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Natural beauty and human potential: Examining aesthetic, cognitive, and emotional states in natural, biophilic, and control environments

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ABSTRACT

The influence of our surroundings on mental processes is a growing area of interest in psychology and architecture research. Understanding how to optimize spaces to support mental well-being and productivity is crucial. This research tested the hypothesis that nature enhances aesthetic appreciation, creativity, executive functioning, and mood by testing participants in a natural forest, a biophilic (nature-inspired) room, and a control laboratory room. The forest was appreciated aesthetically (as indicated by fascination, and hominess) the most, followed by the biophilic room and the control room. The biophilic room scored the highest in coherence compared to the forest and the control room. Divergent thinking was significantly higher in the nature condition compared to the biophilic room and the control room. Convergent thinking, working memory, attention, and delay discounting did not differ significantly between conditions. Participants' negative affect decreased after spending time in the control room or the biophilic room. By examining cognition, mood, and aesthetic appreciation in immersive real-world environments, this work provides a deeper understanding of how environmental settings affect mental processes, enriching knowledge from previous research focused on 2-dimensional images.

1. Introduction

Biophilia refers to the inherent human inclination to affiliate with nature and other forms of life (Wilson, 1984). According to the biophilia hypothesis, this affinity stems from humans' evolutionary history, where coexistence with and adaptation to nature was vital. Not only do humans prefer nature, but exposure to natural environments is also associated with better cardiovascular health, reduced stress and mental illness, enhanced mood, and improved attention and working memory (Berto, 2014; Bratman, Hamilton, et al., 2015; Dadvand et al., 2015; Engemann et al., 2019; Jimenez et al., 2021; Kaplan & Kaplan, 1989; Schertz & Berman, 2019; Song et al., 2015; Ulrich, 1981; Wolch et al., 2011).

Several theories attempt to explain these benefits from exposure to nature. The Attention Restoration Theory (ART) and Stress Reduction Theory (SRT) are two leading useful frameworks. ART posits that nature helps improve the ability to focus by offloading effortful cognitive processing, restoring depleted cognitive resources, and alleviating attentional fatigue (Kaplan & Kaplan, 1989). ART distinguishes between involuntary attention, or effortless attention captured automatically by surrounding stimuli, and directed attention that relies on effortful control mechanisms (James, 1892; Kaplan, 1995). Urban environments, which are recent on an evolutionary timescale, place increased demands on directed attention, leading to "directed attention fatigue" (Kaplan & Kaplan, 1989; White & Shah, 2019). Natural settings, by providing "soft fascination", evoke involuntary, effortless brain function that can restore a capacity for directed attention (Berman et al., 2008; Bowler et al., 2010; Joye, 2007; Kaplan, 1995).

Stress Recovery Theory (SRT) suggests that natural environments, where humans evolved, remain positively adaptive by promoting stress recovery through activation of the parasympathetic nervous system (Ulrich, 1981). Exposure to unthreatening nature helps counteract prolonged sympathetic and cortisol responses triggered by stressors. Nature facilitates faster and more complete stress recovery, as evidenced by self-reports and physiological measures like heart rate, cortisol, and

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blood pressure (Song et al., 2016; Ulrich, 1981). In contrast, urban environments, being visually complex, noisy, and intense, increase stress and fatigue (Berman et al., 2008; Lederbogen et al., 2011). Natural environments are lower in intensity and more perceptually coherent, which may contribute to the stress-reducing effects (Berto, 2014; Ulrich, 1981; Ulrich et al., 1991). Even small urban green spaces can mitigate stress-related effects of dense, noisy environments (Gidlöf-Gunnarsson & Öhrström, 2007; Kühn et al., 2017).

Attention restoration and improvements in mood may explain many of the observed benefits of nature exposure (Baceviciene & Jankauskiene, 2022; Berman et al., 2008; Kondo et al., 2018; Ohly et al., 2016). For example, nature exposure can improve other areas of executive functioning, such as better working memory and reduced impulsive decision-making, perhaps through restoration of attention or enhancement of mood (Berman et al., 2008; Berry et al., 2014; Bratman, Daily, et al., 2015; Ohly et al., 2016).

Other theories attempt to link specific physical properties of environments to benefits. For example, Kuo (2015) links "active ingredients" found in nature (e.g., phytoncides, negative air ions, reduced heat) to benefits in human functioning. They argue that these active ingredients enhance immune system function acting as a "central pathway" to explain nature's ability to improve health. Other studies suggest cognitive improvements, including working memory and attention, stem from lower pollution in areas with natural spaces (Dadvand et al., 2015).

Another possible mechanism for the positive effects of nature involves the perception of low-level environmental features (Schertz & Berman, 2019). Visual properties like color and spatial characteristics (e.g., non-straight edges) influence perceptions of naturalness and image preference (Berman et al., 2014; Kardan et al., 2015). These features shape cognition by affecting thought content—e.g., images with more non-straight edges can evoke thoughts of spirituality and life journeys (Schertz et al., 2018). Humans also have preferences for fractals—self-similar patterns with structural properties that repeat at different spatial scales (Gisiger, 2001; Mandelbrot, 1967). Many natural views (e.g., trees, clouds, coastline contours) exhibit fractal geometry, contributing to their coherence (Joye, 2007; Joye & van den Berg, 2011; Purcell et al., 2001; Yu et al., 2005). Fractals may also partially explain the association between nature and stress reduction (Joye, 2007). Similarly, low-level acoustic features like spectral entropy and dominant frequency differ between natural and urban sounds, influencing cognition and preference (Van Hedger et al., 2019). For example, listening to nature sounds can enhance working memory compared to urban noise (Van Hedger et al., 2019).

Prospect-Refuge Theory explains environmental preference in terms of safety and visibility (Appleton, 1975; Stamps, 2014). The theory proposes that environmental preferences are influenced by prospect (visibility) and refuge (protection), with evolutionary benefits linked to survival. Appleton proposed that aesthetic preferences for certain landscapes function as a mechanism for directing attention based on perceived safety or potential danger.

1.1. Biophilic design

Given humans' preference for nature and the increasing recognition of its benefits, biophilic design aims to bring a natural aesthetic into the built environment (Kellert, 2008; Kellert & Calabrese, 2015). Biophilic design can be as straightforward as adding plants, water features, small trees, or pictures of the outdoors to built spaces (Joye, 2007). Adding natural materials, such as wood, influence preferences and moods, with variations in the amount of wooden material in spaces producing physiological and psychological changes (Tsunetsugu et al., 2007). Drawing on prospect-refuge theory, architects incorporate large windows or balconies to provide extensive vistas of the outdoors, or more subtly design spaces that are bright and open (prospect) or dark and enclosed to induce a sense of safety (refuge) (Hildebrand, 1999). Similarly, these design decisions are often in line with SRT. Modern open, calm, and warm environments can alleviate stress. Ruggles and Boak (2020) highlight the significance of designing buildings that enhance the baseline tone of the parasympathetic nervous system to reduce stress (Ruggles & Boak, 2020). Designers also incorporate natural patterns like edge density, contrast, curvilinear forms, and fractals to enhance mood, cognition, and preference (Coburn et al., 2019; Vartanian et al., 2013). Fractal designs, in particular, balance engagement and relaxation, promoting well-being and evoking a sense of naturalness, making them more preferred in built environments (Joye, 2007; Lavdas et al., 2020; Robles et al., 2021; Taylor, 2021). Contemporary studies link biophilic design in built environments to improved cognition, mood, and health (Gray & Birrell, 2014; Shen et al., 2020). However, the impact of various biophilic design elements in a controlled, immersive setting remains underexplored.

