisted of watching a black and white film about prevention of work accidents ('It Didn't Have to Happen'). Next, participants were randomly assigned to viewing one of six 10-min environmental videos filmed from a stationary standpoint. These conditions were created to compare not just natural and urban settings, but also environments with high arousal potential (Nature Stream, Pedestrian Mall Busy, and Traffic Busy) and environments with low arousal potential (Nature Forest, Pedestrian Mall Quiet, and Traffic Quiet). Participants' stress recovery was assessed via repeated self-reports of affective states at baseline, post-stress and post-environment and via continuous physiological measures of skin conductance, heart period, pulse transit time, and muscle tension.

Findings demonstrated that participants exhibited faster and more complete psychophysiological recovery when exposed to natural compared to urban scenes, independent of arousal level. The observed patterns across the physiological indicators suggested that exposure to nature may facilitate stress recovery through activation of the parasympathetic 'rest and digest' response of the autonomic nervous system, rather than solely through deactivation of the sympathetic 'fight or flight' response. This distinction is nowadays foundational for understanding physiological stress responses (Kreibig, 2010; Shuda et al., 2020; Van den Berg et al., 2015). However, measures used at the time were not optimized for disentangling these pathways.

1.2. *Follow-up studies on viewing nature imagery*

At the time of writing this article, Ulrich e al., (1991) had received over 9.000 citations on Google Scholar, making it one of the most impactful studies in environmental psychology. More recent research has examined the effects of viewing photos and slides (Van den Berg et al., 2014; Wang et al., 2019; Wilkie & Stavridou, 2013), videos (Bielinis et al., 2020; Brancato et al., 2022), and Virtual Reality (VR) simulations (Browning et al., 2020; Li et al., 2021; Newman et al., 2022; Tanja-Dijkstra et al., 2018). Across studies, exposure to nature imagery has been found to promote increases in positive affect and decreases in negative affect (McMahan & Estes, 2015). The evidence from studies examining physiological measures is more mixed. While some research has indicated that viewing nature imagery can promote physiological stress recovery (Annerstedt et al., 2013; Gaertner et al., 2023; Van den Berg et al., 2015), these findings are not consistent across all studies (Mygind et al., 2021).

The available evidence is also subject to limitations. First, much of the work suffers from methodological weaknesses, such as lack of control conditions (Gaertner et al., 2023) and heterogeneity in methods that prevents direct comparison with the original study (Koole & Lakens, 2012). Second, the empirical literature may be subject to publication bias in favor of reporting the beneficial impacts of viewing nature (Browning et al., 2021; Schimmack, 2020; Van den Berg, 2021). Third, the available studies have rarely, if ever, preregistered their research and data-analysis protocols, leaving room for alternative interpretations of the data to support a desired outcome (Simmons et al., 2021). Overall, while much of the follow-up research supports Ulrich et al.'s (1991) findings, variations in outcomes and methodological limitations underscore the need for more stringent tests of the original findings' empirical robustness.

1.3. *The present research and hypotheses*

In this paper, we report a large-scale, multisite collaborative effort across 10 independent laboratories to conduct a direct replication of the stress-reducing effects of viewing nature imagery as reported by Ulrich et al. (1991). Multisite replication projects are relatively new (Nosek et al., 2022) and often rely on self-report methods or behavioral tasks (Baumeister et al., 2023). This study breaks new ground by incorporating psychological and physiological measures, despite the latter's methodological complexity (Garrett-Ruffin et al., 2021). The study protocol, hypotheses, and data analysis plan were pregistered on OSF prior to data analysis (https://osf.io/zhpfd).

Sample size was to a large extent determined by the sample size of the original study and considerations regarding practical and logistical constraints associated with conducting a large multi-lab study involving time-intensive physiological measurements. Nevertheless, we conducted a sensitivity power analysis based on the psychological outcome measure to assess which effect sizes could be detected with adequate power. This analysis indicated that a sample in the range of 880–1320 participants would provide 99% power to detect small effects. Within this range, a total of 1039 participants were enrolled across 10 labs, with 959 randomized to conditions. The final sample, consisting of 941 participants with data analyzed for psychological outcomes and 858 for physiological outcomes, remains sizable for a study involving time-intensive physiological measures.

The coordinating lab consulted the senior authors of Ulrich et al. (1991), to ensure adherence as closely as possible to the original design. However, some adjustments were necessary. Because the original black-and-white stressor and environmental videos were no longer available, new full-color versions that were similar in length and content, as described by the original authors, were created. Furthermore, we used Root Mean Square of Successive Differences (RMSSD) and Respiratory Sinus Arrhythmia (RSA) as contemporary indices of short term parasympathetic cardiac regulation derived from inter beat intervals, whereas the original study relied on mean heart period (HP). Sympathetic activity was assessed using Skin Conductance Responses (SCR), as in the original study, and Pre-Ejection Period (PEP), a more specific cardiac indicator of sympathetic activation (Mendes, 2009; Willemsen et al., 1996). These measures were implemented without introducing additional movement restrictions or discomfort for participants, ensuring comparability with the original study.

Our main hypothesis was that we would replicate the original findings - as discussed above - in a multi-site study that necessarily had to compromise and find alternatives for the original materials and measures. We explicitly note that, diverging from the pregistered files in OSF (available at https://osf.io/zhpfd) we did not give much attention to hypotheses regarding high versus low arousal urban settings, because these were only partly confirmed in the original study and led to the collapsing of conditions into broader categories (nature, traffic, pedestrian). We hence replicated the contrasts in restorative potential between the broader categories (nature, traffic, pedestrian) and explored the separated nature conditions vis-a-vis the collapsed traffic and pedestrian conditions We considered the replication successful if (a) exposure to natural settings resulted in faster and more complete recovery than exposure to urban settings, (b) this pattern was evident across both self-report and physiological indicators, and (c) the overall convergence of measures pointed to a stress-reducing advantage of nature.

2. Method

The coordinating lab of the Vrije Universiteit in Amsterdam, the Netherlands, contacted research teams within their professional networks with expertise in environmental psychology about their willingness to participate. Ten laboratories (including the coordinating lab) from the Netherlands, Belgium, the UK, Sweden, and the USA agreed to participate. Geographic spread was an outcome of this recruitment process rather than an explicit selection criterion. This section presents the methods used in this multisite study. Additional details can be found in Tables A1–A5 in Appendix A.

2.1. Labs and participants

Each lab was asked by the coordinating lab to recruit between 80 and 120 participants through local channels such as email, newspaper advertisements, university participant pools, and flyers. Incentives included course credits or small financial compensation. Inclusion criteria were broad: participants had to be at least 17 years old, able to provide informed consent, and free from health restrictions that would interfere with participation. The inclusion process is summarized in Fig. 1.

Out of 1039 initial volunteers, technical issues reduced baseline completion to 978. After additional withdrawals and technical failures, the final sample consisted of 959 participants (49 percent female, mean age 22.4 years, range 17–55), randomly assigned to six environmental conditions. No participants identified as non-binary, although the option “other” was available. A detailed overview of sample characteristics is provided in Table A1.

