Spring 6-9-2023

The Positive Impact of Exposure to Nature versus Urban-Environment Images on Cognitive Processing: Working Memory and Problem Solving

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The Positive Impact of Exposure to Nature versus Urban-Environment Images on Cognitive Processing: Working Memory and Problem Solving

A Thesis

Presented in

Fulfillment of the

Requirements for the Degree of

Master of Arts

By

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May, 2023

Department of Psychology

College of Science and Health

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Acknowledgments

I would like to thank my advisor, Dr. Kimberly Quinn, for her encouragement and support throughout this journey. Graduate school is hard, research is hard, but it's a little bit easier when you know you have an advisor like Dr. Quinn on your team. I would also like to thank my thesis reader, Dr. Joseph Mikels, for his support and understanding along the path towards the completion of this project. Additional support came from my family entire family, especially my Mom, Dad, and sister, Anya. Thank you for being my rocks throughout this. My boyfriend, Scott, also needs a huge shoutout, as his unconditional love and support has always been reliable. He has carried me through many hurdles in life, but especially graduate school and specifically this thesis. Lastly, my support system would not be the same without my fellow DePaul friends, otherwise known as the "cutie committee." Dev, Lora, and Gibby, thank you for getting me through this – a good thesis is a done thesis!

Biography

The author was born in Chicago, Illinois, on August 14, 1997. She graduated from Naperville North High School, in Naperville, Illinois, in 2015. She received her Bachelor of Science degree from the University of Illinois at Urbana-Champaign in 2019.

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Abstract

The benefit of natural environments, compared to urban environments, to cognitive resources such as working memory have been documented and replicated (e.g., Berman et al., 2012; Berman et al., 2008; Berto, 2005). However, existing data do not extend beyond lower-order cognitive resources to higher-order cognitive processes such as problem solving. The goal of this thesis was to address this gap. The experiment tested both the beneficial effect of nature on executive function and problem solving. Using a backward digit-span task to measure working memory, I hypothesized that participants would repeat a higher number of sequences correctly after versus before viewing nature images, but not urban-environment images. Using a grid-pattern task (Adams et al., 2021) to assess problem solving, I hypothesized that participants would be more likely to make subtractive changes after versus before viewing nature compared to urban-environment images. Results did not support the hypotheses. Participants performed significantly better on the grid task after image viewing, regardless of image type. Participants also liked nature images better than urban-environment images, but liking was not correlated with working-memory or problem-solving performance. I finish with a discussion in which I argue that the lack of significant effects for image type suggests future research should only be conducted outside of the lab, and with the speculation that the restorative effect of nature might be attributed more to affective rather than cognitive mechanisms.

Keywords: nature, urban environment, executive functioning, problem solving, directed attention

The Positive Impact of Exposure to Nature versus Urban-Environment Images on Cognitive Processing: Working Memory and Problem Solving

Currently, more than half of the global population lives in urban environments (Bratman et al., 2015), and over 70% of the world's population is expected to reside in urban areas by 2050 (Heilig, 2012). This urbanization is associated with exponentially declining opportunities for interacting with natural environments (Skár & Krogh, 2009; Turner et al., 2004), a troubling shift given that previous research has demonstrated that interactions with natural environments are associated with better physical (e.g., Gascon et al., 2016; Kardan et al., 2015; Halonen et al., 2014; Sallis et al., 2012) and psychological (e.g., Kardan et al., 2015; Mitchell & Popham, 2007; Ulrich, 1979) wellbeing. Increased urbanization may therefore come with missed opportunities for wellbeing restoration. The goal of the proposed research was to explore the impact of natural- versus urban-environment exposure on two cognitive mechanisms that support wellbeing: executive function and problem solving.

Nature and Wellbeing

There is growing evidence of both physical and psychological benefits to wellbeing after nature exposure. Some of this research comes from survey studies. Halonen et al. (2014), for example, studied overweight and obesity rates based on green and blue space distance within the Finnish Public Sector. They found that long and increasing distances to usable green and blue space was associated with a heightened risk of obesity. Another survey conducted by Toftager et al. (2011) found a pattern where participants who lived further (>1 km) from greenspace than those who lived closer (< 300m) utilized the spaces more frequently. Additionally, those who lived closer and therefore frequented greenspaces more often had lower odds of obesity and higher rates of physical activity.

Other research makes use of archival data to demonstrate the nature–wellbeing link. For example, in a study conducted using self-report data from the Ontario Health Study and both individual ('Street Tree General Data') and satellite imagery (tree-canopy polygon data from 'Forest and Land Cover') tree canopy data, Kardan and colleagues (2015) found a general positive association between physical and psychological health and the tree density of one's neighborhood. When socio-economic and demographic factors were controlled, people who lived in neighborhoods with higher tree density, compared to low tree-density neighborhoods, reported a better self-perception of their personal health as well as better physiological reports like fewer reports of cardio-metabolic health issues. This advantage was seen with as few as 10 more trees on one city block, with results becoming exponentially better as tree density increased. These results exemplify green space as an important and significant factor in evaluating health benefits derived from nature within our communities.

Reviews and meta-analysis also support the beneficial outcomes of nature. Sallis et al. (2012), for example, compiled a collection of studies for a nonsystematic review. Findings revealed a positive association between perceived accessibility to green space and physical activity, obesity, and cardiovascular health. A systematic review by Gascon et al. (2016) revealed a common trend among studies conducted in North America, Europe, and Oceania of a reduced risk of cardiovascular disease mortality in areas with higher accessibility to green space. Finally, a systematic review by Kondo et al. (2018) revealed patterns of negative associations between urban green space use and mortality and heart rate, and a positive association between green space exposure and attention, mood, and physical activity.

The described research is only a handful of the expanding literature examining the benefits of nature. While most of the research here explains the association between urban green space and physical and psychological wellbeing, some work touches on the connection between green space and cognitive functioning. Further empirical work supports this connection, explaining a positive association between the two.

Nature and Cognitive Functioning

One perspective on urbanization suggests that exposure to nature has salubrious effects such as restoring cognitive mechanisms in conjunction with wellbeing resources (Kaplan, 1995). Indirect evidence supports this theoretical framework, as Kaplan (1993) found patterns of greater satisfaction in the workplace and overall wellbeing for those who had a window with a view of nature in their work space. Additionally, neighborhood satisfaction has been shown to correlate positively with access to green spaces like community gardens as well as tree density, and places for walking in nature (Kaplan, 1985). In one of the first studies to provide direct evidence for an impact of environment type on cognitive processes, Berto (2005) tested whether exposure to nature versus urban-environment images would affect attention. In Experiment 1, participants were subjected to a mentally fatiguing task prior to viewing nature or urban-environment image stimuli. The fatiguing task was a sustained attention test, which required participants to respond when a nontarget digit appears on the screen, but not respond when a target digit does appear. Participants were randomly assigned to view blocks of restorative (nature) or nonrestorative (urban-environment) image stimuli after they were cognitively fatigued from the first sustained attention test, and then completed the sustained attention test again after viewing the images. The results demonstrated that participants improved on the sustained attention test after viewing restorative nature images, but not nonrestorative urban-environment images.

