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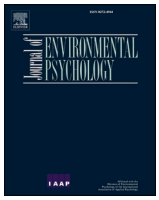

Walking to the urban green: Increases in positive emotions and perceived restorativeness, but not mental representation ability

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ABSTRACT

Research has shown that green outdoor environments are related to emotions and the restoration of cognitive resources. However, it remains unclear whether brief exposure to urban environments with different levels of green could also benefit cognitive abilities, in terms of environmental mental representation, which has been linked to emotionally laden environments. Using a within-subject design, 151 participants (98 women) walked six urban paths with varying green levels (measured by the NDVI) for about 1 min each, reporting their affect, perceived restorativeness, and estimated distance and time. Individual differences measures were also considered. Results showed that higher greenery is related to greater positive affect and perceived restorativeness, but did not improve distance (and time) estimation. Initial trait and state affect showed some involvement in subsequent state affect and perceived restorativeness. These findings highlight important implications of brief urban green walks and provide insights for future research.

1. Introduction

The majority of people in the world live in and frequent urban areas (United Nations, 2024). When higher levels of green spaces are present in urban areas, they appear to positively benefit health (Pereira Barboza et al., 2021). Therefore, further investigation into the impact of exposure to green urban areas is important. The present study aims to further investigate the beneficial effect of brief walks in urban spaces with various degrees of green on affective state, perceived restorativeness, and cognition in individuals. This study newly examines cognition in terms of individuals' mental representation of the environment, i.e., their capacity to acquire, recall, and manipulate information about environments, which is a fundamental aspect of human cognition. This study is the first attempt to combine the environmental psychology domain, in terms of theorization on the beneficial effects of natural environments as proposed by the Attention Restoration Theory (ART; Kaplan, 1995, 2001) and the Stress Reduction Theory (SRT; Ulrich, 1981, 2023), with the spatial cognition domain, in terms of environmental mental representation. Kaplan's theory suggests that natural elements elicit a positive state able to generate a lower attentional load, while urban environments require more cognitive resources. Ulrich's theorization suggests that natural elements elicit a relaxed state, given that nature is the environment most experienced by humans from an evolutionary and biological point of view and it is able, per se, to reduce stress, with indirect benefits for cognitive performance. The common point with the spatial cognition domain, which is interested in the cognition of the environment, is therefore the centrality of the environment and emotions it elicits. Recent studies in spatial cognition have shown that mental representations can be related to the emotions evoked by the environment (e.g., Ruotolo et al., 2019). Building on evidence that natural (green) environments elicit positive emotions and that emotionally salient environments enhance spatial memory, the present study investigates whether the level of greenery in an environment is related to the accuracy of spatial knowledge.

1.1. Green environments and affective state

Research has shown that environmental characteristics can elicit both positive and negative affective states (Bilotta et al., 2019; Meidenbauer et al., 2020). Among the characteristics that elicit the most negative feelings in individuals there are signs of lack of care, ugly and ordinary architecture, presence of trash, noise, air pollution, and

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congestion (Glasgow et al., 2019). On the other hand, the presence of natural elements especially through vegetation (e.g., forests, managed grass; Barnes et al., 2019; Huang et al., 2020) and water (Barnes et al., 2019; Wheeler et al., 2015), are one of the characteristics that elicit positive affective states. This is true even for urban environments: urban environments with vegetation (Olszewska-Guizzo et al., 2022) and those that integrate real or symbolic trees (i.e., columns) and water (e.g., fountains) are associated with positive emotions (Herzog et al., 1982; Joye, 2007). In addition to the characteristics of the environment, the type of exposure to the environment can also play a role. Previous studies have investigated the relationship between green level and affect by both exposing people to the environment statically (e.g., Olszewska-Guizzo et al., 2022; Mioni & Pazzaglia, 2023) and by having them walk through it (e.g., Sella et al., 2023), with the latter typically involving people walking for an extended time (e.g., from 15 min to 1 h; Yao et al., 2021).

While environmental characteristics play a role in shaping emotions, as outlined above, it is important to consider that individual characteristics can also significantly relate to emotional responses (Berto, 2014; Sella et al., 2023). Some individual dispositions like connectedness to nature, (i.e., a trait-level construct reflecting the degree to which one feels a subjective connection to the natural environment and natural entities) may moderate the positive benefit of exposure to (urban) green spaces (Mayer & Frantz, 2004). Indeed, individuals with higher self-reported connectedness to nature seem to benefit more from exposure to green spaces (Capaldi et al., 2014; McMahan et al., 2018).

To sum up, what remains unclear is whether even brief exposures to urban areas with varying levels of green, experienced through walking, may relate to an individual's affective state when accounting for individual differences.

1.2. Green environments and perceived restorativeness

Natural environments are often perceived as having a restorative potential for cognitive resources (see Menardo et al., 2021 for a meta-analysis). The characteristics that contribute to an environment being perceived as restorative include: fascination (attracting involuntary attention), being away (the sensation of being free from obligations), coherence (structured environments), scope (perceiving that the environment offers opportunities), compatibility (correspondence between expectations and qualities of the environment) (Korpela & Hartig, 1996). The restorative potential of an environment can be investigated using physiological and behavioural methods (Berto, 2005), and with the use of self-reports (Menardo et al., 2021). The latter have been found to be reliable estimations of the restorative potential of environments (Staats, 2012). Research has shown that natural environments, compared to urban built environments, are perceived as more restorative (Menardo et al., 2021). This is true even for natural environments integrated into urban contexts, such as urban parks (e.g., Peschardt & Stigsdotter, 2013; Rapuano et al., 2022). Therefore, even urban environments can hold a restorative potential (Weber & Trojan, 2018). However, an analysis of this potential in relation to the degree of urban green and considering individual differences could provide valuable insights.

1.3. Green environments and benefits on cognition

The benefits of natural environments are also typically investigated for their effects on cognitive abilities. These studies are conducted both when participants view pictures (Felsten, 2009; Gamble et al., 2014) and after passive or active exposure to the environment (e.g., by walking in it; Berman et al., 2008). Systematic reviews and meta-analyses have suggested improvements in cognitive processing, both using basic cognitive tasks (such as attention tasks and working memory span, Ohly et al., 2016; Stevenson et al., 2018) and higher-level tasks (e.g., complex working memory span tasks, Scott et al., 2023). Effects have also been found for general cognitive states (e.g., mini-mental state examination; Prohaska et al., 2009) and on cognition applied to daily life contexts, such as academic performance (Mason et al., 2022). It is, however, worth noting that not all studies report a significant effect of nature on these types of cognitive processing, suggesting poor or fair quality of the existing evidence on the relationship between natural environments and cognitive performance (de Keijzer et al., 2016).

