Journal of Environmental Psychology 83 (2022) 101852

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Environmental influences on affect and cognition: A study of natural and commercial semi-public spaces

Kathryn E. Schertz[a,1,*], Jillian E. Bowman[a], Hiroki P. Kotabe[a], Elliot A. Layden[a], Jenny Zhen[a], Tanvi Lakhtakia[a], Muxuan Lyu[a,2], Olivia A. Paraschos[a], Stephen C. Van Hedger[b], Nak Won Rim[a], Kathleen D. Vohs[c], Marc G. Berman[a,**]

[a] University of Chicago, 5848 S University Ave, Chicago, IL, 60637, USA
[b] Huron University College, 1349 Western Rd, London, ON, N6G 1H3, Canada
[c] University of Minnesota, 75 E River Rd, Minneapolis, MN, 55455, USA

ARTICLE INFO

Handling Editor: L. McCunn

Keywords:
Natural environment
Built environment
Thought content
Experience sampling

ABSTRACT

Research has consistently shown differences in affect and cognition after exposure to different physical environments. The time course of these differences emerging or fading during exploration of environments is less explored, as most studies measure dependent variables only before and after environmental exposure. In this within-subject study, we used repeated surveys to measure differences in thought content and affect throughout a 1-h environmental exploration of a nature conservatory and a large indoor mall. At each survey, participants reported on aspects of their most recent thoughts (e.g., thinking of the present moment vs. the future; thinking positively vs. negatively) and state affect. Using Bayesian multi-level models, we found that while visiting the conservatory, participants were more likely to report thoughts about the past, more positive and exciting thoughts, and higher feelings of positive affect and creativity. In the mall, participants were more likely to report thoughts about the future and higher feelings of impulsivity. Many of these differences in environments were present throughout the 1-h walk, however some differences were only evident at intermediary time points, indicating the importance of collecting data during exploration, as opposed to only before and after environmental exposures. We also measured cognitive performance with a dual n-back task. Results on 2-back trials replicated results from prior work that interacting with nature leads to improvements in working-memory performance. This study furthers our understanding of how thoughts and feelings are influenced by the surrounding physical environment and has implications for the design and use of public spaces.

1. Introduction

A growing body of research shows that the physical environment someone spends time in can influence how they think, feel and act. Urban living offers many benefits to individuals (Bettencourt et al., 2007; Stier et al., 2021), however, it may also increase certain stressors (Bettencourt et al., 2007; Milgram, 1970, p. 173; Stier et al., 2021). Interaction with urban greenspace may counter some of these negative effects of urban living (Bratman et al., 2019; Hartig & Kahn, 2016). Acute exposures to urban greenspace, for instance, have been associated with positive, reflective thinking (Schertz et al., 2018; Schwartz et al., 2019), improved working memory (Berman et al., 2008), reduced aggression (Kuo & Sullivan, 2001), and reduced rumination (Bratman et al., 2015). City parks may be particularly useful public spaces given that park visits may support individual wellbeing (Schnell et al., 2019), increase social ties between neighbors (Kaźmierczak, 2013; Peters et al., 2010), and even reduce crime (Schertz et al., 2021).

As much of the world is industrialized and urbanized, the public and semi-public spaces in cities are important places to consider as locations where individuals are spending time outside of their work and home and thus may impact their wellbeing (Carr et al., 1992; Oldenburg & Brissett, 1982). These spaces, however, belong to a variety of categories and have

* Corresponding author.
** Corresponding author.
E-mail addresses: kschertz@uchicago.edu (K.E. Schertz), bermanm@uchicago.edu (M.G. Berman).
[1] Current Address: University of Michigan.
[2] Current Address: Hong Kong Polytechnic Institute.

https://doi.org/10.1016/j.jenvp.2022.101852
Received 7 January 2022; Received in revised form 20 July 2022; Accepted 3 August 2022
Available online 8 August 2022
0272-4944/© 2022 Elsevier Ltd. All rights reserved.

been designed for a multitude of more specific purposes. Public places include outdoor locations such as plazas, parks, and playgrounds, as well as indoor locations such as transit stations, nature conservatories, and shopping malls. In this paper we focus on how various measures of thoughts, affect, and cognitive performance varied between two indoor semi-public spaces, a nature conservatory and a large indoor mall.

One important feature that public spaces might have is their ability to improve or alter thought content. Thought content is an important part of everyone's daily lived experience (Larson & Csikszentmihalyi, 2014). Thoughts may be tied to one's external environment or be relatively independent of it, usually in the case of mind wandering (Smallwood & Schooler, 2015). The content and valence of thoughts have been shown to be associated with changes in mood and mental health (Killingsworth & Gilbert, 2010; Pennebaker & Beall, 1986; Seligman et al., 2005). The temporal aspect of thoughts, that is, whether they are focused on the past, present, or future, have also been associated with the affect and meaningfulness of those thoughts. For example, a recent experience sampling study showed that thoughts focused in the present were happier but less meaningful than thoughts focused on either the past or future (Baumeister et al., 2020). Thought content has also been shown to be influenced by the visual features in one's physical environment (Schertz et al., 2018, 2020). For these reasons, the continued study of thought content as a dependent variable is important in fully understanding the different effects of the external environment on human health and wellbeing (Berman, Kardan, et al., 2019; Berman, Stier, & Akcelik, 2019).

In addition to thought content, affective functioning has been shown to be associated with one's physical environment. In a recent meta-analysis, it was found that exposure to natural environments reliably increased positive affect compared to urban environments, while reductions in negative affect were less consistent (McMahan & Estes, 2015). Furthermore, specific feelings of impulsivity have also been associated with exposure to different environments. Across several studies, Berry and colleagues found that participants exposed to visual nature scenes (e.g., by looking at images) displayed less impulsive decision making than those exposed to images of the built environment or to geometric shapes (Berry et al., 2014, 2015). Feelings of materialism have also been found to be reduced by exposure to nature compared to urban environments (Joye et al., 2020), thus in addition to impulsivity in general, impulsive buying may be reduced by time spent in natural spaces.

Prior research has also found associations between creativity and natural stimuli. Creative performance of artists was judged to be higher when working in a space with natural images on the walls compared to a space without images (McCoy & Evans, 2002). Design students generated more creative design solutions working in a more natural space compared to a regular classroom (Chulvi et al., 2020). Qualitative interviews with creative professionals also indicated that artists often use nature intentionally as an environment for generating creative ideas (Plambech & Konijnendijk van den Bosch, 2015). Given these findings, people may report self-rated feelings of creativity as higher after interacting with natural stimuli.

The potential use of natural environments as an intervention to boost cognitive performance has also been studied (Berman et al., 2008, 2012; Bratman et al., 2012; Schertz & Berman, 2019; Van Hedger et al., 2018). A recent meta-analysis found that tasks requiring working memory (e.g., Backwards Digit Span) and cognitive flexibility (e.g., Trail Making Task B) showed reliable improvements after exposure to nature-based stimuli compared to urban-based stimuli, with attentional control tasks (e.g., Attention Network Task) also showing some improvements, but to a less-reliable degree (Stevenson et al., 2018). This meta-analysis found generally larger effect sizes in experiments that included actual exposure to various real-world environments compared to studies using virtual environmental exposure (e.g., viewing pictures or videos). Given that improvements in cognitive performance have been shown to be separable from improvements in affect (Stenfors et al., 2019), it continues to be important to test changes in both affect and cognition to determine under what environmental exposure conditions benefits in these domains are observed.

Several theories have been proposed to explain the cognitive and affective benefits from interactions with nature. Stress reduction theory posits that exposure to nature increases positive affect and reduces physiological stress, which support improved cognitive performance (Ulrich, 1983; Ulrich et al., 1991). Attention restoration theory on the other hand suggests that natural environments embody four key properties (i.e., soft fascination, extent, compatibility, sense of being away) which support the replenishment of cognitive resources (Kaplan & Kaplan, 1989; Kaplan, 1995) such as top-down directed attention (Kaplan & Berman, 2010). A more recent theory suggests that nature exposure may increase individuals' willingness to work (i.e., motivation) which accounts for its benefits in cognitive performance (Joye et al., 2022).

In comparison to research on the general benefits of interactions with natural elements, relatively little work has been conducted to investigate individual differences, which may predict whether someone shows affective or cognitive benefits from nature exposure. Given that some individuals are more sensitive to their environment than others (Aron & Aron, 1997), it may be the case that there are individual differences, which are important to consider when trying to predict behavioral or cognitive differences after spending time in certain environments. For example, one experience sampling study found that individuals with higher trait impulsivity were more likely to show a difference in positive affect while in natural compared to urban environments (Bakolis et al., 2018). Other personality traits, such as openness to experience or tendency towards reflection for example, may also moderate the effects of the surrounding physical environment on changes in affect and thought content.

Experience sampling methods provide a way for people to provide structured self-reports about what they are thinking and feeling throughout their daily life (Larson & Csikszentmihalyi, 2014). While experience sampling studies often take place over days or weeks, short term experience sampling studies that survey people several times over the course of an hour or so, have shown to be useful for collecting thoughts and feelings as individuals explored one specific area (Doherty et al., 2014). Here, we used an experience sampling methodology combined with a within-subject experimental design to compare various aspects of thought content while people explored two large, indoor semi-public spaces.

Conservatories are often constructed as large greenhouses, designed and curated to display various plants and may also include water features. On a continuum of 'untouched' to 'manicured' natural settings, conservatories belong at the 'manicured' end of the spectrum, most similar to other types of gardens. As public spaces, conservatories offer year-round access to 'green' nature for residents of areas with seasonal climates. On the other hand, indoor malls are traditionally concentrated, commercial spaces. In addition to including stores for both utilitarian and leisure shopping, malls may provide entertainment and are spaces to socialize and exercise (El Hedhli et al., 2013; Farren et al., 2015). Thus, while malls and conservatories are both indoor semi-public places, their purposes and designs are quite different from each other, which may influence the thoughts and feelings of visitors to these spaces. Importantly, research has shown how more natural versus more built spaces may alter individual's thought content in reliable ways (Schertz et al., 2018; Schwartz et al., 2019). Here it is possible to examine place-based influences on thought content in indoor spaces that typically have high positive valence such as conservatories and expensive malls.

In this within-subject study, we used repeated surveys to measure differences in thought content and affect throughout a 1-h environmental exploration of a nature conservatory and a large indoor mall. This allowed us to examine the time course for differences to emerge or fade between the two environments. We also collected measures of working memory performance before and after environmental exposure as a conceptual replication of previous studies examining the impacts of natural environments on cognitive performance (Berman et al., 2008; Stenfors et al., 2019; Stevenson et al., 2018; Van Hedger et al., 2018). Lastly, we examined correlations between numerous trait measures and our dependent variables to explore the role individual differences may play in observing environmental effects on affect and cognition.