After exclusion of participants with protocol violations (see Table A2), 941 participants were included in the psychological analyses and 858 in the physiological analyses. Table A3 provides lab-specific details, including the number of respondents per lab, room size, recruitment methods, and potential confounding factors.

While meta-analytic frameworks often include weighting procedures to account for study-level variation, our multisite design relies instead on the consistency of standardized laboratory procedures across sites. We therefore assumed that contextual variations and individual differences are randomly distributed and therefore tend to balance out across labs, reducing the risk of systematic bias (Borenstein et al., 2021).

2.2. Stressor video

To induce stress, participants watched a modern, full-color YouTube version of a 10-min compilation of work accidents that may occur in industrial settings (e.g., slipping and falling, struck-by, and struck-against injuries). This video closely resembled the original black-and-white stressor film used by Ulrich et al. (1991), which was no longer available. The audio track was replaced with ominous background music to maintain a comparable tone. Following the original article, we define stress as “the process by which an individual responds psychologically, physiologically, and often with behaviors, to a situation that challenges or threatens well-being.” (Ulrich et al., 1991, p. 202). At the time of writing this paper, the video was removed from YouTube for content reasons and thus no longer available.

2.3. Environmental videos

New versions of each of the six 10-min environmental videos (Nature Forest, Nature Stream, Pedestrian Quiet, Pedestrian Busy, Traffic Quiet, Traffic Busy) were made with guidance from the lead authors of the original paper. Following the original study, all videos were shot from a stationary point of view, simulating the experience of sitting on a bench watching the environment, and involved both the sound and visuals of the scene. The two videos of the natural environments were copied from YouTube and reduced to 10 min with permission from the maker. The four videos of the urban pedestrian and traffic settings were filmed in the Netherlands specifically for the purpose of the experiment, with numbers of pedestrians and cars similar to those reported in the original paper. Fig. 2 displays representative screenshots of each of the six environmental videos. The links to all environmental video materials used in the study, if still available on YouTube, can be found in the OSF.

2.4. Psychological measure

Self-reported affect was measured using the Zuckerman Inventory of Personal Reactions (ZIPERS; Zuckerman, 1977). This 12-item assesses current emotional states on five factors: fear/arousal (3 items: ‘I feel fearful’, ‘My heart is beating fast’, ‘I am breathing fast’; Cronbach's alpha: baseline (T_0) = .66, T_1 = .81, and T_2 = .69), anger/aggression (3 items: ‘I am angry or deviant’, ‘I feel like hurting or ‘telling off’ someone’, ‘I feel like getting out of this situation or avoiding it’; Cronbach's

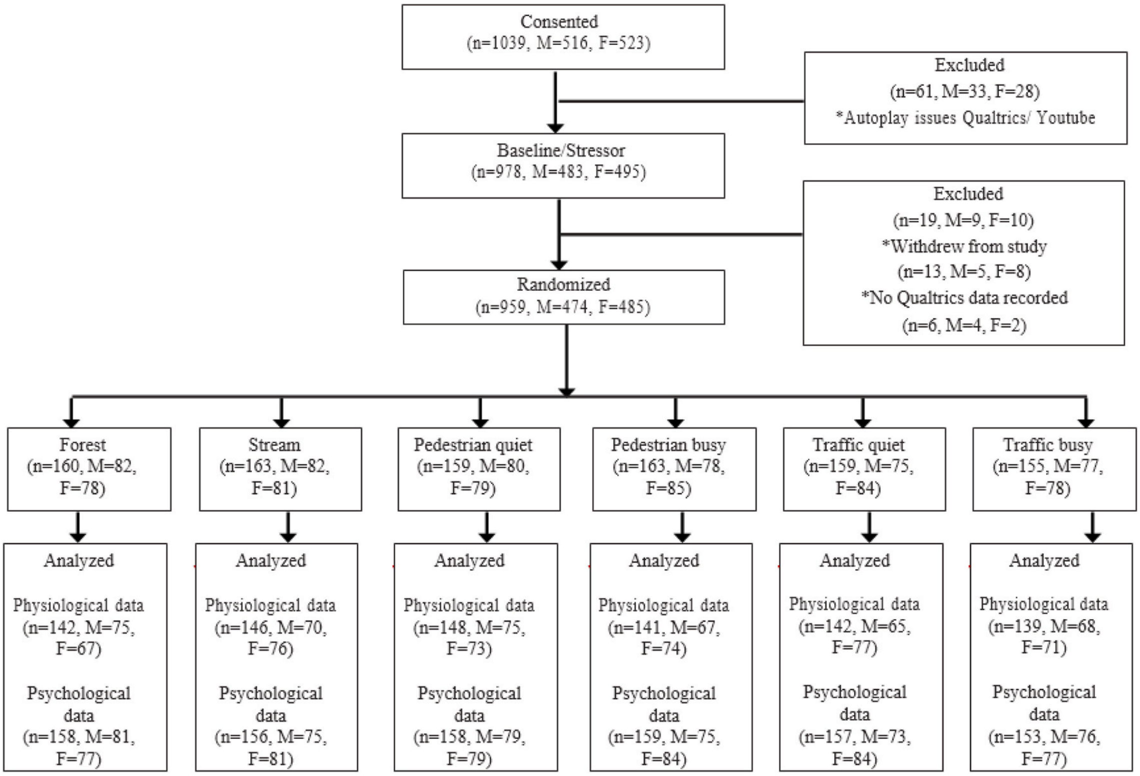

Fig. 1. Diagram for the flow of participants through different phases of the study.

alpha: baseline (T_0) = .38, T_1 = .55, and T_2 = .58), positive affects (4 items: ‘I feel careful or playful’, ‘I feel elated or pleased’, ‘I feel like acting friendly or affectionately’, ‘I feel affectionate or warm-hearted’; Cronbach's alpha: baseline (T_0) = .77, T_1 = .66, and T_2 = .83), sadness (1 item: ‘I feel sad’), and attentiveness (1 item: ‘I feel attentive or concentrating’). Respondents were asked to indicate on a 5-point scale how much each affective state fits with how they feel ‘now’. The ZIPERS was completed three times, before and after the stressor video, and after the recovery video. Following Ulrich et al. (1991) two items (‘My heart is beating fast’ and ‘I am breathing fast’) were excluded from the fear/-arousal factor because these assessed autonomic responses that are already obtained by physiological measures.