What remains to be investigated is the potential benefit of nature exposure to higher-level cognitive abilities, such as the ability to mentally represent the environment. Recent evidence suggests a relationship between affective state and mental representations (e.g., Ruotolo et al., 2019), as described in the following paragraph. Therefore, it is plausible that the levels of green relate to this higher form of cognition.

1.4. Affective state and mental representation of environment

People navigate environments and form mental representations of them (also called cognitive map; Tolman, 1948), which enables flexible management of environmental information (Wolbers & Hegarty, 2010), such as metric and directional information. The ability to form accurate spatial knowledge is useful for successful route planning and reaching destinations (Montello, 2005). Among the factors related to this ability, there are individual cognitive abilities, attitudes and states. A large body of evidence has shown the role of spatial abilities, such as mental rotation, and inclinations, such as individual sense of direction and attitudes toward orientation abilities (Muffato et al., 2023). Recent findings have also shown that emotional states are related to spatial cognition. Landmarks laden with negative emotion have been shown to impair survey knowledge (i.e., the ability to understand spatial relationships between different locations in an environment, regardless of one's own perspective), as measured by distance estimations (e.g., judging routes as longer; Blaison & Hess, 2016; Ruotolo et al., 2019). However, other studies showed that negative landmarks could improve route recognition and repetition (Balaban et al., 2017; Chan et al., 2014). Landmarks laden with positive emotion, in contrast, have shown benefits for route (Rasse et al., 2023) and survey knowledge (Palmiero & Piccardi, 2017; Ruotolo et al., 2019), suggesting that positive emotions may enhance the formation of mental representations. However, most studies have focused on affect induced by emotional images serving as landmarks. To date, no study has investigated whether affect elicited by intrinsic environmental features, such as natural elements, relates to spatial cognition, particularly to mental representations assessed through distance estimation. Besides effects on affective states, it is also plausible that exposure to green spaces, via mechanisms outlined in ART (Kaplan, 1995, 2001), enhances attentional processes critical for accurate distance estimation. Indeed, distance estimation requires activation not only of the hippocampus and parahippocampal areas (e.g., Burgess, 2008; Liang et al., 2023), but also of frontoparietal regions (e.g., Faulmann et al., 2020) and dorsal regions (e.g., Majerus et al., 2018), which are involved in the internal maintenance of mental representations. The level of greenery may thus help individuals restore their attention and focus on the task. Additionally, distance estimation is fundamentally rooted in spatial body perception, with bodily experience playing a crucial role in the process (e.g., Grade et al., 2015). Emotions are also deeply rooted in bodily states. Therefore, it is possible that embodied resources are engaged during information processing, including higher-order cognitive tasks like distance estimation. In this light, both ART theory and embodied cognition theories may support the proposed link between affect and spatial cognition.

To sum up, the theoretical framework underlying our hypotheses draws on two core processes described in the environmental psychology theories of SRT and ART. On one hand, exposure to green urban spaces can improve emotional states and thereby contribute to improved cognitive performance. On the other hand, exposure to green urban spaces, through the mechanisms proposed by ART (Kaplan, 1995), may

enhance attentional processes essential for accurate distance estimation. Given this, the level of green could be an environmental characteristic that relate to individual affect and to spatial cognition. The present study was designed to address this issue. Importantly, since distance estimation is highly sensitive to individual differences, these have been taken into account, as it is plausible that the relationship between green level, affect, and distance estimation may be moderated by them.

1.5. Aims and hypotheses

The present study aimed to investigate whether, after a brief walk, there was a relationship between the levels of green in urban areas and: i) emotional state (Aim 1), ii) perceived restorativeness (Aim 2) and iii) the mental representation of the environment formed, in terms of distance estimation ability (Aim 3). The study examined these relationships also by considering individual differences. These differences included gender, familiarity with the paths, emotional traits (e.g., positive/negative trait affect), and connectedness to nature. For distance estimation, the relation with spatial cognitive abilities (mental rotation ability and baseline ability to estimate distance/time) and wayfinding inclinations (e.g., sense of direction and spatial anxiety) were also considered given their relevance in explaining such ability (Meneghetti et al., 2021). Additionally, given the inherent relationship between distance and time (Gladhill et al., 2024), time estimation was also investigated.

Specifically, we focused on brief walks in real environments, representing a common daily life experience. Some evidence suggests promising effects of natural exposure even for brief durations (e.g., on perceived restorativeness, Wilkie et al., 2023), but further investigation is needed. Moreover, the general aim of the study was to investigate the relationship between urban green environments, affect, perceived restorativeness and cognition using repeated measures across multiple paths (with each participant walking six paths out of a total of 18). This approach was designed to eliminate potential confounding effects associated with the selected routes and to address a common limitation in studies on real environments, which typically compare fewer environments.

Our preregistered hypotheses (https://osf.io/zadm6) were as follows:

- After walking in urban environments, the level of green may be related to self-reported affective state (Aim 1) and perceived restorativeness (Aim 2). Specifically, brief walks on real paths with higher levels of green are expected to result in higher levels of positive emotions and perceived restorativeness, and lower levels of negative emotions than those in environments with lower levels of green (Barnes et al., 2019; Menardo et al., 2021; Olszewska-Guizzo et al., 2022).
- After walking in urban environments, people's distance estimations (a spatial representation measure; Aim 3) might be related to their self-reported affective state. The results for emotion can involve both positive emotional state, higher positive emotions might be related to lower errors in distance estimation (Ruotolo et al., 2020), and/or negative emotional state, higher negative emotions might be related to higher errors in distance estimations (Blaison & Hess, 2016; Ruotolo et al., 2019).
- After walking in urban environments, people's distance estimation performance (Aim 3) might be related to their perceived restorativeness, given that higher restorativeness is associated with better cognitive performance (Berto, 2014), such as attention (Ohly et al., 2016), memory performance (Mayer et al., 2009; Newman & Brucks, 2016), and a better understanding of one's cognitive performance (Pearson & Craig, 2014).
- Individual differences may play a role in positive/negative affective state (Aim 1), perceived restorativeness (Aim 2), and distance estimations (Aim 3). For all these dependent variables, we will consider i) gender, given potential gender differences in emotions and spatial abilities (Meneghetti et al., 2017; Muffato et al., 2024; Nazareth et al., 2019), ii) familiarity with the environment, given the relationship with mental representation of the environment (higher level of familiarity with environments, higher distance estimation accuracy, e.g., Muffato & Meneghetti, 2020) and with emotions (e.g., Ratcliffe & Korpela, 2016). We will also consider individual dispositions: iii) negative and positive trait affect, which can be related to mental representation of the environment (e.g., Cheng, 2019), iv) connectedness to nature, which can be related to emotional state, perceived restorativeness and cognition (e.g., McMahan et al., 2018). Only for distance estimations, given it is the spatial cognitive task used to measure mental representation of the environment, we will consider these individual spatial factors: v) spatial abilities (higher mental rotation ability and distance estimation abilities at the baseline can be related to higher distance estimation accuracy, Hegarty et al., 2006) and vi) wayfinding inclinations (higher level of sense of direction, higher level of distance estimation accuracy expected, Brunyé et al., 2015).
- Finally, after walking in urban environments, we explored whether people's time estimates might be related to their self-reported affective state. Although this was an exploratory hypothesis, there is initial evidence indicating that positive emotional ratings in environments can be related to time estimations (Mioni & Pazzaglia, 2023; Ruotolo et al., 2020). Measures of individual differences were also investigated as potentially related to time estimation abilities (Fink & Neubauer, 2005).

2. Method

2.1. Participants

The study involved 151 participants (98 women) aged 18–31 years (M age = 21.09, SD = 2.08), enrolled either in exchange for course credits or through word of mouth. Inclusion criteria were no motor, visual, or cognitive impairments, age above 18 years. We originally enrolled 170 participants, of whom 15 did not meet the inclusion criteria, and an additional 4 were excluded because they did not complete the first session. The sample size was determined by considering a maximum of 12 coefficients in the regression models, an effect size of .25 and a p value of .001, a sample of 112 people would be sufficient to obtain a power of .80 (power analysis run with the "pwr" library in R). Given that in mixed design analyses an increasing number of clusters (paths in our case) is associated with increased statistical power (Austin & Leckie, 2018), we selected as many paths as possible within our designated study area (i.e., the campus and the nearby park). A total of 18 walkable paths were selected.

The study was approved by the Ethical Committee for Psychological Research at University of Padova. All participants were informed about the purposes of the study and gave their informed consent in accordance with the Declaration of Helsinki (World Medical Association, 2013).

2.2. Materials

2.2.1. Measures of individual differences

Connectedness to Nature Scale (CNS, Mayer & Frantz, 2004). This includes 14 items assessing the extent to which individuals feel a part of nature on a scale from 1 (completely false) to 5 (completely true). Scores are summed (max. 70). The scale has good internal reliability (current sample Cronbach's alpha = .83).

Trait Positive and Negative Affective Status (trait PANAS, Terraciano et al., 2003). This includes 20 items assessing whether people generally (trait measure) feel Positive Affect (PA, e.g., "interested", "excited"; 10 items) and Negative Affect (NA, e.g., "upset", "nervous"; 10 items) on a scale from 1 (not at all) to 5 (extremely). Scores are summed for each factor (each max. 50). The scales have good internal reliability (current

sample: trait PANAS PA Cronbach's alpha = .78; trait PANAS NA Cronbach's alpha = .86).

Wayfinding inclinations questionnaires (De Beni et al., 2014; Pazzaglia & Meneghetti, 2017). This includes two questionnaires. Specifically, the Sense of Direction and Spatial Representation Scale (De Beni et al., 2014) assesses participants' sense of direction, knowledge and use of cardinal points, and preferences for survey, route and landmark modes, on a scale from 1 (not at all) to 5 (very much) (13 items; max. score 65). The Spatial Anxiety Questionnaire assesses people's level of anxiety in wayfinding situations on a scale from 1 (not at all) to 6 (very much) (8 items; max. score 48). The scales have good internal reliability (current sample: Sense of Direction Cronbach's alpha = .80; Spatial Anxiety Cronbach's alpha = .79).

Short Mental Rotation Test (sMRT, De Beni et al., 2014). This requires identifying two out of four objects (assembled cubes) that match a target object in a rotated position (10 items; time limit: 5 min). One point is awarded for correctly identifying both objects (max. 10). The test shows good internal reliability (current sample Cronbach's alpha = .87).

2.2.2. The study area: the paths

The study area includes the School of Psychology at University of Padova and its surroundings, covering about .20 km^2. The selected area is considered a highly walkable area (see walk score https://www.walkscore.com/score/8-via-venezia-padova-veneto-italy) and within this area, we identified walkable paths of similar short lengths, ranging from approximately 70 to 130 m. This was done to avoid the tendency of