1.2. Aesthetic experience: coherence, fascination, and hominess

One recent approach to understanding how preferences for environments, both natural and built, may affect mood and cognition is by assessing people's aesthetic experiences. Aesthetic responses to environments can be distilled into three key psychological dimensions: a sense of coherence (ease of organizing and comprehending a scene), fascination (informational richness and generated interest), and hominess (personal ease, belonging, and comfort) (Chatterjee et al., 2021; Coburn et al., 2020; Vartanian et al., 2021; Weinberger et al., 2021). Each dimension is associated with distinct neural signatures (Coburn et al., 2020). However, how experiencing each psychological dimension relates to cognition and mood is not known. Prior work has relied on responses to 2-dimensional images rather than immersive real-world environments. Investigating if and how aesthetic experiences mediate changes in behavior could help explain a mechanism underlying the benefits of different environments.

1.3. Creativity

While natural environments and biophilic design benefit health, cognition, and mood (Gray & Birrell, 2014; Schertz & Berman, 2019; Shen et al., 2020), their link to creativity remains less explored. Creativity is identified as an essential "21st-century skill" for education and the economy (National Research Council, 2012), and substantial growth is projected in creative sectors (especially in STEM; (Bureau of Labor Statistics, 2024; Frey & Osborne, 2017). As creative thinking becomes increasingly valued across industries, understanding how environmental design can enhance creativity is critical for optimizing learning environments, workplaces, and public spaces.

Two key components of creative cognition are divergent and convergent thinking (Green et al., 2024; Guilford, 1967; Runco & Jaeger, 2012). Divergent thinking is a flexible cognitive style that generates multiple ideas when criteria are vague and multiple solutions exist. Convergent thinking, by contrast, focuses on finding precise solutions to well-defined problems and requires persistence and concentration (Guilford, 1950; Runco, 2010).

A few studies link nature exposure to creativity. Creative professionals report that being in nature enhances curiosity, cognitive flexibility, and idea generation (Plambech and Konijnendijk van den Bosch, 2015). Viewing images with high or moderate perceived naturalness and immersive nature exposure over several days have been shown to enhance creative performance (Atchley et al., 2012; Yeh et al., 2022). However, these studies have relied on 2D images or prolonged outdoor activity (e.g., hiking). The specific mechanisms in which being in nature influences creative thinking, and which aspects of creativity it enhances, remain open questions.

Nature's effects on attention and stress may contribute to its impact on creativity. Creativity is linked to broad attentional scope (Ansburg & Hill, 2003), leaky attention (i.e., noticing "irrelevant" information)

(Carson et al., 2003; Mendelsohn & Griswold, 1964; Rawlings, 1985), selective and flexible attention, and executive cognition (Nusbaum & Silvia, 2011; Zabelina et al., 2016). Attention-modulating techniques, such as meditation and broad perceptual focus, can enhance creativity (Colzato et al., 2012; Friedman et al., 2003). Thus, in line with ART, nature's ability to restore attentional resources may explain its positive effect on creativity. The links between nature and improved mood (Berto, 2014) also present a promising pathway of effect given the substantial evidence that positive mood enhances creative thinking and ideation, including a meta-analysis of 72 mood-creativity studies (Davis, 2009). Therefore, the stress-reducing and mood-improving effects of nature may account for how nature enhances creativity.

1.4. Current study

Despite growing evidence of natural features' cognitive and emotional benefits, little is known about how fully immersive natural and biophilic environments influence creativity. Addressing this gap is important for understanding how different environments can support cognitive performance and well-being. We tested the hypothesis that nature and natural elements in the environment improve aesthetic appreciation, creativity, executive functioning, and mood by testing across three different fully immersive environments: a real forest, a room designed with biophilic features, and a control laboratory room. We predicted that: (a) The natural environment would evoke the highest aesthetic appreciation, with participants rating it highest in coherence, fascination, and hominess. The biophilic room would evoke similar aesthetic experiences but to a lesser degree; b) The natural environment would lead to the greatest increase in positive emotions and the greatest decrease in negative emotions. The biophilic room would also enhance mood but to a lesser extent than nature; (c) Natural elements would improve attention, working memory, and reduce impulsive decision-making. Specifically, participants in the natural environment would score highest on executive functioning tasks, followed by those in the biophilic room, with the control room showing the lowest performance; (d) The natural environment would most enhance divergent creative thinking, followed by the biophilic room. The control room would produce the lowest creativity scores.

In addition to investigating these direct effects, we explored if aesthetic experiences, mood, attention, or working memory mediate the effect of the environments on creativity. These analyses will help clarify if natural environments improve human capacities and if such improvements are related to SRT, ART, and aesthetic experiences. The findings from this study will contribute to our understanding of the role of nature in cognition, creativity, and emotion, highlighting the importance of not only integrating natural elements into built environments but also preserving and increasing access to outdoor spaces that support human cognition and well-being. These insights have broad implications for the design of workspaces, schools, and public spaces, where fostering creativity, cognitive function, and well-being is increasingly valued.

2. Methods

2.1. Participants

Participants were recruited through flyers, online advertisements, and the SONA system at [removed for blind review] and [removed for blind review]. Those assigned to the biophilic and control rooms were tested at [removed for blind review], and participants in the natural environment condition were tested at [removed for blind review]. All were blind to the study's purpose, 18 years or older, and fluent in English. Sessions lasted approximately 60 min for indoor conditions and 70 min for the nature condition, which included a short walk to the forested area. Participants received $20 per hour or course credit.

All study procedures were approved by the [removed for blind review] and [removed for blind review] IRBs. 148 individuals participated in the study. One participant was excluded from the analysis for failing attention checks throughout the task (e.g., not selecting "Very much so" when prompted in a survey), leaving a final sample of 147 participants. Table 1 summarizes demographic information across the three conditions. Despite efforts to match the groups across demographic information, participants in the nature condition were younger than the biophilic condition (linear mixed effect model $F(2,145) = 5.636$, $p = .004$, nature/biophilic condition comparison, $p = .004$). Running the analysis with and without the older biophilic participants and with age as a predictor did not reveal significant differences in the model. Consequently, our analysis includes all participants. The sample size was determined based on previous studies in the literature (Coburn et al., 2019). We conducted a post hoc power analysis on G*Power to evaluate the adequacy of the sample size based on the observed effect size $f2 = 1.15$ and significance level $\alpha = .05$. The analysis showed an achieved power of 1.00 indicating that our study was adequately powered to detect the observed effect.

2.2. Design of the testing environments

2.2.1. Biophilic room

The biophilic room was created following biophilic design principles applying six multisensory elements based on the literature (Fig. 1).

1. Perceived naturalness: Based on low-level visual features, scenes with a greater range of element sizes (higher in scaling) and stronger differences between light and dark areas (higher contrast) are perceived as more natural (Coburn et al., 2019). To increase the perceived naturalness of the space, we added 2 plants, a moss wall, a slab of fir as a desk, and real bamboo on the ceiling.
2. Color: We applied earth tones throughout the room (Nascimento et al., 2021). Through the furniture and plants, we added shades of green and brown. The wallpaper was a pastel beige color.
3. Materiality (Tsunetsugu et al., 2007). We used a bamboo ceiling and wood for a lamp base and moss wall frame. The desk was a slab of fir polished with mineral oil to retain tactile and olfactory properties. We applied textured contact paper to the walls.
4. Fractals: Lab members handcrafted the rug and the moss wall with a mid-complexity fractal pattern (Taylor, 2021).
5. Vegetation: Indoor plants induce positive psychophysiological changes in humans if they are or are perceived as real (Gilis et al., 2015; Jo et al., 2019; Yeom et al., 2021). We placed a mini monstera (Rhaphidophora tetrasperma) and a snake plant (Dracaena trifasciata) on the desk. The moss wall with real moss occupied a central wall.

