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Evaluating the benefits of green exercise: A randomized controlled trial in natural and built environments assessed for their restorative properties

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ABSTRACT

Exercising in natural environments (green exercise, GE) has been shown to offer significant physiological and psychological health benefits compared to urban or indoor environments. This study evaluated the restorative effects of a 1-h light-to-moderate intensity exercise session across three environments: natural (G), urban (U), and indoor (I).

Using a randomized crossover design, 25 male participants (M = 26.3, SD = 4.3) completed a 1-h walk at 6 km/h in each setting. Psychological outcomes, including perceived restorativeness (PRS), restoration (ROS), emotional states, enjoyment, and behavioral intentions, were assessed with validated questionnaires. Physiological measures (cortisol, heart rate, heart rate variability) were collected pre- and post-intervention.

Results showed that G environment consistently elicited greater relaxation, higher positive emotions, and lower negative emotions compared to U and I. Restoration outcomes (PRS, ROS), enjoyment and intentions to exercise were significantly higher in G, while perceived exertion was lower in G compared to I. Physiologically, cortisol levels, heart rate, and heart rate variability differed by environment, with G promoting a more favorable recovery profile than U and I. No interaction effects were observed for physiological measures, suggesting consistent recovery patterns over time.

These findings highlight the restorative and stress-relieving potential of GE, emphasizing its role in enhancing mental well-being and supporting physical activity adherence. The study underscores the importance of natural environments as a resource for promoting health and well-being, while also identifying the need for further research to clarify the nuanced differences between urban and natural settings.

1. Introduction

The steady rise of global urbanization is transforming the landscapes people inhabit, with the urban population projected to grow from 55 % in 2020 to 68 % by 2050 (WHO, 2016). As cities expand, access to green spaces—critical for health and well-being—faces increasing pressure from urban infrastructure. This shift diminishes the quantity and quality of green spaces, reducing their potential as restorative settings (WHO, 2021). Insufficient access to natural areas is particularly concerning given the broad physical and mental health benefits linked to these environments, such as reduced risks of cardiovascular conditions, improved mood, and lower stress levels (Shanahan et al., 2016; White et al., 2021).

Alongside reduced green spaces, sedentary lifestyles pose a significant health risk. Physical inactivity increases the risks of non-communicable diseases, including obesity, cardiovascular disease, and certain cancers (Bull et al., 2020; Warburton et al., 2006). Despite the well-known benefits of physical activity (PA), policies promoting it often fall short, leaving sedentary behaviors a major public health concern (Pratt et al., 2020).

In response to these challenges, there has been growing interest in green exercise (GE)—exercise performed in natural settings (Pretty, 2004; Pretty et al., 2003). GE promotes healthy lifestyles by encouraging PA maintenance throughout life (Eigenschenk et al., 2019). Combining exercise and nature amplifies benefits, fostering positive psychological outcomes and long-term adherence to PA (Hartig et al., 2014; Pretty

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et al., 2005).

This approach builds on the well-documented effects of natural settings, shown to lower stress, enhance mood, and improve overall health, including reduced blood pressure and increased well-being (Bratman et al., 2015; Nguyen et al., 2023). Two key frameworks, Attention Restoration Theory (ART) (Kaplan & Kaplan, 1989; S. Kaplan, 1995) and Stress Recovery Theory (SRT) (Ulrich, 1983), explain how nature facilitates restoration. While ART suggests natural settings engage involuntary attention, allowing cognitive resources to replenish, SRT focuses on affective responses, proposing that nature reduces stress by promoting positive emotions and lowering arousal.

Physiological evidence supports these theories. Nature exposure enhances parasympathetic nervous system (PNS) activity, indicated by increased heart rate variability (HRV), aiding autonomic relaxation (Gladwell et al., 2012). Active engagement with nature, like walking in a forest, further boosts HRV compared to urban environments (Kobayashi et al., 2018). Even during stress, viewing natural scenes improves PNS recovery compared to urban settings (Brown et al., 2013).

Reviews comparing GE to non-natural settings report mixed results. Some studies show GE reduces negative emotions, such as sadness and anger, more effectively than exercise in urban areas, while increasing tranquility and enjoyment (Bowler et al., 2010; Thompson Coon et al., 2011). Short-term improvements in anxiety and fatigue have also been documented (Wicks et al., 2022). However, meta-analyses suggest no significant differences between PA in natural and indoor environments (Kelley et al., 2022; Lahart et al., 2019). Despite mixed results, enjoyment remains a key factor for exercise adherence, as positive experiences during PA support long-term commitment (Jekauc, 2015; Williams et al., 2006).

The relationship between exercise and affect remains complex and not fully understood (Ekkekakis & Brand, 2019). Acute bouts of PA are consistently linked to improved positive affective states (Reed & Ones, 2006), with moderate-intensity exercise increasing pleasure and perceived energy (Ekkekakis et al., 2011). GE introduces unique dynamics, as natural settings can evoke calming (Kinnafick & Thøgersen-Ntoumani, 2014) and activating responses (Niedermeier et al., 2017; Ryan et al., 2010).

However, methodological inconsistencies in GE research need addressing. Control environments vary widely, with some studies focusing solely on indoor settings, others including urban areas, and some combining mixed conditions (Bowler et al., 2010; Lahart et al., 2019; Wicks et al., 2022). Inconsistencies in PA types, ranging from walking to resistance training, further complicate comparisons. Additionally, few studies assess the perceived restorative qualities of settings despite their role in influencing PA engagement (Menardo et al., 2022; Petrunoff et al., 2022).

To address these gaps, our study incorporates validated measures to assess the environment and its perceived restorativeness (Pasini et al., 2014) and restoration (Korpela et al., 2008). Participants exercise in natural, urban, and indoor environments using a within-subject design, minimizing variability. Direct exposure to nature distinguishes our study, providing a clearer understanding of GE's psychological and physiological effects.

1.1. Aim

This study examines the influence of three environments—natural (G), urban (U), and indoor (I)—on psychological responses to controlled exercise. Physiological responses (e.g., cortisol, HR, HRV) are also assessed to confirm psychological findings, focusing on the stress relief and restorative benefits of natural settings.

Hypotheses:

Hp 1. Exercise environments influence emotional states.

Hp 1a. Natural environments will elicit higher positive and lower negative emotions.

Hp 1b. Natural environments will reduce anxiety and promote relaxation.

Hp 2. Natural environments improve physiological responses, including higher HRV, lower HR, and reduced cortisol.

Hp 3. Perceived exertion will be lower in natural settings compared to urban and indoor environments.

2. Methods

2.1. Participants

Twenty-five male participants were recruited for this study (age: M = 26.3, SD = 4.3). They had an average Body Mass Index (BMI) of 22.9, maximum heart rate (HR max) of 191.29 bpm, VO_2 max of 4084 mL/min, and 55.8 mL/kg/min (see Supplementary Materials for details). According to the Pescatello, (2014), the average VO_2 max for 20–29-year-olds is 44 mL/kg/min, indicating this sample is highly fit or above average compared to the general population. A power analysis conducted in G*Power (version 3.1) indicated that 20 participants would be sufficient to detect moderate-to-large within-subject effects (f = 0.30) with 80 % power at $\alpha = .05$. This threshold is supported by previous research findings suggesting that green exercise interventions commonly yield medium to large effects on emotional and restorative outcomes (see for systematic review, e.g., Wicks et al., 2022). Inclusion criteria were male gender, absence of chronic medical conditions, non-smoking status, and no medications affecting cardiovascular or psychological responses. All participants provided written informed consent. The experimental protocol was approved by the University of Verona Ethics Committee.

2.2. Procedure

The study investigated the influence of three environments—natural (G), urban (U), and indoor (I)—on the physiological and psychological responses to a walking session (see Fig. 1). The research was conducted at University Sport Science Laboratory (Sport, Mountains and Health Research Centre; CeRiSM). Participants visited the CeRiSM laboratories on four occasions: one preliminary assessment session followed by three experimental sessions in a randomized order.

2.2.1. Preliminary session

The preliminary session, held before any experimental session, aimed to assess participants' physical fitness and psychological characteristics. Fitness was evaluated through a maximal treadmill test, preceded by a warm-up phase. Respiratory and cardiac data were recorded to determine fitness levels, which will be analyzed in a separate study. Following the treadmill test, participants completed questionnaires to assess individual differences and psychological traits, including emotional intelligence and connection to nature. These data will contribute to additional analyses beyond the scope of this study.