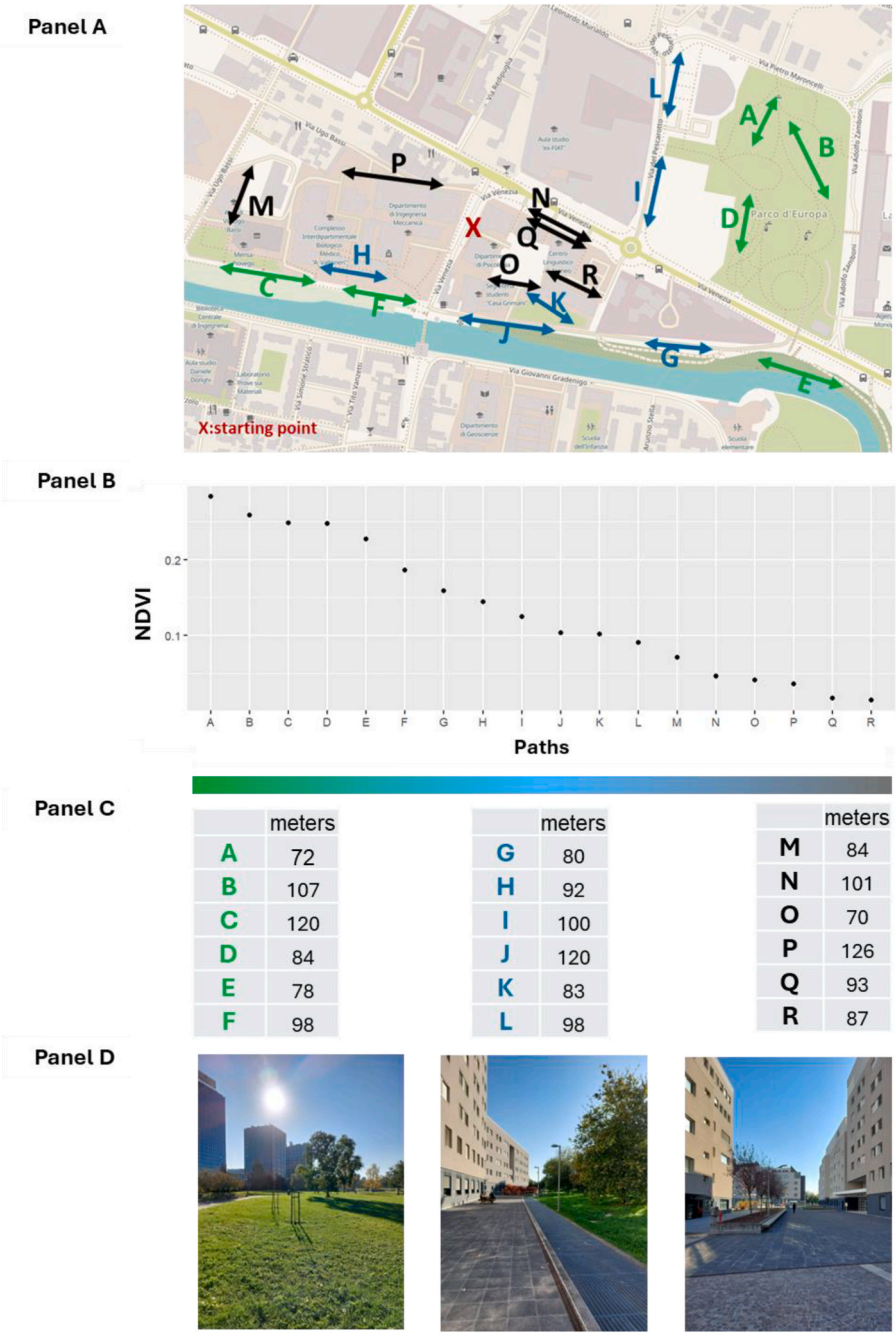

Fig. 1. Location (panel A), NDVI (panel B), length (panel C) for each path and photographs of example (panel D).
Note. In green predominantly natural paths, in blue mix of natural and built paths, and in black predominantly built paths (categorization used only for the semi-randomization of path presentation to participants).

distance estimations to be less accurate over longer distances (Allen & Kirasic, 1985) and to prevent the effort of covering a distance from making it feel longer than it actually is (see metanalysis by Molto et al., 2020). Additionally, having similar lengths is intended to possibly avoid regression to the mean effect (the central tendency bias; Korte et al., 2023), which leads to the underestimation of longer distances and the overestimation of shorter distances. The paths were all in a straight line, as curves in the path and body turns can distort distance estimation (Brunyé et al., 2015; Styrkowiec et al., 2020). The identified paths were selected to have different levels of green. The degree of green was calculated by the Normalized Difference Vegetation Index (NDVI), a valid measure for assessing "greenness" commonly used in environmental psychology studies (Rhew et al., 2011; Spano et al., 2023). The NDVI of the paths was calculated by selecting an image with low cloud coverage from https://glovis.usgs.gov/app (using Landsat 8–9 OLI/TIRS C2 L1). We chose an image from November 24th, 2022, which corresponds to the middle of the experimentation. We then used this image in QGIS to calculate the NDVI (utilizing bands 4 and: NDVI = (B5 − B4)/(B5 + B4)). A 3-m buffer on each side of the path was applied for the analysis. Higher NDVI values indicate denser green vegetation (with a max. NDVI of .28 in our path), while values close to 0 indicate the absence of vegetation. The paths were then divided into three categories to allow a semi-randomization of them among participants. Indeed, each participant walked two predominantly natural paths, two mixed paths, and two predominantly built paths. The path locations, their categorization based on NDVI, and their lengths are shown in Fig. 1.

2.2.3. Baseline and state questionnaires and tasks

State Positive and Negative Affective Status (state PANAS, Terraciano et al., 2003). This involves 20 items assessing whether people feel in that moment Positive Affect (e.g., "interested", "excited"; 10 items) and Negative Affect (e.g., "upset", "nervous"; 10 items) on a scale from 1 (not at all) to 5 (extremely). Scores are summed for each factor (each max. 50). The state PANAS was administered after each path walk, and the scales showed good internal reliability (current sample: state PANAS PA Cronbach's alphas from .85 to .90; state PANAS NA Cronbach's alpha from .87 to .91).

Distance and time estimation baseline (created ad hoc). The task consists of walking until reaching a cone and then reporting distance and time estimations, in meters and seconds, respectively. Two paths of 10 and 7m are identified. Feedback is provided to set a reference for the subsequent distance/time estimation tasks. Errors are calculated as the mean of the absolute differences between the correct answer and the provided answers.

Perceived Restorativeness Scale (PRS-11, Pasini et al., 2014). It consists of 11 items assessing four different factors: being-away (e.g., "Places like this are a refuge from daily worries"; 3 items), fascination (e.g., "It's hard to get bored in places like this"; 3 items), coherence (e.g., "In places like this, everything seems to have its place"; 3 items), and scope (e.g., "Places like this are large enough to be explored in many directions"; 2 items). Participants are asked to answer on a Likert scale ranging from 0 (not at all) to 10 (very much) indicating how much each item corresponds to the experience they had in the environment visited just before. The score is the sum of the points assigned by the participant to each individual item (max. 110). The scale was administered after each walk and showed good reliability (current sample Cronbach's alpha from .84 to .92).

Distance estimation. The task consists of estimating the distance walked in a straight line, in meters. Errors are determined by calculating the absolute difference between the estimated distance and the correct distance (measured with a measuring tape before the study).

Time estimation task. The task consists of estimating the time spent walking in a straight line, in seconds. Errors are determined by calculating the absolute difference between the estimated time and the correct time (measured by a chronometer by the experimenter).