Berman et al. (2008) provided further support for nature's cognitive benefits by directly testing nature's effects on cognition using executive function measures. In two experiments, participants first completed measures of working memory (backward digit-span task), attention (attention network task; only in Experiment 2), and mood before walking through a natural or urban environment (Experiment 1) or viewing images of nature or urban environments (Experiment 2). Participants then completed the measures again after the manipulation. Results supported predictions that exposure to natural, compared to urban, environments would improve working memory: Participants scored significantly better on the backward digit-span task only after nature exposure in both conditions. Specifically, there was a Location × Time interaction in Experiment 1, and a main effect of viewing images of nature on working memory performance in Experiment 2. Lastly, there was an Image Type × Time interaction on the executive component of the attention network task in Experiment 2, further supporting the notion that natural environments are beneficial for executive function.

More recently, Bratman et al. (2015) also corroborated the idea that nature improves cognition. In a between-subjects experiment, participants were randomly assigned to either a nature or urban walk, which they took after first completing several measures of affect and cognition. The cognitive measures included the operation span task, change detection task, attention network task, and the backward digit-span task, employed to assess verbal and visuospatial working memory and executive attention. After the participants completed their assigned walk, they completed the measures again. The results were mixed, with improved performance on the measure of verbal working memory (operation span task), but not the other cognitive measures (change detection task, attention network task, and backward digit task). Nonetheless, the evidence does continue to support the general hypothesis that exposure to nature has beneficial cognitive effects.

Mixed findings also come from Bourrier et al. (2018). Participants completed a backward digit-span task and the Raven matrices task before and after viewing one of two videos (or not viewing a video at all). Participants were randomly assigned to a video condition (nature: Banff National Park; urban environment: Barcelona; control: no video). The analysis yielded a marginally significant Video × Time interaction. When the tasks were analyzed separately, there was significant improvement on the backward digit-span task after nature video exposure compared to the urban-environment and no-video conditions, but these effects were not seen for the Raven matrices task.

Some of the most compelling evidence comes from studies of cognitive improvement after nature exposure in patient populations, particularly populations with known executive or attentional deficits. Berman et al. (2012) recruited patients diagnosed with major depressive disorder, which is typically related to disadvantages of cognitive functioning such as working memory (Lyubomirsky et al., 2003). Participants first completed measures of mood and working memory (backward digit-span) and were then primed with a rumination task. They were then randomly assigned to a nature environment walk (Ann Arbor Arboretum) or an urban environment walk (downtown

Ann Arbor). Once they returned from their walks, they completed measures of mood and working memory for a second time. The results yielded a significant Time × Location interaction. Those in the nature-walk condition improved more on the measure of working memory than those in the urban-walk condition. Importantly, this effect was five times the effect found in healthy populations in Berman et al. (2008).

Taylor and Kuo (2008) also extended evidence for the cognitive benefits of nature to patient populations, specifically children with attention deficit hyperactivity disorder, a disorder associated with irregulated directed or voluntary attention. Individuals diagnosed with ADHD may be able to hold their attention for tasks that are interesting to them (involuntary attention) but less so for tasks that are uninteresting and require voluntary attention. Participants with ADHD were randomly assigned to a guided walk in one of three different locations: an urban park (the most nature-based environment), a downtown area, and a residential area. In each case, participants completed puzzles to fatigue attentional resources prior to completing their guided walk. Afterwards, they completed a backward digit-span working memory task, a Stroop color–word inhibition test, a test of processing speed, and an attentional vigilance task. Analyses reveal improvement on the backward digit-span task after walking through the urban park, but not after walking through the downtown and residential areas, again extending the cognitive benefits of nature to patient populations.

Given the compelling but sometimes mixed findings, systematic reviews and meta-analyses have been conducted to obtain an overall picture of the effects. Schertz and Berman (2019) reviewed the literature assessing nature's ability to improve cognitive performance, with a potential explanation for the nature benefit being the low-level features of natural environments. They reviewed low-level features of natural environments such as "nonstraight edges, less color saturation, and less variability in hues", compared to urban environments, and speculated that these features might contribute to the cognitive benefits of nature by allowing individuals to engage in self-regulatory thought such as spiritual contexts and one's overall life.

Stenfors et al. (2019) conducted a pooled data analysis of 12 studies conducted by them and their collaborators, each with a variety of Environment (nature, urban) × Time interactions. Overall, the significant Environment × Time interactions were a result of improvement on the backward digit-span task after nature (walks, videos, images) exposure, compared to urban-environment exposure. In fact, these interaction effects were more significant when backward digit-span practice effects were identified and removed from analyses. When this step was taken, performance on the backward digit-span task even sometimes declined after urban-environment exposure, suggesting urban environments as fatiguing. In contrast, nature exposure had an even greater effect on backward digit-span performance once practice effects were taken into account. Across studies, there was little relation to mood when it came to cognitive improvement after nature exposure suggesting an independent relationship between environment type and cognitive performance.

Critical Analysis

The foregoing review suggests a nature benefit (or urban-environment deficit) for wellbeing, and also for basic cognitive processes, suggesting that nature restores us at least in part through its cognitive effects. This idea is not new: James (1982) evaluated natural versus urban environments in terms of involuntary and voluntary attention. In

James's analysis, involuntary attention does not require effort and allows the individual to avoid fatigue and replenish directed attention, whereas voluntary attention requires effort and draws on directed attention. James argued that nature elicited resource-replenishing involuntary attention, but that urban environments elicited resource-depleting voluntary attention.

This basic argument was expanded and clarified via Kaplan's (1995) attention restoration theory. According to the theory, exposure to natural environments, compared to urban environments, provides cognitive benefits because nature environments elicit "soft fascination," an opportunity for reflection which allows cognitive mechanisms to replenish. In contrast, urban environments elicit "hard fascination," which requires attention and draws on cognitive resources, depleting them. Note that Kaplan substituted "soft" and "hard" fascination for "involuntary" and "voluntary" attention because James (1982) did not sufficiently address the role of fatigue or its implications for directed attention, which plays an important role in executive functioning. Directed attention is important for numerous mechanisms requiring voluntary control (attention) for daily functioning and appropriate behavior: selection (problem solving), inhibition and affect, perception, thought (reflection), action, and feeling (lack of directed attention leads to irritability; Cohen & Spacapan, 1978; Sherrod & Downs, 1974). Therefore, for appropriate and efficient human behavior and cognition, full directed attention capacities are imperative. As directed attention becomes fatigued, there is a correlated decline of appropriate behavior and efficient cognition as well.

Kaplan (1995) proposed that the restorative benefits of nature are special, and derive from four distinct qualities of the environment. To be restorative, the environment must allow an individual to “be away” from their everyday surroundings, be exposed to a place that is vast (the “extent”), align their behavior with actions which are “compatible” with their intrinsic goals, and have exposure to an environment with “softly fascinating” stimuli (Kaplan, 1995). These four factors combine to stimulate involuntary attention/soft fascination while one’s directed attention capacities replenish. Although other environments like museums or churches or activities like sleeping or reading might offer a chance for relaxation, attention restoration theory argues that they do not allow for reflection like exposure to nature does (Herzog et al., 1997; Kaplan & Berman, 2010).

In sum, attention restoration theory (Kaplan, 1995) is captured in two complementary points: Urban environments are cognitively taxing, and natural environments are inherently restorative. Urban environments require hard fascination—effortful top-down processing—and therefore depletes directed attention. As the resource of directed attention becomes fatigued, an individual is less able to perform efficiently both behaviorally and cognitively. Then, because natural environments require bottom-up processing, a non-effortful mechanism termed soft fascination, they allow for directed attention as a resource to replenish. In other words, experiencing natural environments as innately fascinating underpins reflection and restoration.