Table 1
Demographic information for the three conditions.

Demographics	Biophilic (N = 50)	Control (N = 45)	Nature (N = 52)
Age (M, SD)	23.96, 7.46	22.96, 4.92	20.54, 2.41
Gender			
Woman	34	35	37
Man	13	9	14
Do not identify as man or woman	2	2	0
Native English speakers	40	36	37
Non- native English speakers	10	9	15
Years of education (M,SD)	15.5, 2.3	15, 2.1	14.28, 1.7
Race			
White	19	26	27
Asian	18	13	15
Black or African American	10	3	7
Do not wish to say	1	2	0
Other	1 (mixed)	0	2

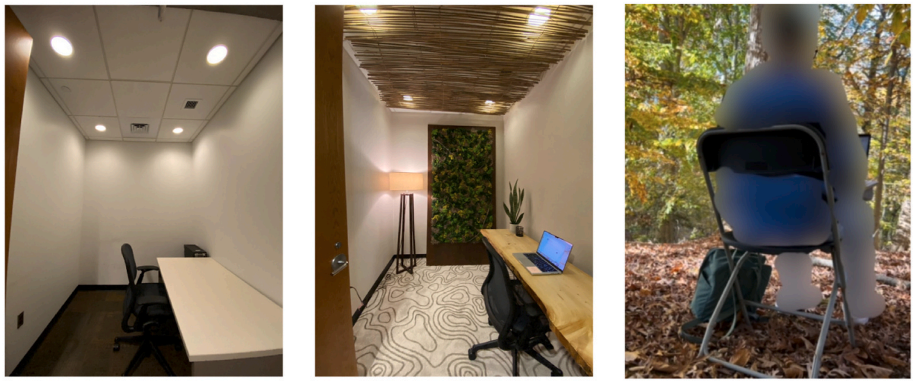

Fig. 1. The experimental environments for the three conditions.
Note: The left picture shows the control room with no biophilic or natural elements, the middle picture shows the biophilic room and the right picture shows the natural environment at the park near [removed for blind review].

6. Light: There were no windows in the rooms. We used diffused light instead of directional for less stimulation (Gilis, 2015) for the lamp shade, bamboo ceiling, and indirect desk lamp placing bulbs of daylight range color temperature (5000–6000K).

2.2.2. Control room

The control room and biophilic room were university testing spaces identical in size and on the same building floor. Other than the inclusion of biophilic elements, the rooms were no different. The control room resembled typical university psychology experiment testing spaces with plain white walls, a simple desk, a computer monitor, an office chair, overhead ceiling lighting, a dark brown carpet, and no decoration or other colors (Fig. 1).

2.2.3. Natural environment

The natural environment was an outdoor, forested area in [removed for blind review], approximately a 5-min walk from the Psychology building at [removed for blind review]. The walk was a route through campus, similar to the kinds of walks participants typically take to reach a lab for research studies at universities. To minimize any potential effects of walking through the forest, the testing site was situated immediately upon entering the forest and was consistent across participants. The space was a secluded, shaded location that looked out over a heavily forested area (Fig. 1). Upon arriving at the testing location, the researcher set up a chair and the participant was given a lap desk on which the computer rested. Sessions were only conducted if the temperature was between 45 and 85 °F ($M_{temperature} = 64.63$ °F, SD = 11.32) and were not conducted in rainy conditions.

2.3. Procedure

When enrolling in the study, participants at [removed for blind review] signed up for specific time slots on SONA. Each time slot was pre-assigned to a condition (biophilic or control). Participants were emailed a link to complete an online Positive and Negative Affect Scale (PANAS; Watson et al., 1988) via Qualtrics. The study coordinator randomized the order of the tasks to ensure a balanced order of tasks across conditions. The researcher conducting the experiment was blinded to the randomization and followed the assignment instructions based on the condition associated with the participant's time slot. Participants completed assessments independently in their assigned room after receiving instructions from the researcher, who remained outside the room. At [removed for blind review], only the nature condition was used, but participants were recruited by the lab coordinator to match the gender distribution of the participants in the other two conditions to ensure comparability between the two sites. At sign-up, participants completed an online PANAS via Qualtrics. On the day of the experiment, participants in the nature environment walked with a research assistant to the testing site. Upon arrival, the researcher set up a chair in a marked location, gave the participant the same instructions as those in the indoor condition, and remained out of sight from the participant. All assessments were counterbalanced and randomized across participants.

2.3.1. Creativity assessments

To assess creative thinking, participants performed the Alternative Uses Task (AUT). They had 2 min to generate unusual and uncommon uses for everyday objects (balloon, rope, lens, pen) (Guilford, 1967). Participants were asked to think creatively when completing the task. Three trained raters, who were blind to the condition, each rated two-thirds of the AUT responses on novelty (how "original" or "new" the response was), appropriateness (how "comprehensible", "understandable", and "accessible" the response was), and creativity (how "clever", "nonobvious", and "useful" the response was) on a scale from 1 to 5. To ensure reliability and consistency, the raters underwent comprehensive training before beginning their evaluations. As part of this training, they reviewed a large set of example responses from pilot data and other studies to develop a shared understanding of what constitutes novelty, creativity, and appropriateness. The two scores for each of these components were then averaged. There was strong interrater reliability for appropriateness (kappa = 0.9165, $p < .001$), novelty (kappa = 0.8539, $p < .001$), and creativity (kappa = 0.7262, $p < .001$). Fluency was scored as the number of responses per participant. Flexibility was scored as the number of unique categories a participant's responses fell into. A single trained rater categorized each response based on predefined category criteria, and the total number of unique categories was summed for each participant. In addition to AUT generation, participants evaluated the creativity of example AUT responses, where they were shown example responses for the same prompt words (e.g., balloon, rope, lens, pen) and were asked to evaluate the creativity of the examples and choose the response they believed to be the most creative. These example responses were pre-determined by the experimenters, who identified one response per object as the most creative. The evaluation score for each participant was calculated as the number of times they selected the experimenter-designated most creative response. An overall AUT score was calculated by averaging each subtest of participants' AUT responses: fluency, flexibility, novelty, appropriateness, and creativity.

Other measures of divergent thinking included Forward Flow and the Divergent Association Task (DAT). Forward Flow (K. Gray et al., 2019) measures the creativity of natural thought. Participants were asked to write the first word that comes to mind from the previous word, starting with a prompt word (e.g., "candle"). They continued until they provided 10 words. Each score, calculated online (http://forwardflow.org/), was the average semantic distance between consecutive words in the chain, with greater semantic distance indicating a higher ability of divergent and flexible associate thinking. The final Forward Flow score was computed as the mean of three-word chains, and internal consistency was moderate (Cronbach's $\alpha = 0.63$), in line with the internal consistency found in other studies using Forward Flow (Beaty et al., 2021).

For the DAT (Olson et al., 2021), participants were asked to name 10 nouns as different from each other as possible. DAT was scored online (https://www.datcreativity.com/) based on the average semantic distance between the 10 words, with higher scores reflecting the ability to produce semantically unrelated, original, and conceptually distinct ideas, essential elements of divergent thinking. There were no time constraints for Forward Flow or the Divergent Association Task.