Questionnaire about what they have observed in the path (created ad hoc). The question consists of reporting what had impressed the individual along the path. We provided a list of six items categorized as perceptual aspects (colours, odours), natural elements (nature, natural sounds), and built elements (buildings, noises). This served as a filler questionnaire to ensure participants focused on the path while walking a point was awarded to a category if one of its elements was selected.

Questionnaire about strategies used to make estimations (created ad hoc). This consists of freely self-reporting the strategies (if any) used to estimate distance and time. The strategies were categorized as follows: i) no strategy used; ii) counting; iii) referencing a personal benchmark; iv) referencing the environment; v) referencing the provided baseline; vi) visual estimation; vii) strategy not specified.

Sketch map task (created *ad hoc*). This consists of marking the walks previously made on a sketch map that includes roads and reference points (e.g., the starting point and the river; see supplementary materials). Participants are then asked to use a pencil to highlight the green areas they remember in the area (as a measure of perceived green). Two independent judges evaluated the position of each drawn path, awarding 1 point if it was correctly placed on the map (inter-rater reliability = .96). In the few cases of disagreement, a third judge intervened. Additionally, 1 point was awarded if the path was marked as a green area, 0 otherwise.

2.3. Procedure

Participants attended two individual sessions: the first, conducted online, lasted about 30 min; the second, held in the field, lasted about 90 min. The study was conducted from the end of October to half December 2022 (43% of participants in sunny day, 50% in cloudy days, 11% during light rain). During the first session, participants completed demographic questions, PANAS trait and, in random order, Connectedness to Nature Scale, short Mental Rotations Test, and Wayfinding inclinations Questionnaires via a Qualtrics link.

The following days (within the week of the first session) participants met the experimenters at the gate of the Psychology department for Session 2. In case of bad weather conditions (rain), the meeting was rescheduled. Participants were reminded not to bring backpacks or bags and to wear comfortable shoes. First, participants completed the PANAS state scale (baseline), then they performed the two baseline trials of distance and time estimation with feedback (instructions are in supplementary materials). Then, the participants walked the six paths chosen semi-randomly from 18. Two paths were randomly selected between the greener paths, two from the six with intermediate levels of green, and two from the six with lower levels of green (see Fig. 1). The experimenter accompanied the participant on foot from one path to the another, while a second experimenter went ahead to place cones at the beginning and end of each path.

At the start of each walk, the experimenter started the stopwatch and walked behind the participant at a distance of about 2 m. At the end of the walk, participants were informed not to turn around with their back to the route and then completed the PANAS state scale, the filler questionnaire about what they observed along the path, the perceived restorativeness scale, and in random order the distance and time estimation tasks. This procedure was repeated for each of the six paths.

At the end of the six routes, participants filled out the questionnaire about strategies used to make estimations on time and distance, followed by the sketch map task.

2.4. Statistical analysis

All analyses were run using R (R Core Team, 2023). The preregistered analyses were as follows. First descriptive statistics and correlations between variables were run (see supplementary materials). Then mixed linear regression models were used to examine the relationships between the factors (see Table 1) and the dependent variable i) positive and negative affect (Aim 1); ii) perceived restorativeness (Aim 2), iii)

Table 1
Model selection based on AIC for the dependent variables of interest.

DVs:	PANAS PA-state	PANAS NA-state	Perceived restorativeness	Distance estimation errors	Time estimation errors
Models tested	AIC	AIC	AIC	AIC	AIC
m0: participants and paths as random factors	1655.0	1726.2	2098.5	10504	8063.2
Predictors related to the hypotheses:					
m1: + green level of the path (NDVI)	**1650.2**	1726.5	**2081.4**	10502	8065.1
m2: + PANAS PA-state	/	/	**2044.9**	10506	8064.3
m3: + PANAS NA-state	/	/	2045.0	10504	8065.2
m4: +perceived restorativeness	/	/	/	10505	8065.0
Individual differences measures:					
m5: +gender	1652.0	1724.3	2046.5	10503	8063.9
m6: + familiarity with the path	1651.9	1728.2	2045.7	10506	8064.9
m7: + PANAS PA-trait	**1621.3**	**1723.4**	2046.4	10505	8065.2
m8: + PANAS NA-trait	1623.0	**1692.2**	2046.7	10504	8064.3
m9: +connectedness to nature	1620.9	**1689.8**	2045.0	10506	8065.1
m10: + PANAS PA-state baseline	**1534.0**	1691.5	2046.7	10504	8064.9
m11: + PANAS NA-state baseline	1535.3	**1658.6**	2046.9	10505	8063.2
m12: +mental rotation ability	/	/	/	**10501**	8065.1
m13: +baseline distance estimation	/	/	/	10502	/
m14: +baseline time estimation	/	/	/	/	8065.1
m15: +wayfinding inclinations (sense of direction + spatial anxiety)	/	/	/	10503	8064.9

Note. In bold type, AIC reduced by two units compared to the previous one.

mental representation: distance estimations and time estimations (Aim 3). A stepwise approach was adopted to enter the factors in the model (with continuous predictors standardized). A variable was only retained in subsequent models if it lowered the AIC (Akaike Information Criterion; Wagenmakers & Farrell, 2004) by at least 2 units. If not, it was considered negligible and disregarded.

For all models (see Table 1), participants were entered into a baseline model (m0) as random factors (because they performed six times positive and negative affect, perceived restorativeness, distance estimations, and time estimations). The paths were also included as random factor to control the results for their intrinsic characteristics. Then we added (m1) green level (NDVI), as the predictor related to our main hypothesis (e.g., Barnes et al., 2019; Tyrväinen et al., 2014). Only for the models on perceived restorativeness and distance and time estimations, we also included positive state affect (m2) and negative state affect (m3) measured after walking (Ruotolo et al., 2020). Additionally, for the distance and time estimation models, we included perceived restorativeness (m4).

Then we added the individual differences measures: gender (m5; Meneghetti et al., 2017), familiarity with the environment (m6; Muffato & Meneghetti, 2020) and individual dispositions (m7 and m8: positive and negative trait affect - PANAS, Cheng, 2019; m9: connectedness to nature, McMahan et al., 2018). Next, we included positive and negative state affect at baseline (models m10 and m11: state positive and negative affect – state PANAS at baseline) to check for the role of participants' state affect at the beginning of the session. We chose to include baseline state affect rather than the difference between post and pre, as we only measured state affect at the beginning of the session and not before each path.