The literature reviewed in the previous section provides support for attention restoration theory in terms of the behavioral consequences of nature exposure: improved performance on a variety of cognitive tasks. Our own preliminary evidence provides perhaps more direct evidence of an impact on cognitive processing: In a reanalysis of event-related potential (ERP) data from an experiment originally designed to compare several positive emotions, we investigated differences in environment-type exposure on the P300 (P3) event-related ERP potential. The P3 component is a marker for a memory updating process requiring cognitive control and can also be used to determine cognitive capabilities of individuals (Kok, 2001; Polich & Criado, 2006). We tested the hypothesis that urban relative to natural spaces would require increased cognitive control, manifesting as larger amplitudes for the P3 ERP component. Aligning with our predictions, exposure to images of man-made spaces elicited a significantly higher P3 component than did exposure to landscape and outer space images.

A systematic review by Ohly et al. (2016) also supports the general hypothesis of attention restoration theory that exposure to natural environments restores cognitive functioning, but also concludes that more work is needed. Across 31 studies, all reporting a variety of cognitive measures, there were only three measures that consistently yielded evidence that supported attention restoration theory: forward digit-span, backward digit-span backward, and trail making test B. Studies implementing these measures found significant evidence for attention restoration theory, as their post-exposure to nature groups performed better than those exposed to non-natural environments (Ohly et al., 2016). Other measures of attention did not yield significant differences, with one measure actually reporting better attention in post-exposure non-nature groups. Thus, more work is needed to understand exactly which cognitive processes reliably benefit from nature exposure.

Critically, little attention has been directed toward the impact of nature on *higher-order* cognitive processes. Nature exposure appears to affect at least some aspects of executive function, most notably working memory (via the backward digit-span test), and executive function is required for several higher-order processes. For example, creativity and innovation require updating and inhibition (Benedek et al., 2014). In a field experiment, Atchley and colleagues (2012) tested how immersion in nature and simultaneous separation from technology impacted creativity by asking participants to complete a cognitive task of convergent creative thinking (the remote associates test; Mednick, 1962, 1968) either before or during a hike in several different states. Results demonstrated that in-hike participants had a 50% increase in performance on the remote associates test compared to the before-hike group.

To the best of my knowledge, Atchley et al.'s (2012) work is the only empirical evidence that examines nature's ability to benefit higher-order cognitive processes. Executive function should also be critical to a number of other higher-order processes, including decision making and problem solving. Problem solving, the act of identifying a problem and curating a solution from multiple options (Frensch & Funke, 1995), is critical to effective decision making, with implications for consequential life outcomes. Indeed, Diamond (2013) described executive functioning as underpinning the higher-order cognitive function of problem solving, as seen in brain studies by the dependence of problem-solving skills on frontal lobe activity known to reflect executive functioning (Luria, 1966).

The Present Study

The goals of the current research were to find additional support for findings from Berman et al. (2008) as well as determine whether the benefits from nature extend beyond previous findings. The previous literature has identified nature's ability to restore executive function. Extending these findings to higher-level cognitive mechanisms like problem solving creates further justification for increasing green space in urban environments.

The proposed research was comprised of a pilot study for stimulus selection and one experiment. The experiment was used to find further support of as well as extend findings of previously published research (Berman et al., 2008, Experiment 2). Participants viewed pictures of natural or urban environments, as research demonstrates that exposure to natural and urban environments via images elicits reliable effects (Berto, 2005). There were two dependent variables in this experiment: working memory and problem solving. The central hypothesis of this thesis was that exposure to natural versus urban environments should be beneficial to cognitive functioning. I hypothesized that this effect would emerge for measures of both executive function and problem solving.

Pilot Test

To ensure that the nature and urban-environment images are equivalent on potentially confounding extraneous variables, I conducted a pilot study to identify images that were equated on complexity, attractiveness, openness, and safety. All of these factors might influence motivation and/or ability to engage with the images: Complex versus simple images might require greater cognitive effort to process; more versus less attractive images might elicit more cognitive engagement; and openness and safety (cf. prospect and refuge; Appleton, 1975) might have implications for emotions such as anxiety, which have implications for cognitive functioning. Equating nature and urban-environment images on these factors is important for eliminating experimental confounds. The pilot study was also used to categorize images: natural images and urban images.

Method

Participants

Participants (n = 144) were undergraduate DePaul University students recruited using DePaul's SONA system, aged 18 years and older, who receive partial course credit toward their Introductory Psychology requirement.

In accordance with IRB requirements, all participants received information on the study procedure prior to participating. Following completion of the study, participants were debriefed and compensated with 1 study credit through DePaul's SONA system.

Procedure

This study was administered online, using the Qualtrics survey platform (http://www.qualtrics.com). Participants viewed and rated a series of 100 images, randomly selected from the full stimulus set of 240 images. To ensure that participants were responding to the terms of the environment pictured rather than the nature of the representation of the environment (a photograph), participants were instructed to "think about what the place represents and imagine yourself in the environment." Each image appeared below the text in the middle of the screen, at the top of the screen, and with five self-report items appearing below the image. Participants self-paced through the images and ratings.

Materials

All materials are presented in Appendix A.

Image Stimuli. Two hundred and forty images were evaluated for use in the pilot study, with the goal to obtain 25 images for each condition. Images were from Chicago, IL, and were images of Lake Michigan, lake trails, rooftop gardens, public gardens, public parks, city streets (e.g., Michigan Ave.), skyscrapers, housing, industrial zones, and urban areas.

Image Categorization. Participants answered the item “Is the place natural (i.e., existing in nature and not human-made), urban (i.e., relating to a city and human-made), or natural and urban? using a 7-point scale with *completely natural*, *much more natural than urban*, “*a bit more natural than urban*, *an equal mix of natural and urban*, *a bit more urban than natural*, *much more urban than natural*, and “*completely urban*” as the scale point labels.

Image Ratings. Participants rated the extent to which each image is *simple* versus *complex* (complexity), *ugly* versus *beautiful* (attractiveness), *closed* versus *open* (openness), and *dangerous* versus *safe* (safety). Ratings were made along 7-point bipolar scales anchored by the descriptive adjectives.

Analysis and Image Selection Criteria

Image Categorization

The 25 nature images with the lowest ratings on the natural–urban scale ($M \leq 2.17$) were considered for the natural environment stimulus set. The 25 urban-environment images with the highest ratings ($M \geq 6.80$) were considered for the urban-environment stimulus set.

Image Ratings

Analyses of image criterion ratings (i.e., attractiveness, complexity, openness, and safety) revealed that there were not enough images used in the stimuli pool to equate on any criterion. Natural images ($M = 5.7$, $SD = .6$) were rated significantly more attractive than urban images ($M = 4.7$, $SD = .8$), $t(140) = 9.3$, $p < .001$. To equate these images on attractiveness, I found the interquartile range for each category, and determined the overlapping range for natural and urban images was 5–5.3. After selecting images in each category within that range, I was left with too few images to use in the experiment. At this point, it was determined that there were not enough images piloted to equate on four criteria and categorize based on participant responses. Therefore, I decided to only use the participants' categorization ratings for image selection.

Based on the natural–urban categorization ratings, images in the bottom 25, or $M < 2.17$ (equated approximately to the "much more natural than urban" scale point) were selected as natural images. Images in the top 25, or $M > 6.8$ (equated approximately to the "completely urban" scale point) were selected as urban images.