2.5. Physiological measures

This replication, like the original paper, focuses on measures that capture short-term physiological stress responses, typically characterized by increased sympathetic activation and reduced parasympathetic (or vagal) counter-regulation. These physiological responses were measured using the Vrije Universiteit Ambulatory Monitoring System' (VU-AMS), a device that has been well-validated in recording psychophysiological responses (Kunkels et al., 2021; Shaffer & Ginsberg, 2017; Willemsen et al., 1996). The VU-AMS records continuous ECGs and changes in thorax impedance (impedance cardiography, ICG) using a seven-electrode configuration. Additionally, a two-electrode configuration was used to measure Electrodermal Activity. Using automated and visual data cleaning, suspicious R-wave peaks were manually corrected or flagged by student assistants blinded to the purpose of the study as an artefact to ensure valid inter-beat interval series. An automated scoring algorithm was also used to detect crucial landmarks in the ICG, which were visually inspected and manually corrected by two or more researchers.

Recordings were sent automatically via the self-paced script to the coordinating lab, which was also responsible for data cleaning. From the recordings, the following outcomes were calculated. Skin Conductance Response (SCR) was included, as in the original study, as a marker of sympathetic arousal. Pre Ejection Period (PEP), defined as the interval between ventricular depolarization and the onset of left ventricular ejection, was used as an additional contemporary cardiac index of sympathetic activation. Root Mean Square of the Successive Differences (RMSSD), derived from inter beat intervals, was used as the contemporary index of heart period variability and parasympathetic regulation. Respiratory Sinus Arrhythmia (RSA) was included as an additional respiration linked index of parasympathetic modulation. RMSSD and RSA were adjusted for respiration rate using linear regression at each interval, with unstandardized predicted mean values serving as adjusted scores. Blood pressure and muscle tension were not included in the replication because these measures would have required extra sensors on the ear and head and thus would have increased participant burden without providing clearer information on autonomic nervous system activity. We therefore considered SCR, PEP, RMSSD, and RSA sufficient to capture the key physiological components of stress. Table A4 gives a more detailed description of the physiological measures and their interpretation.

In the original study, continuously measured physiological data were averaged over 3-min intervals. We followed this protocol and averaged data into seven 3-min intervals: a baseline interval and three intervals of 3 min for both the stressor and recovery period. This resulted in 7 datapoints for each physiological measure: T0 (mean of 3-min baseline interval), T1 (mean of first 3-min stress interval), T2 (mean of second 3-min stress interval), T3 (mean of third 3-min stress interval), T4 (mean of first 3-min recovery interval), T5 (mean of second 3-min recovery interval), and T6 (mean of third 3-min recovery interval). See Fig. 3 for a visualization of the timeline of the study.

Table A5 in Appendix A shows the correlations between changes in the measures during the stressor phase (from stressor onset to post stress) and the recovery phase (from post-stress to post-recovery. Changes in SCR and PEP, both sympathetic markers, showed the expected negative correlations, while changes in RMSSD and RSA, parasympathetic markers, were positively correlated. Additionally, changes

Fig. 2. Screenshots of the environmental videos for each of the six conditions.

in SCR were negatively correlated with RMSSD and RSA, whereas increases in PEP, reflecting reduced sympathetic activation, were positively correlated with increases in RMSSD and RSA. Table A5 also shows that change scores of four out of five ZIPERS factors during the stressor phase, and two subscales (anger/aggression and fear) during recovery were significantly correlated in the expected direction with SCR and PEP as markers of sympathetic activity. Changes in self-reported affects during stress and recovery were not significantly correlated with changes in RMSSD and RSA as markers of parasympathetic activity. These correlations confirm that changes in self-reported affect were associated with sympathetic physiological responses, consistent with the findings of Ulrich et al. (1991).

2.6. Procedure

A self-paced software script for conducting the study and collecting the data was distributed to the labs via a secured file transfer system (SciStor). Data collection took place between Spring and Fall 2018. VU-AMS devices were delivered or mailed to labs as needed. Participants were tested individually, following procedures from the original study. Upon arrival, participants received an information letter and were briefed about the study, including a warning about the disturbing content of the first video. Participation was voluntary, and informed consent was obtained before sensors were applied and calibrated for continuous physiological recording.

Data were collected locally by trained research assistants. They followed detailed written instructions, including a pre-study checklist, and viewed mandatory video tutorials for each procedural step. The study was presented neutrally as a study on “physiological responses while watching film clips”, and assistants were not informed about specific hypotheses regarding differential effects of the video conditions. Principal investigators participated in a preparatory video call with the coordinating investigators before data collection began. In Belgium, the Netherlands, and Sweden, participants could choose their language. Data were uploaded daily and processed centrally to ensure uniform data handling across sites.

A Qualtrics software script randomly assigned participants to one of six environmental conditions, stratified by gender. Participants completed a 4-min baseline recording (watching a blank screen), followed by the first ZIPERS questionnaire. They then viewed a 10-min stressor video depicting industrial work accidents and completed the second ZIPERS questionnaire. Subsequently, participants watched one

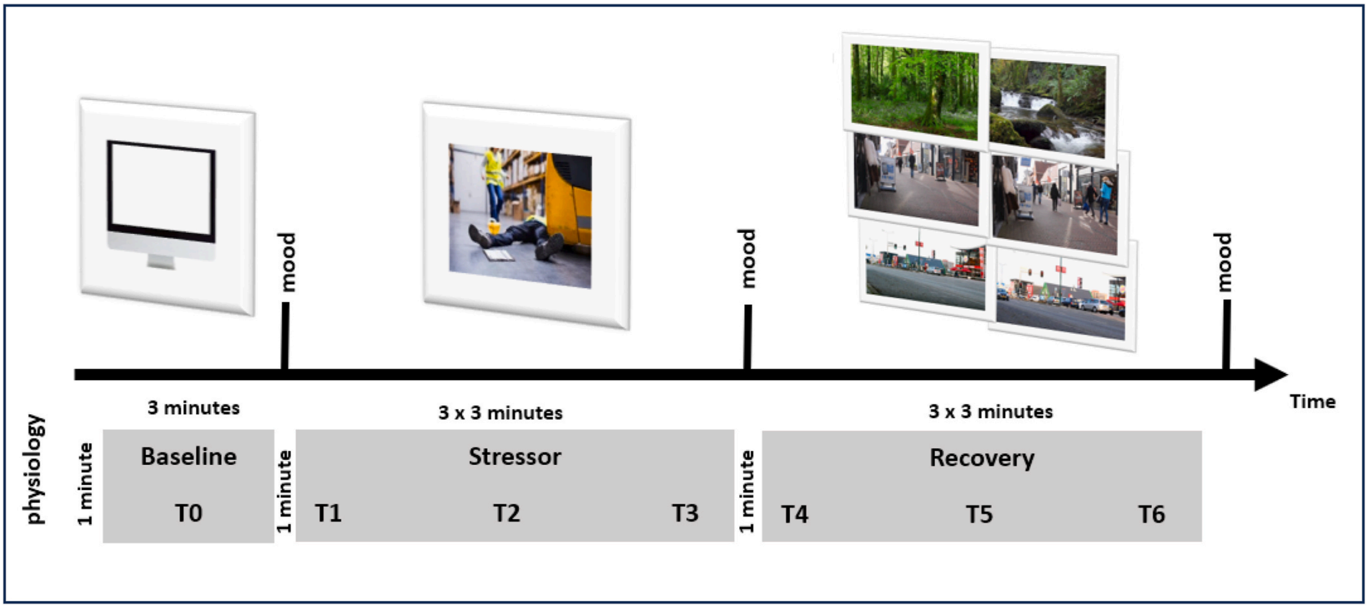

Fig. 3. Timeline of the study.

of six 10-min environmental videos, imagining themselves in the setting, and completed the final ZIPERS questionnaire. Lastly, they provided demographic and covariate data. The coordinating lab at the Vrije Universiteit Amsterdam obtained ethical approval from the Dutch Research Council (project nr. 401.16.055) and was responsible for data transfer, cleaning, and analysis, including visual inspection and manual correction of physiological recordings by trained researchers.

