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Original article

Landscape and soundscape quality promote stress recovery in nearby urban nature: A multisensory field experiment

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ABSTRACT

Cities have different benefits and risks, but are often stressful environments to live in. Everyday contact with nearby nature can be a crucial way to alleviate stress and increase the well-being of citizens. However, there is still limited evidence on how nature-health benefits vary according to the type and quality of natural environments. This study integrated multiple landscape and soundscape objective and perceived assessments to examine stress recovery in different types of neighbourhood nature. We used a field randomised experiment (n=45) to analyse effects of various random and fixed factors on restoration including: environmental conditions (e.g. temperature, wind, air quality), personal characteristics (e.g. age, gender, perceived health, nature connectedness), presence of other people and environmental quality (e.g. Perceived Environmental Aesthetic Qualities Scale and Perceived Sound Affective Quality scale). We found that physiological and psychological restoration is significantly greater in sites with higher visual (% visual natural elements) and acoustic (Normalized Difference Soundscape Index (NDSI)) naturalness i.e. the beach and forest, compared to the urban park (control site). Perceived landscape and soundscape quality were strongly associated with stress recovery, and these results were more pronounced for the soundscape. This highlights that soundscape quality assessments deserve more systematic attention in urban green infrastructure research and planning. Finally, we found important early evidence of reduction in Electrodermal activity (EDA) only within 3 minutes of nature exposure especially in the forest.

1. Introduction

Cities can be stressful living environments due to air pollution, traffic, noise, crowding, unwanted social interactions or feeling of unsafety (WHO, 2016). Stress symptoms and mood and anxiety disorders are also more prominent in urban than in rural residents (Lederbogen et al., 2011; Peen et al., 2010). For example, in Finland, psychological stress affects significantly the adult population reaching 19% in men and 20% in women (THL, 2023). Current evidence suggests that exposure to natural settings has multiple psychological, physiological, social, spiritual and recreational benefits for people (De Keijzer et al., 2016; Hartig et al., 2014; Keniger et al., 2013). Everyday contact with nearby nature can be a crucial way to alleviate stress and increase the well-being of citizens (Elliott et al., 2023; Van Den Berg et al., 2010). Therefore, researchers have argued that urban residents should have easy and short access to green spaces (Konijnendijk, 2023).

Stress recovery (hereafter used synonymously to *restoration*) involves both physiological and psychological elements (Ulrich et al., 1991).

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Common measures to study physiological stress recovery include endocrine system (e.g. measures of cortisol level and other stress hormones) (Antonelli et al., 2019), cardiovascular system (e.g. changes in heart rate variability, blood pressure, pulse rate) (Yao et al., 2021) and more rarely, changes in Electrodermal activity (EDA) (Alvarsson et al., 2010). There have been repeated reports on heterogeneity in results. A review by Corazon et al. (2019) found that the number of studies showing significant decrease in pre-post measures and those reporting no significant decrease was almost equal. Similar reports of residual heterogeneity have been noted by Antonelli et al. (2019) and Yao et al., (2021).

Psychological restoration on the other hand, is mostly studied through self-reported measures of mood (Harmon-Jones et al., 2016; Watson et al., 1988), perceived stress (Cohen et al., 1983) and the perceived restorative potential of a given environment (Hartig et al., 1997). Contrary to literature on physiological measurements, evidence based on psychological outcomes especially related to different measures of emotional change seem to be stronger and mainly positive (Corazon et al., 2019). However, very limited number of studies use a combined approach examining psychological and physiological effects simultaneously (Corazon et al., 2019).

1.1. Environmental quality and restoration

Previous research has found positive associations between restoration measured as physiological markers of stress reduction and amount of nature. In the experimental study by Jiang et al. (2014), after presenting a stressful event, moderate street tree density in a 3D video was most effective in reducing stress, measured by cortisol level and skin conductivity, compared to low and high street tree density videos. Notably, this effect was observed only in men and not in women. In another study, using a one-city population urban sample in the UK, a significant association was found between diurnal pattern of salivary cortisol secretion, as an indicator of stress, self-reported stress, and the amount of green space in the neighborhood, indicating the importance of green spaces nearby residential areas (Ward Thompson et al., 2012). However, in the study by Chiang et al. (2017) the physiological measures (EEG alpha frequency) did not change across the varying vegetation density levels of urban green spaces shown in photographs. Nevertheless, high density environments significantly increased attention (Stroop test) and self-reported mood. A nationally representative survey in the Netherlands indicated that the green and blue space availability in the residential areas were negatively associated with anxiety and positively associated with self-reported mental and general health (De Vries et al., 2016). In addition, blue space availability was also negatively associated with mood disorders (De Vries et al., 2016). Research has also identified links between restoration and quality of the environment. Simkin et al. (2020) found that participants in an experimental study, visiting spruce-dominated forests of different ages, reported higher feelings of restoration, energy, and positive mood in the three natural-looking forests that were more than 95 years old, compared to the forest that was less than 40 years old. Preference studies also indicate the higher restorative potential of different environments. Ríos-Rodríguez et al., (2021) showed that perceived environmental quality, measured as design of spaces, care of spaces, social interaction, and presence of sensorial elements, was a key predictor for perceived restorativeness in urban parks and squares (Ríos-Rodríguez et al., 2021). Liu et al., (2022) reported that the visual quality of water, such as water transparency, can increase audio-visual perceived restorativeness of blue spaces. However, the link between physiological responses and objective and perceived qualities of urban nature (Hedblom et al., 2019), and how restoration varies in environments with different levels of human disturbance remain under-studied (Keniger et al., 2013).

1.2. Soundscapes and other factors affecting restoration

The interplay between visual and auditory stimuli constitutes an important factor for environmental preference and restoration (Payne, 2013; Pheasant et al., 2008). Yet, soundscape research is still scarce in green space and human well-being literature. Soundscape studies examine the relations between the acoustic environment and human experience and perception while emphasizing context (Brown et al., 2011). Previous research has shown that natural sounds (e.g. birdsongs) are perceived to be pleasant and restorative (Buxton et al., 2021; Ratcliffe et al., 2016), while the sounds of the sea or rivers are perceived as more calming than those of urban environments (Emfield and Neider, 2014; Liu et al., 2022). Natural sounds can also contribute to greater stress recovery compared to anthropogenic sounds (Alvarsson et al., 2010; Benfield et al., 2014). Human sounds on the other hand can increase the liveliness and outdoor values in urban parks (Korpilo et al., 2023), but this might in turn decrease their restorative potential depending on loudness and the social context (Cerwén et al., 2016). More research is needed to understand restorative effects of soundscapes from different types of natural environments (Kang et al., 2016; Ratcliffe, 2021).