Participants also performed the Remote Associates Test (RAT), a widely used test of convergent thinking (Mednick, 1962). They saw three words (e.g., "pine", "sauce", "crab") and had to name a fourth word that connected with each of the three words (e.g., "apple") within 15 s per trial. RAT scores were the number of correct responses, with higher scores indicating a stronger ability to converge on a single, correct solution and demonstrate insight-based problem solving. A higher RAT score indicates stronger convergent thinking because it reflects an individual's ability to find the single correct solution by connecting seemingly unrelated concepts in a meaningful way.

After scoring individual creativity assessments, we combined tasks into composite scores for convergent and divergent thinking. While each task captures specific aspects of creativity, the composite scores allow us to measure the broader constructs of divergent and convergent thinking. To standardize scores across different scales, we applied a normalization function in R: ((x - x_min)/(x_max - x_min)).

Convergent thinking involves evaluating, refining, and selecting ideas that are both creative and practical (Cropley, 2006). It's essential to the creative process, helping to ensure that the best ideas are not only original but also feasible and appropriate (Runco, 2003). Measures such as the RAT, AUT appropriateness ratings, and evaluation scores capture different facets of convergent thinking, from identifying correct solutions to selecting the most creative responses (Cropley, 2006). In contrast, divergent thinking is the ability to generate a wide range of novel ideas across different categories in response to open-ended problems (Cropley, 2006). It involves making connections between seemingly unrelated concepts and reshaping information in new and unexpected ways. To assess divergent thinking, we included measures of AUT fluency, AUT flexibility, AUT novelty, Forward Flow, and the Divergent Association Task (DAT), each capturing different aspects of generating varied, category-spanning, and conceptually distant ideas. While each task captures specific aspects of creativity, the composite scores allow us to measure the broader constructs of divergent and convergent thinking.

2.3.2. *Executive function assessments*

To assess working memory, participants completed the Corsi Backward Block Test. This task assesses working memory by having participants report the location of boxes on a screen in reverse order (Kessels et al., 2000). We calculated the working memory capacity score as the highest number of boxes participants reported accurately.

Selective attention was measured using the Posner cueing task (Chun, 2000). Participants respond to a target location as quickly and accurately as possible. Each trial included a directional cue preceding the target, valid in 75 % of trials and invalid (in the opposite direction) in 25 %. Inverse efficiency scoring (IES) (Bruyer & Brysbaert, 2011) was used to integrate speed and accuracy by dividing reaction time (RT) by the proportion of correct responses. The cueing effect, which reflects attentional control, was calculated as the difference between the log-transformed IES for invalid and valid trials (ln(IES_invalid) – ln (IES_valid)) (Butler & Grubb, 2020). A score closer to 0 indicates similar performance across cue types, while a negative log-IES difference reflects greater distraction by invalid cues. The Posner and Corsi tasks were administered in PsyToolkit (Stoet, 2017) which is freely available at: http://psytoolkit.org/.

Delay discounting, the depreciation of a reward in relation to the time of receipt, was assessed using the 27-Item Monetary Choice Questionnaire (Kaplan et al., 2016) measuring the rate of discounting (k), where a larger k means a steeper discounting curve. This measure has been used to assess impulsivity/self-control (Mahalingam et al., 2014). Past literature suggests that exposure to nature may influence people's willingness to wait a longer period for greater reward (Berry et al., 2014; van der Walet al., 2013).

2.3.3. *Affective state*

Halfway through the tasks, participants completed the PANAS (Watson et al., 1988) to report their emotional state at the present moment. The PANAS is a widely used self-report measure of affect, consisting of two subscales: Positive Affect (PA) and Negative Affect (NA), each with 10 items rated on a 5-point Likert scale (1 = very slightly, 5 = extremely). PA reflects the extent to which a person feels enthusiastic, active, and alert, while NA reflects subjective distress and unpleasurable engagement. The PANAS assesses mood across various contexts and has demonstrated strong internal consistency (PA: $\alpha = .86–0.90$; NA: $\alpha = .84–0.87$) and construct validity, showing stable relationships with other affective and psychological well-being measures (Watson et al., 1988). In the present study, internal consistency was excellent for PA ($\alpha = .91$) and good for NA ($\alpha = .82$), aligning with prior research (Watson et al., 1988). Administering the PANAS midway allowed us to assess participants' affective states during, rather than before or after, the task completion process, capturing a snapshot of their emotional experience influenced by the experimental environment. This timing was chosen to allow participants time to experience the environment, while still avoiding post-task relief or fatigue. Average scores for PA and NA were calculated.

2.3.4. *Aesthetic experience*

After completing the creativity and cognitive assessments, participants evaluated 16 aesthetic qualities of the space in relation to coherence (analytic judgments about the organization), fascination (visual richness or interest), and hominess (feelings of comfort or coziness) used previously by our research group to investigate aesthetic responses to the built and natural environment (Chatterjee et al., 2021; Coburn et al., 2020; Vartanian et al., 2021; Weinberger et al., 2021). We calculated coherence by summing ratings including beauty and order (Cronbach's $\alpha = 0.76$), hominess from ratings such as personalness and hominess (Cronbach's $\alpha = 0.87$), and fascination from ratings like complexity and interest (Cronbach's $\alpha = 0.71$). The ratings were scored in a 7- point Likert scale, for example 'How organized or disordered does the space look to you?' with scores from 1 (too disordered) to 7 (very organized). The order of the aesthetic quality questions was randomized for each participant.

2.3.5. *Recall of room features*

Finally, participants left their assigned space and were asked to recall whether certain elements (for example: moss wall, desk, small plant) were present in the environment they were just in. Then, participants rated how much they liked each element they reported seeing in the room in a 5-point Likert scale (1-strongly dislike to 5-strongly like). Some features were real, some were fake (for example 'lavender scent' when there was no added scent). The participants in the control and the biophilic room had the same features to choose from. The participants in the natural environment had a different version adapted to the surrounding space. We added these questions to identify potential patterns of people's aesthetic preferences in the natural elements.

At the end of the study, participants completed the Desire for Aesthetics scale to assess individual differences in the motivation to seek beauty, which could influence aesthetic appreciation of nature and built environments (Lundy et al., 2010). The scale includes 10 items rated on a 7-point Likert scale (1 = strongly disagree to 7 = strongly agree) and had acceptable internal consistency (Cronbach's α = 0.69). Example items include: "When I see beautiful things in daily life, I rarely feel passionate about them" and "I care a great deal about beauty in many areas of everyday life. Measuring this trait would allow us to control for it as a potential confound in case of group differences. However, as it was not significant, we did not include it in our final models. Participants also completed a brief demographic survey.

3. Data analysis

We used R version 4.4.0 and R studio version 2023.06.01 to process, analyze, and visualize data. We ran linear models to compare ratings and scores between environments using the lm function in R. The linear model was: model < - lm (score ∼ environment). For post hoc comparisons between environments, we ran Tukey post hoc tests using the TukeyHSD function. We calculated Cohen's d for the effect size of the linear model.

For PA and NA, we ran Shapiro tests for normality using the shapiro.test function. Because NA was not normally distributed, we ran Wilcoxon signed rank tests for changes in PANAS results before and while in the environment. For effect size, we calculated the r by z-transforming the V statistic and dividing it by the square root of n. For NA between environments, instead of lm, we ran the Kruskal-Wallis chi-squared test using the kruskal.test function. For example, the model for NA during the environment stay was: kruskal_test < - kruskall.test (PANAS_neg ∼ environment). For the effect size of Kruskall- Wallis, we calculated the eta squared.

The Posner attentional cueing task and the delay discounting task had one outlier each whose data was removed following the outlierTest function of R and influencePlot function to visualize the most influential data points. The reported results exclude these outliers.

For data visualization, we used ggplot2 (Wickham, 2016) and ggpubr (Kassambara, 2023).