2. Material & methods

2.1. Participants

A total of 99 participants participated in the study from October 2018 through April 2019. Ten participants did not return for the second session of the two-part study. Data collection issues resulted in the loss of three participants' data, leaving full analyzable data for 86 participants. Participants (mean age = 21.57 years, SD = 3.79 years, Range 18–39) were either University of Chicago students or adults from the surrounding communities recruited through Facebook, flyers posted in the community, and the university's research participation system. There were 39 men, 58 women, and 2 participants who selected 'other' for gender. In terms of ethnicity, 31 participants identified as white/Caucasian, 31 identified as Asian/Asian American, 16 identified as Hispanic, Latino, or Chicano, 15 identified as Black/African American, 5 identified as multiple ethnicities and 1 participant identified as another race/ethnicity. In the final sample of 86 participants (mean age 21.60 years, SD = 3.78 years, Range 18–39), there were 32 men, 53 women, and 1 participant who selected 'other' for gender. Participants were paid $74 to complete the study. This research was approved by the Institutional Review Board of the University of Chicago. Sample size was determined primarily through resource constraints (e.g., time, money) but is similar to other studies examining the effects of nature exposure on affect (McMahan & Estes, 2015). No data analysis was performed until after data collection was finished.

2.2. Locations

The conservatory study location was the Garfield Park Conservatory (referred to as 'conservatory' throughout) located in the Garfield Park neighborhood of Chicago (https://garfieldconservatory.org). The mall location was the Water Tower Place mall (referred to as 'mall' throughout) located in the Near North neighborhood of Chicago (https://www.shopwatertower.com/en.html). See Fig. 1 for a sample scene from each location.

2.3. Procedure

The study was conducted over two sessions, spaced one week apart. The order of environments (i.e., conservatory vs. mall location first) was counter-balanced across participants. In the final sample of 86 participants, 46 visited the conservatory first and 40 visited the mall first. A maximum of 12 participants were included in each study session, due to practical limitations in transporting participants to the testing locations and the goal of maintaining a manageable ratio of participants to research assistants. The trait questionnaire was completed online via Qualtrics before participants arrived at their first session (i.e., this was done at home after signing up to participate in the study).

When participants arrived at the laboratory building for each session, they were met by research assistants and directed to a shuttle bus. Research assistants collected participants' personal mobile devices (so that they would not be distracted by their own mobile devices during the walks) and distributed the experimental cell phones (Moto G5 Androids). All tasks during the study sessions were completed on these experimental phones. Participants completed the baseline survey and working memory task (dual n-back) on the bus while it was stationary at the laboratory building. Headphones were distributed for use during the working memory task. The bus then drove participants and research assistants to one of the study locations, which were both approximately 30 min away from the laboratory. Upon arrival at the study location, participants were instructed to explore the environments and answer survey questions on the experimental cell phone when prompted. Participants were also instructed not to interact with each other. In the mall, they were told they could enter the shops but not to make purchases. Participants were prompted by a timer on the cell phone to complete the ambulatory survey after 20 min (Survey 1), 40 min (Survey 2), and 60 min (Survey 3). After completing the third survey, participants were directed to meet the research assistants at the entrance. They were then instructed to complete the working memory task again, which was completed in the lobby area of the locations. Finally, the shuttle bus drove everyone back to the laboratory building. Each session lasted approximately 2–2.5 h. Fig. 2 shows a diagram representation of the study procedure.

Fig. 1. Example images of Garfield Park Conservatory (left) and Water Tower Place mall (right). Images from Wikimedia Commons (Jrissman, 2010; Kenraiz, 2016).

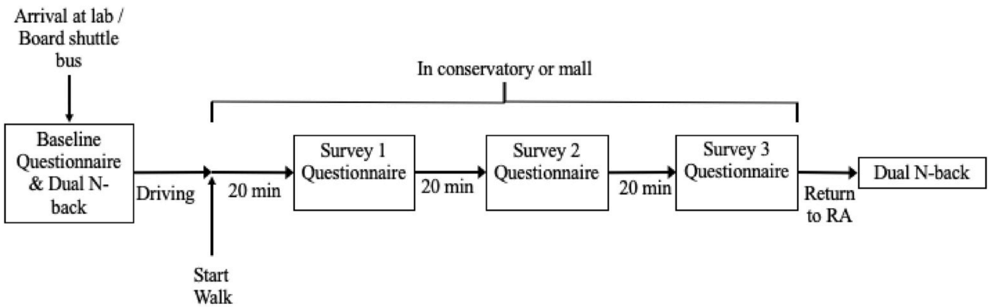

Fig. 2. Study Procedure
Note. RA = Research Assistant.

2.4. Survey questions

2.4.1. Trait questionnaire

In addition to providing demographic information, participants responded to a short form Big Five Inventory (mini-IPIP) (Donnellan et al., 2006), the Reflection-Rumination Questionnaire (RRQ) (Trapnell & Campbell, 1999), the Subjective Vitality Score (SVS) (Ryan & Frederick, 1997), the Valuing Emotions (VE) scale (Mangelsdorf & Kotabe, 2017, April), the Trait Rash Impulsivity Scale (TRIS) (Mayhew & Powell, 2014), and the 3-question loneliness scale (Hughes et al., 2004). The mini-IPIP assesses five facets of personality – extraversion, agreeableness, conscientiousness, neuroticism, and intellect (or openness to experience). While previous research has not linked Big Five measures to nature exposure, it is a widely utilized personality measure in psychology. The RRQ assesses two facets of private self-attentiveness - rumination, generally thought to be a maladaptive pattern of self-referential thought, and reflection, which is considered intellectual self-attention (Trapnell & Campbell, 1999). VE was developed to assess belief in one's own emotions as being helpful or harmful (Mangelsdorf & Kotabe, 2017, April). Given that reflection, rumination, and valuing emotions are all measures interrogating different aspects of focus on the self, these scales were included as it may be that people scoring higher on these measures are more or less sensitive to environmental effects on their mental state. SVS assesses the construct of vitality, defined as having physical and mental energy (Ryan & Frederick, 1997). This measure was included as exposure to nature has been associated with increased levels of state vitality (Ryan et al., 2010). TRIS measures general levels of impulsivity (Mayhew & Powell, 2014). Higher trait impulsivity has previously been found to be associated with greater increases in positive affect in response to exposure to natural environments (Bakolis et al., 2018).

2.4.2. Baseline questionnaire

Upon arrival to each study session, before being transported to the study locations, participants filled out the baseline questionnaire. Participants were asked questions about their most recent thought including when in time it was focused (e.g., focused on the past, present, or future) and its valence. To assess thought valence, they reported how much the thought aligned with seven adjectives: positive, exciting, imaginative, deep, spontaneous, stressful, and negative. To assess participants' affective state more broadly, positive affect was measured by asking how much they felt the following four emotions: energetic, grateful, in awe, and optimistic. Negative affect was measured using the four adjectives: bored, stressed, mentally fatigued, and insignificant. These words were chosen due to their alignment with theories related to the cognitive and affective benefits of nature (e.g., attention restoration theory and stress reduction theory). A separate study validating these measures and comparing them to previously developed affect scales was run and is reported in the Supplemental Materials. Participants also reported if they felt like they had 'gotten away' from everyday concerns, how creative they felt, and how impulsive they felt. Given that one environment was a shopping mall, impulsive buying was assessed specifically, in addition to general impulsivity. The questions about impulsive buying were taken from the Buying Impulsiveness Scale (Rook & Fisher, 1995), but framed as state rather than trait measures (see Supplemental Table 1 for exact wording). Other questions were also asked that are not analyzed in this manuscript. The full list of questions and possible answers is shown in Supplemental Table 1. Due to a coding error, Likert scales in the baseline questionnaire went from 0 to 7 while Likert scales in the ambulatory questionnaire went from 0 to 10. For all analyses, baseline responses were rescaled to 0–10.

2.4.3. Ambulatory questionnaire

While participants were walking around the study locations, they filled out the ambulatory survey three times. These surveys included the same questions as the baseline questionnaire, with a few exceptions: 1) Participants were only asked about impulsive buying at the third (final) survey, (i.e., not at survey 1 and 2), 2) at the third survey participants were asked their overall time perception of their walk and 3) at the third survey participants reported whether they had visited the study location before, and if so, how recently.

2.5. Cognitive task

Participants completed an audio-visual dual n-back task as a measure of working-memory performance. In an n-back task, participants are instructed to press a button if the current visual or auditory stimulus matches the stimulus that was presented 'n' previous trials back. The dual n-back (DNB) is a variant of this task in which two stimuli are presented simultaneously. Here, these stimuli were spoken integers, 1–9, and a blue square whose position varied in a 3 x 3 grid. On each trial of the dual n-back task, participants pressed their right index finger, right middle finger, both fingers, or neither finger, to indicate a position match, a number match, both a position and number match, or no match, respectively. Each trial lasted 3000 ms and the button press was permitted throughout the trial. Immediate feedback was provided to participants via red (incorrect press) or green (correct press) text at the bottom of the screen. Participants were first shown instructions and then completed a practice block for both 2-back and 3-back trials. Participants completed two blocks of 2-back and two blocks of 3-back, with each block containing 20 + n trials. The paradigm was implemented in Android (Layden, 2017). Performance is reported as A′, which accounts for both hits and misses, as in (Kardan et al., 2020). A′ is more robust to non-normality of responses than similar sensitivity indices, such as d' (Stanislaw & Todorov, 1999). The scale of a' is 0–1 with chance performance at 0.50. A′ is calculated as:

$$A' = 0.5 + sign(H - FA)*\frac{\left[(H - FA)^2 + abs(H - FA)\right]}{(4*\max(H, FA) - 4*H*FA)}$$

where H is the hit rate; FA is the false alarms rate (i.e., rate of responses when no response should have been given); sign(H – FA) is 1 if H is greater than FA, −1 if H is less than FA, and 0 if H is equal to FA; and max (H, FA) is the larger of the two values.

2.6. Statistical analyses

Statistical analyses were conducted using a Bayesian framework for multi-level models, with participant as a random intercept. Linear regression models were used for continuous dependent variables. Logistic regressions were used for categorical dependent variables (i.e., temporal focus of thought). The independent variables were the interaction term between condition (i.e., conservatory and mall) and survey/timepoint (i.e., Baseline, Survey 1–3) for all models. Main effects are not included as the Baseline survey was completed for each session before participants were taken to the respective locations. The dimensionality of the thought valence variables was reduced using principal component analysis (PCA). The first and second principal components were then used as the dependent variables in mixed linear regressions.