Experiment

The focal experiment had two goals. One goal was to find further support for Berman and colleagues' (2008, Experiment 2) finding that participants showed better performance on a measure of executive function following exposure to images of nature versus urban environments, in line with attention restoration theory's assertion that exposure to natural environments is cognitively restorative. I partially replicated the study, administering a backward digit-span task to participants after exposure to nature images and images of urban environments. Although the original study included a number of executive function measures, I focused on this task because the backward digit-span task places high demands on multiple aspects of attention and executive control (encoding, maintenance, manipulation, and updating of information) and so was more likely to be sensitive to the differential influence of nature versus urban-environment images. In contrast, the other cognitive measure used in the original study, the attention network task, purports to measure three facets of attention separately: alertness, orientation, and executive function. Attention restoration theory focuses only on executive function and only the facet of the attention network task that targeted executive function yielded reliable effects in the original study (Berman et al., 2008). Furthermore, it was noted in a systematic review that the attention network task has only been used in one study thus far, leaving the appropriateness of the measure in question (Ohly et al., 2016).

The second goal of the experiment was to extend the findings from Berman and colleagues (2008) by testing natural- versus urban-environment effects on a higher-order component of cognitive functioning: problem solving. Previous research has identified an extension of nature's benefits to cognition to creativity by using a measure of convergent thinking after a nature immersion experience (Atchley et al., 2012). However, further research is necessary to extend these findings to other higher-order cognitive processes such as problem solving. While Atchley et al. (2012) measured creativity (i.e., how many connections participants could make using word cues; the Remote Associates Test; Mednick, 1968; 2007), the goal here was to test nature's effect on problem-solving skills. As evidence already points to nature as beneficial for lower-order cognitive mechanisms such as working memory, it is crucial to extend these findings to higher-order cognitive mechanisms like problem solving, as this executive function is supported by sufficient working memory (Diamond, 2013). Problem solving requires the ability to hold multiple ideas in memory while simultaneously evaluating each idea in relation to a particular goal, this, is working memory (Diamond, 2013).

Overview and Hypotheses

The experiment was a partial replication and extension of Berman et al. (2008, Experiment 2). Participants completed a backward digit-span task and the problem-solving grid-pattern task (task order randomized) both before and after viewing stimulus images of either natural environments or urban environments (randomized between participants). On each trial of the backward digit-span task, participants listened to a sequence of three to nine digits, and then typed the sequence in reverse order; the sequences lengthened as the task continued. Cowan (2001) reports backward digit-span as a measure of directed-attention abilities (a component of executive function) because the task requires participants to move items continuously in and out of attentional focus. This movement in and out of attentional focus is a significant factor of short-term memory (Jonides et al., 2008).

In the grid task, following Adams et al. (2021), participants were presented with a series of asymmetrical grid patterns and asked to change them in as few steps as possible to be symmetrical along both the horizontal and vertical axis, by either adding or subtracting pattern components both before and after image viewing. The grids were constructed so that subtractive strategies were more effective (i.e., so that removing components would yield pattern symmetry in fewer steps), and yet Adams et al. (2021) found that participants had a bias toward additive strategies. According to Adams et al. (2021), adding to a scenario requires more effort and resources, but also requires less cognitive effort. Therefore, although less effective, people tend to choose additive strategies when problem solving. Additive changes are a common default, suggesting they are a mental heuristic and that people should be particularly likely to lean toward them when cognitive capacity is lower. Recalling that exposure to nature is assumed to be cognitively restorative (e.g., Berman et al., 2008), the idea that individuals rely more heavily on additive transformations when cognitive capacity is diminished suggests that individuals might use subtractive transformations more frequently after nature exposure than after urban-environment exposure.

Hypothesis I

Participants will repeat a higher number of sequences correctly after versus before viewing nature images; there will be no pre-/post-viewing difference when participants view urban-environment images (a Type × Time interaction).

Note that I did not make predictions as a function of image type. It might seem reasonable to predict a higher backward digit-span score after viewing nature versus urban-environment images, but this would require no score difference at baseline (i.e., before the viewing task). As I could not assume a priori that this requirement would be met, I could not make a confident prediction.[1] Importantly, Stenfors et al. (2019) also argued that it is the *change* in task performance after nature versus urban-environment exposure that provides the critical test.

Hypothesis II

Participants will be more likely to make subtractive changes after versus before viewing nature images; there will be no pre-/post-viewing difference when participants view urban-environment images (a Type × Time interaction).

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[1] Note, however, that I did look at the pattern. Assuming no pre-viewing backward digit-span score differences between sessions where participants subsequently view nature versus urban-environment images, I expected higher post-viewing scores among participants after viewing nature rather than urban-environment images.

Method

Participants and Design

Similar to the pilot study, participants included undergraduate DePaul University students who received partial course credit toward their Introductory Psychology requirement. Additional participants were recruited from Prolific, the online research platform. The experiment was based on a 2 (Image Type: nature, urban-environment) × 2 (Time: pre-, post-image viewing) mixed design with time as a within-participants factor. Student participants from SONA were granted 0.5 study credits; Prolific participants were awarded $4.65.

Using the *t*-statistic reported by Berman et al. (2008, Study 2)[2] to quantify the effect of viewing nature images on backward digit-span scores yielded an effect size dz of 0.87. We used G*Power (Faul et al., 2007) to estimate a sample size to replicate this effect, using dz = 0.87 as the effect size and setting power to 0.90; the analysis yielded an estimate of 14 participants. However, there is some concern that point estimates of power are often inaccurate and inflated (McShane et al., 2020), and this effect size does seem unrealistically large given the method. Brysbaert (2019) suggests a sample size of 34 for a 2 × 2 within-subjects design with dz = 0.5. Because I collected data for two measures, I aimed to recruit 68 participants. My final sample, once participants with incomplete responses were removed, was 228. Participant demographics are presented in Table 1.

In accordance with IRB requirements, all participants received information on the study procedure and provide informed consent prior to participating. Following

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[2] Berman et al. (2008) did not provide enough details for us to calculate the effect size for the Image Type × Time interaction.

completion of the second session of the study, participants were debriefed and compensated.

Procedure

This study was conducted online via Qualtrics (http://www.qualtrics.com). Participants were randomly assigned to view either nature or urban-environment image. Participants completed a backward digit-span task as an initial measure of working memory and a grid-pattern task as an initial measure of problem solving skills (order randomized), viewed and rated the images, then completed the digit-span task and grid task again (order randomized). The image-viewing task comprised of 25 nature or urban-environment images, presented individually in random order. Participants rated how much they would like to be in the pictured environment along a 5-point scale (0 = *not at all*, 1 = *slightly*, 2 = *moderately*, 3 = *very much*, 4 = *extremely*). Participants self-paced through the image viewing task.