2.2.2. Experimental sessions

Participants completed three experimental sessions, each lasting approximately 2.5 h, on separate days. A washout period of 7–15 days was maintained between sessions to ensure recovery and comparable environmental conditions. The interval was adjusted based on participant availability, weather forecasts, and minimize carryover effects due to fatigue or previous testing. To ensure balanced exposure and minimize order effects, the sequence of environmental conditions was randomized for each participant prior to data collection using randomization.org. All six possible orders of the three environments (Natural, Urban, Indoor) were represented and distributed evenly across the sample.

In each session, participants performed two 30-min walking periods separated by a 10-min seated rest, totaling 70 min of activity. The same

Fig. 1. Pictures of the three environments where participants performed the physical activity.
Note: on the left, natural (G; forest park of Rovereto, Italy); in the middle, urban (U; a city route through the centre of Rovereto, Italy); and on the right, indoor built (I; the CeRiSM laboratory).

routine was conducted across all environments (see Fig. 2). For the natural and urban sessions, participants followed pre-defined outdoor routes totaling 6 km with 80 m elevation gain/loss. This route was simulated on a treadmill using incline adjustments for the indoor session.

Outdoor walking sessions were performed in small groups of 2–3 participants. Participants walked in line with approximately 4–5 m between each individual. An experimenter walked at the front of the group to set the pace and ensure the pre-established speed of 6 km/h. Throughout all sessions, including walking and the mid-walk rest, interactions among participants and with the experimenter were minimized to social influence. In the indoor condition, each participant walked individually on a treadmill set to maintain a constant speed of 6 km/h. The treadmill followed a speed- and elevation-matched protocol to replicate the outdoor conditions as closely as possible. The experimenter manually adjusted the treadmill walk's elevation profile to mirror the outdoor routes' elevation gain and loss (totaling 80 m), reproducing the sequence of ascents and descents encountered in the natural and urban settings.

Upon arriving at the laboratory, participants changed into sportswear and wore a chest strap to monitor heart rate. They rested supine on a medical bed for 20 min while heart rate (HR) and heart rate variability (HRV) were continuously recorded. Before the walk, participants completed baseline emotional state questionnaires (AEAL) and provided a saliva sample for cortisol assessment. They also reported their baseline perceived exertion using the CR-10 scale.

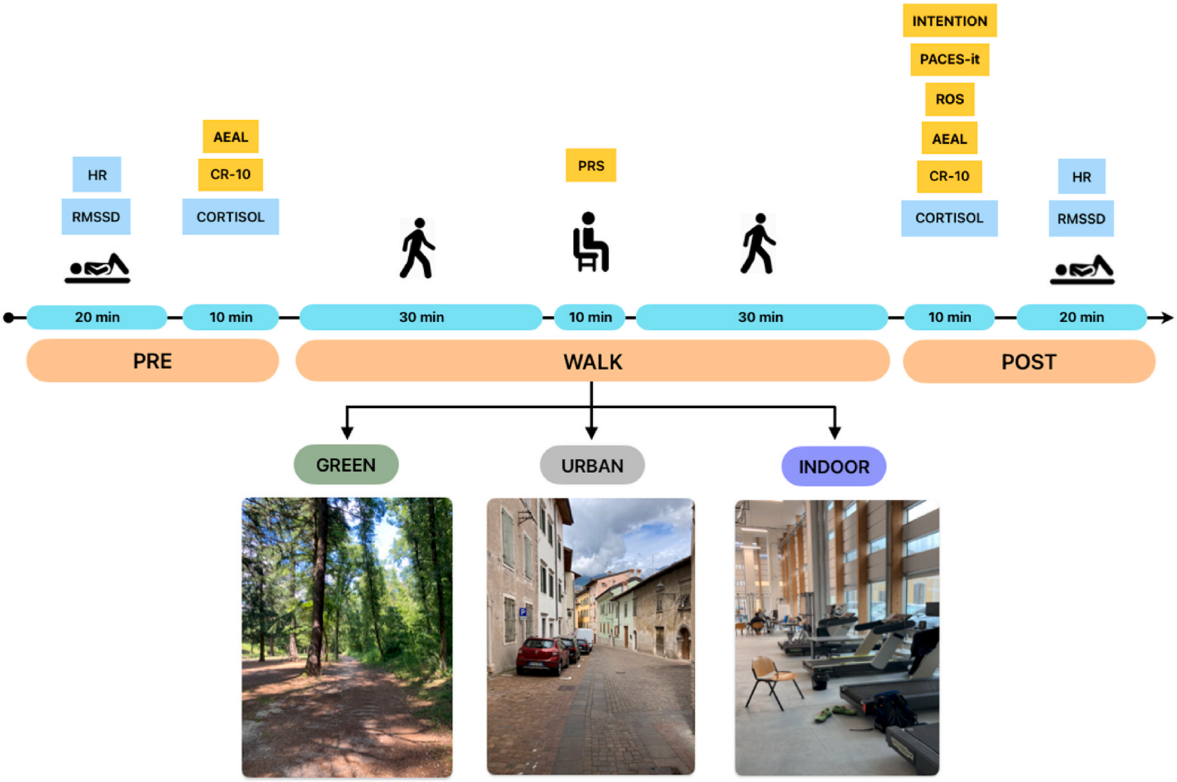

Fig. 2. Experimental session procedure.
Note: the figure displays the procedure repeated across the environments. Heart Rate (HR); Heart Rate Variability (HRV, RMSSD); Borg's rate of perceived exertion (CR-10); Achievement Emotions Adjective List (AEAL); Perceived Restorativeness Scale (PRS); Restoration Outcome Scale (ROS); Physical Activity Enjoyment Scale (PACES-it); Intention (ad hoc item).

At the halfway point of the walk (after 30 min), participants took a 10-min seated break to complete the Perceived Restorativeness Scale (PRS).

Upon completing the exercise, they provided a second saliva sample and filled out post-walk questionnaires assessing emotional state (AEAL), perceived exertion (CR-10), psychological restoration (ROS), enjoyment (PACES-It), and future intention to exercise in the same environment. Finally, participants underwent another 20-min supine rest for post-exercise HR and HRV assessment.

2.3. Measures

Restorativeness. The Perceived Restorativeness Scale (PRS) (Hartig et al,. 1997; Hartig et al., 1997; Pasini et al., 2014), grounded in Kaplan and Kaplan's Attention Restoration Theory (ART), was used to assess each environment's restorative qualities. The PRS evaluates four core dimensions: *Being Away* (escape from routine or demands), *Fascination* (effortless attention), *Coherence* (organization and comprehensibility), and *Scope* (opportunities for exploration). Participants rated statements on an 11-point Likert scale (0 = not at all, 10 = very much), providing a comprehensive measure of restorative potential. Internal consistency was strong, with McDonald's ω of 0.88, 0.85, and 0.93 for the indoor, natural, and urban environments, respectively.

Psychological restoration. The Restoration Outcome Scale (ROS; Korpela et al., 2008) assessed immediate restorative experiences in each environment. The scale includes six items across key areas: relaxation, attention restoration, and clearing one's thoughts. Participants rated statements like "I am calm" and "I am able to forget everyday worries" on a 7-point Likert scale, with higher scores reflecting greater restoration. The ROS is widely validated for measuring nature's emotional and cognitive effects (Pasanen et al., 2018), showing strong internal consistency with McDonald's ω of 0.93, 0.77, and 0.97 for indoor, natural, and urban environments, respectively.

Emotional state. The Achievement Emotions Adjective List (AEAL; Raccanello et al., 2022) measured emotional states based on the circumplex model of activation and valence. A total of 14 items were used. Participants rated each item on a 5-point Likert scale (1 = not at all, 5 = very much). Initially developed for educational contexts, the AEAL is adaptable to other domains, including sports, where it effectively captures performance-related emotions that influence motivation and experience (see Results and Supplementary Table 47).

Perceived exertion. Perceived exertion was assessed before and after the walk using the Borg Category Ratio Scale (CR-10; Borg, 1998). The scale ranges from 0 (nothing at all) to 10 (maximal exertion) and above for absolute maximum exertion (Foster et al., 2001).

Enjoyment of physical activity. The Physical Activity Enjoyment Scale (PACES-It; Carraro et al., 2008), validated in Italian, assessed enjoyment. It includes 16 items rated on a 7-point Likert scale from 1 ("totally disagree") to 7 ("totally agree"), with higher scores indicating greater enjoyment. This scale helps evaluate how different settings influence the pleasure of exercise and its potential impact on adherence. Internal consistency was excellent, with Cronbach's α of 0.95, 0.88, and 0.96 for indoor, natural, and urban environments.

Intention to exercise. Participants' intentions to engage in future PA in similar environments were measured using a single ad-hoc item. They rated their intention on a 7-point frequency scale ranging from 1 ("Never") to 7 ("More than three times a week"). This self-reported measure captured participants' behavioral intentions, serving as an indicator of exercise adherence.