2.7. Statistical analysis

Ulrich et al. (1991) tested for changes in psychological and physiological functioning during stress and recovery with 2-level mixed-model ANOVAs to adjust for non-independence due to clustering of the data within individuals. In the current study, data were not only clustered within individuals but also within labs, potentially further reducing the independence of the data. We therefore initially assessed whether the clustering in labs justified a 3-level mixed model, incorporating lab as an additional level. Using SPSS Mixed Models, we calculated the intraclass correlation (ICC) through the execution of a null model (also known as an empty or intercept-only model, lacking predictors). Results of these analyses indicated that the ICC for the lab level was close to zero (<.04) for all measures. Based on these findings, also taking into account the relatively small number of labs, we chose repeated measures ANOVA in SPSS using the mean data from all labs, as a parsimonious and easy to interpret statistical approach.

Consistent with the analytic structure of the original study, which reported results at the level of collapsed natural and urban conditions, we first conducted analyses using the three collapsed condition categories (nature, pedestrian, traffic). Within each category, we examined whether the respective sub-conditions (forest vs stream; many vs few pedestrians; heavy vs light traffic) differed. Separate results are reported only where meaningful differences were observed.

For each of the five ZIPERS factors, a first series of analyses included Time (baseline and post-stress measurements) as a within-subjects factor to examine the stress-inducing effects of the work-accidents video. A second series included Time (post-stress and post-recovery measurements) as a within-subjects factor and Condition (Nature, Pedestrian, Traffic) as a between-subjects factor to examine potential differences in recovery in the three collapsed environmental conditions, with baseline measurements as a covariate.

For each of the four physiological measures, a first series of analyses included the baseline period (T0) and the three stressor periods (T1, T2, T3) as a within-subjects factor to examine the stress-inducing effects of the work-accidents video, with Condition (Nature, Pedestrian, Traffic) as a between-subjects factor. A second series included the last stressor period (T3) and the three recovery periods (T4, T5, T6) as a within-subjects factor with the collapsed environmental conditions (Nature, Pedestrian, Traffic) as a between-subjects factor, and baseline (T0) as a covariate. Time was entered as a polynomial, allowing linear, quadratic and cubic trajectories over time. Follow-up checks assessed the validity of collapsing the six conditions into three broad categories (Nature, Pedestrian, and Traffic), and if appropriate, the analyses were re-run with individual conditions. Consistency across labs for significant condition effects during recovery was tested with repeated measures ANOVAs split by lab.

Differences between the nature, pedestrian and traffic conditions are graphically illustrated in figures similar to the original paper, with overall mean unadjusted values for the baseline and stressor phase, and separate lines with unadjusted mean values for each condition in the recovery phase. Rather than showing changes from baseline we include the original values to give a better impression of the range of the data.

3. Results

This section starts with the results for the psychological measure (ZIPERS, Zuckerman, 1977), followed by results for physiological measures (SCR, PEP, RMSSD, RSA). Both parts begin with a summary of the original findings from Ulrich et al. (1991) and conclude with an evaluation of the extent to which the findings replicate the original results. For each of the psychological and physiological measures, results are presented as follows: 1) preliminary assessments of baseline and stressor offset differences 2) results for the stressor phase regarding the effectiveness of the stressful video, 3) results for the recovery phase regarding the effects of the environmental videos on stress recovery, and 4) an evaluation of the consistency of recovery findings across the ten labs. Appendix B (Tables B1 to B5) provides mean values and test statistics for each measure across conditions and time points.

3.1. Psychological results

Ulrich et al. (1991) found that participants exhibited more negatively toned emotional states following the stressor for all ZIPERS factors (fear, anger/aggression, positive affect, sadness, attentiveness). During recovery, viewing natural environments resulted in greater increases in positive affect and reductions in anger/aggression and some reduction in fear compared to urban settings. Sadness and as attentiveness generally decreased across conditions, but these decreases were not significant.

3.1.1. Results of the replication

Mean values and standard deviations for the ZIPERS factors across environmental conditions at baseline, post-stress, and post-recovery can be found in Appendix B1. There were no significant differences between the six environmental conditions in baseline or post-stress scores for all ZIPERS factors, *p*-values $\geq .077$ and $\eta_p^2 \leq .011$.

All ZIPERS factors revealed a significant change from baseline to post-stress across conditions. Participants reported significant decreases from baseline in positive affect, $M_{\mathrm{dif\ T0\_T3}} = -.99$, 95% CI [−1.04, −.94], and attentiveness, $M_{\mathrm{dif\ T0\_T3}} = -.28$, 95% CI [−.37, −.20]. They also reported significant increases in fear, $M_{\mathrm{dif\ T0\_T3}} = 1.34$, 95% CI [1.26, 1.43], anger/aggression, $M_{\mathrm{dif\ T0\_T3}} = .82$, 95% CI [.77, .87], and sadness, $\mathrm{M}_{\mathrm{dif\ T0\_T3}} = 1.80$, 95% CI [1.71, 1.89]. Thus, the observed pattern is consistent with the intended stress induction.

Table 1 summarizes changes in affective states from post-stress to post-recovery. Across conditions, positive affect increased significantly during recovery, $M_{\mathrm{dif\ T2\_T3}} = .65$, 95% CI [.64, .70], with the largest increase observed in the nature condition, followed by the pedestrian condition, and the smallest increase in the traffic condition. Anger/aggression showed a similar but less pronounced pattern, with a general decrease across conditions, $M_{\mathrm{dif\ T2\_T3}} = -.68$, 95% CI [−.73, −.63], and the largest decrease in natural settings, followed by the pedestrian condition, and the smallest decrease in the traffic condition. Fear, $M_{\mathrm{dif\ T2\_T3}} = -1.38$, 95% CI [−1.46, −1.30], and sadness, $M_{\mathrm{dif\ T2\_T3}} = -1.47$, 95% CI [−1.54, −1.39], generally decreased, with no statistically significant differences between conditions. Instead of recovery, attentiveness showed a further general decrease following the stressor, $M_{\mathrm{dif\ T2\_T3}} = -.77$, 95% CI [−.86, −.66].