All models had regularizing priors. Regularizing priors prevent models from overfitting to the sample by slowing the model's rate of learning from the data. Full specification of the models, including their priors, is shown the Results section for each variable. Every model was run with 10,000 draws and 1000 warmup draws in four Markov Chain Monte Carlo (MCMC) chains, for a total posterior distribution of 36,000 post-warmup draws. We summarize the posterior distributions by reporting the 89% percentile intervals (PI). PIs may also be referred to as quantile intervals and indicate the probability mass centered around the mean of the posterior distributions. Since PIs are not the same as frequentist confidence intervals, the 89th percentile interval was chosen to avoid both conscious and subconscious attempts at hypothesis testing that may occur if presented with a conventional 95% interval, as suggested by McElreath (McElreath, 2020).

2.7. Transparency and openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. All data and analysis code are available at https://osf.io/npwrj/. Data were analyzed using R, version 3.6.3 (R Core Team, 2017) using the 'brms' package (Bürkner, 2017). This study's design and its analysis were not pre-registered. Additional dependent measures were collected during this study that are not reported here; these variables were not the focus of this manuscript. Most of the additional dependent measures are reported in (Schertz et al., 2022). The full list of dependent measures is shown in Supplemental Table 1.

3. Results

3.1. Thought content

3.1.1. Temporal aspects of thought

Participants answered the question "Was your most recent thought about the past, present (within 5 min before or 5 min after right now), or future, or did it have no time aspect?" They were allowed to choose more than one response. Each of the four single response options (i.e., 'past', 'present', 'future', 'no time aspect') was modeled as a logistic regression in the form:

$Response_i \sim \text{Binomial}(1, p_i)$	Likelihood
$\text{logit}(p_i) = 1 + \beta_{\text{condition*survey[j]}} + \alpha_{\text{participant[i]}}$	Logistic Regression Model
$\beta_j \sim \text{Normal}(0, 0.5)$, for j=1-8	Prior for betas
$\alpha_i \sim \text{Normal}(\overline{\alpha}, \sigma)$, for $i = 1-86$	Adaptive prior for each participant
$\overline{\alpha} \sim \text{Normal}(0, 1.5)$	Prior for Average Participant
$\sigma \sim \text{Exponential}(1)$	Prior for SD of participant

Where i represents the 86 participants and j represents the 8 condition*survey combinations (e.g., Conservatory-Baseline, Mall-Survey1).

Participants reported more thoughts focused on the past in the conservatory compared to the mall at Survey 1 and Survey 2 (Fig. 3). The odds ratio at Survey 1 was 2.39, 89% PI [1.25, 4.04], with 98.8% of MCMC chains showing odds ratio greater than one. In terms of probability, this equates to a difference of thinking past related thoughts 15% of the time in the conservatory and 7% of the time in the mall. The odds ratio at Survey 2 was 2.18 (89% PI [1.15, 3.66], with 97.7% of MCMC chains showing odds ratio greater than one. For probability, this equates to a difference of thinking past related thoughts 14% of the time in the conservatory and 7% of the time in the mall. There was no evidence of a difference in past-related thoughts between conditions at Survey 3 (Odds Ratio = 1.23, 89% PI [0.65, 2.07]).

Participants reported more thoughts focused on the future in the mall compared to the conservatory, with the largest odds ratio and strongest evidence at Survey 1 and weaker evidence at Survey 3 (see Fig. 3). The odds ratio at Survey 1 was 1.77, 89% PI [1.12, 2.64], (i.e., 27% future thoughts in the mall vs. 16% future thoughts in the conservatory), with 97.7% of MCMC chains showing odds ratio greater than one). The odds ratio at Survey 2 was 1.62, 89% PI [1.08, 2.31], (i.e., 32% future thoughts in the mall vs. 20% future thoughts in the conservatory), with 97.1% of MCMC chains showing odds ratio greater than one. The odds ratio at Survey 3 was 1.31, 89% PI [0.91, 1.82], (i.e., 33% future thoughts in the mall vs. 26% future thoughts in the conservatory), with 87.3% of MCMC chains showing odds ratio greater than one.

There was no evidence of interactions between surveys and condition for reporting thoughts about the present or thoughts with no time aspect, see Fig. 3 and Supplementary Table 2. Although able to, participants did not often select more than one choice for the time aspect; the multi-choice models are presented in the supplementary materials (Supplemental Table 3).

3.1.2. Valence of thought

Participants rated their thoughts on seven dimensions – deep, exciting, imaginative, negative, positive, spontaneous, and stressful. After using principal component analysis for data reduction, we used the first and second principal components (PC) as the dependent variables in our linear regression models. The first PC accounted for 40% of the variance across the seven dimensions. Ratings of exciting and positive showed the strongest loadings overall, with imaginative, deep, and spontaneous also loading positively, and negative and stressful loading negatively. We refer to this first PC as positive/exciting thinking. The second principal component accounted for 25% of the variance in the seven dimensions. This PC mostly reflected highly negative and stressful ratings of thoughts, with deep, imaginative, and spontaneous also loading positively. We refer to this second PC as negative/stressful thinking. Loadings of the seven dimensions onto these two PCs are shown in Fig. 4.

The loadings of participants' responses on these PCs were modeled as linear regressions in the form:

$$\text{Response}_i \sim \text{Normal}(\mu, \sigma)$$
$$\mu_i = 1 + \beta_{\text{condition*survey[j]}} + \alpha_{\text{participant[i]}}$$
$$\beta_j \sim \text{Normal}(0, 0.5), \text{ for } j = 1\text{–}8$$
$$\alpha_i \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha), \text{ for } i = 1 - 86$$
$$\overline{\alpha} \sim \text{Normal}(0, 3)$$
$$\sigma \sim \text{Exponential}(1)$$
$$\sigma_\alpha \sim \text{Exponential}(1)$$

Compared to baseline, thoughts were rated as higher on exciting/positive thinking while on both walks (see Fig. 5), but there was also a time by condition interaction, such that thoughts were reported as more exciting/positive in the conservatory compared to the mall at survey 1 and survey 2. As the ratings were standardized for the principal component analysis, differences in the posterior distribution are in standard deviations (SD). At survey 1, thoughts were 0.51 SD higher

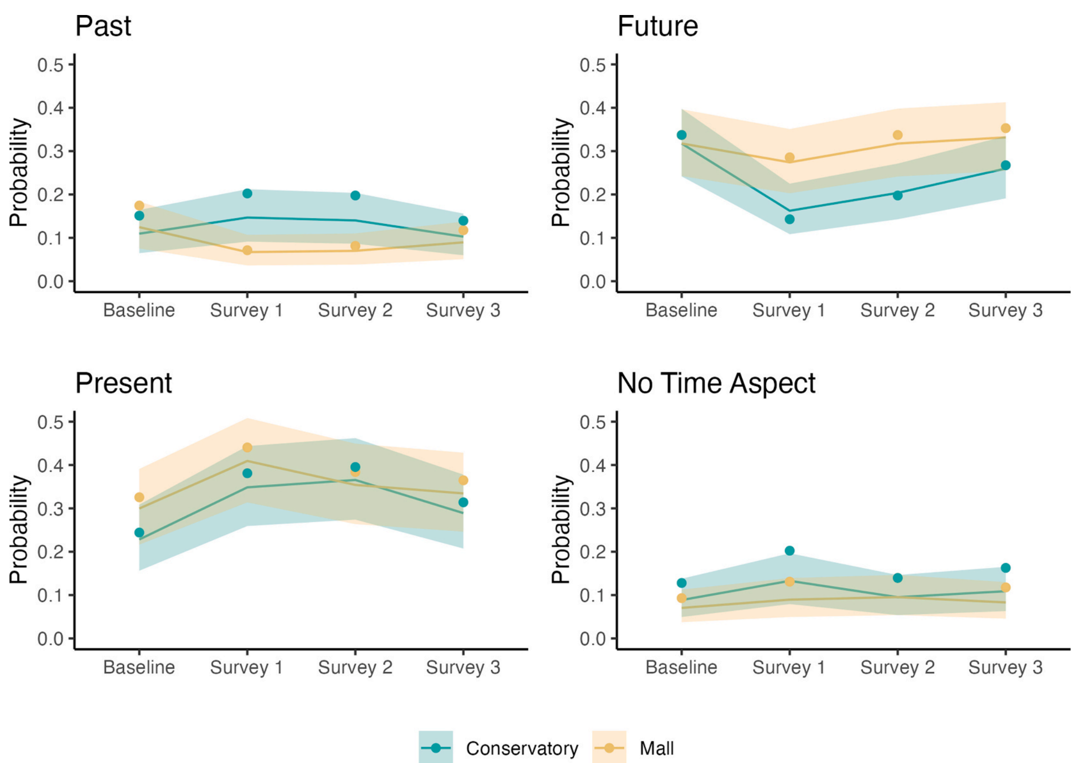

Fig. 3. Observed and modeled selection of temporal aspect of thoughts. Points are observed probabilities from the raw data. The fitted line is the logistic regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

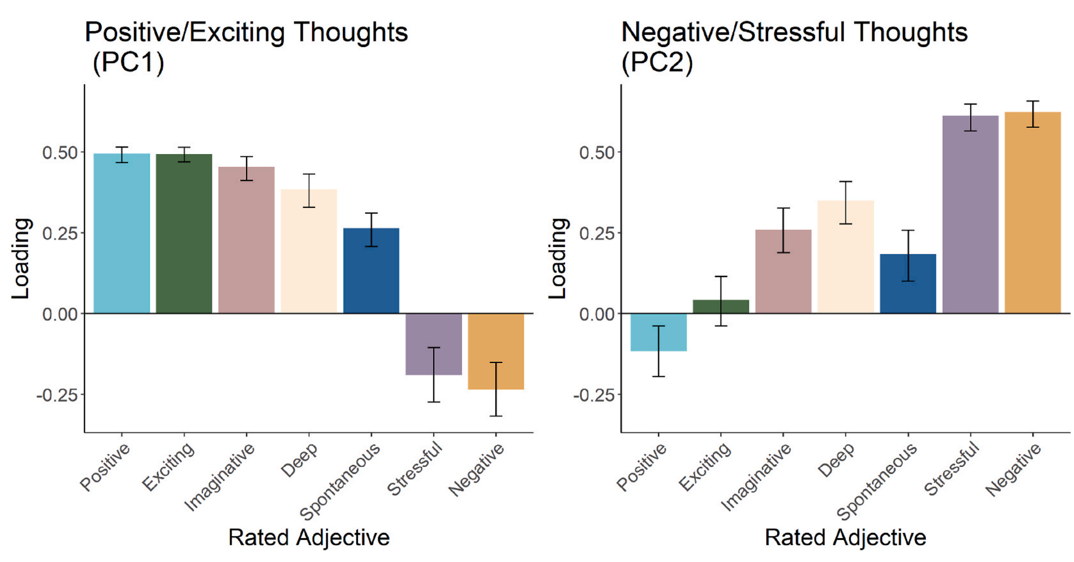

Fig. 4. Loadings of thought valence onto the first and second principal components with bootstrapped 89% confidence intervals.