Heart Rate and Heart Rate Variability. Cardiac indices were continuously monitored for 20 min before and after the walk using a Polar H10 heart rate monitor while participants rested supine. Heart Rate Variability (HRV) was analyzed using the RMSSD time-domain index, which estimates vagally mediated HRV changes (Malik et al., 1996). Data were processed using a moderate error correction filter with Kubios HRV software (Version 3.5.0, Biosignal Analysis and Medical Imaging Group, Kuopio, Finland).

Cortisol. As a stress marker, salivary cortisol concentrations were measured before and after walking using Salivette® (Sarstedt). Samples were centrifuged for 5 min immediately after collection and stored at −18 °C for later analysis at the University.

2.4. Analyses overview

To investigate the impact of time (pre, post) and environment (natural = G, indoor = I, urban = U) on dependent variables such as emotions, cardiovascular indices, and perceived exertion, linear mixed modelling (LMM) with residual maximum likelihood estimations was employed. This method, widely used in restorative environments research (Oswald et al., 2023; Suko & Korpela, 2024), incorporates both fixed and random effects, accounting for the hierarchical structure of the data and within-subject variability.

For emotions, perceived exertion (CR-10), and cortisol, pre- and post-walk measurements were included in the linear mixed models. Heart rate (HR) and heart rate variability (RMSSD) were assessed across five time points: pre-walk and 5, 10, 15, and 20 min post-walk, allowing for a more detailed examination of recovery trajectories. Cortisol and RMSSD values were log-transformed before analysis.

Repeated measures ANOVA was used to analyze ROS and PRS scores, with the environment (natural, urban, indoor) as a within-subject factor. Post-hoc pairwise comparisons with Bonferroni correction were performed to analyze significant effects ($p < .05$).

Participants' intentions to engage in future PA in each environment were assessed using a non-parametric Friedman's ANOVA due to the non-normal distribution of intention scores. Pairwise comparisons with the Wilcoxon signed-rank test and Bonferroni correction explored differences between environments.

All mixed model analyses were conducted in Jamovi using the GAMLj module (version 2.6.6). In the main text, we report β coefficients and p-values to emphasize the strength and significance of the effects. Full model outputs, including model fit indices (AIC, BIC, log-likelihood), marginal and conditional R^2, and variance components (random effects, ICC), are provided in the Supplementary Materials (Supplementary Table 1) to facilitate transparency and interpretation. Additional analyses, including repeated-measures ANOVA and non-parametric tests, were conducted using Jamovi and R Statistical Software (version 4.3.1). Descriptive statistics and post-hoc results are presented in the Supplementary Materials.

3. Results

3.1. Psychological outcomes

3.1.1. Restoration

Results showed that the perceived restorativeness (PRS) varied significantly across the different environmental conditions ($F(2,48) = 105.9$, $p < .001$, $\eta^2 = 0.82$; Fig. 3). Post hoc comparisons showed that participants perceived the natural environment as the most restorative, followed by the urban and the indoor (all $ps < 0.001$).

Restoration outcomes (ROS) differed significantly across environments ($F(2,48) = 38.03$, $p < .001$, $\eta^2 = 0.61$; Fig. 3). Post hoc comparisons indicated that the natural environment yielded significantly higher restoration scores than urban and indoor settings ($ps < 0.001$). At the same time, no significant difference was found between U and I ($p = .104$).

3.1.2. Emotions

Emotions were assessed using a short version of the Achievement Emotions Adjective List (AEAL; Raccanello et al., 2022), grounded in the circumplex model of affect. This model categorizes emotions along two dimensions: activation (activating/deactivating) and valence (positive/negative), resulting in four distinct groups: positive activating

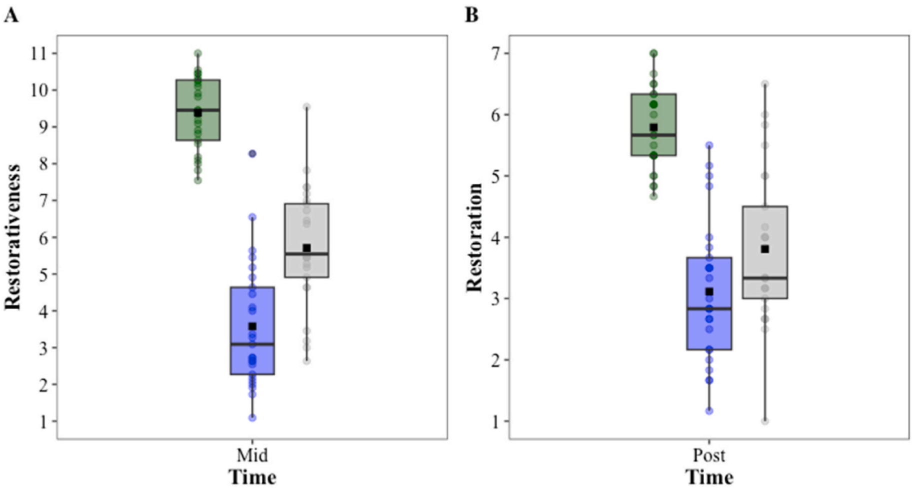

Fig. 3. Perceived restorativeness (PRS) and psychological restoration (ROS) for the three environments.
Note: the plot displays the reported levels of perceived restorativeness (PRS; Panel A) and psychological restoration (ROS; Panel B) for each environment. Perceived restorativeness (PRS) was assessed during the 10-min stop in the middle of the walk while participants were immersed in each of the three environments. The psychological restoration (ROS) was assessed at the end of the walk. Environments are represented by different colors: green for the natural environment, grey for the urban environment, and blue for the indoor environment. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

emotions (PAE; i.e., happy, satisfied, optimistic), positive deactivating emotions (PDE; i.e., relaxed, relieved), negative activating emotions (NAE; i.e., anxious, angry, embarrassed), and negative deactivating emotions (NDE; i.e., demoralized, bored).

For this study, participants responded to a total of 14 items. Ten items measured one specific emotion within the circumplex categories. Additionally, three items were used to enhance reliability for the key target emotions of relaxation and anxiety. Relaxation was assessed with the items relaxed, calm, and tranquil, while anxiety was measured with anxious, worried, and nervous.

This tailored version of the AEAL allowed for calculating composite scores for each emotional category while providing a robust and detailed evaluation of relaxation and anxiety as primary outcomes.

Positive Emotions. Our results revealed a significant main effect of the environment (F(2,120) = 6.36, p = .002). Participants reported significantly higher positive emotions in G compared to U ($\beta = -0.36$, p = .005) and I ($\beta = -0.40$, $p < .001$), confirming Hp 1a. While no significant effect of time alone was found (p = .190), there was a significant interaction effect of time and environment on positive emotions (F (2,110) = 6.67, p = .002; see Fig. 4). Specifically, positive emotions decreased more in I compared to G from pre to post ($\beta = -0.90$, $p <$ .001). The decrease in positive emotions in U was marginally significant compared to G ($\beta = -0.46$, p = .068). No significant changes were found in G and U from pre to post.

Positive deactivating emotions (PDE). The analysis revealed significant main effects of both time (F(1,120) = 10.57, p = .001) and environment (F(2,120) = 7.57, $p < .001$) on positive deactivating emotions. Post-walk, participants experienced a significant reduction in positive deactivating emotions compared to pre-walk levels ($\beta = -0.41$, p = .001). Participants reported significantly lower positive deactivating emotions in I ($\beta = -0.48$, p = .003) and U ($\beta = -0.56$, $p < .001$) compared to G. A significant interaction between time and environment was also observed (F(2,120) = 5.95, p = .003; see Fig. 4). Participants in I experienced a larger reduction in positive deactivating emotions post-walk than G ($\beta = -1.0$, p = .002). Similarly, participants in U showed a significant reduction in these emotions post-walk compared to G ($\beta = -0.84$, p = .008).

Positive activating emotions (PAE). The analysis showed a significant effect of the environment on positive activating emotions (F (2,120) = 3.52, p = .033). Participants reported lower positive activating emotions in I compared to G ($\beta = -0.37$, p = .010). No statistically significant difference between U and G (p = .105) existed. While no main effect of time was observed (p = .628), there was a significant interaction between time and environment (F(2,120) = 5.32, p = .006; see Fig. 4). Participants in I showed a greater reduction in positive activating emotions post-walk than G ($\beta = -0.84$, p = .002). No significant interaction was found in U compared to G (p = .459).