Follow-up checks did not reveal any significant differences in recovery in ZIPERS scores between individual conditions within the three collapsed environmental conditions, *ps* $\geq .062$ and $\eta_p^2 \leq .011$. This indicates that, based on self-reported affect, the two natural conditions (forest and stream), and the two pedestrian and traffic conditions (quiet and busy) elicited comparable levels of recovery.

3.1.2. Consistency across labs during recovery

The pattern of greater improvement in positive affect from post-stress to post-recovery in natural compared to all urban conditions was significant in the data from eight labs, *ps* $\leq .028$, $\eta_p^2 > .058$. The pattern of improvement in positive affect in pedestrian compared to traffic conditions did not reach significance for any of the individual labs, *ps* $\leq .139$, $\eta_p^2 = .042$. The pattern of greater reductions in anger/aggression in natural compared to traffic conditions was significant in three labs, *ps* $\leq .043$, $\eta_p^2 > .054$. The general decline in fear, sadness and attentiveness independent of condition was present in the data of all labs, *ps* $\leq .028$, $\eta_p^2 \geq .058$.

3.1.3. Evaluation

The findings for self-reported affective states broadly replicate those of Ulrich et al. (1991), with some nuances. Participants experienced more negatively toned emotional states following the stressor, including increases in fear, anger/aggression, and sadness, along with decreases in positive affect and attentiveness. During recovery, participants in natural environment conditions showed greater increases in positive affect and reductions in anger/aggression compared to those in urban conditions, consistent with the original findings. Similarly, greater increases in positive affect were observed in pedestrian compared to traffic conditions. Unlike the original findings, recovery from fear did not differ significantly across conditions. Attentiveness, rather than improving, declined further during recovery, mirroring results from the original study. Follow-up checks revealed no significant differences within the collapsed environmental conditions. Overall, the findings affirm key aspects of the original study.

3.2. Physiological results

Ulrich et al. (1991) found that sympathetic responses, as indicated by SCR, PTT, and EMG, generally increased from baseline to post-stress, confirming the effectiveness of the stress induction. In contrast, parasympathetic responses, measured through changes in heart rate (referred to as HP or heart period in the original paper), showed an unexpected initial relaxation during the first periods of the stressor, with signs of increased stress emerging only in the final period.

During recovery, sympathetic measures (SCR, PTT, EMG) showed a decrease in stress, which was more pronounced in natural compared to urban conditions. HP exhibited a different recovery pattern: in urban conditions, it indicated further increases in stress, whereas in natural conditions, it showed an initial decrease in stress, followed by a slight increase during later periods. The latter findings were tentatively interpreted as reflecting parasympathetically dominated responding to natural settings.

3.2.1. Skin conductance (SCR)

SCR, a sympathetic stress marker included in the original study, showed no significant differences between the six environmental conditions at baseline (T0) or at stressor offset (T3), *ps* $\geq .651$, $\eta_p^2 \leq .002$ (See Appendix B2). During the stressor phase, SCR generally increased, $\mathrm{M}_{\mathrm{dif\ T0\_T3}} = 2.52$, 95% CI [2.28, 2.76]. As shown in Fig. 4 this increase, indicating an increase in stress, was strongest in the first period of viewing the stressful video, $\mathrm{M}_{\mathrm{dif\ T0\_T1}} = 2.18$, 95% CI [1.96, 2.39].

The interaction of Time with Condition (Nature, Urban, Pedestrian, Traffic) during recovery did not reach significance for any of the trends, $\eta_p^2 \leq .002$. SCR generally decreased independent of condition, $\mathrm{M}_{\mathrm{dif\ T3\_T6}} = -3.48$, 95% CI [−3.70, −3.26], with the strongest decrease in the first period of recovery, $\mathrm{M}_{\mathrm{dif\ T3\_T4}} = -3.04$, 95% CI [−3.23, −2.83]. Follow-up checks did not reveal significant differences in recovery between individual conditions within the three collapsed environmental conditions, *ps* $\geq .061$ and $\eta_p^2 \leq .013$.

3.2.2. Pre-Ejection Period (PEP)

PEP, a specific sympathetic stress marker not included in the original

Table 1

Change scores from post-stress to post-recovery for ZIPERS factors, with test statistics for the Time (post-stress, post-recovery) by Condition (Nature, Pedestrian, Traffic) interaction. Statistics calculated with T0 as baseline.

					Time * Condition		
ZIPERS factor	All conditions	Nature [95% CI]	Pedestrian [95% CI]	Traffic [95% CI]	*F*	*P*	η_p^2
Fear	−1.38	−1.36	−1.39	−1.35	.33	.722	.001
Anger/Aggression	−.68	-0.75^{a}	-0.70^{ab}	-0.60^{b}	3.21	.041	.007
Positive affect	.65	0.88^{a}	0.59^{b}	0.46^{c}	28.69	<.001	.058
Sadness	−1.47	−1.42	−1.54	−1.43	1.38	.252	.003
Attentiveness	−.77	-0.66^{a}	-0.89^{b}	-0.78^{ab}	2.11	.121	.004

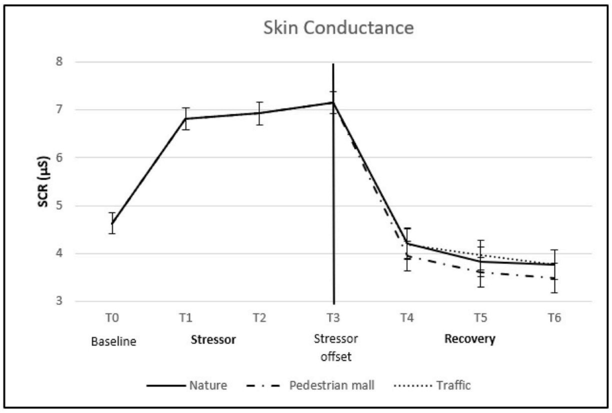

Fig. 4. Changes in unadjusted Skin Conductance Response (SCR) during baseline (T0), stress (T1-T3) and recovery (T3-T6) in natural, urban pedestrian and urban traffic conditions. Error bars represent ±1.96 SE.

study, also did not show significant differences between the six environmental conditions at baseline (T0) or stressor offset (T3), $\eta_p^2 \leq .005$ (See Appendix B3).

During the stressor phase PEP initially decreased (indicating increased stress), $M_{\mathrm{dif}\ T0\_T1} = -.80$, 95% CI [−1.13, −.46], followed by increases in later periods, $M_{\mathrm{dif}\ T1\_T3} = 1.24$, 95% CI [.94, 1.55]. As shown in Fig. 5, this resulted in a small but significant overall increase and thus decrease in stress from baseline to the last period of viewing the stressful video, $M_{\mathrm{dif}\ T0\_T3} = .45$, 95% CI [.02, .88].