3.1. Exploratory analysis

We explored potential relationships between PA and NA, divergent thinking, and aesthetic ratings. The first analysis focused on the effect of PANAS on aesthetic dimensions. We used the lm function for linear models (model: PANAS score ∼ aesthetic dimension * environment) and the emmeans package (Lenth et al., 2024) for post hoc comparisons.

The second analysis focused on the aesthetic dimensions mediating the effect of the environment on divergent thinking. We used the mediation package (Tingley et al., 2019). Because the mediation analysis in R can have only one control condition and one treatment condition, we ran three mediation analyses to compare the pairs (pair 1: control vs biophilic, pair 2: control vs nature, pair 3: biophilic vs nature). We also planned to explore a potential mediation of attention or working memory on the effect of the environment on divergent thinking, but because of statistically non-significant results as reported in the following section, we did not run this exploratory analysis.

The third analysis focused on PA and NA mediating the effect of the environment on divergent thinking using the same package as the second analysis.

4. Results

4.1. Aesthetic experience

The model predicting desire for aesthetics showed there were no significant differences between groups (F(2,145) = 0.202, p = .8, R^2 = 0.00279). Therefore, desire for aesthetics was not included as a control variable modeling aesthetic experience.

The analyses revealed significant differences in aesthetic experience ratings across the different environments. The linear model assessing the effect of environment on coherence was statistically significant (F(2,145) = 83.86, p < .001, R^2 = 0.536). The natural environment had higher coherence than the control room but lower coherence than the biophilic room. The biophilic room was more coherent than the control room. For fascination, the linear model was statistically significant (F(2,145) = 122.9, p < .001, R^2 = 0.630). The natural environment was more fascinating than the control room and the biophilic room. The biophilic room was more fascinating than the control room. The model predicting hominess of the environment was also statistically significant (F(2,145) = 131.8, p < .001, R^2 = 0.645). The natural environment was more homey than the control room and the biophilic room. The biophilic room was also more homey than the control room (see Fig. 2 for aesthetic ratings and Table 2 for detailed results). All comparisons between the natural environment or biophilic room and the control room showed very large effect sizes (d > 2.2 for all comparisons).

4.2. Creativity assessments

Analyses revealed significant differences in divergent thinking performance across environments. The linear model assessing the effect of environment on the divergent thinking composite score was statistically significant (F(2, 145) = 7.453, p < .001, R^2 = 0.093) (Fig. 3). Participants in the natural environment outperformed those in both the control room (d = 0.76) and the biophilic room (d = 0.59). There was no significant difference between participants in the control and biophilic rooms.

To further understand the differences in divergent thinking, we ran linear models for each subtest of divergent thinking: DAT, Forward Flow, AUT fluency, AUT novelty, and AUT flexibility. For the DAT, the model was significant (F(2, 144) = 5.061, p = .007, R^2 = 0.066), with participants in the natural environment having significantly higher semantic distance scores than those in the biophilic room.

For novelty in the AUT responses, the linear model revealed a significant difference between conditions (F(2, 145) = 6.384, p = .002, R^2 = 0.081). Participants in the natural environment scored higher in novelty than those in both the control room and the biophilic room. The model predicting the flexibility score of the AUT approached significance (F(2, 145) = 3.031, p = .051, R^2 = 0.040). However, post hoc analyses revealed participants in the natural environment had significantly higher flexibility scores (i.e. generated more ideas in unique categories) than the participants in the control room. For the overall AUT score (which averaged fluency, flexibility, novelty, appropriateness, and creativity), there was a significant difference across environments (F(2, 145) = 5.829, p = .003, R^2 = 0.074). Participants in the nature condition had higher overall AUT scores than those in both the control room and the biophilic room.

The model examining the convergent thinking composite score showed no significant difference between conditions (F(2, 145) = 1.788, p = .171, R^2 = 0.028).

4.3. Executive function assessments

The models for the executive function tasks were not significant. The working memory model (F(2,143) = 2.969, p = .055, R^2 = 0.040), the model examining attentional cueing effects in the Posner task (F(2,144) = 0.956, p = .39, R^2 = 0.013), and the model assessing delay discounting (F(2,144) = 1.031, p = .36, R^2 = 0.014) did not reach significance. More details on the results are provided in Table 2.

4.4. Affective state

We ran Wilcoxon signed rank tests to compare participants' PA and NA before and during their stay in the space. Participants in the control room had significantly lower NA while in the room compared to baseline (V = 736.5, p = .005, small effect size, r = 0.117) and no significant difference in PA (p > .5). Similarly, participants in the biophilic room had a significant reduction in NA (V = 553.5, p = .022, small effect size,

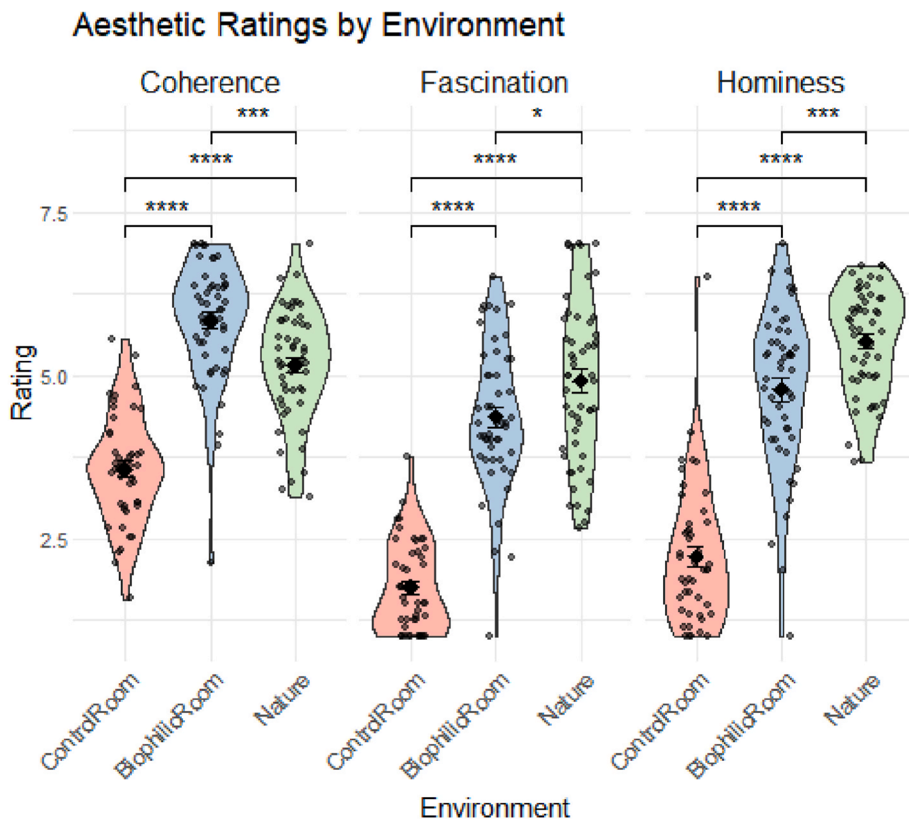

Fig. 2. Aesthetic ratings on Coherence, Fascination, and Hominess for the three environments
Note: Aesthetic ratings on coherence, fascination, and hominess between the control room, biophilic room, and natural environment.

r = 0.116) and no significant difference in PA ($p > .5$). Participants in the natural environment had no significant differences in their PA and NA ($p > .5$).