Materials

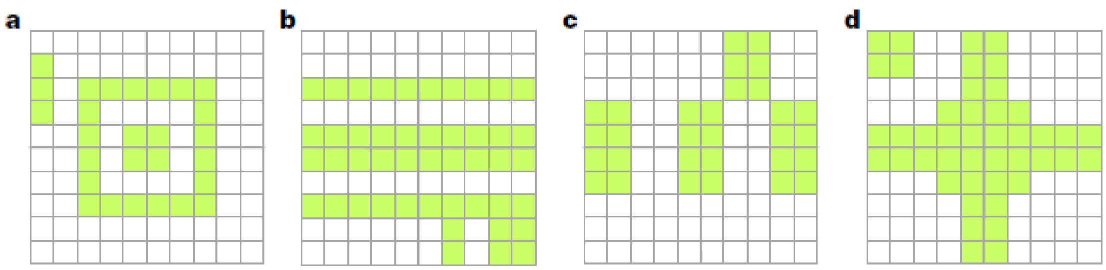
All materials are presented in Appendix B.

Backward Digit-Span Task. A total of 14 trials were administered at each time (pre- and post-image viewing), blocked by digit sequence length (with two trials per block). Across blocks, digit sequence length increased from three to nine digits. On each trial, digit sequences were presented on the screen at a rate of one digit per one second; at the end of each digit sequence, participants repeated them in reverse order by typing their responses into a textbox that appeared on the next screen.

Grid-Pattern Task. The task was adapted from Adams et al. (2021). Participants were shown 10 × 10 grid patterns comprised of white and green boxes; clicking any box on the grid toggled the box to the opposite color (see Figure 1). The task required participants to transform each pattern to make it fully symmetrical; each grid pattern is designed so that it can be transformed more efficiently (i.e., in fewer steps) by "turning off" (i.e., subtracting) rather than "turning on" (i.e., adding) squares. Specifically, to make the patterns symmetrical, boxes could be toggled either from green to white in one quadrant (a subtractive change) or from white to green in the other three quadrants (an additive change). Ten patterns (order randomized) were presented at each time (pre- and post-image viewing), for a total of 20 patterns.

Figure 1

The Grid-Pattern Task



Note. Participants can attain symmetry across all four quadrants by adding green squares to three quadrants (more clicks) or subtracting green squares from one quadrant (fewer clicks).

To begin, participants learned that the task involved working on a set of patterns. They were shown a 10 × 10 trial grid pattern (i.e., the same size as the test grid patterns), where the left half of the grid consists of green boxes, and the right half consists of white boxes. They read the following instructions, adapted from Adams et al. (2021): "First, take a moment to familiarize yourself with the workspace. Click below to see how you can change colors on the grid." This stage allowed participants to orient themselves to the task, learning how toggling squares changes the grid pattern. Once participants were accustomed to the method, they were given further instructions, learning that their task was to adjust the grid pattern, "***Using the fewest mouse-clicks possible, change the pattern below so that it is perfectly symmetrical from left to right, AND from top to bottom***" (Adams et al., 2021; italicized and emphasized in original).

Image Stimuli. The image stimuli were 50 images taken from the pilot study, 25 each of nature and urban environments. Example images of each image condition can be found in Appendix A.

Image Liking Rating. The liking rating asked participants how much they'd like to be in the pictured environment, along a 5-point scale (0 = *not at all*, 1 = *slightly*, 2 = *moderately*, 3 = *very much*, 4 = *extremely*).

Results

Descriptives statistics for demographics are presented in Table 1. Descriptive statistics for all measures are presented in Table .

Hypothesis Tests

Because data were collected through two different samples and task order varied across participants, I first conducted 2 (Image Type: nature, urban-environment) × 2 (Time: pre-, post-stimuli) × 2 (Sample: student, Prolific) × 2 (Order: digit-span first, grid-pattern first) mixed-model analyses of variance (ANOVAs) to look for sample and order effects. The inclusion of these factors made little difference to the patterns of data for the factors of interest and substantially decreased statistical power, so below I report analyses without the sample and order factors. ANOVA summary tables for the full analyses are presented in Appendix C.

Table 1

Sample Demographics, Experiment 1

Student Sample (N = 74)			
	Age		
		Mean (SD) in years	20.10(3.21)
		Range	18-38
	Gender identity		
		Woman	69%
		Man	24%
		Non-binary	4%
		Other	0%
		Undisclosed	3%
	Ethnicity		
		Hispanic	30%
		Non-Hispanic	68%
		Undisclosed	3%
	Racial identity		
		Alaskan Native / American Indian / Indigenous	0%
		Black / African / African American	8%
		East Asian	3%
		Latinx	23%
		Middle Eastern / North African	0%
		Native Hawaiian / Pacific Islander	1%
		South Asian / Southeast Asian	18%
		White	39%
		Multiracial	1%
		Other racial identity	0%
		Undisclosed	7%
Prolific Sample (N = 154)			
	Age		
		Mean (SD) in years	39.6(14.4)
		Range	19-83
	Gender identity		
		Woman	49%
		Man	47%
		Non-binary	4%
		Other	0%
		Undisclosed	0%
	Ethnicity		
		Hispanic	8%
		Non-Hispanic	91%
		Undisclosed	1%
	Racial identity		
		Alaskan Native / American Indian / Indigenous	1%
		Black / African / African American	13%
		East Asian	6%
		Latinx	6%
		Middle Eastern / North African	1%
		Native Hawaiian / Pacific Islander	0%
		South Asian / Southeast Asian	5%
		White	65%
		Multiracial	3%
		Other racial identity	0%
		Undisclosed	1%

Table 2

Means (SDs) as a Function of Image Type, Task, and Time

Image Type	Pre-Viewing	Post-Viewing
Nature (n = 106)		
Backward digit span task	6.25 (3.65)	6.16 (4.03)
Grid task	6.42 (3.47)	7.76 (3.60)
Image liking ratings		3.18 (0.69)
Built Environment (n = 122)		
Backward digit span task	5.75 (3.84)	5.56 (3.86)
Grid task	7.04 (3.35)	8.28 (3.18)
Image liking ratings		2.58 (0.76)

Note. Possible range: Backward digit span: 0–14; grid task, 0–10; liking 1–5.

Backward Digit-Span Task. The backward digit-span task required the participant to listen to a sequence of digits and type them in reverse order. The task was complete once the participant completed all 14 sequences. The score is the number of sequences the participant can reproduce successfully before reproducing a sequence incorrectly, independent of sequence length; the highest score a participant could achieve was 14 (one point for each correct sequence before failure, with 14 sequences).

Backward digit-span scores were analyzed using a 2 (Image Type: nature, urban-environment) × 2 (Time: pre-, post-stimuli) mixed-model analysis of variance (ANOVA), with image type as a between-participants factor and time as a within-participants factor.

Hypothesis I stated there would be a significant Type × Time interaction effect. The predicted pattern was an increase in backward digit-span scores when viewing nature images (i.e., a significant effect), and no change in scores after viewing urban-environment images (i.e., a nonsignificant effect).

Results revealed no significant effects. Participants performed slightly worse on the backward digit span task post image viewing in both image type conditions, but this effect was not significant.

Grid-Pattern Task. The grid-pattern task required participants to transform unsymmetrical grid patterns to symmetrical patterns using a subtractive transformation. The task was complete once the participant changed all the presented grid patterns to be symmetrical. The score of the task was the number of grids on which the participant used a subtractive transformation to achieve symmetry.

Grid-pattern task scores were analyzed using a 2 (Image Type: nature, urban-environment) × 2 (Time: pre-, post-stimuli) mixed-model ANOVA, with image type as a between-participants factor and time as a within-participants factor.

Hypothesis II stated there would be a significant Type × Time chi-square interaction effect. The predicted pattern was an increase in subtractive changes after versus before viewing nature images (a significant effect), and no difference after versus before viewing urban-environment images (a nonsignificant effect).