The interaction of Time with Condition (Nature, Urban Pedestrian, Traffic) during recovery did not reach significance for any of the trends, all $ps \geq .177$, $\eta_p^2 \leq .004$. Across the collapsed conditions, PEP showed a further increase and thus decrease in stress, $M_{\mathrm{dif}\ T3\_T6} = 3.02$, 95% CI [2.62, 3.43]. This increase in PEP was most pronounced during the first period of viewing the environmental video, $M_{\mathrm{dif}\ T3\_T4} = 2.71$, 95% CI [2.37, 3.05]. Follow-up checks did not reveal significant differences in recovery between individual conditions within the three collapsed environmental conditions, $ps \geq .329$, $\eta_p^2 \leq .003$.

3.2.3. *Heart Rate Variability (Root Mean Square of Successive Differences; RMSSD)*

RMSSD, a parasympathetic marker of stress replacing HP in the original study, showed no significant differences between the six environmental conditions at baseline (T0) or at stressor offset (T3), $ps \geq .27$, $\eta_p^2 \leq .008$ (See Appendix B4).

During the stressor phase RMSSD showed an initial increase, and thus decrease in stress, $M_{\mathrm{difT0\_T1}} = 2.33$, 95% CI [2.0, 2.66] (note that HP was reverse-coded in the original paper such that an increase indicated increase in stress). As shown in Fig. 6, this initial relaxation was followed by a decrease, and thus increase in stress in later periods, resulting in a net overall reduction in stress from baseline to the last period of viewing the stressful video, $M_{\mathrm{dif}\ T0\_T3} = 1.35$, 95% CI [1.00, 1.70].

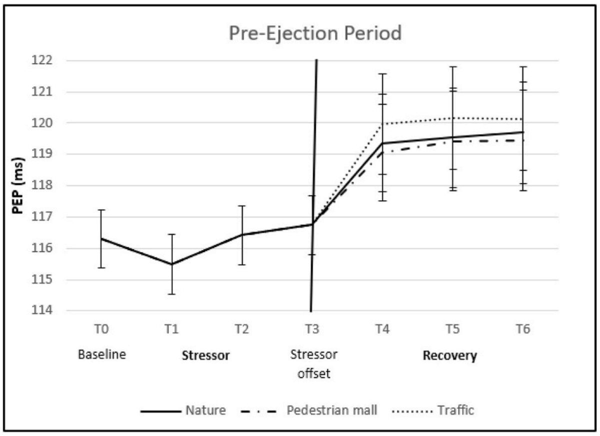

Fig. 5. Changes in unadjusted Pre-Ejection Period during baseline (T0), stress (T1-T3), and recovery (T3-T6) in natural, urban pedestrian and urban traffic conditions. Error bars represent ±1.96 SE.

During recovery, participants in the two nature conditions showed no statistically significant change during the first period of viewing the environmental video, $M_{\mathrm{dif}\ T3\_T4} = .36$, 95% CI [−.16, .87], with decreases and thus increases in stress during later periods, resulting in a return to baseline, $M_{\mathrm{dif}\ T3\_T6} = -1.17$, 95% CI [−1.56, −.78]. In contrast, those in the pedestrian conditions, $M_{\mathrm{dif}\ T3\_T6} = -1.45$, 95% CI [−1.92, −.99], showed a steady decrease and thus increase in stress, while those in the traffic conditions showed initial stabilization followed by a stress increase, $M_{\mathrm{dif}\ T3\_T6} = -.86$, 95% CI [−1.33, −.39] These differences were supported by a significant interaction of Time with Condition (Nature, Urban Pedestrian, Traffic) for the quadratic trend, all $p = .002$, $\eta_p^2 = .015$.

Follow-up checks revealed that only participants in the forest condition showed an initial significant increase in RMSSD, indicative of relaxation, $M_{\mathrm{dif}\ T3\_T4} = .88$ 95% CI [.15, 1.61], whereas participants in the stream condition showed a general decline and thus increase in stress during the entire recovery period, $M_{\mathrm{dif}\ T3\_T6} = -1.35$, 95% CI [−2.00, −.70], similar to the strong decline of those in pedestrian conditions. There were no significant differences in recovery between individual conditions within the collapsed traffic and environmental conditions, $ps \geq .273$, $\eta_p^2 \leq .004$.

3.2.4. *Respiratory Sinus Arrhythmia (RSA)*

RSA, a component of HRV not included in the original study and more specifically tied to the parasympathetic branch of the autonomic nervous system, showed no significant differences between the three environmental conditions at baseline (T0) or at stressor offset (T3), $ps \geq .688$, $\eta_p^2 \leq .004$ (See Appendix B5).

RSA decreased during the first two periods of viewing the stressful video, indicating an initial increase in stress, $M_{\mathrm{dif}\ T0\_T2} = -4.62$, 95% CI [−5.64, −3.60]. As shown in Fig. 7, this initial increase was followed by some relaxation in the last period. Nevertheless, by the end of the stressor period, RSA levels remained significantly lower than at baseline, reflecting an overall increase in stress, $M_{\mathrm{dif}\ T0\_T3} = -3.43$, 95% CI [−4.52, −2.33].

During recovery, RSA showed a consistent pattern across conditions, with an initial increase indicative of relaxation, followed by decreases, as indicated by a significant main effect of Time for the quadratic trend, $p < .001$, $\eta_p^2 = .039$. However, the initial increase in RSA was more pronounced in the natural conditions, $M_{\mathrm{dif}\ T3\_T4} = 4.60$, 95% CI [3.11, 6.09], than in the traffic conditions, $M_{\mathrm{dif}\ T3\_T4} = 3.33$, 95% CI [1.81, 4.85] and the pedestrian conditions, $M_{\mathrm{dif}\ T3\_T4} = 2.17$, 95% CI [.67, 3.66]. This difference was supported by a significant interaction of Time with Condition (Nature, Urban Pedestrian, Traffic) for the quadratic trend, $p = .010$, $\eta_p^2 = .011$.

Follow-up checks revealed that initial recovery was most pronounced in the forest condition, $M_{\mathrm{dif}\ T3\_T4} = 6.05$, 95% CI [3.92, 8.17], whereas participants in the stream condition showed much less initial recovery, $M_{\mathrm{dif}\ T3\_T4} = 3.20$, 95% CI [1.11, 5.29], similar to those in the pedestrian conditions. Notably, while stress levels of participants who viewed the forest and traffic videos returned to baseline by the end of the recovery period, those in the stream and pedestrian conditions exhibited incomplete recovery, ending with stress levels comparable to the increased level at stressor offset.