The presence of other people can be another important modifier in nature-restoration effect mechanisms. Previous studies have shown that presence of others can aid restoration when supporting feelings of safety (Herzog and Rector, 2008; Staats and Hartig, 2004) and as long as the number of people is moderate (Nordh et al., 2011). Other important predictors of restoration include environmental conditions such as air quality and temperature (Hipp and Ogunseitan, 2011), nature-orientedness (Ojala et al., 2019), place attachment and place identity (Knez et al., 2018; Subiza-Pérez et al., 2020), and the level of human disturbance in terms of naturalness (Knez et al., 2018) or degree of urbanization (Liu et al., 2022).

1.3. Current study

We present a field-based quasi-experiment from Helsinki, Finland that integrates multiple objective and perceived environmental assessments with the aim to better understand physiological and psychological restoration in different types of urban natural environments. To our knowledge, there is no other field study to date that combines psychological and physiological measures of stress recovery, and landscape and soundscape quality assessment in real life environments. We exposed the residents of one neighbourhood (Kalasatama) to their local environments simulating everyday contact with nearby nature. Our study includes three different sites used for recreation - a remnant forest, a beach next to the sea and a recently established urban park. The urban park was used as a control site as a relatively novel green space with low vegetation and high built infrastructure. The study had two main hypotheses:

Hypothesis 1. : There are differences in physiologically and psychologically assessed restoration between the three types of urban nature. Restorative effect is higher in places where there is higher level of naturalness i.e. in the forest and beach, compared to the urban park (control site).

Hypothesis 2. : Environmental conditions, landscape and soundscape quality, personal characteristics and presence of other people in each place affect physiological and psychological restoration levels and interact with each other. Higher landscape and soundscape quality is associated with greater physiological and psychological restoration.

2. Methodology

2.1. Study procedure

This study received an ethical review approval by [blinded for review] Ethical Review Board in Humanities and Social and Behavioral Sciences. The study employed a field quasi-experimental design with a group walk. The walking route was planned to include three stopping locations in the three types of natural environments: forest, beach, park (Fig. 1).

In total 45 participants were recruited as a volunteer sub-sample from a survey conducted in March 2021 as part of the same research project (for participants' background, see Table 1, Supplementary material). Participants were grouped randomly and according to their availability into five walks (walk 1=10 participants, walk 2 = 8, walk 3 = 9, walk 4 = 8, walk 5 = 7) taking place in June, August, and September 2021. Each individual joined a group walk just once and visited all three locations. A day before each walk, study participants took part in a one-hour training workshop to set up the smart ring measuring Electrodermal activity (EDA) (see 2.3). Participants wore the ring for about 24 hours from the training session, overnight (to allow for individual calibration) and during the walk on the next day (Fig. 2).

The experiment took place in the afternoon during weekdays after working hours between 17.00 – 19.00. We opted against any pre-test/post-test or prior fatiguing intervention to reduce any "artificial" effect and simulate as close as possible an everyday life setting. Each walk lasted for about 1.5 hours. The direction of the walk and the start/ending point were randomized to avoid order effect.

Participants were instructed to have no interaction with each other to avoid the stimulating effect of social interactions. Walking speed was normal (5 km/h) and controlled by one of the researchers. In each stop, participants were instructed to sit or stand in a row looking in a fixed direction (see Fig. 1 for a photo of the fixed view in each place). The participants were asked to observe and listen to the environment in silence for five minutes (Rest period). Then, they were given about 10–15 min to fill in a paper questionnaire. After ending the experiment, all participants returned the rings and were given a gift card and a certificate for participation.

2.2. Objective and perceived measurements

2.2.1. Field environmental recordings

During the experiment, various environmental and human objectively and subjectively measured data was collected. Location data was recorded using a GPS device (Garmin Etrex 32X) carried by one of the researchers. Air quality including nitrogen dioxide NO_2 (ppb), volatile organic compounds (VOCs) (ppb), particulate matter PM10 (μg/m^3) and PM2.5 (μg/m^3) were measured during the walk with a portable sensor device. The data were registered to a mobile application Flow Solution (PLUME LABS) and recorded once per minute.

Weather data on temperature (°C), wind speed (m/s) and direction (degrees), and relative humidity (%) were retrieved from the Finnish Meteorological Institute Kumpula weather station (Finnish Meteorological Institute, 2023) and recorded as the average of every ten minutes. Wind direction is defined as the direction the wind is blowing from and recorded in 0–360 degrees clockwise starting from north (eastern winds at 90, southern winds at 180, western winds at 270 and northern winds at 360 degrees) (Finnish Meteorological Institute, 2023).

At each stopping location, the researchers also performed five-minute acoustic binary recordings using a Zoom H4n Pro field recorder mounted on a tripod at 1.6 m height at around 3 m distance behind participants with similar direction as participants' orientation. The recordings were made in PCM (.wav) with 44100 samples per second and a 16-bit resolution. In addition, at each location, researchers took six to seven photos covering a 180 degree-view from the site. The photos show the direction of the view that participants were asked to observe as well as the surrounding biophysical characteristics of each place. Number and activities of other people at each location were also recorded.

2.2.2. Physiological measurements

Real-time physiological measurement of participants' stress levels was gathered using a smart ring developed by Vigofere Ltd., Finland. The ring was chosen as an easy to use and non-obstructive wearable device suitable for in-situ experimentation. The ring captures Electrodermal activity (EDA) as a result of activation of the sympathetic nervous system (SNS), which is associated with the fight-or-flight response. High values indicate SNS being very active, while low levels indicate dominance of the parasympathetic nervous system and relaxation. The ring detects skin conductance changes between two silver coated electrodes with a resolution above the 0.01 μS threshold as a minimum level of responsivity (Boucsein, 2012). It uses as default 3 Hz sampling rate to optimize battery life. To measure EDA levels, the ring uses an algorithm as a double normalized index of different phasic and tonic measures: skin reactions per minute (SCR frequency), % of SCL value (SCV value) and raw level of skin conductance (SCL). The produced EDA level index is on a scale from 0 to 100 indicating low to high EDA levels.