Negative Emotions. The analyses showed a significant main effect of the environment on negative emotions (F(2,120) = 11.81, $p < .001$). Participants reported lower levels of negative emotions in G compared to I ($\beta = -0.45$, $p < .001$) and U ($\beta = -0.24$, p = .012), confirming Hp 1a. There was no significant main effect of time (p = .596). However, a significant interaction between time and environment was found (F (2,120) = 4.36, p = .015, see Fig. 4). Negative emotions decreased more from pre to post in G than I ($\beta = -0.54$, p = .004). No significant interaction was found for U compared to G (p = .181). A significant decrease was found in G from pre to post exercise ($\beta = -0.30$, p = .021).

Negative activating emotions (NAE). The analysis revealed a significant main effect of the environment on negative activating emotions (F (2,120) = 5.65, p = .005). Participants reported higher negative activating emotions in both I ($\beta = 0.23$, p = .006) and U ($\beta = 0.24$, p = .003) compared to G. No main effect of time (p = .060) or significant interactions were found between time and environment (p = .408).

Negative deactivating emotions (NDE). The analysis revealed a significant main effect of the environment on negative deactivating emotions (F(2,120) = 15.31, $p < .001$). Participants reported higher negative deactivating emotions in I compared to G ($\beta = 0.78$, $p < .001$). No significant differences were found between U and G (p = .115). No main effect of time was found (p = .465). A significant interaction between time and environment was observed (F(2,120) = 8.64, $p < .001$). Participants in I reported an increase compared to G in negative deactivating emotions from pre-to post-walk ($\beta = 1.16$, $p < .001$). No significant effect was found in U compared to G (p = .303).

Relaxation. Our study revealed a significant main effect of environment on relaxation (F(2,120) = 7.08, p = .001), with participants in G reporting higher relaxation levels compared to both I ($\beta = -0.48$, p = .001) and U ($\beta = -0.47$, p = .002). We also found a significant main effect of time on relaxation (F(2,120) = 17.06, $p < .001$), with relaxation that decreased from pre to post exercise across conditions ($\beta = -0.49$, $p < .001$). Our results also showed a significant interaction between time and environment (F(2,120) = 3.23, p = .043, see Fig. 5), indicating that relaxation decreased more in I than in G from pre to post ($\beta = -0.72$, p =

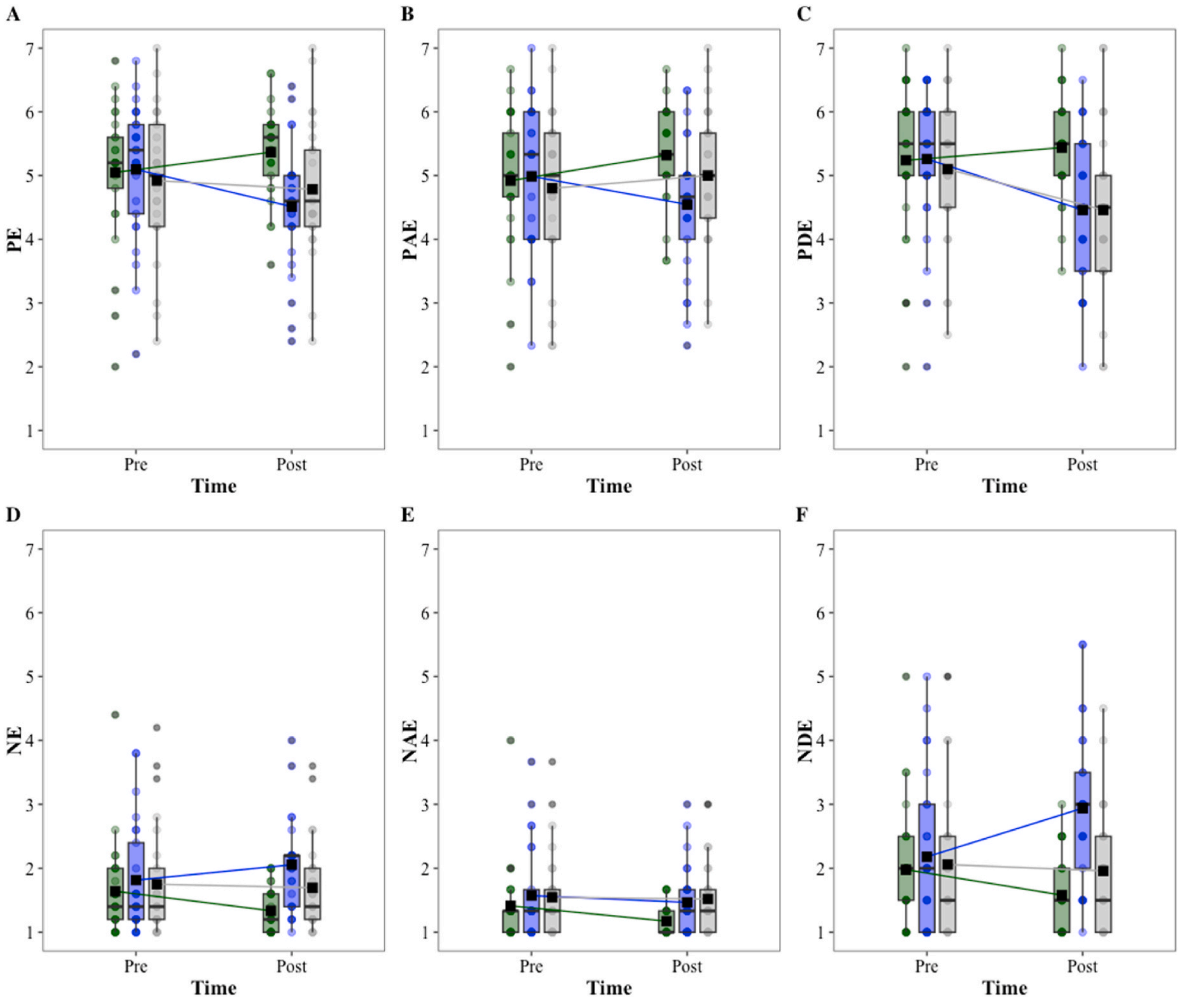

Fig. 4. Positive and negative activating and deactivating emotions pre- and post-activity in green, urban, and indoor environments.
Note: the top panels show the interactions between time and environment for overall positive emotions (PA; panel A), positive activating emotions (PAE; panel B), and positive deactivating emotions (PDE; panel C). In the bottom panels, there are the interactions between time and environment for overall negative emotions (NE; panel D), negative activating emotions (NAE; panel E), and negative deactivating emotions (NDE; panel F). Environmental conditions are represented by different colors: green (natural environment), grey (urban environment), and blue (indoor environment). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

.015). No significant interaction was found for U compared to G (p = .078).

Anxiety. The analysis revealed a significant effect of the environment on anxiety levels (F(2,120) = 4.50, $p = .013$). Participants reported higher anxiety in I compared to G ($\beta = 0.26$, $p = .022$) and in U compared to G ($\beta = 0.31$, $p = .006$). There was no significant effect of time ($p = .356$) and no significant interaction between time and environment ($p = .542$).

These results confirmed Hp 1b, demonstrating that natural environments promote relaxation and maintain lower anxiety levels than urban and indoor settings.

3.1.3. *Perceived exertion (CR-10)*

The analysis of perceived exertion revealed a significant main effect of time (F(1,120) = 333.18, $p < .001$), indicating that participants reported higher levels of exertion post-exercise compared to pre-exercise ($\beta = 1.74$, $p < .001$). There was also a significant main effect of environment (F(2,120) = 5.23, $p = .007$), with participants reporting higher perceived exertion in I compared to G ($\beta = 0.33$, $p = .005$). No significant difference in perceived exertion was found between the U and G ($p = .925$). This finding partially supports Hp 3, as perceived effort was lower in natural settings than in indoor environments, though no significant differences emerged between natural and urban settings. The interaction between time and environment was not significant (F (2,120) = 2.29, $p = .106$; see Fig. 6).

3.1.4. *Behavioral intentions and enjoyment of exercise*

PACES (Physical Activity Enjoyment Scale). Enjoyment scores varied significantly across environmental conditions (F(2,48) = 41.09, $p < .001$, $\eta^2 = 0.63$, Fig. 7). Aligning with Hp 1a, post-hoc analyses revealed that participants reported significantly higher enjoyment in G compared to both I and U (all $ps < 0.001$), with no significant difference between I and U settings ($p = .506$).

Intentions. A Friedman test revealed a significant effect of the environment on participants' intention to engage in future PA within the same environment where they completed the experiment ($\chi^2(2)$ = 15.88, $p < .001$, Kendall's W = 0.318, indicating a moderate effect; Fig. 8). Post-hoc pairwise comparisons using the Wilcoxon signed-rank test with Bonferroni correction showed that the intention score was significantly higher in G compared to I ($p = .002$, W = −2.31) and U (p = .004, W = −2.30) environments, aligning with Hp 1a No significant difference was found between I and U ($p = 1.00$).