3.2.5. *Consistency across labs during recovery*

The general pattern in SCR and PEP of greater initial recovery followed by stabilization in all conditions was present in the data of all ten labs. For SCR, the overall main effect of Time was significant for all labs with $p < .001$, $\eta_p^2 \geq .106$. For PEP, the overall main effect of Time

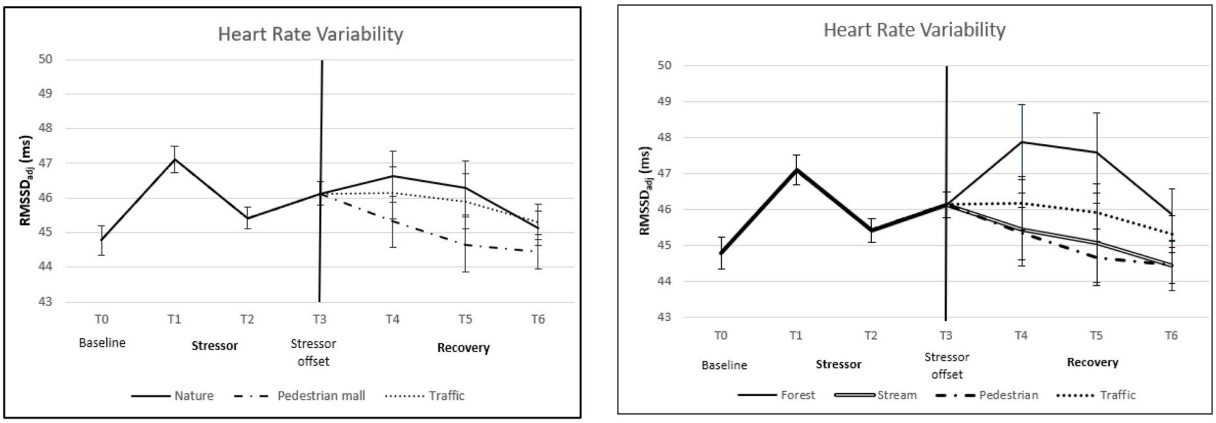

Fig. 6. Changes in Heart Rate Variability (measured by RR-adjusted RMSSD) in collapsed natural, pedestrian and traffic conditions (left panel) and with the natural condition further divided into individual forest and stream conditions (right panel) for forest and stream (right panel). Error bars represent ±1.96 * SE.

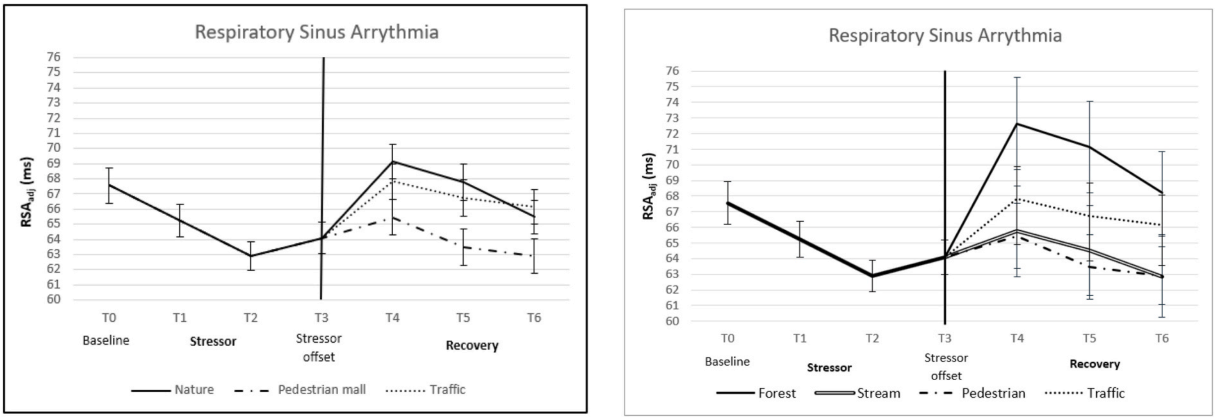

Fig. 7. Changes in RSA (adjusted for RR) in collapsed natural, pedestrian and traffic conditions (left panel) and with the natural condition further divided into individual forest and stream conditions (right panel) for forest and stream (right panel). Error bars represent ±1.96 * SE.

reached significance for only one lab, $p = .023$, $\eta_p{}^2 = .035$.

The condition-specific pattern of greater initial recovery in RMSSD and RSA in the forest condition compared to the stream and pedestrian conditions was present in the data of nine out of ten labs, but the pattern was significant for only two labs, $p \leq .026$, $\eta_p^2 = .098$.

3.2.6. *Evaluation*

The findings broadly confirm the findings of the original study regarding the effects of the stress induction, with SCR and PEP showing significant increasesing sympathetically mediated across all environmental conditions, and RMSSD as a parasympathetic measure of HP variability mirroring initial relaxation and subsequent stress responses. RSA, as another parasympathetic measure related to RMSSD exhibited distinct dynamics, with an early decrease and thus increase in stress followed by partial recovery. These contrasting parasympathetic responses challenge the robustness of the original findings but confirm the effectiveness of the stressor.

In the recovery phase, sympathetic measures did not show greater recovery in the natural conditions, contrasting with the original findings by Ulrich et al. (1991). However, parasympathetic measures did reveal environmental differences: the forest condition facilitated a faster return to baseline, whereas the stream condition showed a slower recovery trajectory, with patterns resembling those of the urban environments. Thus, only the forest condition replicated some of the restorative effects in physiological measures observed in the original study. These differences suggest that specific characteristics of the stream setting that were not present in the original study may have influenced its restorative potential.

4. Discussion

The present multisite study replicated the groundbreaking experiment by Ulrich et al. (1991) on the greater stress recovery effects of viewing natural compared to urban settings among a final sample of 959 participants across ten different research teams in the Netherlands, Belgium, the UK, Sweden, and the USA. The results for psychological recovery largely aligned with the findings of the original study. Following the stress induction, which caused emotional states as measured by the ZIPERS (Zuckerman, 1977) to become more negatively toned, participants reported greater improvements in positive affect as well as greater decreases in anger/aggression after viewing videos of a forest and a stream compared to urban pedestrian and traffic scenes.

Results for physiological recovery presented a more complex picture. Sympathetic measures, SCR and PEP, confirmed stress induction but did not replicate greater recovery in natural conditions. They showed similar recovery patterns across conditions, with initial decreases in stress stabilizing in later phases.

RMSSD and RSA, reflecting parasympathetic activity, showed differential patterns during the stressor phase. RMSSD showed a modest net increase during the stressor phase, a pattern comparable to the heart period deceleration reported by Ulrich et al. (1991), which was interpreted as reflecting heightened attentional engagement. RSA showed a net decrease at stressor offset, indicating parasympathetic withdrawal. During recovery, both measures showed greater initial parasympathetic activation in the natural in the forest condition. However, this pattern was not observed in the stream condition, which exhibited responses more similar to the pedestrian environments.

Taken together, the present multisite study partially confirmed the original findings by Ulrich et al. (1991), demonstrating that viewing nature imagery promotes psychophysiological recovery. However, the results for physiological responses highlight the nuanced ways in which exposure to natural and urban environments may influence psychophysiological stress recovery. Tentatively, the unexpected increase instead of a decrease in stress during recovery in the stream condition may be related to the high-decibel sounds of cascading water in this condition. Compared to the more subdued trickling sounds in the original study, these louder sounds may have been perceived as intrusive noise, thereby reducing the stream's efficacy as a restorative setting (Hsieh et al., 2023).