Finally, only for distance and time estimations (i.e., the cognitive dependent variables), we added spatial abilities (m12: mental rotation ability, m13/m14: baseline distance or time estimation respectively, Hegarty et al., 2006) and wayfinding inclinations (m15, Brunyé et al., 2015).

The final models were discussed then. Models were checked for multicollinearity (VIF values) and outliers (Cook's distances for mixed models). The strategies participants reported to solve the distance and time estimation tasks were also described.

Then, a sketch map task was considered as a control measure. We verified that participants perceived the green in the environment by analysing the correlation between perceived green highlighted in the sketch map and the NDVI. Since participants drew the paths on the sketch map to indicate the perceived green, we were also able to assess the accuracy of their path positioning. Finally, we checked what participants reported as being impressed by (perceptual, natural, and built aspects) along the path.

3. Results

We ran linear mixed models and compared them using the AIC to retain or exclude predictors that were entered. See Table 1 for model selection for each dependent variable: positive and negative affective state (Aim 1), perceived restorativeness (Aim 2), distance estimations (Aim 3), and time estimations (as an additional measure).

3.1. State positive and negative affect after the walk (aim 1)

Concerning positive affect (PANAS PA) state, after each path, we found that the significant predictors (see Fig. 2, panel A) of the selected model were green level of the path (NDVI; $\beta = .04$, CI [.01 – .08], $p = .005$) and PANAS PA state baseline ($\beta = .65$, CI [.53 – .77], $p < .001$). PANAS PA trait did not emerge as a significant predictor ($\beta = .03$, CI [-.09 – .15], $p = .601$). The model had a marginal $R^2 = .45$, and a conditional $R^2 = .79$. The model had VIF values < 1.4 and Cook's distances <1.

Concerning negative affect (PANAS NA) state, after each path, we found that the significant predictors (see Fig. 2, panel B) were PANAS PA trait ($\beta = -.13$, CI [-.25 – -.02], $p = .023$), PANAS NA trait ($\beta = .19$, CI [.06 – .33], $p < .004$), and PANAS NA state at baseline ($\beta = .41$, CI [.27 – .54], $p < .001$). Connectedness to nature did not emerge as a significant predictor ($\beta = .09$, CI [-.02 – .21], $p = .114$). The model had a marginal $R^2 = .57$, and a conditional $R^2 = .95$. The model had VIF values < 1.4 and Cook's distances <1.

3.2. Perceived restorativeness after the walk (aim 2)

Concerning the perceived restorativeness, after each path, we found that the significant predictors (see Fig. 2, panel C) were green level (NDVI; $\beta = .49$, CI [.31–.66], $p < .001$) and PANAS PA state ($\beta = .22$, CI [.15 – .29], $p < .001$). The model had a marginal $R^2 = .28$, and a conditional $R^2 = .60$. The model had VIF values < 1 and Cook's distances <1.

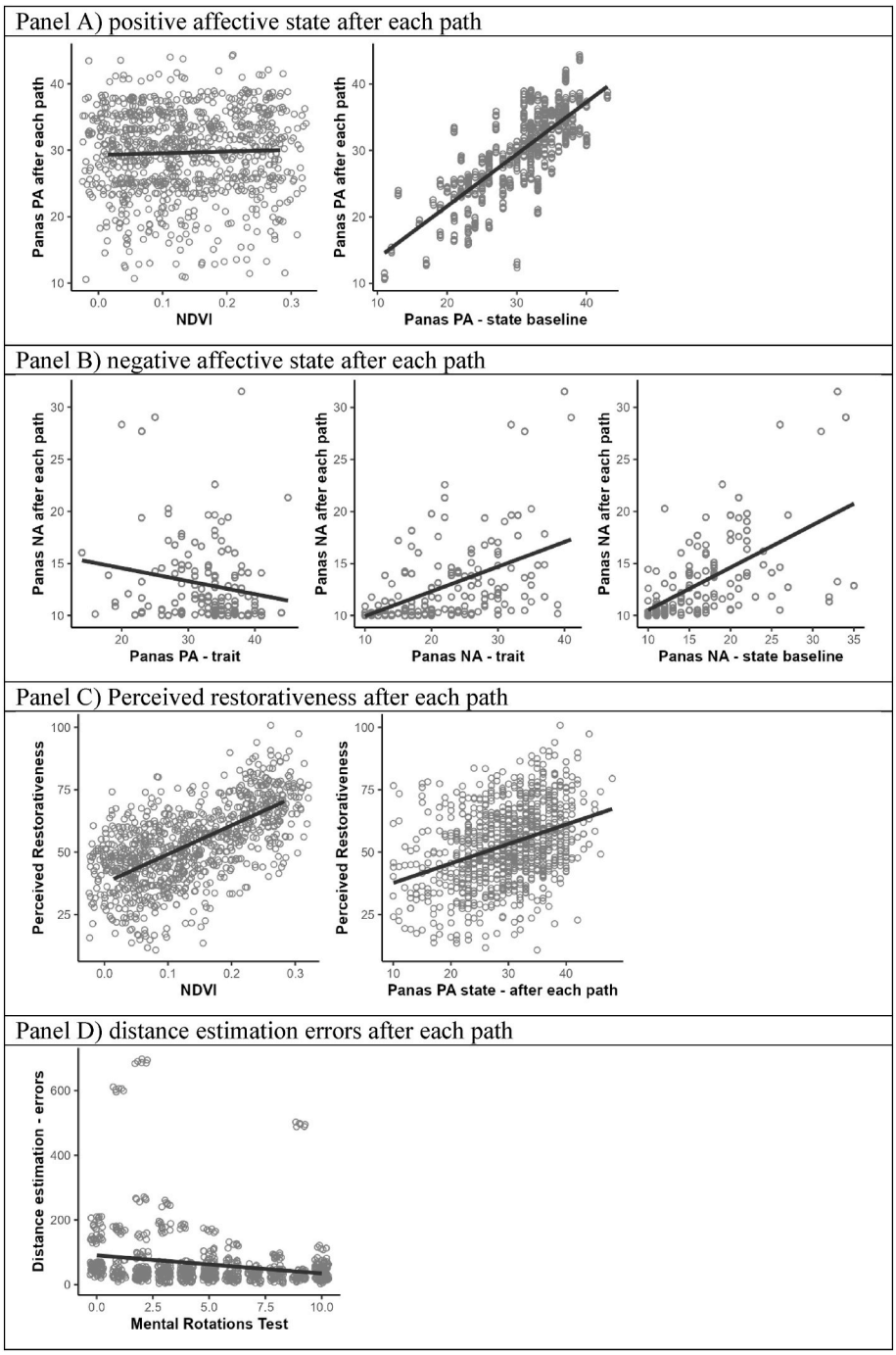

Fig. 2. Significant predictors in the models.