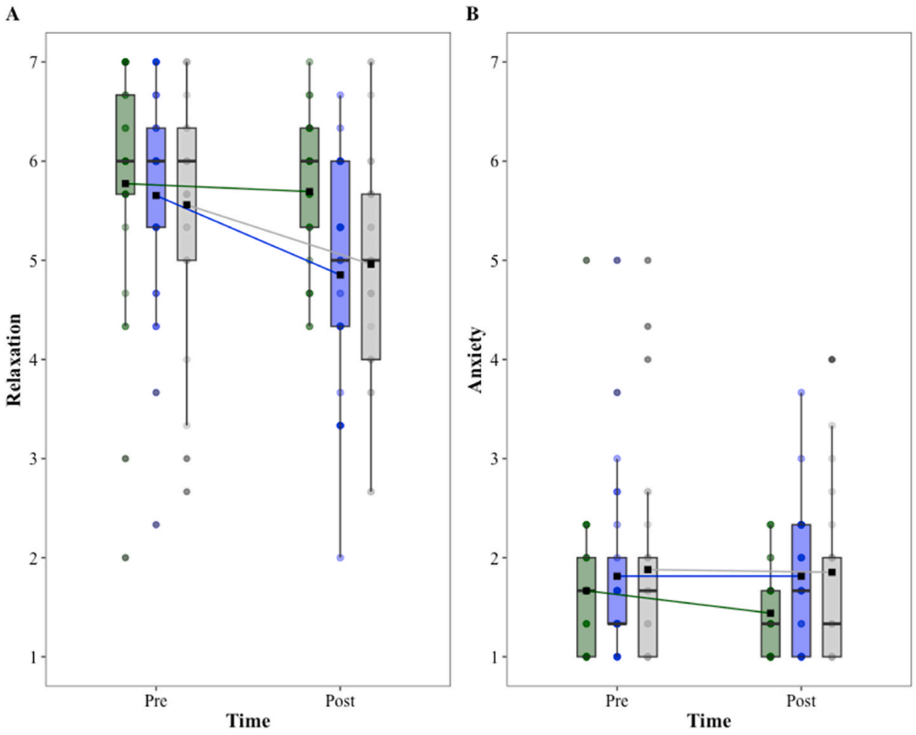

Fig. 5. Relaxation and anxiety pre- and post-activity in green, indoor and urban environments.
Note: the plot displays the interactions between time and environment for relaxation (panel A) and anxiety (panel B). Environmental conditions are represented by different colors: green (natural environment), grey (urban environment), and blue (indoor environment). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.2. *Physiological measures*

Heart Rate. The analysis revealed significant effects of time on heart rate (F(4, 336) = 8.27, $p < .001$), indicating that HR significantly decreased across time points. Compared to the pre-walk baseline, HR was significantly lower at post-5 ($\beta = -1.81$, $p = .002$), post-10 ($\beta = -2.52$, $p < .001$), post-15 ($\beta = -2.88$, $p < .001$), and post-20 ($\beta = -2.86$, $p < .001$). A main effect of the environment was also found (F(2, 336) = 3.31, $p = .038$). HR was significantly higher in I compared to G ($\beta = 1.08$, $p = .019$) and in U compared to G ($\beta = 0.95$, $p = .040$), supporting Hp 2. No significant interactions between time and environment were found ($p = .889$; see Fig. 9).

RMSSD. The analysis revealed a significant effect of time on log-transformed RMSSD (F(4, 336) = 4.67, $p = .001$), with significant increases from pre-walk to 5 min post ($\beta = 0.12$, $p = .020$), 10 min post (Estimate = 0.11, $p = .026$), 15 min post ($\beta = 0.17$, $p < .001$), and 20 min post ($\beta = 0.19$, $p < .001$), showing a steady increase over time. Supporting further Hp 2, a significant main effect of the environment was found (F(2, 336) = 16.44, $p < .001$), with log-RMSSD being lower in I compared to G ($\beta = -0.21$, $p < .001$) and lower in the U compared to G ($\beta = -0.13$, $p < .001$). No interaction between time and environment was observed ($p = .784$; see Fig. 9).

Cortisol. The analysis of log-transformed cortisol revealed a significant main effect of time (F(1, 120) = 209.10, $p < .001$), showing a substantial decrease in cortisol levels from pre-to post-walk across all conditions ($\beta = -0.82$, $p < .001$). Additionally, a significant main effect of the environment was observed (F(2, 120) = 10.43, $p < .001$). Cortisol levels were significantly higher in I compared to G ($\beta = 0.19$, $p = .009$) and in U compared to G ($\beta = 0.32$, $p < .001$). These results confirm Hp 2, demonstrating that natural environments are associated with lower cortisol levels, reflecting reduced physiological stress. No significant interaction between time and environment was found ($p = .730$, see Fig. 10).

See Table 1 for a summary of the results.

4. Discussion

This study examined the effects of different environmental contexts—natural, urban, and indoor—on both psychological outcomes (e.g., affective states, restoration, perceived restorativeness, enjoyment, and intention to exercise) and physiological responses (e.g., heart rate, heart rate variability, and cortisol) during moderate-intensity PA. Participants completed 1 h of exercise in each environment, and their responses were assessed physiologically and through self-report measures.

We hypothesized that natural environments would lead to greater psychological restoration, more positive emotional states, lower perceived exertion, and improved physiological recovery compared to urban and indoor settings.

4.1. *Psychological outcomes*

4.1.1. *Restoration*

Participants perceived the natural environment as significantly more restorative than indoor and urban settings, with the urban environment rated as moderately restorative but surpassing the indoor setting. These results emphasize the superior restorative potential of natural settings over built environments.

The PRS assesses key environmental qualities that promote restoration, such as fascination (effortless attention), compatibility (alignment with individual goals), extent (perceived scope), and being away (escape from routine; Kaplan & Kaplan, 1989; S. Kaplan, 1995). In contrast, the ROS measures immediate restorative effects, including relaxation, attention recovery, and the ability to clear one's thoughts (Korpela et al., 2008, 2010). Together, these tools provide a comprehensive understanding of how natural environments facilitate psychological recovery.

The higher perceived restorativeness of natural settings aligns with Attention Restoration Theory (ART), which suggests that environments rich in fascination and free from cognitive demands restore directed attention (Collado et al., 2017). Natural environments inherently offer

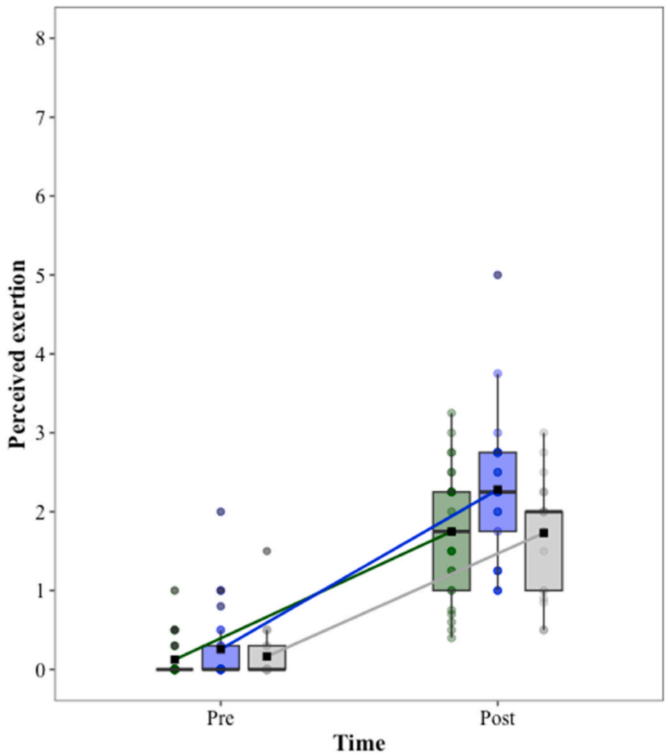

Fig. 6. Perceived exertion (CR-10) before and after the walk in green, urban, and indoor environments.
Note: the plot displays the interactions between time and environment for the perceived exertion (CR-10). Environmental conditions are represented by different colors: green (natural environment), grey (urban environment), and blue (indoor environment). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

these qualities, enabling a sense of psychological distance from daily routines and fostering coherence and mental space (Menardo et al., 2021).

The elevated ROS scores observed in natural settings further reinforce this, reflecting enhanced emotional and cognitive restoration following activity. This aligns with studies like Takayama et al. (2014), which found that walking in forests significantly improved ROS outcomes compared to urban settings, where distractions often hinder restorative experiences.