(89% PI [0.19, 0.84] for exciting/positive thinking in the conservatory compared to the mall, with 99.5% of MCMC chains showing a difference greater than 0. At survey 2, thoughts were also 0.51 SD higher (89% PI [0.19, 0.82] for exciting/positive thinking in the conservatory compared to the mall, with 99.4% of MCMC chains showing a difference greater than 0. There was weaker evidence of a difference in these thought ratings at survey 3, with a mean difference of 0.24 SD (89% PI [−0.08, 0.55]) and 88.3% of MCMC chains showing a positive difference between conditions. Although baseline thoughts were reported before participants were taken to the study locations, there was an observed baseline difference for this PC. Thus, we repeated the analysis after subtracting the baseline reported valence in each condition. The results were similar, but weaker (see Supplemental Table 5 and Supplemental Fig. 1).

For negative/stressful thinking, we found a reduction in ratings for this PC through the walk in both conditions, with no evidence of an interaction between time and condition (see Fig. 5). Full models are shown in Supplemental Table 4.

3.2. State level affect

In addition to reporting the valence of their last thought, participants reported on their general affect. State affect variables were modeled as linear regressions in the form:

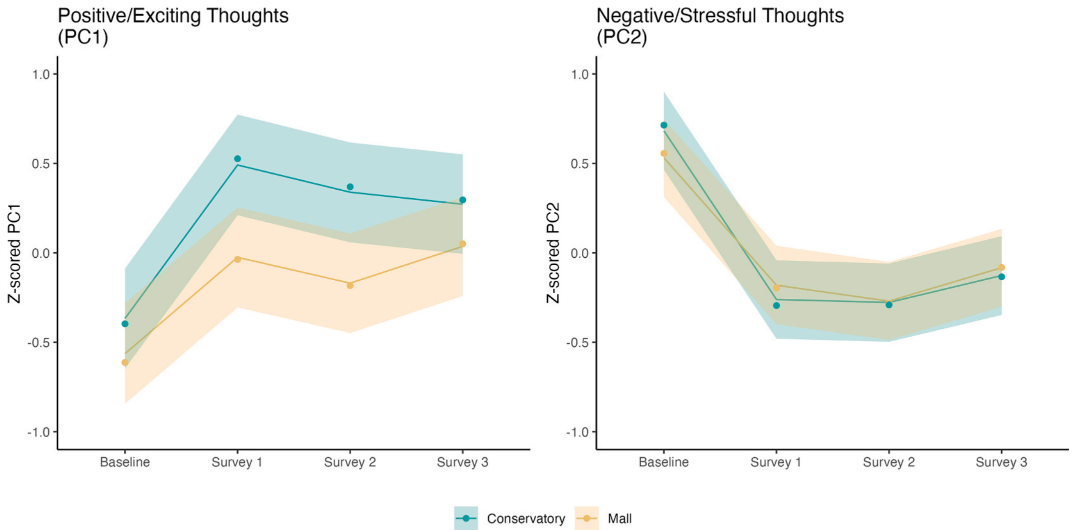

Fig. 5. Observed and modeled thought valence for PC1 (exciting/positive thinking) and PC2 (negative/stressful thinking). Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

$\text{Response}_i \sim \text{Normal}(\mu, \sigma)$
$\mu_i = 1 + \beta_{\text{condition*survey}[j]} + \alpha_{\text{participant}[i]}$
$\beta_j \sim \text{Normal}(0, 1)$, for $j = 1\text{–}8$
$\alpha_i \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha)$, for $i = 1 - 86$
$\overline{\alpha} \sim \text{Normal}(5, 1.5)$
$\sigma \sim \text{Exponential}(1)$
$\sigma_\alpha \sim \text{Exponential}(1)$

Participants reported higher levels of positive affect at all three surveys in the conservatory compared to the mall (Fig. 6). On a 10-point scale, the posterior distribution showed that positive affect was 1.34 points higher (89% PI [0.99, 1.7]) in the conservatory compared to the mall at Survey 1, 1.18 points higher (89% PI [0.83, 1.54]) at Survey 2, and 1.08 points higher (89% PI [0.73, 1.43]) at Survey 3. All MCMC chains showed a difference greater than 0 for all three interactions.

For the negative affect, we found participants reported lower levels throughout the walk in both conditions, with no evidence of an interaction between time and condition (see Fig. 6). Full models are shown in Supplemental Table 6.

In addition to positive and negative affect, participants reported how impulsive and creative they were feeling, as well as how much they felt like they had 'gotten away' from everyday concerns (see Fig. 7). Participants reported higher levels of creativity in the conservatory

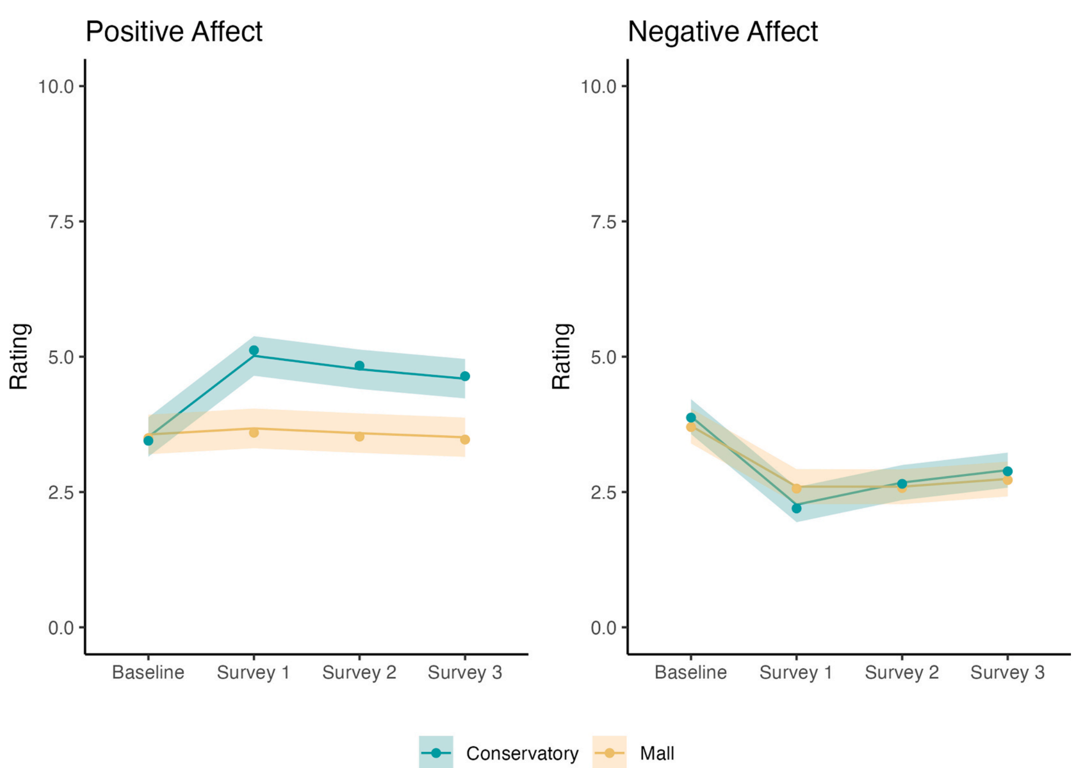

Fig. 6. Observed and modeled levels of positive and negative affect. Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

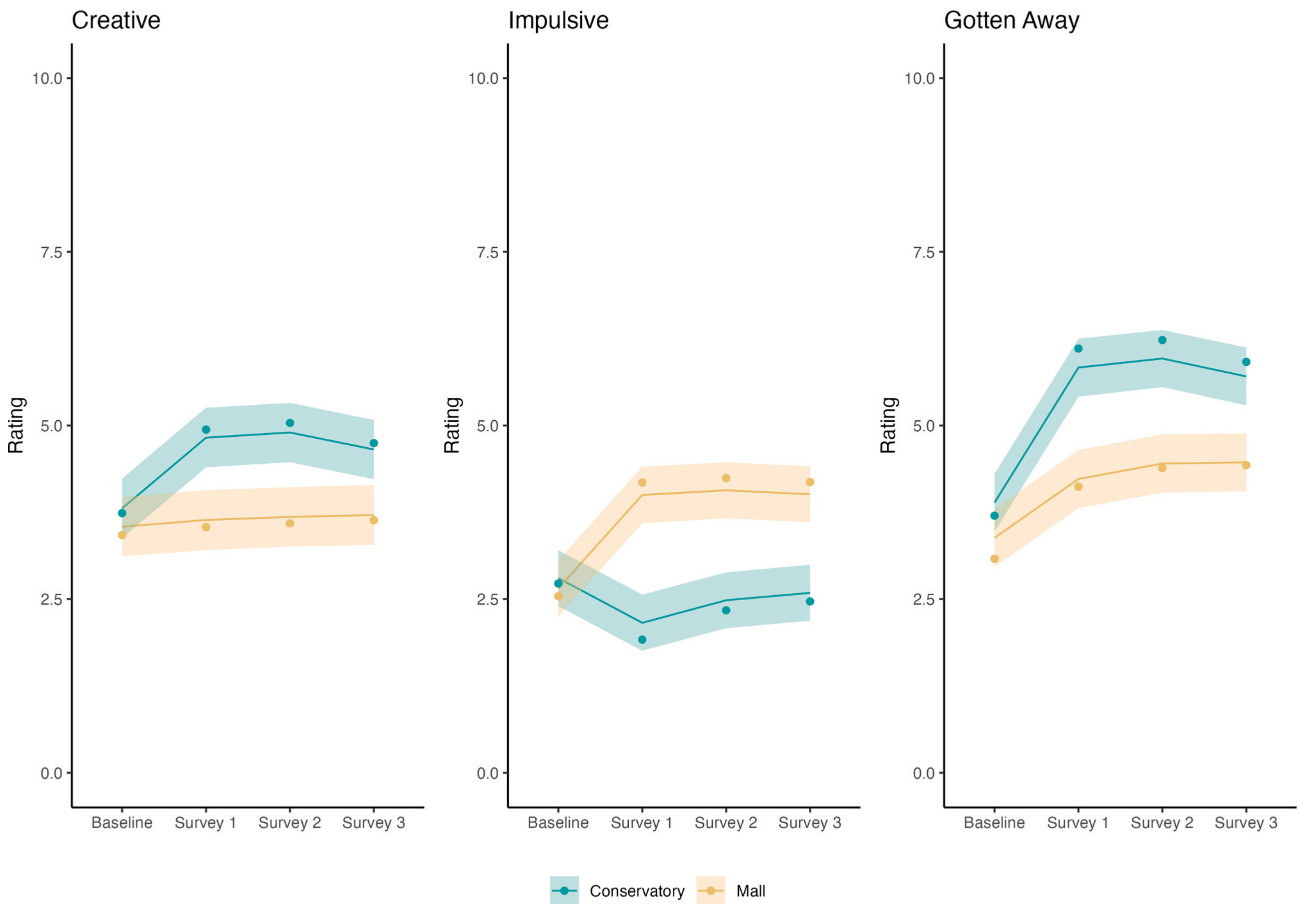

Fig. 7. Observed and modeled feelings of creativity, impulsivity, and 'gotten away'. Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

compared to the mall at all three surveys (Fig. 7). On a 10-point scale, the posterior distribution showed mean difference at Survey 1 was 1.18 (89% PI [0.73, 1.64]). The mean difference was 1.21 (89% PI [0.76, 1.67]) at Survey 2, and 0.94 (89% PI [0.5, 1.39]) at Survey 3. All MCMC chains showed a difference greater than 0 at all three surveys.