3.3. Distance (and time) estimations after the walk (aim 3)

Concerning the distance estimation errors, after each path, we found that the only significant predictor (see Fig. 2, panel D) was mental rotation ability ($\beta = -.16$, CI [-.30 – -.02], $p = .021$). The model had a marginal $R^2 = .03$, and a conditional $R^2 = .69$. The model had Cook's distances <1 (VIF values were not calculated given there was only one predictor).

Concerning the time estimation errors, after each path, no significant predictor was found.

3.4. Additional analyses

Relationship between NDVI and variables at participant level. Given the high conditional variance in the models, we visualized the relationship between the level of green (NDVI) and all dependent variables at the individual participant level (see Supplementary materials). These visualizations reveal considerable variability across individuals: some participants showed a positive or negative relationship, while others showed no relationship at all. See the Figures in the supplementary materials for details.

NDVI and reported impressions. We ascertained what people reported being impressed by during the walks in relation to the NDVI of the path. We found that at higher NDVI levels of the path, people report being

more impressed by natural characteristics ($r = .51$, $p < .001$) and perceptual ones ($r = .29$, $p < .001$), and less by built ones ($r = -.30$, $p < .001$). To control, we included what people were impressed by during the path in the models, but it did not emerge as a significant predictor in either model.

NDVI and perceived green. We ascertained that the level of green was perceived as green: the correlation between the NDVI of the paths and the perceived green reported in the sketch map is high, $r = .63$, $p < .001$.

Map drawing accuracy. We also checked spatial memory of the paths walked by analysing the accuracy in positioning them on the map and found an overall mean accuracy of 68% of paths positioned in the sketch maps.

Strategies to make distance estimation. We also checked the strategies people reported to use for distance and time estimations. For distance estimations, 38% of participants reported no strategy, 25% counting; 4% referencing a personal benchmark, 3% referencing the environment, 15% referencing the provided baseline, 2% visual estimation, and 13% using an unspecified strategy. For time estimations, 36% of participants reported no strategy, 40% counting, 1% referencing a personal benchmark, 10% referencing the provided baseline, 13% using an unspecified strategy. To control, we included the strategy used in the models described above, but strategy type did not emerge as a significant predictor in either model.

4. Discussion

Based on environmental psychology and spatial cognition theories, the present study aimed to investigate the role of urban green levels (calculated with NDVI) on emotion (affect and perceived restorativeness) and cognition, as assessed by mental representations formed after the walk. The present study is the first, to our knowledge, to investigate jointly the features of paths (i.e., levels of green), individual differences and mental representation of the environment using a repeated measures design. In this pre-registered study, participants were exposed to six short walks (about 1 min each) in pedestrian urban areas with varying levels of green (for a consideration of 18 paths in total). Individual differences in trait affect, baseline affect before starting the study, connectedness to nature (for all variables), and visuospatial abilities and wayfinding inclinations (for mental representation abilities) were considered.

Concerning affect, results showed that even after short walks in urban environments, higher levels of green were related to higher levels of positive emotions after the paths (but not lower levels of negative emotions). Baseline positive and negative affect measured before conducting the study played a role respectively in both positive and negative affect after exposure to the environment. Trait affect (both positive and negative) was related only to negative affect after exposure to the environment.

Concerning perceived restorativeness, even after short walks in urban environments, higher levels of green were associated with higher levels of perceived restorativeness. Additionally, people who reported higher positive affect after exposure to a path also reported higher perceived restorativeness.

Concerning mental representation, however, the increase in positive affect and perceived restorativeness in relation to the green level of the paths was not related to individuals' mental representation ability in terms of distance (and time) estimations. Distance estimation ability was related only to individual cognitive ability in mental rotation.

Results on the effect of green levels on affect (post each path) and perceived restorativeness confirmed previous literature on the role of natural elements in these psychological aspects (e.g., Bardhan et al., 2023; Barnes et al., 2019; Olszewska-Guizzo et al., 2022; Yao et al., 2021). Research has generally found increased emotions and perceived restorativeness after a prolonged exposure to environments, such as more than 30 min (e.g, Peschardt & Stigsdotter, 2013). The new finding of this study is that this relationship is present even for a short period of exposure to the environment (about 1 min) while walking. In other words, brief exposure to real urban green areas appears to benefit people's positive emotions and perceived restorativeness, with stronger associations observed as the amount of green increases. This finding is consistent with evidence from brief passive exposures (e.g., viewing pictures) that are related to individual perceived restorativeness (e.g., Wilkie et al., 2023). However, it is important to note that this short exposure does not appear to be related to negative emotions after the exposure. It is possible that pre-existing negative affect tends to persist regardless of short-term environmental conditions, or that the exposure was too brief to be related to the negative affect. Longer or more immersive exposure to wilder, more natural green environments may be necessary to more effectively examine the impact of affect (Yao et al., 2021).

We found no significant relationship between green level, positive emotions, and perceived restorativeness in the ability to mentally represent the environment as tested by distance (and time) estimations. The restorative potential of the urban green environment does not seem to apply to higher levels of cognition, such as cognitive maps, as shown for basic cognitive abilities (Berto, 2014), such as attention and working memory (Ohly et al., 2016), and global cognition (e.g., MMSE) and memory performance (Ricciardi et al., 2022). Additionally, contrary to expectations, higher positive emotions were not found to be related to higher distance estimation accuracy. Unlike studies suggesting a role of emotional landmarks in relation to distance accuracy (e.g., Blaison & Hess, 2016; Ruotolo et al., 2019), our real exposure to environments eliciting emotions did not show such a relationship.