The consistency between PRS and ROS results underscores the integrated benefits of natural environments. They possess attributes conducive to restoration and effectively translate these into measurable psychological recovery. These findings add to the growing evidence base highlighting the positive impacts of nature exposure on mental health and stress reduction (Hyvönen et al., 2023).

By contrast, while urban and indoor environments offer some restorative benefits, their capacity for fostering recovery appears more limited. This suggests a critical need to incorporate natural elements into urban design and indoor spaces to enhance their restorative potential, especially when individuals engage in exercise or other forms of PA.

4.1.2. Emotions

Participants reported notably higher positive and lower negative emotions in the natural environment compared to urban and indoor settings. While no overall effect of time emerged, a significant interaction between time and environment revealed that positive emotions declined post-activity in the indoor setting, a trend less pronounced in the urban environment but absent in the natural environment. In contrast, negative emotions remained relatively stable but were consistently lowest in the natural setting. Post-walk increases in

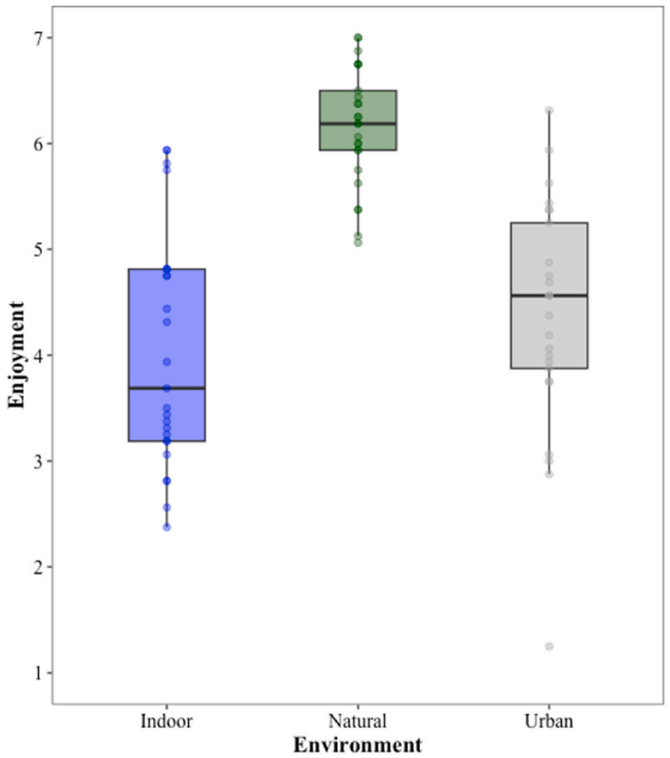

Fig. 7. Enjoyment ratings of physical activity (PACES-it) across different environments.
Note: boxplot showing participants' enjoyment ratings (PACES-it) in each environment following physical activity. Environmental conditions are represented by different colors: green (natural environment), grey (urban environment), and blue (indoor environment). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

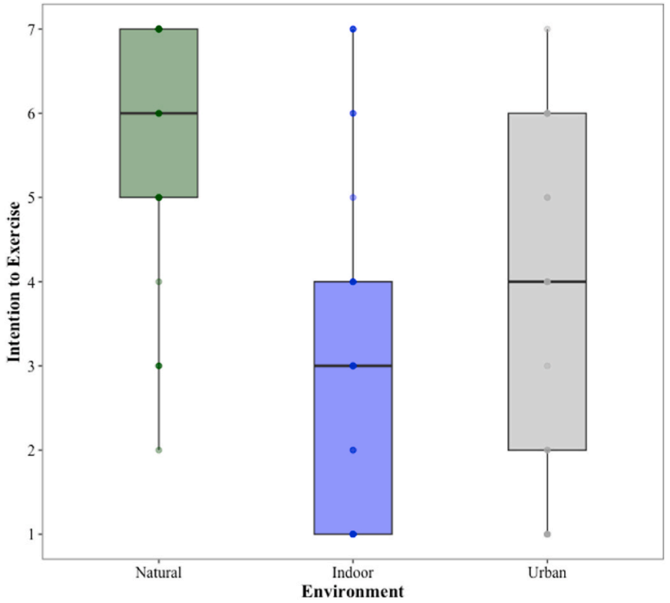

Fig. 8. Intention to repeat physical activity across different environments.
Note: boxplot showing participants' intention to repeat physical activity in the same environment (natural, indoor, or urban), rated on a frequency scale. The scale ranges from 1 (never) to 7 (more than three times a week), with intermediate points: 2 (once a month), 3 (twice a month), 4 (once a week), 5 (twice a week), and 6 (three times a week).

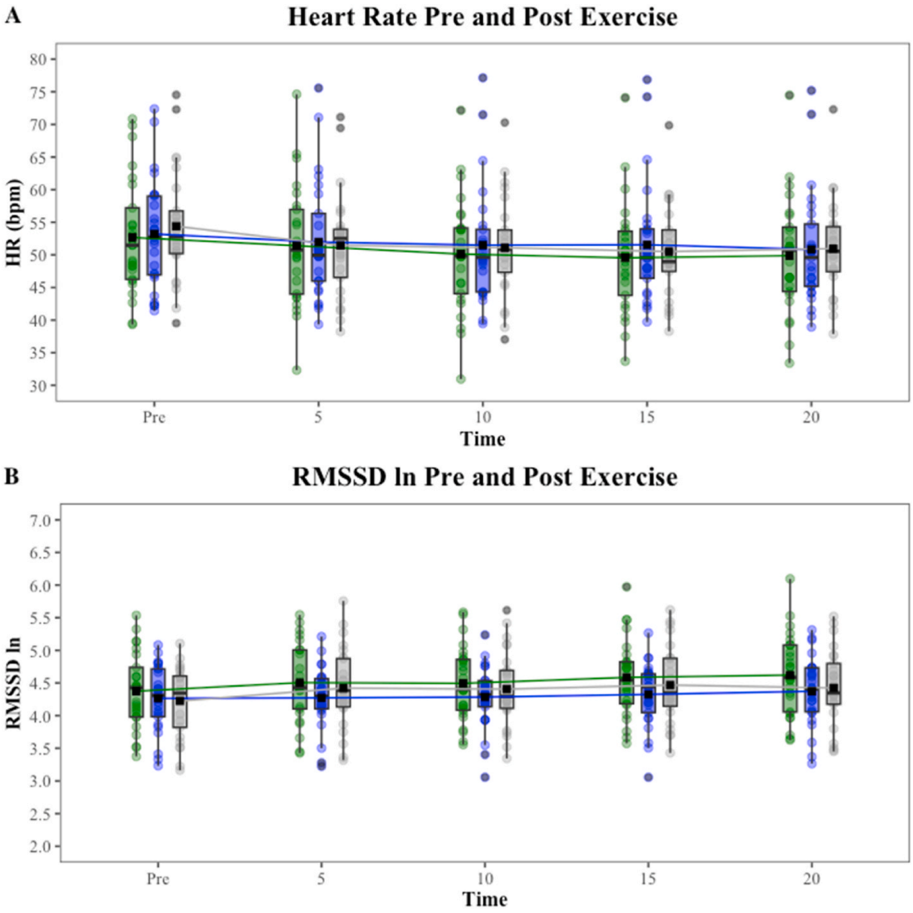

Fig. 9. Heart Rate (panel A) and ln RMSSD (Panel B) across different environments. Note.
Boxplots displaying participants' physiological responses - Heart Rate (Panel A) and log-transformed Heart Rate Variability (RMSSD, Panel B) - across three environmental conditions: natural (green), urban (grey), and indoor (blue). For each environment, values are shown for the pre-walk baseline (Pre) and four successive time points during the 20-min post-walk recovery phase (5, 10, 15, and 20 min). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

negative emotions were most prominent indoors, whereas urban environments remained closer to the green setting.

These findings underscore the emotionally restorative potential of natural environments, where individuals experience more positive and fewer negative emotional outcomes than in urban and indoor spaces. Importantly, these results align with prior studies (Hartig et al., 2003; Mayer et al., 2009) and a meta-analysis demonstrating that even brief contact with nature enhances positive affect and moderately reduces negative affect, promoting overall emotional well-being (McMahan & Estes, 2015). These results highlight the value of natural environments for sustaining positive emotional states during and after PA. For practitioners designing exercise programs, incorporating outdoor settings can enhance psychological outcomes and motivation, contributing to better adherence and long-term mental health benefits. Participants also reported significantly greater relaxation in the natural environment, with the sharpest decline occurring indoors post-activity. Similarly, anxiety levels were consistently lower in natural settings compared to urban and indoor environments, though no significant time-related changes emerged in any condition. These results emphasize the synergistic effects of movement and restorative environments, where natural settings promote sustained relaxation and lower baseline anxiety. This aligns with prior research on GE, highlighting its ability to enhance emotional well-being through the combined influence of PA and nature exposure (Kotera et al., 2021; Wicks et al., 2022). For exercise and health psychology, these findings are particularly relevant for populations managing stress, anxiety, or mood disorders, as natural settings offer a dual intervention for physical and mental health.