2.2.3. Questionnaires and psychological measurements

The field questionnaire combined questions related to participants' personal characteristics as well as perceived landscape and soundscape assessments. Personal characteristics included age, gender, highest education obtained, and general stated physical and mental health (on a 5-point Likert scale from "Very poor" to "Very good"). Participants were also asked how stressful their day was before the start of the walk on a scale of 0–10 (1 = Extremely stressful, 5 = Somewhat stressful; 10 = Not at all stressful). To measure participants' subjective connectedness with nature, the study used the Inclusion of Nature in Self (INS) scale (Shultz, 2002). The scale was chosen because of its graphical representation, being short and concise.

The second part of the questionnaire, which was repeated during each stop, included participants' evaluations of the visual and sound environment. Participants were asked to assess the overall pleasantness (5-point Likert scale from "Very unpleasant" to "Very pleasant") of the visual and sound environment around them. In addition, six statements from the Perceived Environmental Aesthetic Qualities Scale (PEAQS) (Subiza-Pérez et al., 2019) were included and adapted to respond to mainly visual characteristics e.g. "It's beautiful here", "The view here is diverse", "Visibility here is good" (for full list, see Fig. 1A, Supplementary Material).

Soundscape assessment questions followed the guidelines by Method A for questionnaire data collection protocol reported in the ISO/TS 12913–2:2018 using soundwalks (Aletta et al., 2019). Participants were first asked to identify the sound sources they hear (natural, human, technological) and their level of dominance (on a 10-point scale from "Do not hear at all" to "Dominates completely"). Participants were asked to describe the sound environment using several items: *pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, monotonous* (Aletta et al., 2019; Axelsson et al., 2010) (see Fig. 1B, Supplementary Material). Soundscape appropriateness was also studied using a 5-point Likert scale from "Not at all appropriate" to "Very appropriate".

Perceived restoration was measured using the Restoration Outcome Scale (Korpela et al., 2008). The ROS scale includes six items related to relaxation and calmness ("I feel calm being here", "I feel restored and relaxed here", "I get enthusiasm and energy from being here"), attention restoration ("I feel focused and alert here"), and two reflecting clearing one's thoughts ("I can forget everyday worries here", "Being here is a way to clear and clarify my thoughts").

2.3. Data analysis

2.3.1. Level of naturalness

As an indicator of level of naturalness of the landscape, we calculated *% of visual natural elements* based on the 180-degree photos taken in each place. The proportion of natural and man-made features was assessed using a combination of computer vision and manual assessment. First, a

"The urban park is newly built recreational area, surrounded by residential buildings, shopping and cultural centers in Kalasatama. It is mostly open land comprised of new vegetation such as grass, shrubs and few young trees. It includes playgrounds and sport facilities."

"The forest site, located in the middle of the island of Mustikkamaa, is mostly comprised of pine-dominated remnant forest and rocks. The forests have high biodiversity and are also highly popular for recreation."

"The beach, on the southern side of Mustikkamaa island, is a natural environment surrounded by trees and the sea, overlooking towards Korkeasaari island. It is very popular for recreation especially in the summer."

Fig. 1. Route of the walk and stopping locations.

Table 1
The estimates of the fixed effects of place and phase for EDA level (A) and ROS scores (B). The beta estimates, standard errors, degrees of freedom, t-values, p-values, and confidence intervals are reported for each variable. The assumption of beta distribution was used for EDA level and Gaussian for ROS score, respectively. Degrees of freedom were calculated using the Kenward-Roger method. The models were adjusted for age group, gender and stress level. The reference level for each categorical variable is mentioned in the table and its beta is set to 0. For example, park is the reference level, so the betas for beach and forest are interpreted as the change in the dependent variable for a one-unit change in the categorical variable compared to park, holding all other independent variables constant.

A) Parameter estimates for EDA level								
Effect	Place	Phase	Beta	SE	DF	t	p	95% CI
Place	Beach		0.034	0.209	356	0.160	0.869	(-0.377, 0.446)
Place	Forest		-0.159	0.209	356	-0.760	0.446	(-0.570, 0.252)
Place	Park		0					
Phase	Walking		0.096	0.149	247	0.640	0.521	(-0.198, 0.390)
Phase	Questionnaire		0.707	0.160	251	4.430	<0.001	(-0.392, 1.021)
Phase	Rest		0					
Place x Phase	Beach	Walking	0.124	0.210	247	0.590	0.558	(-0.291, 0.538)
Place x Phase	Beach	Questionnaire	-0.364	0.219	249	-1.660	0.097	(-0.795, 0.067)
Place x Phase	Beach	Rest	0					
Place x Phase	Forest	Walking	0.320	0.211	246.8	1.520	0.130	(-0.095, 0.735)
Place x Phase	Forest	Questionnaire	-0.194	0.219	249.0	-0.880	0.378	(-0.625, 0.238)
Place x Phase	Forest	Rest	0					
B) Parameter estimates for ROS score								
Effect	Place	Beta		SE	DF	t	p	95% CI
Place	Beach	1.053		0.167	63.1	6.32	<0.001	(0.719, 1.386)
Place	Forest	0.746		0.169	55.2	4.41	<0.001	(0.407, 1.085)
Place	Park	0						