We compared PA between environments (both before and while in the space) with linear models and NA with the Kruskal-Wallis chi-squared tests. No comparison was statistically significant (all p = .09). We also calculated the change in PA and NA before and while in the space. The PA change ~ environment and the NA change ~ environment Kruskal- Wallis chi-squared tests were not statistically significant (p = .64 and p = .14).

4.5. *Features of the environment*

After completing the creativity and cognitive assessments, participants completed a questionnaire about the features they remembered from the space they were in and how much they liked those features. In the control room, all participants noticed the computer and 50 % noticed the wooden desk. In the biophilic room, 80 % or more of the participants noticed the moss wall, the small plants, the wooden desk, the computer, the bamboo ceiling, the patterned rug, the standing lamp, and the large plant. Only 37 % of participants noticed the wallpaper. 47 % of participants responded they were unsure if there was a lavender scent. From the 80 % or more of participants who noticed the features above, more than 60 % liked the moss wall, the small and large plants, the patterned rug, the bamboo ceiling, and the floor lamp.

In the natural environment, 70 % or more of the participants noticed large trees, small rocks, leaves on the ground and small trees, the computer, the sun, other humans around, small plants, and the sound of birds chirping. 50 % or more of the participants noticed forest smell, leaves on trees, birds, clouds, moss, large plants and rocks, and grass. Of the participants who noticed the features above, 60 % or more liked the sun, large trees and plants, small trees, seeing and hearing birds, squirrels, flowers, leaves on the trees and the forest smell. Only a few participants noticed trash and insects or bugs and they disliked them. In a few sessions, deer passed close to the testing location and participants reported enjoying it. Participants were split about the presence of other humans.

4.6. *Exploratory analysis*

The first exploratory analysis focused on the effect of PA and NA on the aesthetic dimensions. All models for PA on aesthetic dimensions (PA ~ coherence or fascination or hominess * environment) were statistically significant (for coherence $p < .001$, for fascination p = .025, for hominess p = .001) but there were no significant post hoc comparisons. The models for NA on coherence and hominess (NA ~ coherence or hominess * environment) were not statistically significant (p = .5 and p = .25). The model for NA and fascination was trending (p = .06).

The exploratory analyses for the aesthetic dimensions and PA or NA mediating divergent thinking using the mediation R package were not statistically significant, therefore the natural environment increases divergent thinking irrespective of mood and aesthetic ratings.

There were no significant direct effects of condition on executive functioning measures, so we did not run the planned mediation analyses to investigate if attention or working memory explain the effects on creativity.

5. Discussion

The current study investigates how environmental conditions impact aesthetic experience, creativity, executive functioning, and mood. While biophilic design is gaining popularity as a way to enhance cognitive functioning and well-being, there is limited empirical evidence on its effectiveness compared to direct nature exposure. Furthermore, the impact of nature and biophilic spaces on creative thinking is underexplored. This study aims to fill these gaps by testing the hypothesis that

Table 2
Results for each group.

Measure	Group	Mean (SD)	Linear Model Results	Tukey post hoc comparisons
Aesthetic Experience				
- **Coherence**	Control	3.56 (0.84)	F = 83.86 p < .001 R^2 = 0.536	Biophilic > control, p < .001, 95 % CI: 1.85–2.70, d = 2.80
	Biophilic	5.84 (0.92)		Biophilic > nature, p < .001, 95 % CI: −1.10 to −0.279, d = −0.764
	Nature	5.15 (0.86)		Nature > control, p < .001, 95 % CI: 1.17–2.014, d = 2.86
-**Fascination**	Control	1.75 (0.69)	F = 122.9 p < .001 R^2 = 0.630	Biophilic > control, p < .001, 95 % CI: 2.10–3.12, d = 2.80
	Biophilic	4.36 (0.1.11)		Nature > biophilic, p = .023, 95 % CI: 0.061–1.05, d = 0.470
	Nature	4.91 (1.25)		Nature > control, p < .001, 95 % CI: 2.66–3.67, d = 3.08
-**Hominess**	Control	2.23 (1.1)	F = 131.8, p < .001, R^2 = 0.645)	Nature > control, p < .001, 95 % CI: 2.80–3.80, d = 3.53
	Biophilic	4.78 (1.23)		Biophilic > control, p < .001, 95 % CI: 2.05–3.06, d = 2.21
	Nature	5.53 (0.8)		Nature > biophilic, p < .001, 95 % CI: 0.260–1.24, d = 0.723
Divergent Thinking Composite	Control	0.46 (0.09)	F = 7.453 p = .001 R^2 = 0.093	Nature > control, p = .001, 95 % CI: 0.019-0.101, d = 0.76
	Biophilic	0.47 (0.1)		Nature > biophilic, p = .006, 95 % CI: 0.012-0.092, d = 0.59
	Nature	0.49 (0.09)		
-**DAT**	Control	80.27 (6.26)	F = 5.061 p = .007 R^2 = 0.066	
	Biophilic	78.66 (6.49)		Nature > biophilic, p = .005, 95 % CI: 0.025-0.173, d = 0.297
	Nature	82.48 (5.4)		
-Forward Flow	Control	0.76 (0.04)	F = 1.077 p = .34 R^2 = 0.015	
	Biophilic	0.77 (0.06)		
	Nature	0.76 (0.06)		
-**AUT Novelty**	Control	2.76 (0.43)	F = 6.384 p = .002 R^2 = 0.081	Nature > control, p = .049, 95 % CI: 0-0.173, d = 0.457
	Biophilic	2.78 (0.42)		Nature > biophilic, p = .002, 95 % CI: 0.039-0.208, d = 0.698
	Nature	3.1 (0.6)		
-AUT Flexibility	Control	10.52 (2.85)	F = 3.031 p = .051 R^2 = 0.040	Nature > control, p = .044, 95 % CI: 0.002-0.167, d = 0.519
	Biophilic	11.08 (3.42)		
	Nature	12.04 (2.98)		
-AUT Fluency	Control	24.68 (10.73)	F = 2.793 p = .064 R^2 = 0.037	Nature > control, p = .057, 95 % CI: −0.002-0.17, d = 0.505
	Biophilic	28.64 (13.42)		
	Nature	30.23 (11.24)		
AUT Creativity	Control	2.8 (0.4)	F = 2.397 p = .095 R^2 = 0.032	
	Biophilic	2.76 (0.48)		
	Nature	2.88 (0.38)		
Overall AUT	Control	0.44 (0.1)	F = 5.829 p = .003 R^2 = 0.074	Nature > control, p = .019, 95 % CI: 0.006-0.081, d = 0.539
	Biophilic	0.45 (0.1)		Nature > biophilic, p = .006, 95 % CI: 0.011-0.085, d = 0.594
	Nature	0.48 (0.1)		
Convergent Thinking (RAT, AUT appr., AUT selection)	Control	0.83 (0.57)	F = 1.788 p = .171 R^2 = 0.028	
	Biophilic	0.6 (0.6)		
	Nature	0.69 (0.65)		
Working Memory (Corsi)	Control	4.17 (2.59)	F = 2.969 p = .055 R^2 = 0.0400	
	Biophilic	5.16 (1.72)		
	Nature	5.08 (2.19)		
Attentional cueing (Posner)	Control	123.05 (100.66)	F = 0.9557 p = .39 R^2 = 0.013	
	Biophilic	111.1 (83.02)		
	Nature	96.38 (101.17)		
Delay discounting	Control	0.02 (0.02)	F = 1.031 p = .36 R^2 = 0.014	
	Biophilic	0.02 (0.04)		
	Nature	0.01 (0.02)		
Affective State				
-Pre-Positive Affect	Control	27.5 (11–42)		
	Biophilic	25 (11–45)		
	Nature	28.5 (15–47)		
-Positive Affect	Control	26 (12–47)		
	Biophilic	25.5 (10–48)		
	Nature	28.5 (15–47)		
-Pre-Negative Affect	Control	15.5 (10–38)		Pre-Negative Affect < Negative Affect, V = 736.5, p = .005, r = 0.117
	Biophilic	14 (10–30)		Pre-Negative Affect < Negative Affect, V = 553.5, p = .022, r = 0.116
	Nature	13 (10–32)		
-Negative Affect	Control	14 (10–28)		Pre-Negative Affect < Negative Affect,