Further analysis along the activation-deactivation axis revealed distinct emotional patterns across environments: positive activating emotions (PAE) were significantly higher in natural settings, fostering happiness, satisfaction, and optimism. Positive deactivating emotions (PDE) were also higher, emphasizing calming and tranquil qualities. Urban settings provided intermediate benefits for PAE and PDE, while indoor environments consistently elicited the lowest levels, lacking energizing or soothing effects. Negative emotions were mitigated most effectively in natural environments. Negative activating emotions (NAE) were highest indoors and moderately present in urban environments. Negative deactivating emotions (NDE) were lowest in natural settings but increased post-walk indoors, highlighting the limited capacity of indoor spaces to support psychological well-being.

These patterns indicate that natural environments provide a unique combination of activation and relaxation, supporting energizing emotions (important for motivation) and calming emotions (essential for stress recovery). These findings suggest that green settings optimize psychological outcomes, improving mood and recovery for athletes, recreational exercisers, or individuals in stress-reduction programs.

4.1.3. *Perceived exertion*

Furthermore, participants reported higher perceived exertion after the walk in the indoor environment, while natural and urban settings showed comparable levels. These findings partly align with prior research. For example, Rogerson et al. (2016) found no difference in

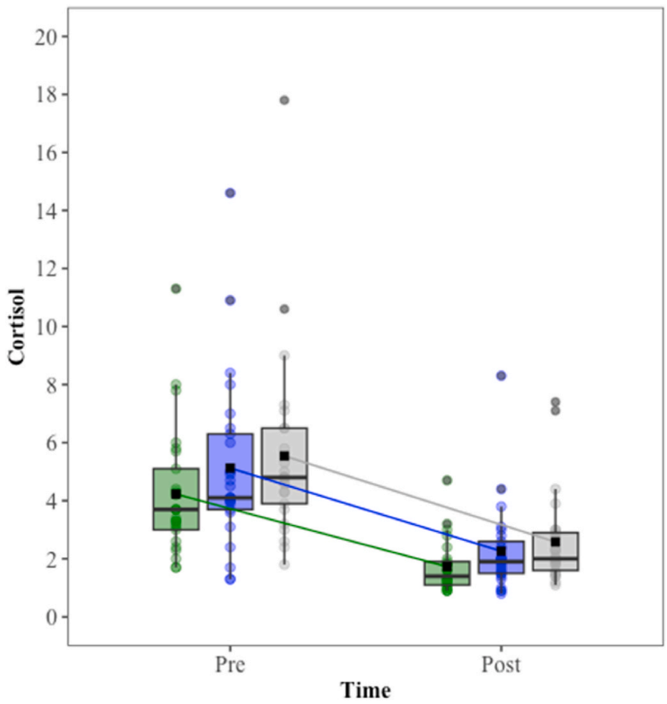

Fig. 10. Cortisol levels pre and post exercise across different environments. Note. Boxplot showing participants' salivary cortisol levels across the three environments, represented by different colors: green for the natural environment, grey for the urban environment, and blue for the indoor environment. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Summary of main effects and interactions for all dependent variables.

Outcome	Effect of Time	Effect of Environment			Time*Environment
	Pre vs Post	G vs I	G vs U	U vs I	
PRS	–	↑ in G	↑ in G	↑ in U	–
ROS	–	↑ in G	↑ in G	ns	–
PE	ns	↑ in G	↑ in G	ns	Yes
PDE	↓ post	↑ in G	↑ in G	ns	Yes
PAE	ns	↑ in G	ns	ns	Yes
NE	ns	↓ in G	↓ in G	ns	Yes
NAE	ns	↓ in G	↓ in G	ns	ns
NDE	ns	↓ in G	ns	ns	Yes
Relaxation	↓ post	↑ in G	↑ in G	ns	Yes
Anxiety	ns	↓ in G	↓ in G	ns	ns
CR-10	↑ post	↓ in G	ns	ns	ns
PACES	–	↑ in G	↑ in G	ns	–
Intentions	–	↑ in G	↑ in G	ns	–
HR	↓ post	↓ in G	↓ in G	ns	ns
RMSSD	↑ post	↑ in G	↑ in G	ns	ns
Cortisol	↓ post	↓ in G	↓ in G	ns	ns

Note: the table reports significant main effects of time, environment, and their interaction for each dependent variable. Symbols indicate whether the effect was statistically significant ($p < .05$). For significant effects of the environment, post hoc comparisons are briefly summarized, showing which environmental conditions differed significantly (G = green; I = indoor; U = urban). For non-significant results, "n.s." is reported.

exertion during outdoor and indoor cycling, potentially due to passive exposure to the outdoor environment. Similarly, Lahart et al. (2019) noted that lower perceived exertion in GE emerged mainly in longitudinal studies, while acute studies yielded mixed results. Wicks et al. (2022), in a meta-analysis comparing GE with urban PA, highlighted the consistent benefits of GE for increasing energy and reducing fatigue. However, heterogeneity in measurement tools complicates direct comparisons. In short, our results suggest that nature's restorative and distracting qualities may mitigate perceived exertion. Still, this effect appears to depend on PA type and engagement factors. Also, lower perceived exertion in green settings may contribute to greater enjoyment and adherence to PA programs. This might have implications for health promotion initiatives, where green spaces can encourage individuals to engage in regular PA without the added psychological burden of exertion.

4.1.4. Behavioral intentions and enjoyment of exercise

Our findings provide novel insights into how environmental settings influence the enjoyment of PA and intentions for future engagement. Using a rigorous methodological approach, which assessed well-characterized natural, urban, and indoor environments, this study highlights the specific attributes of natural settings that enhance exercise experiences.

Consistent with prior reviews (Lahart et al., 2019), participants reported the highest levels of enjoyment in the natural environment. This reinforces the idea that GE amplifies the positive experience of PA. Enjoyment is a key determinant in sustaining regular PA, as it fosters motivation and satisfaction—critical factors for long-term adherence. Our study is among the first to compare behavioral intentions across diverse environmental settings systematically. Participants expressed a significantly greater intention to repeat PA in natural environments, with higher anticipated frequency compared to urban and indoor settings. This finding underscores the long-lasting impact of GE, as its perceived benefits extend beyond the immediate session to shape future behavior.

No significant differences in intention were observed between urban and indoor settings. This suggests that natural environments' unique restorative and engaging qualities are central to encouraging long-term adherence to PA. These results diverge slightly from Rogerson (2016), which underscores the importance of methodological differences. While Rogerson's study may have used less immersive or controlled conditions, our research incorporated light-to-moderate intensity walking in real-world environments. This approach aimed to capture the dynamic and context-rich benefits of GE.

Our results emphasize that PA type and environmental context are pivotal in shaping behavioral intentions. The findings highlight the unique motivational value of natural settings, which enhance the immediate enjoyment of PA and foster a greater willingness to maintain such behavior over time.

4.2. Physiological outcomes

Our findings provide further evidence for the role of environmental settings in shaping physiological recovery following PA. Across all environments, cortisol levels significantly decreased post-walk, reflecting stress recovery. However, cortisol levels remained consistently lower in the natural environment compared to indoor and urban settings, suggesting a stronger restorative effect. These results align with studies by Park et al. (2007) which also reported significant cortisol reductions after exposure to nature.

In contrast, studies such as Tyrväinen et al. (2014) and Gidlow et al. (2016) found no significant differences in cortisol reduction between environments. Such discrepancies may stem from methodological differences. First, our study employed individually paced, light-to-moderate intensity exercise, whereas Tyrväinen et al. used group walking at controlled speeds, potentially introducing social dynamics that could influence stress responses. Second, Tyrväinen's sample included middle-aged females, who may exhibit lower cortisol reactivity due to hormonal factors (Kudielka et al., 2004), contrasting with our younger male participants, who are more comparable to those in Park et al. (2007). Finally, our inclusion of a distinctly restorative natural environment likely enhanced the observed effects, highlighting the importance of clear environmental contrasts in studying the stress-relieving potential of nature.