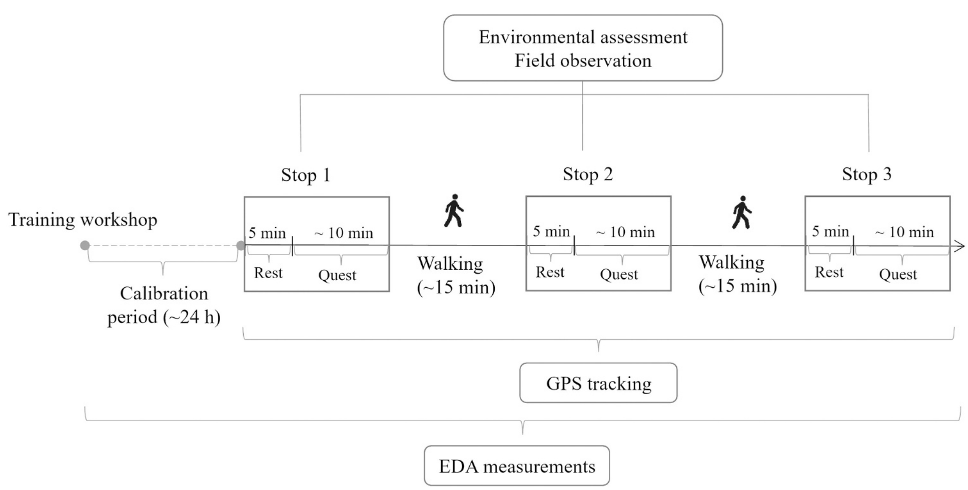

Fig. 2. Study procedure. Stops refer to the three locations in randomized order (forest, beach, park). Rest = rest period; Quest = filling in the questionnaire; EDA = Electrodermal Activity.

panoptic segmentation algorithm from Detectron2 library using a pre-trained model (COCO panoptic FPN R101) (Wu et al., 2019) was applied on the images. Panoptic segmentation is a method that brings together semantic and instance segmentation by identifying both uncountable structures (stuff), such as sky by, labelling pixels and countable objects (things) such as a person, by detecting and delineating objects (Kirillov et al., 2019). As a result, the features and textures in an image are identified and labelled according to the predefined classes in the applied model. The detected classes from the sites included grass, dirt, tree, rock, sand, river, sea, water, bird, bench, pavement, person, road, building, car, traffic light and sky. Next, the classifications were checked, corrected and reclassified manually by the authors, and further classified into two categories; natural and man-made features. Pixels detected as sky and people were excluded from the analysis.

In order to assess the level of naturalness of the soundscape (i.e. ratio between anthrophonic and biophonic sounds), field recordings (n=15) from each place were analysed using *Normalized Difference Soundscape Index (NDSI)*. The NDSI index identifies biophonic sounds as prominent in the frequency range between 2 kHz and 8 kHz, and anthrophonic sounds- between 1 kHz and 2 kHz (Kasten et al., 2012). NDSI was calculated using the soundscape ecology package in R (Villanueva-Rivera and Pijanowski, 2018): function multiple_sounds() and standard settings for frequency ranges. The index produces a value between −1 (anthrophonic dominance) and +1 (biophonic dominance).

2.3.2. Statistical analysis

First, the EDA data was cleaned for missing values due to a loss of signal, a momentary malfunction of the firmware or a person being hypo-responsive in terms of EDA readings (one participant). We then examined crude differences in stress recovery between places. We calculated changes in physiological (EDA levels) and psychological (ROS scores) restoration from the individual mean values and compared these using Kruskal-Wallis multiple comparisons for pair-wise testing using the Holm method. Then, we investigated time differences in physiological stress recovery only during the Rest period since answering the questionnaire involves a cognitive task and may lead to arousal of SNS due to being alert and focused. To test if the EDA levels during the Rest period differed significantly from the starting time point (minute 1), we used a linear regression model assuming Gaussian error distribution.

We further investigated the multiple factors affecting stress recovery including various predictors and covariates. The EDA level and ROS scores were modelled separately with two different approaches by using generalised linear mixed models (GLMM). The first model (Model 1) investigated if the difference in stress recovery between places is affected by possible interaction between the phase of the experiment (walking, rest or answering questionnaire), order of places and date of the walks. For both response variables (EDA and ROS), three control variables describing differences between participants (age group, gender and stress level during the day) were added in the models. Further, temperature and relative humidity as covariates were added to the models since previous evidence suggest their influence on EDA levels (Boucsein et al., 2012). Significance of two-way interactions were also studied. The assumption of beta (with logit link) distribution was used for the model on EDA levels and Gaussian (with identity link) for the model on ROS measures (Gbur et al., 2012).

In the second model (Model 2) the main predictor of the Model 1, i.e. place, was omitted. Many of the other predictors were strongly place-based and related to the biophysical characteristics of the forest, beach, or park. Hence, in Model 1, this can hide the role of other predictors potentially providing detailed understanding of the association between individual factors and restoration. The EDA level of walking was used as a covariate for the EDA level in each place. A measure of perceived landscape quality (PLQ) and perceived soundscape quality (PSQ) from a human perspective was developed for each place as follows:

$$PLQ_{place} = \frac{1}{2}\left(\frac{PEAQS_{place}}{6} + VP_{place}\right)$$

$$PSQ_{place} = \frac{1}{4}\left(\frac{DS_{place}}{3} + \frac{PSAQ_{place}}{4} + SA_{place} + SP_{place}\right)$$

where PEAQS stands for Perceived Environmental Aesthetic Qualities Scale and VP for visual pleasantness. DS stands for dominant sound source identified by respondents, PSAQ stands for Perceived Soundscape Affective Quality, SA for Soundscape Appropriateness and SP for Soundscapes pleasantness. All predictors and their correlations were tested (Table 2, Supplementary Material), and significant ones were kept in the models. Due to multiple predictors and their interactions, the stepwise selection method based on The Akaike information criteria (AICC) was used for advisory purposes to ensure that no important effects were missed in the models.

In both models, correlated observations between each respondent were taken into account using the compound symmetry (CS) structure that assumes a constant covariance between all points. Other structures were tested also, but CS had the lowest AICC value. The effect of group, order of stops and the last place visited were used in random effects. The marginal and conditional R^2-values were calculated using SAS Macro % GOF (Vonesh and Chinchilli, 1996). The former measures the explanatory power of fixed effects, while the latter takes into account both fixed and random effects.