Results revealed only that participants performed significantly better on the grid task post image viewing, with no Type × Time interaction effect, suggesting practice effects.

Exploratory Analysis

To explore possible affective[3] effects, I examined participants' liking ratings. Ratings showed good internal consistency for both nature images ($\alpha = .92$, $\omega = .92$) and

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[3] I originally planned to include the Modified Differential Emotions Scale (mDES; Fredrickson et al., 2003), but funding constrained the length of experiment I could

urban-environment images ($\alpha = .95$, $\omega = .95$). An independent-samples *t*-test demonstrated that participants liked nature images ($M = 3.18$) more than urban-environment images ($M = 2.58$), $t(226) = 6.25$, $p < .001$. In line with Berman et al., 2008), there was no evidence that liking was associated with performance on the backward digit-span task, $r(0.03)$ or the grid-pattern task, $r(0.06)$.

Discussion

This study was conducted to partially replicate previous findings of the benefits of nature on lower-order cognitive mechanisms such as working memory, as well as extend these findings to higher-order cognitive mechanisms such as problem solving. Significant findings would have added support to the body of literature on attention restoration theory (Kaplan, 1995), which suggests urban environments are cognitively taxing while natural environments are inherently restorative. The cognitive tax from urban environments is assumed to be a result of hard fascination, which requires effortful top-down processing and depletes directed attention. The depletion of this resource leaves individuals less able to perform efficiently both behaviorally and cognitively. Natural environments are restorative because of soft fascination, which allows for non-effortful bottom-up processing, allowing attentional resources a chance to replenish.

According to this theoretical model, participants should perform better on cognitive tasks after viewing images of nature, and there should be no performance effects after viewing images of urban environments. Using images to expose participants

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conduct. However, liking ratings correlate with emotion valence (Danner et al., 2016) so this exploratory analysis provides some insight.

to natural versus urban environments, no significant effects were observed besides a potential practice effect of the grid task regardless of image type.

In retrospect, the lack of significant findings are likely the result of having conducted the experiment online. Participants' exposure to environment were images on a computer screen instead of immersive exposure to the environments in real life. To quote Kaplan (1995),

> The environment must have extent. It must, in other words, be rich enough and coherent enough so that it constitutes a whole other world. And endless stream of stimuli both fascinating and different from the usual world would not qualify as restorative for two reasons. First, lacking extent, it does not qualify as an environment, but merely an unrelated collection of impressions. And second, a restorative environment must be of sufficient scope to engage the mind. It must provide enough to see, experience, think about so that it takes up a substantial portion of the available room in one's head. (p. 173)

Although others, including Berman et al. (2008), have reported effects in the lab, it is possible that at least some of these findings are false positive effects, or at least that the effects are extremely small. Lab-based or online testing using image stimuli might simply not be appropriate. Future work studying attention restoration theory should fully immerse participants in the specified environments rather than expose them to image or video stimuli.

Another explanation for the lack of significant findings might be the chosen cognitive tasks. The backward digit-span task was chosen because it seems to produce the most robust results on the cognitive effects of natural versus urban environments

(Stenfors et al., 2019). However, the results of the current study call into question its appropriateness in this domain. My results showed that 21 out of 228 participants achieved a perfect score of 14 on the task post image viewing, which is a higher ratio of participants at ceiling than has been found in previous research (Grégoire & Van Der Linden, 1997). Moreover, the systematic review by Ohly et al. (2016) called for greater specification in attention restoration theory of which aspects of directed attention are likely to show restoration effects from nature exposure.

The chosen problem-solving task was also problematic. According to Adams et al. (2021), the grid task is an effective measure of problem-solving as it can be used to determine an individual's problem-solving efficiency. In the grid task, the presented unsymmetrical grid patterns were constructed so subtractive strategies were more effective and efficient; however, Adams et al. (2021) reported that participants had a bias towards additive strategies because adding scenarios, although more effortful, requires less cognitive effort.

Because performance on the grid task is assumed to depend on cognitive effort, it was chosen as the measure of problem-solving skills for this experiment. Participants should have had more cognitive resources in the nature-environment condition than in the urban-environment condition. However, the current experiment yielded no effects on grid task performance by image type.

When looking at the raw data, I noted that although some participants' final answer on a grid pattern may have matched the subtractive answer/pattern, many records had more than four click counts. I followed Adams et al.'s (2021) data analysis protocol, analyzing participants' final grid patterns, but subtractive outcomes do not necessarily reflect a subtraction process. Participants were frequently able to arrive at the correct grid pattern transformation according to instructions given; however, they often did not do so using the fewest clicks possible, as they were instructed. Participants were not able to see their click count; perhaps altering the task to provide this feedback to participants would yield a different pattern of results.

In addition to these methodological issues, it is important to consider the clear preference that participants showed for nature images over urban-environment images. The theoretical model suggests the benefits of nature are cognitive. However, instead of cognitive restoration, perhaps the nature benefit is affective restoration. In the present study, participants liked the images of natural environments significantly more than images of the built environments, and the differences in liking ratings were not correlated with post image viewing task performance.

While this experiment did not yield the significant findings that were predicted in the hypothesis, it does begin the conversation regarding the robustness of effects using in-lab stimuli such as images and videos of natural and urban environments compared to real-world exposure. It also calls the theoretical model, attention restoration theory, into question. There is an entire body of literature that exists supporting this theory, however, no theory exists suggesting nature may have an affective restoration effect not in addition to, but instead of a cognitive restoration effect. This research suggests this new model, potentially shifting the way we understand the benefits of interacting with nature.

References

Adams, G. S., Converse, B. A., Hales, A. H., & Klotz, L. E. (2021). People systematically overlook subtractive changes. *Nature*, *592*(7853), 258–261. https://doi.org/10.1038/s41586-021-03380-y

Appleton, J. (1975). *The experience of landscape*. Wiley.

Benedek, M., Jauk, E., Sommer, M., Arendasy, M., & Neubauer, A. C. (2014). Intelligence, creativity, and cognitive control: The common and differnential involvement of executive functions in intelligence and creativity. *Intelligence, 46,* 73–83. https://doi.org/10.1016/j.intell.2014.05.007

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19*(12), 1207–1212. https://doi.org/10.1111/j.14679280.2008.02225.x

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., Hout, M. C., Kardan, O., Hunter, M. R., Yourganov, G., Henderson, J. M., Hanayik, T., Karimi, H., & Jonides, J. (2014). The perception of naturalness correlates with low-level visual features of environmental scenes. *PLoS One, 9*(12). https://doi.org/10.1371/journal.pone.0114572

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology*, *25*(3), 249–259. https://doi.org/10.1016/j.jenvp.2005.07.001

Bratman, G. N., Daily, G. C., Levy, B. J., & Gross, J. J. (2015). The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning*, *138*, 41–50. https://doi.org/10.1016/j.landurbplan.2015.02.005

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), 1–11. https://doi.org/10.3389/fpsyg.2018.01248

Brysbert, M. (2019). How many participants do we have to include in properly powered experiments? A tutorial of power analysis with reference tables. *Journal of Cognition*, *2*(1), 16. https://doi.org/10.5334/joc.72

Cohen, S., & Spacapan, S. (1977). The aftereffects of stress: An attentional interpretation. *Environmental Psychology and Nonverbal Behavior*, *3,* 43–57. https://doi.org/10.1007/BF01114531