Heart rate (HR) also decreased over time in all conditions, reflecting ongoing physiological recovery. Participants in the natural environment displayed consistently lower HR than indoor and urban settings, supporting the idea that natural environments facilitate autonomic recovery. These results contrast with previous studies, such as those by Gidlow et al. (2016), which found no clear environmental effects on HR, emphasizing the variability of findings in this area. Similarly, heart rate variability (HRV), measured through log-transformed RMSSD, significantly increased during the recovery period, with the highest values observed in the natural environment. This suggests enhanced parasympathetic activation in green settings, consistent with the stress-reducing properties attributed to natural environments (Brown et al., 2013; Gladwell et al., 2012). However, not all findings align with this pattern. For example, Gidlow et al. (2016) reported inconclusive HRV responses across environments, while Scott et al. (2021) observed a counterintuitive decrease in HRV and an increase in HR during immersion in nature compared to urban or control settings. This unexpected shift toward sympathetic activation highlights the complexity of physiological responses and suggests that individual or situational factors may moderate these effects.

These findings suggest that natural environments may support physiological recovery during light-to-moderate exercise, as indicated by lower heart rate, higher HRV, and reduced cortisol levels compared to urban and indoor settings. However, it is worth noting that while the environment had a significant effect, no interaction between time and environment emerged for any of the physiological indices. This points to a partial dissociation between physiological markers and participants' self-reported psychological restoration, particularly the marked improvements in perceived restoration (ROS), relaxation, and affective states observed after the walk in the natural setting.

This dissociation, already reported in literature (Scott et al., 2021), challenges the original Stress Recovery Theory (SRT) assumptions, which posits a direct alignment between affective and physiological responses to natural environments. Although SRT and Attention Restoration Theory (ART) offer useful frameworks for interpreting the immediate affective and cognitive benefits of nature exposure, they often conceptualize individuals and environments as separate entities, focusing primarily on internal recovery from stress or attentional fatigue.

Recent theoretical developments have proposed a transactional and integrative approach to enrich these perspectives. The ecological dynamics framework (Araújo et al., 2019) emphasizes the person–environment system as the unit of analysis. According to this view, experiences of nature are not simply the result of passive exposure but emerge from dynamic, embodied engagement with the affordances offered by natural settings. These affordances—more varied and less constrained than those in built environments—enable meaningful interactions that may enhance psychological functioning, motivation, and overall well-being during and after physical activity.

This framework helps explain why, in our study, natural environments elicited higher enjoyment and stronger behavioral intentions, despite the relatively subtle physiological differences across settings. It suggests that the restorative benefits of green exercise are not solely tied to stress recovery but also reflect a deeper person–environment synergy that facilitates positive emotional and motivational states.

4.2.1. *Practical implications*

These findings underscore the potential of GE for enhancing cardiovascular recovery and stress reduction and promoting greater enjoyment and engagement in PA. Such benefits hold significant implications for both athletic recovery and public health.

For athletes and avid sports practitioners, more in general, incorporating natural environments into recovery protocols could accelerate physiological and psychological restoration, leading to improved performance and a reduced risk of burnout. GE has been shown to facilitate parasympathetic activation (Brown et al., 2013; Gladwell et al., 2012) and reduce cortisol levels (Park et al., 2007), which are key markers of stress recovery. This aligns with evidence suggesting that exposure to nature enhances mental relaxation and cognitive restoration, critical for maintaining consistent athletic performance (Hartig et al., 2003; Takayama et al., 2014).

GE can be a powerful motivator for the general population, particularly those who are moderately active or new to exercise. By making PA more enjoyable and less physically demanding (Lahart et al., 2019; Wicks et al., 2022), natural environments help lower perceived barriers to exercise. Increased enjoyment fosters a positive relationship with PA (Ekkekakis et al., 2011; Jekauc, 2015), improving adherence and encouraging long-term behavioral changes toward a healthier lifestyle.

From an exercise and health psychology perspective, these findings highlight the importance of affective responses—such as enjoyment, stress relief, and perceived effort—in shaping exercise adherence. Positive emotional experiences during PA are strongly linked to sustained motivation and long-term engagement (McMahan & Estes, 2015; Williams et al., 2006), making GE a promising strategy for addressing physical inactivity and improving mental well-being (Kotera et al., 2021).

Additionally, our results emphasize the potential value of integrating natural elements into urban design and public health strategies. Creating accessible green spaces has increased PA levels and improved mental health across diverse populations (Thompson Coon et al., 2011; Shanahan et al., 2016). Promoting outdoor group activities in these spaces can provide inclusive opportunities for exercise, fostering social connection while improving physical and mental health outcomes (Hyvönen et al., 2023; Pasanen et al., 2018).

Future research should explore the long-term effects of GE interventions and investigate how the restorative qualities of natural environments can be optimized for specific populations, including those with chronic health conditions, mental health challenges, or limited access to outdoor spaces (Gidlow et al., 2016; Menardo et al., 2021). Tailoring GE programs to meet these unique needs may amplify its benefits and address disparities in PA participation.

4.2.2. *Limitations and future studies*

This study has several limitations that should be addressed in future research. The sample consisted of 25 male participants with varying fitness levels, which may limit the generalizability of findings to broader populations, including women, older adults, and individuals with diverse fitness backgrounds. However, by including participants with different activity levels, we added variability to the sample, providing valuable insights into how individuals perceive and respond to various environments.

While representative of a typical city setting, the urban environment selected yielded relatively high fascination scores on the PRS, suggesting qualities that may enhance its restorative potential compared to more stressful urban areas. This setting was intentionally chosen as a real-world context free from overwhelming stressors such as heavy traffic or excessive noise. This approach addresses a common limitation in the literature, where appealing natural environments are contrasted with stressful urban settings. By selecting an engaging yet not overly stressful urban environment, the study provides a more balanced comparison, ensuring that observed benefits of nature reflect its inherent restorative qualities rather than unfavorable urban conditions. Nonetheless, future studies should examine a broader range of urban settings to better capture their variability and influence on restorative outcomes.

Temperature differences between environments may have influenced participants' physiological and psychological responses. While the study prioritized ecological validity by maintaining real-world conditions, future research could better control thermal comfort to isolate environmental effects.

Although participants were screened for familiarity with the study locations, prior exposure cannot be entirely ruled out. To minimize this risk, efforts were made to recruit individuals from diverse regions, enhancing the robustness of the findings.

Additionally, participants reported high relaxation and low negative emotions at baseline, which may have influenced subsequent measurements. However, these baseline states reflect participants' natural disposition and indicate that the study design effectively captured authentic responses to the environments.

Despite these limitations, the study provides valuable evidence of the restorative potential of natural environments during PA. Future research with larger and more diverse samples, varied urban contexts, and controlled thermal conditions will help build on these findings and further advance our understanding of GE and its benefits.

5. Conclusion

This study highlights the important role of environmental context in shaping psychological and physiological responses to PA. Our findings demonstrate that natural environments yield superior benefits, enhancing perceived restoration, enjoyment, and intentions to engage in future activity. Participants reported greater positive emotions, lower negative emotions, and higher relaxation in natural settings compared to indoor environments, which emerged as consistently less favorable. However, the comparison between urban and natural environments revealed more nuanced results. Specific psychological outcomes, such as anxiety and some deactivating emotions, showed limited differentiation between the two. This suggests that the restorative advantages of nature over urban settings may depend on specific outcomes, highlighting the need for further investigation into the mechanisms underlying these effects.

Physiological measures provided strong support for the stress-relieving properties of nature. Participants in the green environment exhibited lower heart rates, lower cortisol levels, and higher HRV compared to indoor and urban settings, reinforcing nature's role in facilitating autonomic recovery. Notably, the absence of significant time-environment interactions for physiological variables indicates that nature's stress recovery effects are consistent over time, further underscoring its robustness.

The novelty of this study lies in its rigorous comparison of natural, urban, and indoor settings, integrating both psychological and physiological measures to provide a comprehensive understanding of environmental influences. While the benefits of nature are clear across multiple domains, the subtle differences observed in the urban-natural comparison suggest an opportunity to explore how urban environments can be optimized to enhance their restorative potential.

In conclusion, engaging in PA in natural environments is a powerful resource for promoting psychological well-being and physiological recovery. These findings advocate for the greater integration of natural spaces in urban planning and public health strategies. They also highlight the need for future research to further differentiate the unique contributions of urban and natural settings to health and well-being.

CRediT authorship contribution statement

Luca Laezza: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Martina Vacondio:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alessandro Fornasiero:** Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Barbara Pellegrini:** Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Margherita Pasini:** Project administration, Methodology, Funding acquisition, Conceptualization. **Margherita Brondino:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Stefano De Dominicis:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Ethics approval

This study received ethical approval from the University of Verona Ethics Committee (approval number 2023_27).

Data availability statement

The dataset generated and analyzed during the current study and the supplementary materials is available on the Open Science Framework (OSF) at https://osf.io/rfxgm/?view_only=e2bc0f4b02db422788a4d8ac0070e1ce.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

The authors declare no personal relationship which may be considered as potential competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2025.102883.

Data availability

We have shared the link to our data repository.

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