Furthermore, given the close relationship between space and time, we expected to find a benefit of exposure to nature even on time estimation (Pazzaglia & Mioni, 2023; Ruotolo et al., 2020). However, as with distance estimation, no relationship was found between green level and time estimations. It is worth noting, though, that a correlation between distance and time estimations was confirmed in our sample. These failures to find relationships may be attributable to the fact that our greener paths may have increased emotions, but not sufficiently enough to have an impact on mental representation (distance and time estimations); some correlation indeed emerged between the variables, although they did not emerge in the regression models. Another explanation is that arousal, rather than the positive/negative valence of emotions, may contribute more significantly to mental representation abilities (Ruotolo et al., 2020), and we did not specifically measure this. It is also worth noting a key difference between our study and previous studies on spatial cognition and emotion. Those studies used virtual environments, typically presented passively, whereas we investigated real environments involving active walking. These differences in environmental context may have contributed to the inconsistencies in findings.

On the other hand, a well-established relationship between mental representation and mental rotation ability was found (e.g., Hegarty et al., 2006). This finding suggests that pre-existing visuospatial cognitive abilities play a central role in the capacity to mentally represent environments, potentially overshadowing any role of the environmental exposure, particularly when such exposure is brief, as in our study. Additionally, a correlation has been observed between mental representation and wayfinding inclinations (Hegarty et al., 2006). It is worth noting that, although no outliers were identified, some participants have performed poorly on this task, suggesting that distance estimation may be a particularly challenging cognitive task, regardless of the strategies adopted, as indicated by our additional analyses. This further supports the notion that distance estimation may reflect a higher-level visuospatial ability that may not be sufficiently modulated by brief environmental exposures. In future research, other spatial memory tasks could offer deeper insight into the mental representation of the environment, taking into account both location and paths (van der Ham et al., 2020). Taken together, these findings suggest that the ability to mentally represent the environment (as measured by distance estimations) is a

higher-level cognitive ability more closely related to visuospatial abilities than to emotional factors, at least those elicited by varying levels of green environments.

However, it is worth noting that for some participants, the relationship is present, suggesting that, at the individual level, some may have experienced this benefit. It is worth investigating which individual factors may contribute to this variability. Our hypothesis was that individual connectedness to nature could have played a role; however, we did not find a significant role of this individual disposition. It is possible that the short exposure did not allow this factor to emerge as important, contrary to findings in previous literature (McMahan et al., 2018). Other individual factors such as gender and familiarity with the environment were not found to play a role. Only baseline and trait positive affective states were somewhat related to the reported affect after the exposure; however, again, these aspects were not able to relate to environmental mental representation (Cheng, 2019). Nonetheless, it is plausible that baseline and trait affect may interact with green space exposure in more complex ways, potentially mediating the relationship between green level and mental representations (distance estimation). For instance, individuals with higher baseline or trait positive affect may be more sensible to environmental cues, which could, in turn, benefit their distance estimations. Therefore, further research is needed to understand why some participants show the relationship while others do not. In particular, it is important to explore whether individual factors may moderate or mediate the relationship between green levels and cognitive performance.

The present study offers valuable insights into the importance of even brief exposure to urban green spaces in enhancing positive emotions and feelings of restoration, which are significantly greater with higher levels of green. These findings have significant practical implications for both urban planning and public health policies. Urban planners should prioritize the incorporation of natural elements in city spaces, as a greater presence of green appears to lead to increased benefits. Public health initiatives should promote even short walks, as these brief exposures to urban green can positively relate to people's emotions and restoration. Although the benefits of these brief exposures did not appear to extend to mental representation abilities, this study opens up new avenues for research on this topic.

Although providing insights, the present study has several limitations to address. First, it only involves brief exposures to the environment, which may have contributed to the null results observed for negative emotions and distance (and time) estimations. Future research should compare different durations of exposure to better understand potential differences in outcomes. Moreover, the range of green levels in our environment was relatively low; future studies should investigate exposure to paths with a broader range of green levels. Our additional analyses revealed that participants recognized the urban green environment as green and paid more attention to natural elements in the greener environments. However, it is possible that our null findings reflect this limitation. More pronounced levels of green could elicit stronger associations, particularly regarding negative emotions and distance estimations. Another important aspect is that we only considered emotional state after the path (controlling for baseline affect), so it was not possible to clearly analyze change in affect directly. Measuring the change in affect from pre-to post-exposure is crucial for drawing conclusions about the effects of the exposure, and this should be addressed in future studies. Additionally, the study was conducted in autumn, and it is possible that the relationships between the investigated variables may vary in other seasons. Future studies should also consider generalizing to other age groups (not only students) and other urban environments (e.g., larger cities). Furthermore, participants walked six paths, which may have led to fatigue; although the presentation of paths was randomized, this could have somewhat impacted the results. Future research could also introduce a cognitive fatigue task before the experiment; it is possible that our results were affected by the fact that participants were not cognitively fatigued at baseline. Finally, emotions and perceived restorativeness were assessed via self-report, which may introduce biases. Participants might have reported more positive responses simply because they were aware they had just walked through a greener environment. Future studies should consider including more objective measures (e.g., heart rate variability, skin conductance).

To conclude, the present study has shown a role of urban green levels on affect and perceived restorativeness, but not on mental representation ability. Our findings – supported by the within-participant design in which each participant walked in areas with different levels of green – indicate that the greener the elements present in an urban environment, the greater the effects are on affect and perceived restorativeness. These findings have important implications for urban planning and mental health policies. On the other hand, higher cognitive abilities, such as mental representation ability, did not appear to be related to the emotions elicited by the environment. However, further studies are needed to explore this topic in greater depth. Investigating the role of green space levels in urban areas is important due to its potential benefits on affect, restoration and cognition.

CRediT authorship contribution statement

Veronica Muffato: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Laura Miola:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Anahita Soltantouyeh:** Writing – review & editing, Formal analysis. **Francesca Pazzaglia:** Writing – review & editing, Supervision, Conceptualization. **Chiara Meneghetti:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Ethical approval and informed consent

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by The Ethical Committee for Psychological Research at University of Padova (Date October 07, 2022, No. DA18D2B96480796D2DAE4C79E2B8CD06). Informed consent was obtained from all participants included in the study.

Preregistration

The study was preregistered at https://osf.io/zadm6.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to proofread portions of the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2025.102734.

Data availability

Data are available on osf at https://doi.org/10.17605/OSF.IO/R2GPM.

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