Participants reported lower levels of impulsivity in the conservatory compared to the mall at all three surveys (Fig. 7). On a 10-point scale, the posterior distribution showed a mean difference at Survey 1 of −1.84 (89% PI [−2.31, −1.38]). The mean difference was −1.59 (89% PI [−2.05, −1.12]) at Survey 2, and -1.42 (89% PI [−1.88, −0.96]) at Survey 3. All MCMC chains showed a difference less than 0 for all three surveys.

Participants reported that they felt a greater sense of having "gotten away" from everyday concerns in the conservatory compared to the mall at all three surveys (Fig. 7). On a 10-point scale, the posterior distribution showed a mean difference at Survey 1 of 1.6 (89% PI [1.13, 2.08]). The mean difference was 1.51 (89% PI [1.04, 1.99]) at Survey 2, and 1.24 (89% PI [0.76, 1.71]) at Survey 3. All MCMC chains showed a difference greater than 0 for all three surveys. Full models for all state-level reports are shown in Supplemental Table 7.

3.3. Impulsive buying

Impulsive buying was measured only at Baseline and at Survey 3. Impulsive buying (z-scored) was modeled in a linear regression with the following form:

$$Response_i \sim \text{Normal}(\mu, \sigma)$$
$$\mu_i = 1 + \beta_{\text{condition*survey[j]}} + \alpha_{\text{participant[i]}}$$
$$\beta_j \sim \text{Normal}(0, 1), \text{ for } j = 1\text{–}4$$
$$\alpha_i \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha), \text{ for } i = 1 - 86$$
$$\overline{\alpha} \sim \text{Normal}(0, 1)$$
$$\sigma \sim \text{Exponential}(1)$$
$$\sigma_\alpha \sim \text{Exponential}(1)$$

We found that at Survey 3, impulsive buying was 0.82 standard deviations higher in the mall compared to the conservatory, 89% PI [0.62, 1.01], with all MCMC chains showing a difference greater than 0. See Fig. 8. Full model is shown in Supplemental Table 8.

3.4. Working memory

Mean performance (A') on the dual n-back was 0.76 (sd = 0.19). Working memory performance was modeled in a linear regression with the following form:

$$Response_i \sim \text{Normal}(\mu, \sigma)$$
$$\mu_i = 1 + \beta^{*}\text{condition*pre\_post*session}_{[j]} + \alpha_{\text{participant[i]}}$$
$$\beta_j \sim \text{Normal}(0, 0.2), \text{ for } j = 1\text{–}8$$
$$\alpha_i \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha), \text{ for } i = 1 - 86$$
$$\overline{\alpha} \sim \text{Normal}(0.5, 1)$$
$$\sigma \sim \text{Exponential}(1)$$
$$\sigma_\alpha \sim \text{Exponential}(1)$$

We found evidence of a small main effect of time (b = 0.03, 89% PI [0.00, 0.06], 96.5% MCMC chains greater than 0), and a main effect of session (b = 0.06, 89% PI [0.01, 0.11], 98.8% MCMC chains greater than

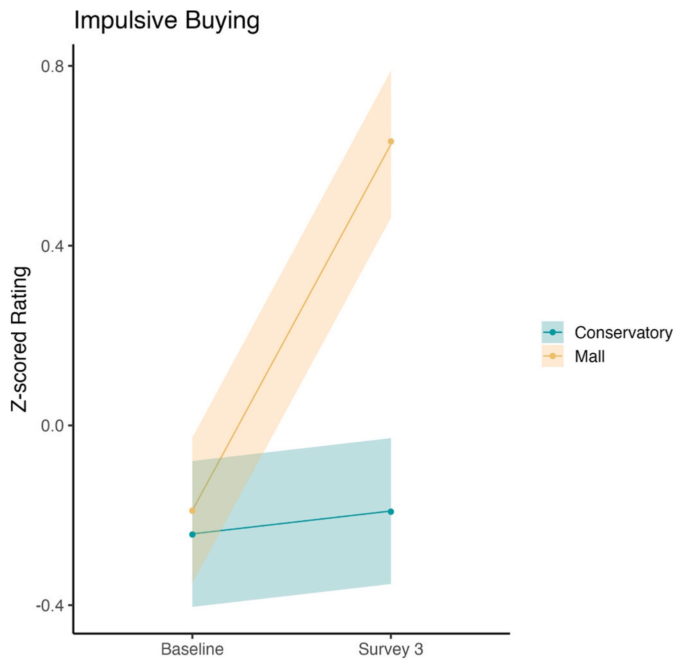

Fig. 8. Observed and modeled feelings of impulsive buying. Points are mean observed standardized ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

0) but no effect of interactions between environment, session, and time on performance (see Supplemental Fig. 2). Performance on 3-back trials for our participants was very poor as overall hit rate was under 50% (HR = 0.39, SD = 0.20) and mean A′ on 3-back was 0.67 (SD = 0.19), suggesting that there was a lot of noise in the 3-back data. As such, we ran an additional analysis, which only included the 2-back blocks where mean performance was much higher; A' on the 2-back blocks was 0.85. This model showed a main effect of session, such that scores were higher in the second session (beta = 0.04, 89% PI [0.00, 0.08], with 94.9% of MCMC chains showing a beta greater than 0). Importantly, we also found an interaction between time and environment, such that performance change scores were higher after the walk in the conservatory compared to after the walk in the mall (beta = 0.04, 89% PI [0.01, 0.08] with 97.1% of MCMC chains showing a beta more than 0), indicating

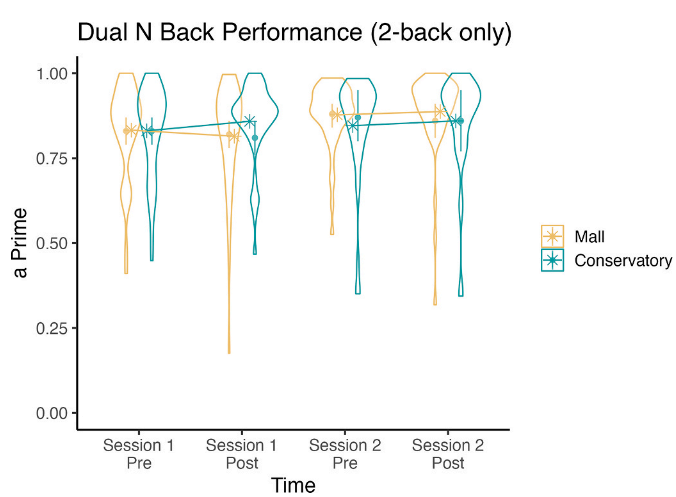

Fig. 9. Modeled and observed Dual N-back performance on 2-back blocks. Dots represent the mean and lines represent the 89% percentile interval of the model's posterior distribution. Violin plot represents the distribution of observed performance. Stars represent the observed mean performance.

more improvement after the conservatory walk compared to the mall walk (Fig. 9). See Supplemental Table 9 for the full models.

3.5. *Relationships between personality measures and thought content, state affect, and cognitive performance*

We computed Bayesian bivariate linear correlation estimates (rho) between participant trait measures (e.g., Agreeableness) and the dependent variables (e.g., state positive affect) that had shown time by environment interactions in the main analyses (Fig. 10). Cronbach's alphas for composite dependent measures are reported in Supplemental Table 10 and for composite trait measures in Supplemental Table 11. All were in the acceptable to good range. Each participant's reported ratings within each environment were averaged (i.e., responses at Surveys 1–3). For dual n-back, we used the change in 2-back performance (post score – pre score). Correlations were computed separately for each environment. While this approach does not test the formal interaction between location and personality, it does show how different traits are associated with outcome variables in each location.

Trait intellect (also called "openness to experience") was positively correlated with positive thoughts, positive affect, and feelings of creativity in the conservatory but did not show strong relationships with outcomes in the mall. Trait reflection was also positively correlated with creativity in the conservatory. Although in general, participants were more likely to think about the past in the conservatory, trait intellect and reflection were both negatively correlated with past thinking in the conservatory. This means that participants high on trait intellect and reflection were less likely to think about the past in the conservatory.

As prior research had found a positive correlation between trait impulsivity and the difference in positive affect between natural and non-natural environments, we wanted to directly test if we replicated that effect (Bakolis et al., 2018). We did not find evidence of a correlation between trait impulsivity and the difference in positive affect between the conservatory and mall (r = −0.05, 89% PI [-0.24, 0.16]). Within each condition separately, there was a negative correlation between trait impulsivity and positive affect.

3.6. *Correlations between dependent variables*

Bayesian bivariate linear correlations between dependent variables were calculated as well, see Fig. 11. Positive affect, positive/exciting thoughts, and creativity all positively correlated with each other in both the conservatory and the mall. Improvements in dual n-back performance was positively correlated with positive thinking, positive affect, state impulsivity, and creativity in the conservatory, but those relationships were not seen in the mall. Future thinking was positively correlated with state impulsivity in the mall but was negatively correlated with state impulsivity in the conservatory. Broadly, the patterns between past and future thinking with the other dependent variables is different between the two environments.

4. Discussion

We found numerous differences in thought content and affective state when walking in the conservatory compared to the mall environment. Regarding the temporal aspect of thoughts, we found evidence that participants had more 'past' related thoughts in the conservatory and more 'future' related thoughts in the mall. Participants also reported thoughts that were more positive/exciting in the conservatory compared to the mall. In terms of general affective state, participants reported higher positive affect in the conservatory compared to the mall, while a reduction in negative affect was reported for both the conservatory and mall throughout the walks. Participants reported feeling more creative while walking in conservatory but more impulsive while in the mall.