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24*(1), 87–185. https://doi.org/10.1017/S0140525X01003922

Danner, L., Ristic, R., Johnson, T. E., Meiselman, H. L., Hoek, A. C., Jeffery, D. W., & Bastian, S. E. P. (2016). Context and wine quality effects on consumers' mood, emotions, liking and willingness to pay for Australian Shiraz wines. *Food Research International, 89*(1), 254–265. https://doi.org/10.1016/j.foodres.2016.08.006

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64,* 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/bf03193146

Frederickson, B. L., Tugade, M. M., Waugh, C. E., & Larkin, G. R. (2003). What good are positive emotions in crisis? A prospective study of resilience and emotions following the terrorist attacks on the United States on September 11th, 2001. *Journal of Personality and Social Psychology*, *84*(2), 365–376. https://doi.org/10.1037/0022-3514.84.2.365

Frensch, P. A. & Funke, J. (Eds.). (1995). *Complex problem solving: The European perspective.* Lawrence Erlbaum Associates, Inc.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016). Residential green spaces and mortality: A systematic review. *Environment International*, *86*, 60–67. https://doi.org/10.1016/j.envint.2015.10.013

Grégoire, J. & Van Der Linden, M. (1997) Effect of age on forward and backward digit spans. *Aging, Neuropsychology, and Cognition*, *4*(2), 140–149, https://doi.org/10.1080/13825589708256642

Halonen, J. I, Kivimäki, M., Pentti, J., Stenholm, S., Kawaki, I., Subramanian, S. V., & Vahtera, J. (2014). Green and blue areas as predictors of overweight and obesity in an 8-year follow-up study. *Obesity*, *22*(8), 1910–1917. https://doi.org/10.1002/oby.20772

Hartig, T., Korpela, K., Evans, G. W. & Gärling, T. (1997). A measure of restorative quality in environments. *Scandinavian Housing and Planning Research, 14*(4), 175–194. https://doi.org/10.1080/02815739708730435

Heilig, G. K. (2012). *World Urbanization Prospects: The 2011 Revision.* New York: United Nations, Department of Economic and Social Affairs (DESA), Population Division, Population Estimates and Projections Section.

Herzog, T. R., Black, A. M., Fountaine K. A., & Knotts, D. J. (1997).Reflection and attentional recovery as distinctive benefits of restorative environments. *Journal of Environmental Psychology, 17,* 165–70. https://doi.org/10.1006/jevp.1997.0051

James, W. (1892). *Psychology: The briefer course*. Holt.

Jonides, J., Lewis, R. L., Nee, D. E., Lustig, C. A., Berman, M. G., & Moore, K. S. (2008). The mind and brain of short-term memory. *Annual Review of Psychology, 59,* 193–224. https://doi.org/10.1146/annurev.psych.59.103006.093615

Kaplan, R. (1985). Nature at the doorstep: Residential satisfaction and the nearby environment. *Journal of Architectural and Planning Research, 2*(2), 115–127.

Kaplan, R. (1993). The role of nature in the context of the workplace. *Landscape and Urban Planning, 26*(1–4), 193–201. https://doi.org/10.1016/0169-2046(93)900167

Kaplan, S. (1995). The restorative benefits of nature toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

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

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L. J., Paus, T., & Berman, M. G. (2015). Neighborhood greenspace and health in a large urban center. *Scientific Reports, 5*(11610). https://doi.org/10.1038/srep11610

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38*(3), 557–577. https://doi.org/10.1017/S0048577201990559

Kondo, M.C., Fluehr, J. M., Mckeon, T., & Branas, C. C. (2018). Urban green space and its impact on human health. *Journal of Environmental Research and Public Health*, *15*(3), 445. https://doi.org/10.3390/ijerph15030445

Lakens, D. (2014). Performing high-powered studies efficiently with sequential analyses. *European Journal of Social Psychology*, *44*, 701–710. https://doi.org/10.1002/ejsp.2023

Luria, A. R. (1966). *Human brain and psychological processes.* Harper and Row.

Lyubomirsky, S., Kasri, F., & Zehm, K. (2003). Dysphoric rumination impairs concentration on academic tasks. *Cognitive Therapy and Research, 27*(3), 309–330. https://doi.org/10.1023/A:1023918517378

McShane, B. B., Böckenholt, U., & Hansen, K. T. (2020). Average power: A cautionary note. *Advances in Methods and Practices in Psychological Science*, *3*(2), 185–199. https://doi.org/10.1177/2515245920902370

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review, 69*(3), 220. https://doi.org/10.1037/h0048850

Mednick, S. A. (1968). The Remote Associates Test. *The Journal of Creative Behavior, 2*(3), 213–214. https://doi.org/10.1002/j.2162-6057.1968.tb00104.x

Mitchell, R. & Popham, F. (2007). Greenspace, urbanity and health: Relationships in England. *Journal of Epidemiological Community Health, 61*(8), 681–683. http://dx.doi.org/10.1136/jech.2006.053553

Ohly, H., White, M. P., Wheeler, B. W., Bethel, A., Ukoumunne, O. C., Nikolaou, V., & Garside, R. (2016). Attention restoration theory: A systematic review of the attention restoration potential of exposure to natural environments. *Journal of Toxicology and Environmental Health*, 19(7), 305–343. http://dx.doi.org/10.1080/10937404.2016.1196155

Polich J. & Criado, J. R. (2006). Neuropsychology and neuropharmacology of P3a and P3b. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology, 60*(2), 172–185. https://doi.org/10.1016/j.ijpsycho.2005.12.012

Sallis, J. F., Floyd, M. F., Rodríguez, D. A., & Saelens, B. E. (2012). Role of urban environments in physical activity, obesity, and cardiovascular disease. *Circulation, 125*(5), 729–737. https://doi.org/10.1161/CIRCULATIONAHA.110.969022

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

Sherrod, D. R., & Downs, R. (1974). Environmental determinants of altruism: The effects of stimulus overload and perceived control on helping. *Journal of Experimental*

Social Psychology, 10(5), 468–479. https://doi.org/10.1016/0022-1031(74)90015-8

Skår, M. & Krogh, E. (2009). Changes in children's nature-based experiences near home: From spontaneous play to adult-controlled, planned and oganised activites. *Children's Geographies, 7*(3), 339–354. https://doi.org/10.1080/14733280903024506

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*(1413). https://doi.org/10.3389/fpsyg.2019.01413

Taylor, A. F. & Kuo, F. E. (2008). Children with attention deficits concentrate better after walk in the park. *Journal of Attention Disorders, 12*(5), 402–409. https://doi.org/10.1177/1087054708323000

Toftager, M., Ekholm, O., Schipperijn, J., Stigsdotter, U., Bentsen, P., Grøbæk, Randrup, T. B., & Kamper-Jørgensen, F. (2011). Distance to green space and physical activity: A Danish national representative survey. *Journal of Physical Activity and Health, 8,* 741–749. https://doi.org/10.1123/jpah.8.6.741

Ulrich, R. S. (1979). Visual landscapes and psychological well-being. *Landscape Research, 4*(1). https://doi.org/10.1080/01426397908705892

Ulrich, R. S. (1983). Aesthetic and affective response to natural environment. *Behavior and the Natural Environment, 6.* https://doi.org/10.1007/978-1-4613-3539-9_4

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science, 224*(4647), 420–421. https://doi.org/10.1126/science.6143402

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*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7

Appendix A: Pilot Study Materials

On the following screens, you will be presented with a series of images depicting a variety of spaces.