The models were fitted by using the residual pseudo likelihood (for beta) and restricted maximum likelihood (for Gaussian) estimation methods, respectively. The method of Westfall (Westfall, 1997) was used for pairwise comparisons of treatments with a significance level of 0.05. However, in the model selection phase a significance level of 0.10 was used. The degrees of freedom were calculated using the Kenward-Roger method (Kenward and Roger, 2009). The analyses were performed using the GLIMMIX procedure in the SAS Enterprise Guide 7.15 (SAS Institute Inc., Cary, NC, USA). Other statistical analyses were done in R version 4.2.2.

Table 2
The estimates of the fixed continuous effects for EDA level (A) and ROS scores (B). The beta estimates, standard errors, degrees of freedom, t-values, p-values, and confidence intervals are reported for each variable. All variables were standardized, and the assumption of beta distribution was used for EDA level and Gaussian for ROS score, respectively. All predictors and their two-way interactions were tested, and all statistically significant were kept in the models using a significance level of 0.10. Degrees of freedom were calculated using the Kenward-Roger method.

A.) Parameter estimates for EDA level						
Effect	Beta	SE	DF	t-value	p-value	95% CI
EDA walking	3.780	0.429	68.1	8.810	<0.001	(2.923, 4.636)
Wind direction	-0.004	0.001	104.9	-4.330	<0.001	(-0.006, -0.002)
Nature connectedness (INS)	-0.148	0.069	33.9	-2.160	0.038	(-0.287, -0.009)
NDSI	-0.488	0.251	113.5	-1.940	0.055	(-0.986, 0.010)
Stressful day	0.057	0.031	30.2	1.860	0.073	(-0.006, 0.119)
B) Parameter estimates for ROS score						
Effect	Beta	SE	DF	t-value	p-value	95% CI
N people	-0.156	0.067	91.9	-2.320	0.022	(-0.289, -0.023)
NDSI	0.187	0.091	114.4	2.060	0.042	(0.007, 0.367)
N people x NDSI	0.200	0.081	105.9	2.470	0.015	(0.039, 0.360)
Mental health	0.276	0.076	38.4	3.620	0.001	(0.122, 0.431)
PLQ	0.284	0.078	112.3	3.620	<0.001	(0.128, 0.439)
PSQ	0.362	0.075	114.7	4.840	<0.001	(0.214, 0.510)

3. Results

3.1. Objective and subjective environmental assessments

Environmental conditions including temperature, relative humidity, wind speed, wind direction and air quality did not show significant differences between locations, although they slightly varied between the walks (Fig. 3). Percentage of visual natural elements describing the naturalness of view at each place and the number of other people present at each place differed between locations (Kruskal-Wallis rank sum test, $p<0.01$). The urban park had significantly lower visual naturalness (84%) (mainly grass) compared to the beach (mainly water and sand) and forest (mainly trees), for both of which 99% of the landscape views consisted of natural elements. The lowest number of people was observed in the forest (6–18 people), while the park was the busiest during all walks (52–90 people).

The park and forest had a higher ratio of anthrophonic sounds than the beach as measured by NDSI (Fig. 3), although those differences were not statistically significant. Similarly, participants identified technological and human sounds to be most dominant in the park, while natural sounds were identified mostly in the beach, followed by the park (Fig. 1B in Supplementary Material). The park received generally lower scores in the subjective evaluation of both landscape and soundscape quality, while the beach received mostly highest scores (Figs. 1A and 1B in Supplementary). In all three locations, soundscape overall pleasantness was rated lower than the landscape overall pleasantness.

3.2. Differences in restoration between places

Supporting Hypothesis 1, psychological restoration (ROS) in the park differed from both forest and beach ($p<0.001$). The highest perceived