(continued on next page)

Table 2 (*continued*)

Measure	Group	Mean (SD)	Linear Model Results	Tukey post hoc comparisons
	Biophilic	13 (10–31)		V = 736.5, p = .005, r = 0.117 Pre-Negative Affect < Negative Affect, V = 553.5, p = .022, r = 0.116
	Nature	13 (10–32)		

Note: Aesthetic appreciation, creativity and cognitive assessments, and affective state results for each group. Significant effects are in bold followed by the significant group interactions. Standardized values are shown for the composite divergent thinking score, composite convergent thinking score, and overall AUT score. Median and (minimum-maximum) values are shown for Affective State instead of Mean (SD).

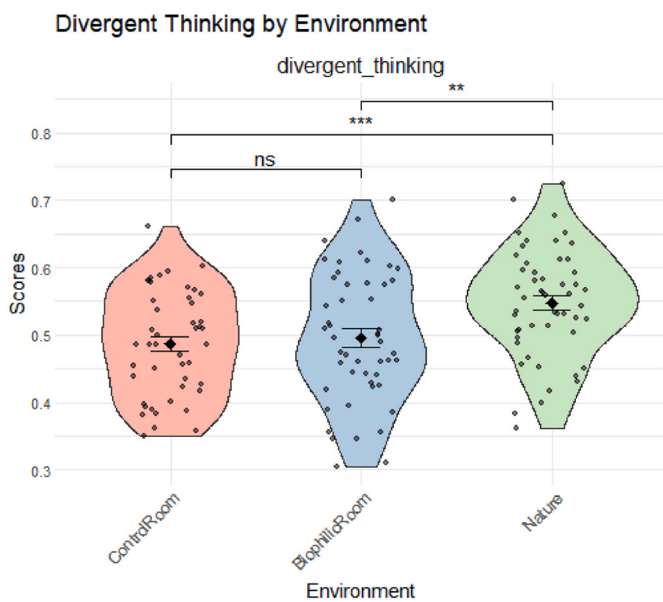

Fig. 3. Divergent thinking in the three environments
Note: Divergent thinking scores for the control room, biophilic room, and natural environment.

exposure to nature and natural elements enhances aesthetic experiences, creativity, and cognition, and improves mood. We tested our hypothesis in three distinct environments: a natural forest, a biophilic-designed room, and a typical laboratory testing room.

Aesthetic experience was indexed by the constructs of coherence, fascination, and hominess. Overall, the natural and biophilic environments evoked similar aesthetic responses, both surpassing the control room. The natural environment was rated highest in fascination, followed by the biophilic room, with the control room lowest. For hominess, the natural environment also ranked highest, with the biophilic room rated higher than the control room. In contrast, coherence was rated highest in the biophilic room, followed by the natural environment, with the control room rated lowest. The results for aesthetic experience are consistent with the literature and the definitions of coherence, fascination and hominess (Coburn et al., 2020) providing evidence from real world spaces for the first time with very large effect sizes. The natural environment had more informational richness than the two indoor spaces, and the biophilic room had more than the control room. The biophilic room elicited a higher sense of coherence and order. We would not expect a natural environment to be 'orderly' as an office space, and the control room was potentially too bare to create a sense of coherence. The hominess rating being highest for nature seemed more perplexing. However, the indoor spaces were experimental testing rooms with no personalized touch that participants might have seen for the first time. The outdoor environment was close to a university building in an area potentially familiar to the participants. The pre-existing familiarity with the location or the type of environment might explain the highest rating for nature followed by the biophilic room. Together, these results suggest that natural environments produce feelings of coherence, fascination, and hominess and that biophilic elements in built spaces evoke these same feelings, albeit to a lesser extent than the natural environment.

The analysis of participants' affective states across different environments revealed some differences in the emotional impact of different environments. Participants in the control room and the biophilic room had reduced negative affect. Surprisingly, the natural environment did not change either PA or NA, which contradicts previous findings (Berto, 2014; Ulrich et al., 1991). This suggests that merely being in a natural setting may not be sufficient to reduce negative affect within the timeframe of the experiment. One potential explanation for this finding is that participants were engaged in tasks throughout the experiment and were not specifically instructed to focus on or absorb their environment. As a result, the hypothesized cognitive benefits associated with nature exposure may not have been realized. The lack of instruction to engage with the environment or the relatively short exposure period in this study may have prevented nature's mood-improving effects from manifesting. Additionally, there were no significant differences in affective changes between environments, indicating that while individual rooms influenced mood, there was no overall impact across conditions. This may reflect individual variability in responses to different spaces or the need for a longer exposure period to detect nature's mood-improving effects.

The creativity assessments revealed that the natural environment enhanced components of performance compared to the other settings. Specifically, people in nature were better at divergent thinking (composite score) compared to the control and biophilic group, had higher AUT novelty scores than both other groups, higher DAT scores than the biophilic group, and higher AUT flexibility than the control group. In addition, participants in the nature condition had higher overall AUT scores compared to those in both the control group and the biophilic group. These results suggest that elements of nature benefit divergent thinking. We did not see a similar effect in the biophilic room compared to control. We do not know if it is unrealistic to expect such effects during a short stay in an interior, or if our design itself needed to better incorporate and simulate natural elements. The lack of effects on convergent thinking across environments suggests that while divergent thinking benefits from nature exposure, convergent thinking might not be influenced by natural stimuli.

These results highlight the specific components of creativity that being in nature may enhance. Being in nature can improve divergent thinking or help people when needing to generate novel solutions to open-ended problems but might not be the ideal setting to hone in on the best final responses. These results align with qualitative research that finds that some creative professionals go to nature as an essential part of their process of generating new, different ideas and thinking more flexibly. In contrast, they synthesize and analyze the results of their generative process most often at home or in a workspace (Plambech & Konijnendijk van den Bosch, 2015). Similarly, creative professionals find that being in nature helps during the Preparation and Incubation phases of the creative process and less so with the Idea and Evaluation phases (Plambech & Konijnendijk van den Bosch, 2015). Furthermore, the improvement in divergent thinking performance may be explained by mind-wandering, which might be a potential mechanism for how nature enhances creativity (Williams et al., 2018). The ART suggests that in unthreatening natural environments, the mind effortlessly wanders (Kaplan & Kaplan, 1989), and mind-wandering has been linked to better divergent thinking (Baird et al., 2012; Mooneyham & Schooler, 2013;

Yamaoka & Yukawa, 2016). Another possible mechanism for why our natural environment facilitated divergent thinking while the biophilic room did not could relate to the openness of the physical space. Prior research indicates that spatial openness can shape cognitive processing, with larger, open spaces priming notions of freedom and encouraging more expansive thought, while confined environments may induce a sense of restriction (Ichimura, 2023; Meyers-Levy & Zhu, 2007). For example, variations in ceiling height have been shown to influence cognitive style, with higher ceilings promoting relational and abstract thinking, whereas lower ceilings encourage discrete and concrete processing (Meyers-Levy & Zhu, 2007). Similarly, open landscapes have been linked to greater environmental preference and perceived safety, suggesting that openness may play a fundamental role in supporting creativity by reducing cognitive constraints and fostering a broader sense of possibility (Franěk, 2023; Appleton, 1975). Lastly, exposure to natural stimuli can increase neural activity in the default mode network (DMN) (Hunter et al., 2010) and increase functional connectivity between the DMN and attention networks (Kühn et al., 2021), neural activity that both have been associated with divergent creative thinking (Beaty et al., 2015; Maillet et al., 2019; Marron et al., 2018). In practice, the results from the current study and related literature suggest that spending time in nature would be helpful for brainstorming and generating new, different ideas, but selecting the best idea and moving forward with that idea may be better suited to an interior working environment.