Some of the results can be grouped in terms of similar patterns. For instance, feelings of positive affect and creativity both increased in the

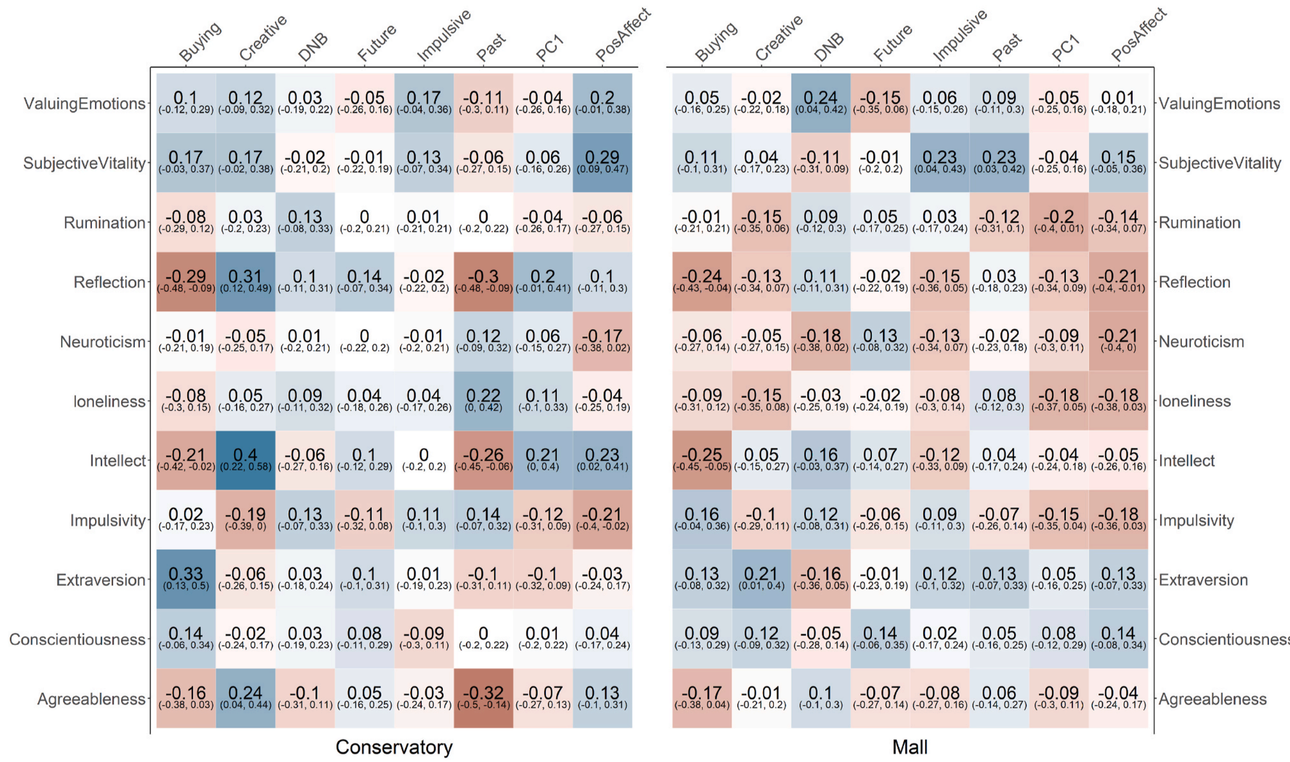

Fig. 10. Bivariate linear correlations between individual trait measures (rows) and dependent variables (columns) in the conservatory (left) and mall (right). PC1 is positive/exciting thoughts. DNB is change in dual n-back performance. Positive correlations are shown in blue and negative correlations are shown in red. 89% confidence intervals are shown in paratheses. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

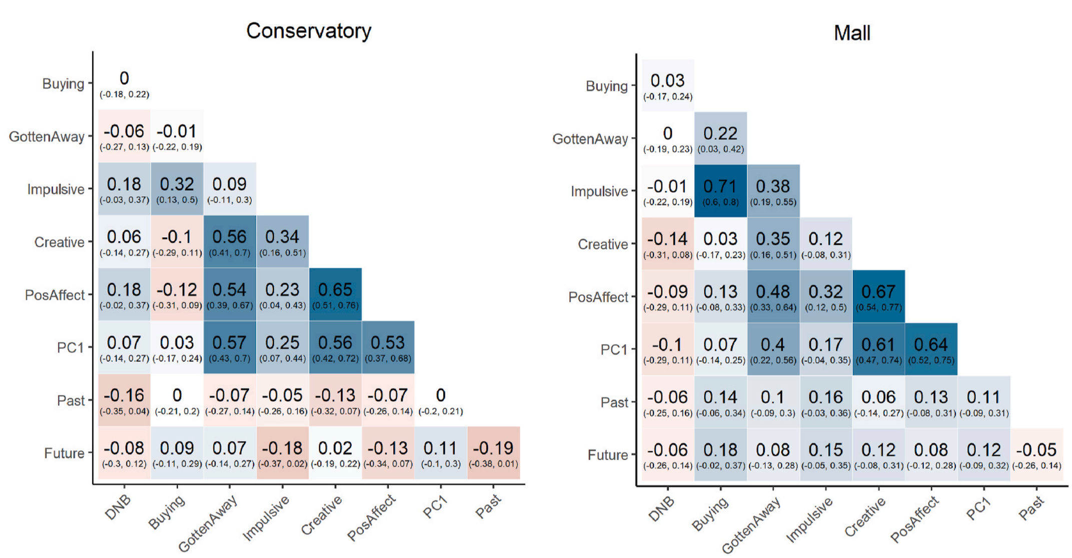

Fig. 11. Bivariate linear correlations between dependent measures in the conservatory (left) and mall (right). PC1 is positive/exciting thoughts. DNB is change in dual n-back performance. Positive correlations are shown in blue and negative correlations are shown in red. 89% confidence intervals are shown in paratheses. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

conservatory and stayed unchanged from baseline in the mall. Another group of dependent variables showing a similar pattern was negative thoughts and negative mood; these both decreased from baseline during the walks without showing an interaction by condition.

Many of these results are in accordance with previous research. For example, the finding of increased creativity in the conservatory is in line with previous research showing increases in creative performance following exposure to images, sounds, and immersive experiences of natural environments (Chulvi et al., 2020; McCoy & Evans, 2002). While those studies all tested creative performance, here participants were asked directly how creative they were feeling at the time. We also replicated previous findings that spending time in natural environments, either wild or manicured, can increase positive affect (McMahan & Estes, 2015). Our findings are also in line with previous work which found that in open-ended free response people described “an experience in nature” more positively than they did “an experience shopping”

(Craig et al., 2018). Recent research has found that changes in affect after viewing nature stimuli are associated with individual preferences for those images (Meidenbauer et al., 2020). Unfortunately, here we do not have preference ratings of the environments so we cannot investigate this pathway with the data from this study. While it is possible that the conservatory is more preferred over the mall, it is our sense that both environments would be relatively high on preference for most people.

We did not find overall interaction effects on the dual n-back task, likely because participants were barely above chance on 3-back trials and thus those blocks were likely adding a lot of noise to the model. When modeling the 2-back blocks of the task, where performance was more stable, we did find an environment by time interaction, such that performance was better after the walk in the conservatory compared to after the walk in the mall. Previous work has shown improvements in working memory performance after interactions with nature (Berman et al., 2008; Bourrier et al., 2018; Bratman et al., 2012; Stenfors et al., 2019; Van Hedger et al., 2018). The dual n-back has not been widely used in studies examining the cognitive benefits of exposure to nature (see (Stevenson et al., 2018) for a review of common tasks) but was chosen for this study due to its heavy reliance on working memory processes. Tasks that tax working memory and attention seem to show greater improvements after interacting with nature compared to pure attention tasks (Stenfors et al., 2019; Stevenson et al., 2018). A study by Van Hedger and colleagues used the dual n-back as part of a composite cognitive score and found improvements in performance after exposure to nature sounds and our results partially replicate those findings (Van Hedger et al., 2018). In the study by Van Hedger et al. (2018), performance improved on both 2-back and 3-back trials, but performance on 3-back was much higher in that study compared to this study.

While we can only speculate about the small effect size and lack of interaction effect when modeling 3-back and 2-back together, it should be noted that testing was not done under ideal experimental conditions. Logistics of the study led to post-environment testing being conducted on cell phones in the lobby/entry way of the locations, which was likely distracting for participants. These may also be reasons for worse overall performance by these participants compared to Van Hedger et al. (2018), which included participants from a similar population, but had them perform the dual n-back in the laboratory. Additionally, there may have been reduced potential for improvement given that participants were pinged on cell phones and required to take multiple surveys throughout their walk. Along these lines, previous research has found that using portable electronic devices while in a natural environment diminished attention restoration (Jiang et al., 2019). Future work should attempt to replicate these results, which may help determine boundary conditions under which cognitive improvements are or are not seen after exposure to natural environments.

We did not replicate previous findings which found an association between trait impulsivity and an increase in positive affect while in a natural environment (Bakolis et al., 2018). We used the same trait impulsivity scale as Bakolis and colleagues, however our study design was quite different. Our study was experimental, and we directly compared positive affect between the two environments. The original study was an observational experience sampling study collecting data over a one-week period, which examined the immediate and time-lagged effect of seeing different natural features. Additional studies of both types may help clarify the role of trait impulsivity in shaping individuals' reactions to the physical environment.

Other interesting individual differences were observed. In particular, it appears that individuals who scored higher on trait reflection seemed to attain more of the benefits from interacting with nature, given that this trait was positively correlated with positive/exciting thinking, and creativity, with some evidence of improvement in general positive affect as well, while exploring the conservatory. However, these individuals also showed negative correlations with positive affect and creativity in the mall, which may indicate a general sensitivity to environmental context. Participants scoring high on extraversion, on the other hand, were more likely to show higher positive affect in the mall, but not in the conservatory. It should be noted that we had less power to observe relationships for individual differences as these are necessarily between-subject analyses (unlike the other models presented). Future research attempting to replicate these effects, and other work linking personality traits and outcomes from environmental exposures is needed and will be important for both theoretical understanding and real-world applications. There are also other trait measures not included in this study but that have been related to the beneficial effects of nature, which measure connection to nature in various ways. These include the Connectedness to Nature scale (Mayer et al., 2009) and Inclusion of Self in Nature scale (Schultz, 2001), among others (see Tam, 2013), which could be included in future work to see how these traits are related to changes in affect and cognition after nature exposure.