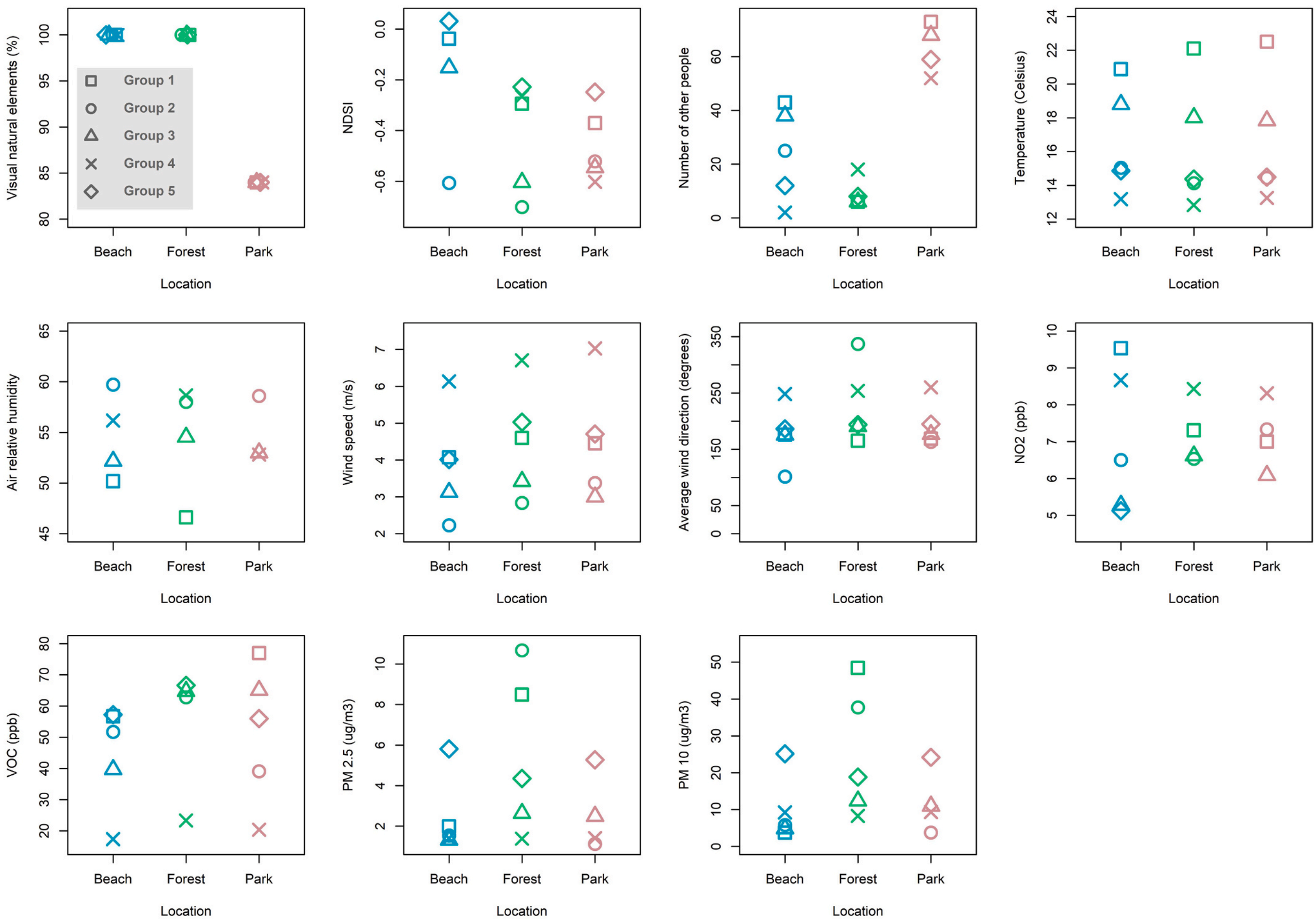

Fig. 3. Differences in environmental conditions between locations and study groups (walks).

restoration (ROS scores) stated by participants was in the beach, followed by the forest and was lowest in the park (Fig. 4; for individual ratings see Fig. 2, Supplementary material). Generally, EDA levels were lower during Rest compared to Questionnaire phase in all locations, but the difference was significant only at the forest ($p<0.001$) (Fig. 4).

Next, we studied the role of other predictors. In both models (GLMM 1 and 2), the group, stop order and last place visited did not have an effect on EDA or ROS outcomes. In Model 1, after controlling background variables (age, gender and stress level during the day) and random factors (stop order, date of the walk), the results still showed significant differences in stress recovery between places. In the forest, the EDA level of Rest phase was significantly lower than Rest period in the beach and park ($p<0.020$), while in the park, the EDA level in the Questionnaire phase was higher than Questionnaire phase in the beach and in the park ($p<0.001$). In addition, the phase of the experiment (walking, rest, questionnaire) was found to be significant predictor for

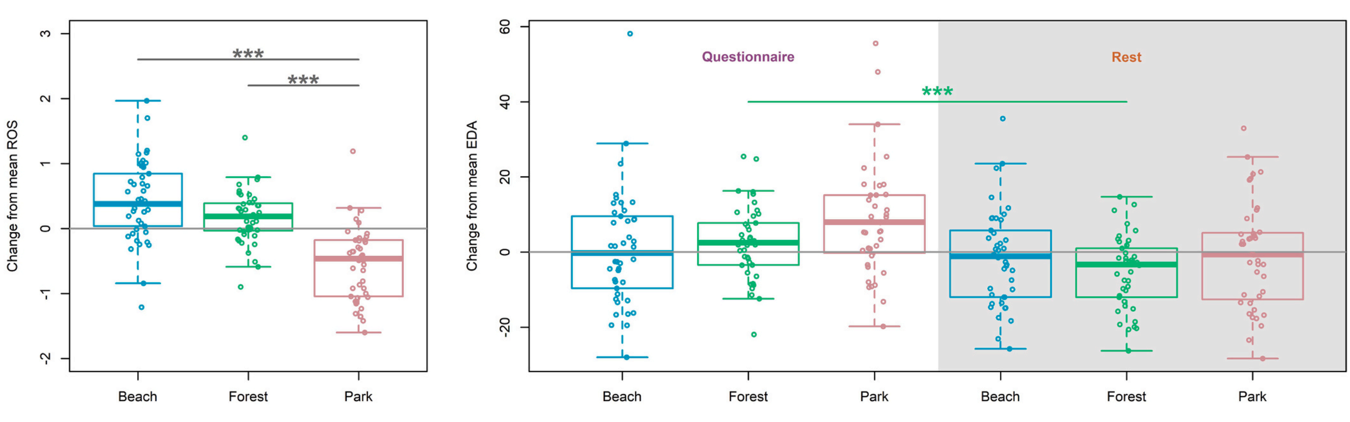

Fig. 4. Psychological and physiological restoration in the studied places. Left: Differences in psychological restoration between places measured as change from mean Restoration Outcome Scale (ROS) scores. Higher values indicate higher perceived restoration. Right: Differences in physiological restoration between places measured as change from mean Electrodermal Activity (EDA) levels. Lower values indicate reduction of stress levels. The connection lines above the bars describe statistically significant differences among variables (*** indicates $p<0.001$).

EDA levels (Table 1A), while place was a significant predictor for ROS scores (Table 1B).

The change of EDA levels of each participant during the five-minute Rest phase showed differences between places. In the beach and forest, the EDA levels generally decreased from individual mean values already on the third minute of rest, while no stress recovery was shown in the park (Fig. 5). The decrease in EDA levels was most prominent in the forest while in the beach the differences between study subjects were large and increasing with time. In the forest, the EDA levels showed a decrease of 5.9 units (CI: 0.6–12.4) at minute four of rest and 6.1 (CI: 0.3–12.5) at minute five from the individual mean EDA when compared to the starting minute, but these showed only marginal significance ($p=0.070$ and $p=0.060$, respectively).

3.3. *Factors affecting stress recovery and their interactions*

Next, we studied which personal characteristics and environmental factors explained the EDA level and the ROS score when place as variable was not taken into account. Different predictors were found significant for the EDA and ROS response variables (Table 2). In the GLMM 2, the effect of feeling less stressed during the day was associated with increased EDA level ($\beta=0.057$, $p=0.073$). The wind direction (blowing from West or Northwest) ($\beta=-0.004$, $p<0.001$), higher nature connectedness (INS) ($\beta=-0.148$, $p=0.038$) and higher NDSI (more biophonic sounds) were associated with decrease in EDA level ($\beta=-0.488$, $p=0.055$). These fixed effects explained 53% of total variation, and 57% together with the random effect of the respondent.