The results of this study contribute to the ongoing debate regarding the effects of natural environments on attention and executive functioning. While prior studies have reported improvements in these domains following exposure to natural stimuli (Berry et al., 2014; Kaplan & Kaplan, 1989; Schertz & Berman, 2019), our findings did not show significant effects. This discrepancy aligns with broader inconsistencies in the literature. For instance, a meta-analysis found overall cognitive benefits of nature exposure but also highlighted several studies with null results (Nguyen & Walters, 2024). In particular, results seem to be mixed when cognitive performance is assessed during exposure rather than after (Mancuso et al., 2006; Mygind et al., 2018). One possible explanation is that attentional restoration, as suggested by ART, requires time to emerge and may not be fully realized when cognitive tasks are administered mid-exposure. Alternatively, the immersive nature of the natural environment may have introduced distractions that interfered with executive functioning rather than enhancing it. These mixed findings underscore the need for further research to clarify whether the benefits of nature for executive function are immediate or require a recovery period. Future studies should also consider individual differences (Mcfarland et al., 2008, van den Berg et al., 2010), baseline cognitive load, and task demands to better determine when and how nature exposure supports cognitive performance.

Although the present study shows that natural environments can enhance divergent thinking and aesthetic experiences of coherence, fascination, and hominess, these aesthetic experiences did not mediate the effect of nature on divergent thinking. Furthermore, the effect of nature on divergent creative thinking could not be explained by improvements in executive functioning or changes in affect. Thus, the results do not clearly support the ART or SRT. Physical elements of the outdoor natural environment that were absent in the biophilic room may have influenced cognition, either directly or through alternative mechanisms. The results regarding the specific features of the environment that participants noticed suggest that people like and remember natural elements such as plants, natural sounds, and smells. While we did not have hypotheses for which specific features may affect aesthetic experience, mood, or cognition, this information is valuable for the decision-making process of researchers and designers on how to design a beautiful nature-inspired space.

This study contributes to the growing literature on biophilia and biophilic design by empirically examining how natural environments and biophilic indoor settings affect creativity, executive functioning, mood, and aesthetic perceptions. Understanding these effects is essential for both preserving natural spaces and designing environments that support human well-being, particularly as urbanization increases and access to nature declines. While our findings do not offer direct guidance for designers on integrating natural features into built spaces, they underscore the unique role of natural environments in fostering divergent thinking. Since divergent thinking is essential for problem-solving and innovation, increasing access to outdoor natural spaces in schools, workplaces, and public areas could enhance creativity. At the same time, both natural and biophilic environments improved aesthetic experiences by increasing perceptions of coherence, fascination, and hominess. While biophilic design may not fully replicate the cognitive benefits of direct nature exposure, it appears to foster more emotionally engaging and aesthetically appealing spaces compared to traditional built environments. These findings suggest that biophilic design could be particularly valuable for improving emotional well-being, while direct nature exposure may be more effective for enhancing elements of creative thinking.

5.1. Strengths, limitations, and future studies

Unlike many previous studies that investigate the effects of natural and biophilic environments by using simulations of natural stimuli (e.g., photos, videos, virtual reality) (Li et al., 2021; Mostajeran et al., 2021; Ohly et al., 2016; Stevenson et al., 2018; Ulrich, 1981), our participants were tested in real natural and biophilic spaces. This ecologically relevant framework has both strengths and limitations. By testing in a real natural environment, we could fully capture the effects of being immersed in the multisensory experience of these spaces (i.e., visual, auditory, olfactory stimuli). Additionally, our study directly compared natural and biophilic environments, allowing for a more nuanced understanding of how built environments with natural elements compare to actual nature exposure. However, conducting an experiment in a real natural forest also makes controlling stimuli difficult, and thus participants within the same condition may have had differing sensory experiences. As our study was one of the first to investigate creativity and aesthetic experience in real spaces and 'in the wild,' it was not pre-registered. Future studies could pre-register their hypotheses to increase transparency. Although we took steps to minimize potential confounds, such as using standardized inclusion criteria and matching demographic characteristics across conditions, a potential limitation of the study is that participants in the nature condition were recruited from a different site. In addition, while the walking distance was minimal and comparable to typical campus routes in the nature condition, the potential physical activity differences could have introduced some variability. Another potential limitation of the current study is participants were only exposed to environments for a short duration. The lack of changes in mood and executive functioning may have resulted from the short exposure time. Future studies could explore how different exposure lengths to natural and biophilic environments may impact cognition and affect differently. Studies could also explore how the effects of the environments differ if participants completed their tasks after exposure. For example, is attention more fully restored *after* exposure to nature rather than *during* exposure? Having participants complete creative problems after exposure may help to confirm which phases of the creative process natural environments can better enhance. Additionally, future studies could incorporate measurements pre- and post-exposure. In our study we tested participants during their exposure to their assigned environment. Pre- and post-design allows for direct comparisons within individuals controlling for baseline differences and could help isolate the impact of the exposure. Our study did not examine how noticing specific natural features relates to experience or cognitive performance, but future research could explore which features contribute to these effects. In addition, future studies could incorporate a broader range of biophilic design elements, including multisensory elements such as auditory and olfactory, to further explore how biophilic spaces can be designed to more closely mimic nature's cognitive effects, particularly in fostering expansive, flexible thinking. Future studies could also hone more into the role of coherence, fascination and hominess in aesthetic experience. For example, different natural and biophilic spaces can be used by participants with variable levels of exposure to these spaces to understand better how people feel about familiar and not familiar spaces. Investigating the neural correlates of aesthetic experiences in these environments could also provide deeper insights into the mechanisms driving the observed benefits. Mobile neuroimaging techniques such as EEG and fNIRS could provide valuable insight.

5.2. Conclusion

This study provides insight into the effects of natural environments and biophilic design on aesthetic experience, creativity, executive functioning, and mood. The findings demonstrate that natural environments and biophilic designed spaces evoke similar aesthetic experiences. Nature can foster greater divergent thinking, a critical component of creativity. These results suggest that while biophilic elements may mimic some of the benefits of nature, our rendition of a biophilic room may not fully replicate the advantages, particularly for creativity. The lack of significant findings in executive functioning and decision-making tasks, coupled with the absence of clear mediators like mood or aesthetic experiences, indicates that the cognitive benefits of nature are complex and not entirely explained by existing theories like ART or SRT. While biophilic design holds promise for improving well-being, direct exposure to nature may have the biggest impact on fostering creativity.

CRediT authorship contribution statement

D. Holzman: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **V. Meletaki:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **I. Bobrow:** Writing – review & editing, Project administration, Investigation. **A. Weinberger:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **R.F. Jivraj:** Writing – review & editing, Investigation, Data curation. **A. Green:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **A. Chatterjee:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Data availability statement

The data and code for this study are openly available in OSF: https://osf.io/nv4f5/?view_only=e59444b92f764c579c978cf9d9a1ff38.

This study was not pre-registered.

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Declaration of interests

None.

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