Many of the differences in affect and thought content were present at all three surveyed timepoints. Any difference between the two environments that was observed was evident by the first survey. This indicates that approximately 20 min in an environment is sufficient to induce differences in affect and cognition. Some aspects though, such as past and future directed thoughts which showed an interaction with environment, were only observed at Surveys 1 and 2, thus not seeming to last the entire hour long walk. With these data, we do not know why some differences last longer than others. Given the size of the particular environments that were used in this study, it is possible that participants had fully explored the spaces by the end of 1 h, which attenuated some of the differences later in the survey. It would be useful to replicate this study in larger spaces to see how the extent of the space is related to the time course of thought content, especially as Kaplan (1995) theorized that environments with greater extent would lead to greater psychological benefits. Findings like this indicate the importance of repeated measurements *during* exploration of different environments. Most research into acute environmental exposures uses a pre-post design with arbitrary exposure length. Our repeated measures design sets a foundation for comparisons to difference environments in future studies – e.g., do different sized environments also show effect by 20 min that last a whole hour? Future research could also modify the first measurement point to be earlier to test minimum exposure needed to observe these effects.

Although this study has provided evidence that some differences in affect and thought content between the two environments were observed across all three timepoints, it remains unknown how long after leaving each environment would those differences persist. One experience sampling study found that people who had seen certain natural elements (i.e., trees and sky) showed a delayed boost in mood, in that they reported a more positive mood 2.5 h after exposure. In comparison, people who had a different type of nature exposure (i.e., hearing birds or being outside) reported a positive mood boost during the exposure but not 2.5 h later (Bakolis et al., 2018).

While our study revealed interesting differences in thought content between natural and commercial public spaces, and, importantly, largely replicated previous findings related to affective states, open questions remain that could be answered by different follow-up studies. For example, previous research had found associations between the thought content of park visitors and the visual features of those parks (Schertz et al., 2018). It would be informative to have participants take pictures each time they completed a survey to compare individualized visual features that participants were seeing at that moment with thought content. We did not implement that procedure for the current study due to technical difficulties of having participants switch between applications on the experimental mobile devices. Observational or experimental studies that have participants report thought content after leaving specific environments will inform how long differences in thought content persist after exposure.

There are also several limitations for the generalizability of this study. While the study was conducted in an ecologically valid manner, with participants visiting the locations during normal operating hours with other visitors present, and using mobile devices, participants visited these locations without companions. How these environments may shape conversation (and thus thoughts) for people visiting these locations with others should be researched. This study was also limited to one natural and one commercial space in one North American city. The design and amenities at conservatories and malls around the world may lead to other types of thought content. Cultural differences in the purposes of, and comfort in, these types of public spaces may also influence the results. These particular locations were chosen in part because they were free to enter, accessible year-round, similar in size to each other, desirable, frequently visited, and approximately equal driving time from our research lab. It should also be noted that these locations also differ from each other beyond just their degree of naturalness. For instance, the demographics of other visitors (such as age and ethnicity) and the purpose of their visits are likely different between these two places. How other public (and semi-public) spaces, such as plazas, museums, places of worship, or sculpture gardens, that differ along a variety of dimensions such as naturalness, crowdedness, educational opportunity, etc., compare to conservatories and malls is an open and interesting question. Replicating this study in additional locations will be informative in determining more universal impacts of environments on thought content and affect.

In conclusion, this study adds to the growing body of work indicating the immediate impact of our surrounding physical environment on affect and cognition. Public spaces are important locations within cities, and access to urban greenspace seems to be particularly beneficial given the thoughts and feelings experienced by people while exploring these types of environments. These types of natural environments are also able to improve cognitive performance, which could help urban dwellers to be more productive. Equitable access to safe areas with natural stimuli should be a goal for healthy, sustainable, and productive cities.

Funding

This work was supported by the National Science Foundation (DGE-1746045 to K.E.S.; BCS-1632445 and S&CC-1952050 to M.G.B.).

CRediT statement

Kathryn E. Schertz: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Software, Visualization, Writing – Original Draft. Jillian E. Bowman: Formal Analysis, Investigation, Writing – Review & Editing. Hiroki P. Kotabe: Conceptualization, Writing – Review & Editing. Elliot A. Layden: Software, Writing – Review & Editing. Jenny Zhen: Investigation, Software, Writing – Review & Editing. Tanvi Lakhtakia: Investigation, Writing – Review & Editing. Muxuan Lyu: Investigation, Writing – Review & Editing. Olivia A. Paraschos: Investigation, Writing – Review & Editing. Stephen C. Van Hedger: Writing – Review & Editing. Nak Won Rim: Formal Analysis, Writing – Review & Editing. Kathleen D. Vohs: Conceptualization, Supervision, Writing – Review & Editing. Marc G. Berman: Conceptualization, Funding Acquisition, Project Administration, Supervision, Writing – Review & Editing.

Data and materials availability

Data and code are available on OSF (https://osf.io/npwrj/).

Declaration of competing interest

The authors declare that they have no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2022.101852.

References

Aron, E. N., & Aron, A. (1997). Sensory-processing sensitivity and its relation to introversion and emotionality. *Journal of Personality and Social Psychology, 73*(2), 345–368. https://doi.org/10.1037/0022-3514.73.2.345

Bakolis, I., Hammoud, R., Smythe, M., Gibbons, J., Davidson, N., Tognin, S., & Mechelli, A. (2018). Urban mind: Using smartphone technologies to investigate the impact of nature on mental well-being in real time. *BioScience, 68*(2), 134–145. https://doi.org/10.1093/biosci/bix149

Baumeister, R. F., Hofmann, W., Summerville, A., Reiss, P. T., & Vohs, K. D. (2020). Everyday thoughts in time: Experience sampling studies of mental time travel. *Personality and Social Psychology Bulletin, 46*(12), 1631–1648. https://doi.org/10.1177/0146167220908411

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19*, 1207–1212.

Berman, M. G., Kardan, O., Kotabe, H. P., Nusbaum, H. C., & London, S. E. (2019). The promise of environmental neuroscience. *Nature Human Behaviour, 3*, 414–417.

Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., Kaplan, S., Sherdell, L., Gotlib, I. H., & Jonides, J. (2012). Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders, 140*(3), 300–305. https://doi.org/10.1016/j.jad.2012.03.012

Berman, M. G., Stier, A. J., & Akcelik, G. N. (2019). Environmental neuroscience. *American Psychologist, 74*(9), 1039–1052. https://doi.org/10.1037/amp0000583

Berry, M. S., Repke, M. A., Nickerson, N. P., Iii, L. G. C., Odum, A. L., & Jordan, K. E. (2015). Making time for nature: Visual exposure to natural environments lengthens subjective time perception and reduces impulsivity. *PLoS One, 10*(11), Article e0141030. https://doi.org/10.1371/journal.pone.0141030

Berry, M. S., Sweeney, M. M., Morath, J., Odum, A. L., & Jordan, K. E. (2014). The nature of impulsivity: Visual exposure to natural environments decreases impulsive decision-making in a delay discounting task. *PLoS One, 9*(5), Article e97915. https://doi.org/10.1371/journal.pone.0097915

Bettencourt, L. M. A., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences, 104*(17), 7301–7306. https://doi.org/10.1073/pnas.0610172104

Bourrier, S. C., Berman, M. G., & Enns, J. T. (2018). Cognitive strategies and natural environments interact in influencing executive function. *Frontiers in Psychology, 9*, 1248. https://doi.org/10.3389/fpsyg.2018.01248

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., Vries, S. de, Flanders, J., Folke, C., Frumkin, H., Gross, J. J., Hartig, T., Kahn, P. H., Kuo, M., Lawler, J. J., Levin, P. S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. *Science Advances, 5*(7), Article eaax0903. https://doi.org/10.1126/sciadv.aax0903

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences, 1249*(1), 118–136. https://doi.org/10.1111/j.1749-6632.2011.06400.x

Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C., & Gross, J. J. (2015). Nature experience reduces rumination and subgenual prefrontal cortex activation. *Proceedings of the National Academy of Sciences, 112*(28), 8567–8572. https://doi.org/10.1073/pnas.1510459112

Bürkner, P.-C. (2017). brms: An R package for bayesian multilevel models using stan. *Journal of Statistical Software, 80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01

Carr, S., Francis, M., Rivlin, L. G., & Stone, A. M. (1992). *Public space*. Cambridge University Press.

Chulvi, V., Agost, M. J., Felip, F., & Gual, J. (2020). Natural elements in the designer's work environment influence the creativity of their results. *Journal of Building Engineering, 28*, Article 101033. https://doi.org/10.1016/j.jobe.2019.101033

Craig, T. P., Fischer, A., & Lorenzo-Arribas, A. (2018). Shopping versus nature? An exploratory study of everyday experiences. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2018.00009

Doherty, S. T., Lemieux, C. J., & Canally, C. (2014). Tracking human activity and well-being in natural environments using wearable sensors and experience sampling. *Social Science & Medicine, 106*, 83–92. https://doi.org/10.1016/j.socscimed.2014.01.048

Donnellan, M. B., Oswald, F. L., Baird, B. M., & Lucas, R. E. (2006). The mini-IPIP scales: Tiny-yet-effective measures of the Big five factors of personality. *Psychological Assessment, 18*(2), 192–203. https://doi.org/10.1037/1040-3590.18.2.192

El Hedhli, K., Chebat, J.-C., & Sirgy, M. J. (2013). Shopping well-being at the mall: Construct, antecedents, and consequences. *Journal of Business Research, 66*(7), 856–863. https://doi.org/10.1016/j.jbusres.2011.06.011

Farren, L., Belza, B., Allen, P., Brolliar, S., Brown, D. R., Cormier, M. L., Janicek, S., Jones, D. L., King, D. K., Marquez, D. X., & Rosenberg, D. E. (2015). Mall walking program environments, features, and participants: A scoping review. *Preventing Chronic Disease, 12*. https://doi.org/10.5888/pcd12.150027

Hartig, T., & Kahn, P. H. (2016). Living in cities, naturally. *Science, 352*(6288), 938–940. https://doi.org/10.1126/science.aaf3759

Hughes, M. E., Waite, L. J., Hawkley, L. C., & Cacioppo, J. T. (2004). A short scale for measuring loneliness in large surveys. *Research on Aging, 26*(6), 655–672. https://doi.org/10.1177/0164027504268574

Jiang, B., Schmillen, R., & Sullivan, W. C. (2019). How to waste a break: Using portable electronic devices substantially counteracts attention enhancement effects of green spaces. *Environment and Behavior, 51*(9–10), 1133–1160. https://doi.org/10.1177/0013916518788603