The ROS measure was explained by the number of other people present in each place (N people), NDSI, self-reported mental health, perceived landscape quality (PLQ) and perceived soundscape quality (PSQ) (Table 2). In addition, the effect of NDSI depended on the presence of people as higher NDSI (more biophonic sounds) together with a higher number of people increased the ROS measure, although with a very low number of people the effect was slightly negative. Higher PLQ and PSQ, and better self-reported mental health all increased ROS outcomes, and their effects for PLQ and PSQ were moderate ($\beta=0.284$ and $\beta=0.362$, $p<0.001$), as was the effect of self-reported mental health ($\beta=0.276$, $p=0.001$). These fixed effects explained 57% of total variation, and 75% together with the random effect of the respondent.

4. Discussion

4.1. *Natural environments (green and blue) have significantly higher restorative potential than urban parks with little green infrastructure*

The aim of this study was to assess the physiological and psychological restorative value of different types of urban nature including a remnant forest, a beach next to the sea and an urban park (a control site) that are located near one's home. In line with previous work (Knez et al., 2018; Tyrväinen et al., 2014) and supporting our hypothesis, we found that restoration effects are stronger in areas of higher naturalness (in the forest and beach sites that have significant higher % of visual natural elements and higher level of biophonic sounds) compared to the urban park, where no stress recovery was shown. Importantly, our results indicated significant differences in both psychological and physiological responses, while in many previous field-based studies, differences in self-reported restoration were evident, but results of physiological effects were contradicting or insignificant. We speculate that this may be a methodological issue since previous experiments used salivary cortisol levels (Tyrväinen et al., 2014), salivary cortisol and heart rate variability (HRV) (Gidlow et al., 2016) or blood pressure measures (Ojala et al., 2019) that may be less capable of eliciting subtle differences between different types of natural environments.

Further, similarly to other studies (De Vries et al., 2016; Subiza-Pérez et al., 2020), the results indicated that the blue space had the highest psychological restoration potential. However, the forest had the highest physiological restoration potential. This suggests that different natural environments can induce different psychophysiological mechanisms of restoration, highlighting the need for environmental complexity. Related to Attention Restoration Theory, a greater range of available neighbourhood nature and more biodiverse environments are more likely to fascinate and draw effortless attention due to the richness of different kinds of stimuli (Korpela et al., 2017).

4.2. *Higher landscape and soundscape quality positively affect restoration*

Our results showed that perceived landscape and soundscape quality had a significant positive effect on self-reported restoration (ROS scores). This provides important further evidence on the role of environmental quality of neighbourhood nature, which has been a major gap in greenspace –health literature (Collins et al.2020). In addition, more natural sounds (i.e. higher NDSI) were also associated with higher restoration effects. Importantly, NDSI was the only significant predictor of both physiological and psychological restoration, although its effect was moderated by the presence of other people for perceived restoration. More people together with higher natural sounds increased self-reported restoration ratings, but affected ratings negatively when the number of people was very low. This highlights the potential for people to act as important moderators (positive or negative) of restoration. EDA level decreased fastest in the forest and the presence of people had a positive effect on this, while in the park and on the beach,

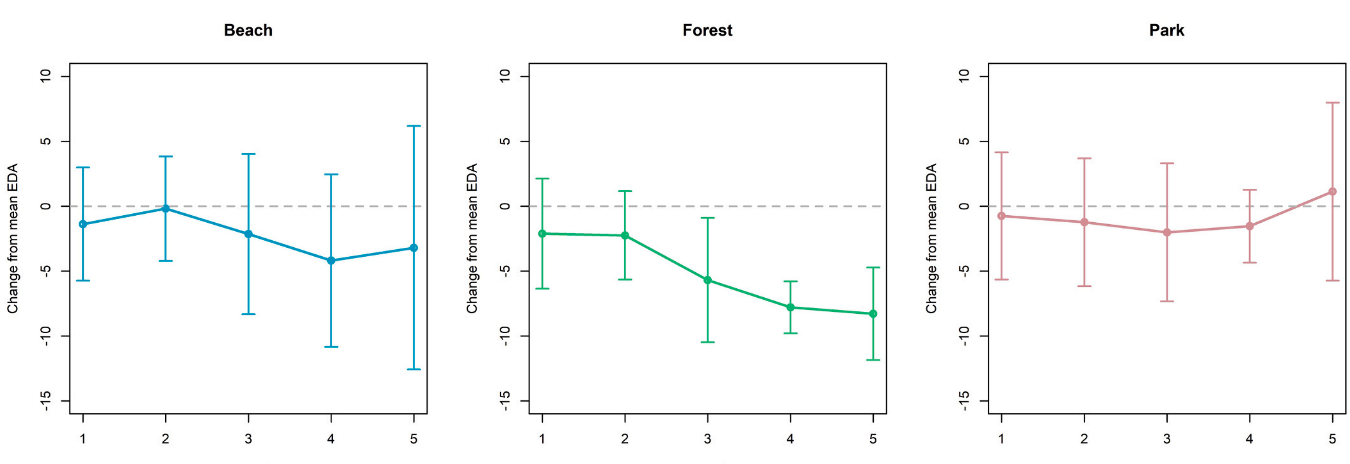

Fig. 5. EDA level changes from the individual mean levels and standard deviation for each minute for each place.

presence of people decreased the effect. One explanation can be that the number of other people was significantly lower in the forest. Perceived crowding can have a negative effect on well-being outcomes (Guite et al., 2006), while a moderate amount of people is shown to aid restoration e.g. through increased feelings of safety (Nordh et al., 2011; Staats and Hartig, 2004). Most likely the perceived threshold value for social crowding was not achieved in the forest and most of the people were observed in distance doing some activities (walking, walking a dog). The negative effects of presence of people in the beach could be attributed to the higher number of people, although crowding effects were not empirically assessed.

4.3. The restorative potential of 3 minutes of nature exposure

Although we expected that more natural areas will have a higher restorative potential, somewhat surprisingly, we also found a very rapid stress reduction effect. EDA levels were reduced within only 3 minutes of nature exposure, especially in the forest. Differences between minutes were only borderline significant, potentially due to the small sample. Previous research on dose-response relationships has indicated that short exposure times can have a positive effect on restoration, and that repetition of nature exposure might be of higher importance than the length of exposure (Cox et al., 2017). Our research provides further insight on this topic, by illustrating psychophysiological changes in different types of nature environments in situ, during a relatively short exposure.