The present findings suggest that restorative effects of viewing nature imagery may be more readily observed in self-reports, especially those assessing positive affect, than in physiological measures. This pattern aligns with meta-analytic reviews, which have consistently shown that nature viewing has restorative effects on self-report measures, while physiological measures have yielded weaker and more inconsistent results (Bowler et al., 2010; Corazon et al., 2019; McMahan & Estes, 2015; Ohly et al., 2016; Stevenson et al., 2018).

Why would restorative effects of viewing nature imagery emerge more readily for self-report measures than for physiological measures? A possible explanation lies in the relative sensitivity of self-report measures, which capture subjectively experienced feelings that emerge from higher-level neural processes integrating physiological responses, action tendencies, and cognitive appraisals (Scherer & Moors, 2019). If central cognitive processes indeed mediate these effects, they could be shaped by personal and cultural learning. For instance, individuals living in countries or regions where nature is associated with leisure and relaxation, may experience stronger restorative effects than those in traditional areas, where nature is more linked to survival or labor (Collado et al., 2016; Egner et al., 2019). This variability highlights the need for nature-based interventions tailored to align with cultural and personal contexts, maximizing their effectiveness across diverse populations. At the same time, subjective measures have limitations, such as their vulnerability to social desirability bias, especially in the present study, where it was difficult to mask the hypotheses.

Notably, physiological responses to both the stressor video and the environmental videos were most pronounced during the initial 3-min periods, replicating the original findings. However, this initial responsiveness may hold additional relevance for the younger participants in this study, potentially due to increased exposure to short-format content on social media (Marathe & Kanage, 2024). This sensitization to visual materials could partly explain the overall less pronounced response patterns observed in the current multisite study.

The present research has some notable strengths. First, as far as we know, this is the first multisite collaboration in the branch of environmental psychology that studies the impact of the environment on people (compared to studies of the impact of people on the environment). With a sample of 959 participants, almost eight times the sample examined by Ulrich et al. (1991). Due to this relatively large sample, the present study had considerable statistical power to detect effects. A second strength of this study is the inclusion of labs from different countries, spanning the US and various countries in Europe. This geographic diversity enhances the generalizability of the findings and ensures that the results are not limited to a single cultural or regional context. A third strength is the effort taken to include physiological measures, which is rare for multisite studies, and provides a more objective perspective on stress responses.

At the same time, the present research has limitations. First, our study only examined passive engagement with nature imagery. Whilst we were constrained to this focus as our scope was to replicate Ulrich et al. (1991), restorative effects may be stronger and more enduring when people actively engage with real nature for longer periods (Hartig et al., 1991; Rickard & White, 2021; Sheffield et al., 2022), potentially enhancing the immune system (Rook & Lowry, 2022) and building psychological resilience (White et al., 2023). Another limitation that also applied to the original study is that the present research focused on just two nature environments and four types of urban environments. Furthermore, our videos were not recorded under uniform lighting, sound and weather conditions although we tried to keep them as comparable as possible. Future research on restorative effects of viewing nature should explore a broader range of environments, ideally in real-world settings (Marvier et al., 2023). In doing so, multilevel modeling could be a valuable tool for data analysis.

A brief note is warranted regarding the use of the ZIPERS. This measure would probably not meet current psychometric standards, but it was retained to ensure comparability with Ulrich et al. (1991). From this perspective, the ZIPERS was an appropriate instrument for a high-fidelity replication of the original study. However, many new scales and methods are available and, in future work on psychological effect of nature, the choice of the appropriate affective measures should be guided by the research question, theoretical model, and practical design constraints (Williams & Rhodes, 2023).

A further possible limitation of this replication is that not all physiological measures included in the original study were retained. Ulrich et al. (1991) also recorded muscle tension (EMG) and blood pressure, the latter derived indirectly from pulse transit time using an optical sensor attached to the ear. In our multisite setup, adding these measures would have required extra sensors and increased participant burden without providing additional conceptual clarity. EMG primarily reflects voluntary or posture-related muscle activity rather than autonomic stress responses, and blood pressure represents a mixed outcome of sympathetic and parasympathetic influences. By focusing on SCR, PEP, RMSSD, and RSA, we aimed to capture the key and functionally distinct components of short-term physiological stress regulation in a more targeted and comparable way. Finally, lab inclusion was based on labs with expertise in doing experimental research and willingness to participate, which may have limited geographical coverage but ensured methodological consistency across sites.

Finally, we introduced minor analytic refinements relative to the original study. Baseline (T0) measures were included as covariates in the analyses of recovery to improve statistical precision. In line with the preregistration, primary analyses were conducted on the collapsed environmental conditions. Follow-up analyses examined individual conditions only when the aggregated results indicated meaningful differences. These additional analyses revealed an unexpected contrast between the two nature conditions. We offer a tentative explanation for this pattern and note that it was not hypothesized a priori.

Despite these caveats, the present multisite replication represent, as far as we know, the largest and most comprehensive empirical test to date of the psychophysiological effects of nature imagery. The present findings partially replicate Ulrich et al. (1991), showing that viewing nature imagery can promote restoration from negatively toned emotional states and support rapid physiological recovery through increased parasympathetic activity. As such, the present research attests to importance of nature as a vital resource in dealing with the stress of modern life.

CRediT authorship contribution statement

A.E. Van den Berg: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **K. Dijkstra:** Writing – review & editing, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **D. Meuwese:** Writing – review & editing, Visualization, Supervision, Software, Project administration, Methodology, Data curation, Conceptualization. **F. Beute:** Writing – review & editing, Validation, Methodology, Investigation. **P.M. Darcy:** Writing – review & editing, Supervision, Methodology. **S. Dewitte:** Writing – review & editing, Supervision, Investigation. **B. Gatersleben:** Writing – review & editing, Project administration, Investigation. **C.J. Gidlow:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis. **C.M. Hägerhäll:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **J.A. Hipp:** Writing – review & editing, Validation, Supervision, Methodology, Investigation. **Y. Joye:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Y.A.W. De Kort:** Writing – review & editing, Validation, Investigation. **S.C.M. Lechner:** Supervision. **C. Neale:** Writing – review & editing, Validation, Supervision, Methodology. **Å. Ode Sang:** Writing – review & editing, Supervision. **J. Roe:** Writing – review & editing, Supervision. **D.T. Scheepers:** Writing – review & editing, Supervision, Conceptualization. **K. Smolders:** Writing – review & editing, Methodology, Formal analysis. **H. Staats:** Writing – review & editing, Conceptualization. **R.S. Steensma:** Writing – review & editing, Methodology. **K.J. Wyles:** Writing – review & editing, Supervision, Formal analysis. **S.L. Koole:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Conceptualization.

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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.2026.102956.

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