Joye, Y., Bolderdijk, J. W., Köster, M. A. F., & Piff, P. K. (2020). A diminishment of desire: Exposure to nature relative to urban environments dampens materialism. *Urban Forestry and Urban Greening, 54*, Article 126783. https://doi.org/10.1016/j.ufug.2020.126783

Joye, Y., Lange, F., & Fischer, M. (2022). Does beautiful nature motivate to work? Outlining an alternative pathway to nature-induced cognitive performance benefits. *New Ideas in Psychology, 66*, Article 100946. https://doi.org/10.1016/j.newideapsych.2022.100946
Jrissman. (2010). English: This is a photograph of the Water Tower Place mall in Chicago, IL. It has eight levels and opened in 1975. Own work https://commons.wikimedia.org/wiki/File:WaterTowerPlaceMall.JPG.
Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182.
Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science, 5*(1), 43–57. https://doi.org/10.1177/1745691609356784
Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. CUP Archive.
Kardan, O., Layden, E., Choe, K. W., Lyu, M., Zhang, X., Beilock, S. L., Rosenberg, M. D., & Berman, M. G. (2020). *Scale-invariance in brain activity predicts practice effects in cognitive performance*. https://doi.org/10.1101/2020.05.25.114959, 2020.05.25.114959.
Kaźmierczak, A. (2013). The contribution of local parks to neighbourhood social ties. *Landscape and Urban Planning, 109*(1), 31–44. https://doi.org/10.1016/j.landurbplan.2012.05.007
Kenraiz, K. Z. (2016). English: Garfield Park Conservatory in Chicago. Own work https://commons.wikimedia.org/wiki/File:Garfield_Park_Conservatory_kz16.jpg.
Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy mind. *Science, 330*(6006), 932. https://doi.org/10.1126/science.1192439
Kuo, F. E., & Sullivan, W. C. (2001). Aggression and violence in the inner city: Effects of environment via mental fatigue. *Environment and Behavior, 33*(4), 543–571. https://doi.org/10.1177/00139160121973124
Larson, R., & Csikszentmihalyi, M. (2014). The experience sampling method. In M. Csikszentmihalyi (Ed.), *Flow and the foundations of positive psychology: The collected works of mihaly Csikszentmihalyi* (pp. 21–34). Springer Netherlands. https://doi.org/10.1007/978-94-017-9088-8_2.
Layden, E. A. (2017). N-back memory training [Android] https://play.google.com/store/apps/details?id=science.eal.n_backmemorytraining&hl=en.
Mangelsdorf, H. H., & Kotabe, H. P. (2017, April). *Psychological consequences of valuing emotions*. Chicago, IL, US: *University of Chicago Cog*nitive Brown Bag.
Mayer, F. S., Frantz, C. M., Bruehlman-Senecal, E., & Dolliver, K. (2009). Why is nature beneficial?: The role of connectedness to nature. *Environment and Behavior, 41*(5), 607–643. https://doi.org/10.1177/0013916508319745
Mayhew, M. J., & Powell, J. H. (2014). The development of a brief self-report questionnaire to measure 'recent' Rash impulsivity: A preliminary investigation of its validity and association with recent alcohol consumption. *Addictive Behaviors, 39*(11), 1597–1605. https://doi.org/10.1016/j.addbeh.2014.03.022
McCoy, J. M., & Evans, G. W. (2002). The potential role of the physical environment in fostering creativity. *Creativity Research Journal, 14*(3–4), 409–426. https://doi.org/10.1207/S15326934CRJ1434_11
McElreath, R. (2020). *Statistical rethinking: A bayesian course with examples in R and STAN*. CRC Press.
McMahan, E. A., & Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *The Journal of Positive Psychology, 10*(6), 507–519. https://doi.org/10.1080/17439760.2014.994224
Meidenbauer, K. L., Stenfors, C. U. D., Bratman, G. N., Gross, J. J., Schertz, K. E., Choe, K. W., & Berman, M. G. (2020). The affective benefits of nature exposure: What's nature got to do with it? *Journal of Environmental Psychology, 72*, Article 101498. https://doi.org/10.1016/j.jenvp.2020.101498
Milgram, S. (1970). *The experience of living in cities: A psychological analysis*. American Psychological Association. https://doi.org/10.1037/10042-011
Oldenburg, R., & Brissett, D. (1982). The third place. *Qualitative Sociology, 5*(4), 265–284.
Pennebaker, J. W., & Beall, S. K. (1986). Confronting a traumatic event: Toward an understanding of inhibition and disease. *Journal of Abnormal Psychology, 95*(3), 274.
Peters, K., Elands, B., & Buijs, A. (2010). Social interactions in urban parks: Stimulating social cohesion? *Urban Forestry and Urban Greening, 9*(2), 93–100. https://doi.org/10.1016/j.ufug.2009.11.003
Plambech, T., & Konijnendijk van den Bosch, C. C. (2015). The impact of nature on creativity – a study among Danish creative professionals. *Urban Forestry and Urban Greening, 14*(2), 255–263. https://doi.org/10.1016/j.ufug.2015.02.006
R Core Team. (2017). R: A language and environment for statistical computing. (3.3.3) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/.
Rook, D. W., & Fisher, R. J. (1995). Normative influences on impulsive buying behavior. *Journal of Consumer Research, 22*(3), 305–313. https://doi.org/10.1086/209452
Ryan, R. M., & Frederick, C. (1997). On energy, personality, and health: Subjective vitality as a dynamic reflection of well-being. *Journal of Personality, 65*(3), 529–565. https://doi.org/10.1111/j.1467-6494.1997.tb00326.x
Ryan, R. M., Weinstein, N., Bernstein, J., Brown, K. W., Mistretta, L., & Gagné, M. (2010). Vitalizing effects of being outdoors and in nature. *Journal of Environmental Psychology, 30*(2), 159–168. https://doi.org/10.1016/j.jenvp.2009.10.009
Schertz, K. E., & Berman, M. G. (2019). Understanding nature and its cognitive benefits. *Current Directions in Psychological Science, 28*(5), 496–502. https://doi.org/10.1177/0963721419854100
Schertz, K. E., Bowman, J. E., Kotabe, H. P., Layden, E. A., Zhen, J., Lakhtakia, T., Lyu, M., Paraschos, O. A., Van Hedger, S. C., Vohs, K. D., & Berman, M. G. (2022). *Nature's path to thinking about others and the surrounding environment*. https://doi.org/10.31234/osf.io/q27bc
Schertz, K. E., Kardan, O., & Berman, M. G. (2020). Visual features influence thought content in the absence of overt semantic information. *Attention, Perception, & Psychophysics*. https://doi.org/10.3758/s13414-020-02121-z
Schertz, K. E., Sachdeva, S., Kardan, O., Kotabe, H. P., Wolf, K. L., & Berman, M. G. (2018). A thought in the park: The influence of naturalness and low-level visual features on expressed thoughts. *Cognition, 174*, 82–93. https://doi.org/10.1016/j.cognition.2018.01.011
Schertz, K. E., Saxon, J., Cardenas-Iniguez, C., Bettencourt, L. M. A., Ding, Y., Hoffmann, H., & Berman, M. G. (2021). Neighborhood street activity and greenspace usage uniquely contribute to predicting crime. *NPJ Urban Sustainability, 1*(1), 1–10. https://doi.org/10.1038/s42949-020-00005-7
Schnell, I., Harel, N., & Mishori, D. (2019). The benefits of discrete visits in urban parks. *Urban Forestry and Urban Greening, 41*, 179–184. https://doi.org/10.1016/j.ufug.2019.03.019
Schultz, P. W. (2001). The structure of environmental concern: Concern for self, other people, and the biosphere. *Journal of Environmental Psychology, 21*(4), 327–339. https://doi.org/10.1006/jevp.2001.0227
Schwartz, A. J., Dodds, P. S., O'Neil-Dunne, J. P. M., Danforth, C. M., & Ricketts, T. H. (2019). Visitors to urban greenspace have higher sentiment and lower negativity on Twitter. *People and Nature, 1*(4), 476–485. https://doi.org/10.1002/pan3.10045
Seligman, M. E. P., Steen, T. A., Park, N., & Peterson, C. (2005). Positive psychology progress: Empirical validation of interventions. *American Psychologist, 60*(5), 410–421. https://doi.org/10.1037/0003-066X.60.5.410
Smallwood, J., & Schooler, J. W. (2015). The science of mind wandering: Empirically navigating the stream of consciousness. *Annual Review of Psychology, 66*(1), 487–518. https://doi.org/10.1146/annurev-psych-010814-015331
Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers, 31*(1), 137–149. https://doi.org/10.3758/BF03207704
Stenfors, C. U. D., Van Hedger, S. C., Schertz, K. E., Meyer, F. A. C., Smith, K. E. L., Norman, G. J., Bourrier, S. C., Enns, J. T., Kardan, O., Jonides, J., & Berman, M. G. (2019). Positive effects of nature on cognitive performance across multiple experiments: Test order but not affect modulates the cognitive effects. *Frontiers in Psychology, 10*. https://doi.org/10.3389/fpsyg.2019.01413
Stevenson, M. P., Schilhab, T., & Bentsen, P. (2018). Attention restoration theory II: A systematic review to clarify attention processes affected by exposure to natural environments. *Journal of Toxicology and Environmental Health, Part A B, 21*(4), 227–268. https://doi.org/10.1080/10937404.2018.1505571
Stier, A. J., Schertz, K. E., Rim, N. W., Cardenas-Iniguez, C., Lahey, B. B., Bettencourt, L. M. A., & Berman, M. G. (2021). Evidence and theory for lower rates of depression in larger US urban areas. *Proceedings of the National Academy of Sciences, 118*(31). https://doi.org/10.1073/pnas.2022472118
Tam, K.-P. (2013). Concepts and measures related to connection to nature: Similarities and differences. *Journal of Environmental Psychology, 34*, 64–78. https://doi.org/10.1016/j.jenvp.2013.01.004
Trapnell, P. D., & Campbell, J. D. (1999). Private self-consciousness and the five-factor model of personality: Distinguishing rumination from reflection. *Journal of Personality and Social Psychology, 76*(2), 284–304. https://doi.org/10.1037/0022-3514.76.2.284
Ulrich, R. S. (1983). Aesthetic and affective response to natural environment. In *Behavior and the natural environment* (pp. 85–125). Springer.
Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*, 201.
Van Hedger, S. C., Nusbaum, H., Clohisy, L., Jaeggi, S. M., Buschkuehl, M., & Berman, M. G. (2018). Of cricket chirps and car horns: The effect of nature sounds on cognitive performance. *Psychonomic Bulletin & Review*. https://doi.org/10.3758/s13423-018-1539-1