This result is also in line with previous research that has revealed stress recovery effects in short periods of time. For example, in an indoor experiment made by Ulrich et al. (1991) subjects watched stressful movies and approached recovery baseline within 4 minutes. Similar results were found in a laboratory experiment where participants were exposed to mild electrical shocks and then three multisensory environments including sound and smells – in an urban setting, a park and a forest (Hedblom et al., 2019). The two more natural areas (forest and parks) reduced physiological stress significantly within 3 minutes. Both Ulrich et al. (1991) and Hedblom et al. (2019) induced stress, while no stress was explicitly induced in this study. In contrast, stress was 'carried in' by participants and controlled for in the analysis as part of natural daily life. Thus, this field-based trial confirms previous controlled indoor experiments. However, caution from this study is that such a rapid response may only be possible when participants experience greater "flow" i.e. immersive experience in nature without distractions such as interacting with other people or technology.

4.4. Other influential factors

In addition, multiple other predictors affected restorative outcomes in this study including higher self-reported mental health and greater nature connectedness (INS). This builds up on previous evidence showing relations between nature connectedness, psychological well-being and stated mental health (Dean et al., 2018; Nisbet et al., 2020). Further, our results suggest that physiological restoration is affected by participants' "stress baggage" i.e. level of stress before entering the place that was measured objectively (EDA level during walking) or subjectively (self-reported level of stress before joining the experiment). Lower level of stress during the day was associated with higher EDA levels, which could be explained by earlier evidence that restoration and well-being benefits of nature can be greater for more stressed individuals (Barton and Pretty, 2010; Ulrich, 1983). These findings also highlight that urban nature should not be considered as isolated "oasis of recovery" in the built environment, but rather a place that stands in relation to other places in recurrent activity cycles within a social ecology of stress and restoration (Hartig et al., 2003; Markevych et al., 2017).

In addition, contrary to our expectations, environmental conditions such as air quality, temperature, humidity etc. did not have a significant effect, with the exception of wind direction affecting EDA levels. Research on the effects of wind and especially wind direction is scarce, but one study found that patients' energy levels were significantly lower when winds blew from the southeast (Bos et al., 2012). This is somewhat in line with our results showing that EDA levels were significantly higher when wind blue from northwest. However, future studies can examine if similar results are observed with more pronounced seasonal weather differences.

4.5. Strengths, limitations and future implications

This study was conducted as 'real-life' field-based experiment, which inevitably has its strengths and limitations. The main advantage of this study is that it embraces the complexity of everyday exposure to nearby nature. Thus, the method allows for simultaneous analysis of the interacting effects of multiple landscapes and soundscape variables on psycho-physiological restoration, moving beyond dominant visual or cross-sectional spatial assessments. In addition, we showed that the EDA measurements obtained by a smart ring were sensitive and accurate enough to portray changes in physiological effects in a very detailed spatio-temporal scale, presenting an important methodological advancement.

However, several limitations should be acknowledged. First, it was difficult to achieve full randomisation of participants in this field experiment since participants could join the different groups according to their availability, but we could not control for the environmental conditions in each walk. In addition, as expected with an *in situ* study design, there are limited possibilities to control for unexpected occurrences in an outdoor setting, but such occurrences are also an important part of the natural experience and the ecological validity the study is aiming to achieve. Nevertheless, no major external disturbances were observed by researchers or reported by participants during the experiments. We did not control for use of non-psychiatric and psychiatric medications, intoxicating substances or caffeine- containing drinks 72 hours before the experiment, which can affect EDA levels (Boucsein et al., 2012). Future studies should exclude or at least ask participants to report their usage (timing and dose), especially related to medications. In addition, effects of other sociodemographic factors such gender, preferences, culture, or age, warrant further investigation with a larger and more diverse sample, so conclusions applicable to broader populations can be drawn. Future studies can also examine sound intensity level (dB), perceived loudness or individual noise sensitivity that can also play a role in restorative experiences (Cerwén et al., 2016; Ojala et al., 2019).

Finally, this study presents some urban planning implications. The results indicated a very rapid stress reduction potential of urban forests, which highlights the need for adding a temporal dimension to the '3–30-300 rule of thumb' for urban forestry and urban greening requiring every citizen to be able to see at least 3 trees from their home, have 30 percent tree canopy cover in their community and not live more than 300 m away from a green space that have closed green view and high tree structural diversity (Konijnendijk, 2023). Therefore, such initiatives could be coupled with nature-dose recommendations responding to the specific needs of different groups and populations. In addition, our results indicated the importance of nature exposure 'while on the move' being even difficult to disentangle whether part of the observed effects in the study settings might be attributed to the walk between them and the actual experience there. This adds on a growing evidence in literature showing the need to expand measures of green accessibility and residential nature health-exposure to incorporate mobility-based approaches including activity spaces and travel trajectories (Liu et al., 2023).

5. Conclusion

This study showed that both physiological and psychological restoration is greater in environments with higher visual and acoustic naturalness i.e. the beach and forest, compared to the urban park. Perceived and objective soundscape quality were strongly associated with stress recovery, highlighting that soundscape assessments deserve more systematic attention in research and urban planning. Finally, our temporal analyses showed early evidence that only short periods of time (3 minutes) are needed for stress recovery to be observed, with the most rapid reduction shown in forests. These results seem promising, although further validation and larger sample is needed.

CRediT authorship contribution statement

Ann Ojala: Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Kati Vierikko**: Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Data curation, Conceptualization. **Elina Nyberg**: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Gunnar Cerwén**: Writing – review & editing, Writing – original draft, Formal analysis. **Leena Kopperoinen**: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Jenni Lehtimäki**: Writing – review & editing, Writing – original draft, Formal analysis. **Janne Kaseva**: Writing – review & editing, Writing – original draft, Formal analysis. **Christopher M.Raymond**: Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Silviya Korpilo**: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Eugenia Castellazzi**: Writing – original draft, Project administration, Formal analysis. **Marcus Hedblom**: Writing – review & editing, Writing – original draft, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2024.128286.

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