You will categorize each image according to the type of space it represents and then rate the spaces along four dimensions.

For each image, think about what the place represents and imagine yourself in the environment.

Image Categorization

Is the place natural, urban, or natural and urban?

- ☐ Natural
- ☐ Urban
- ☐ Natural and urban

Image Ratings (presented in random order)

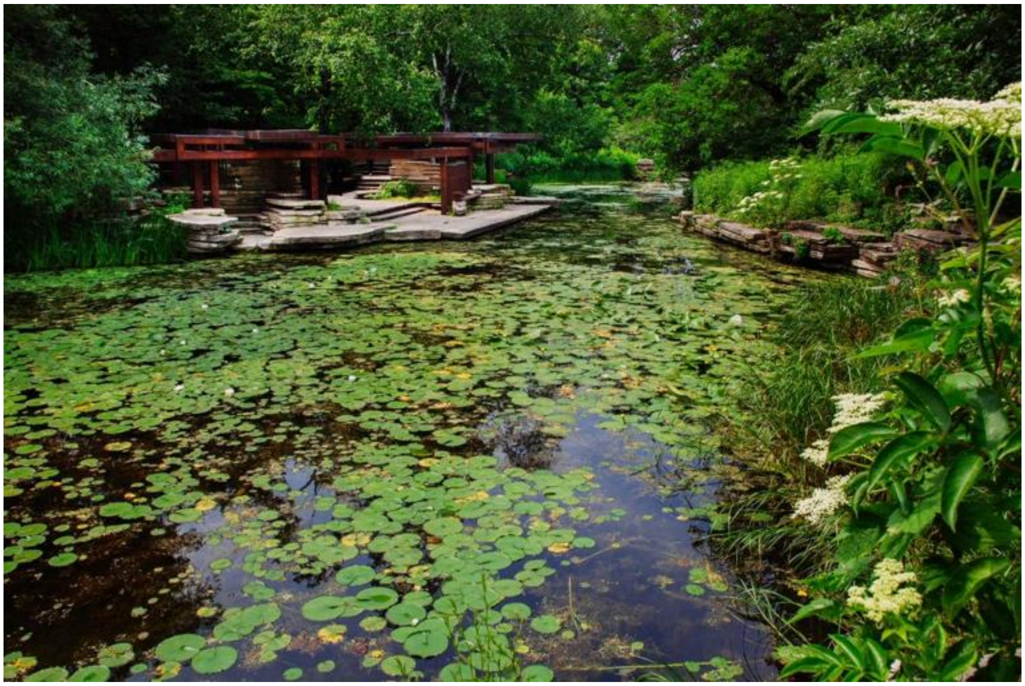
I would describe this place as…

simple	☐ ☐ ☐ ☐ ☐ ☐ ☐	complex
ugly	☐ ☐ ☐ ☐ ☐ ☐ ☐	beautiful
closed	☐ ☐ ☐ ☐ ☐ ☐ ☐	open
dangerous	☐ ☐ ☐ ☐ ☐ ☐ ☐	safe

Appendix B: Experiment Materials

Sample Images

Nature



Alfred Caldwell Lilly Pool, Chicago IL

Urban Environment

Northalsted Neighborhood, Chicago IL

Liking Ratings

In this task, you will view a series of images. For each, take a moment to imagine yourself in the environment pictured, and rate how much you'd like to be in it.

To what extent would you like to be in the pictured environment?

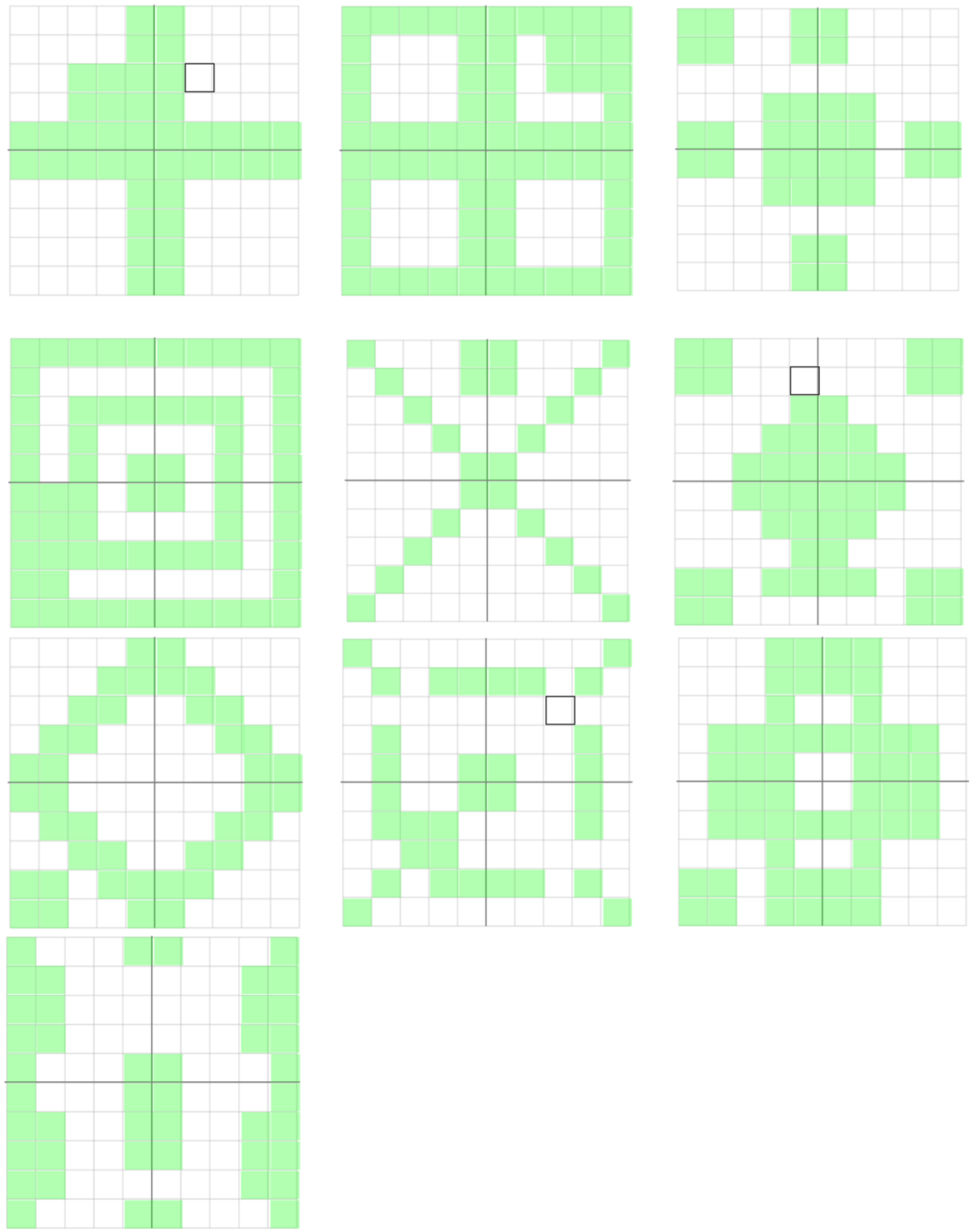
- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Very much
- ☐ Extremely

Backward Digit Span Sequences

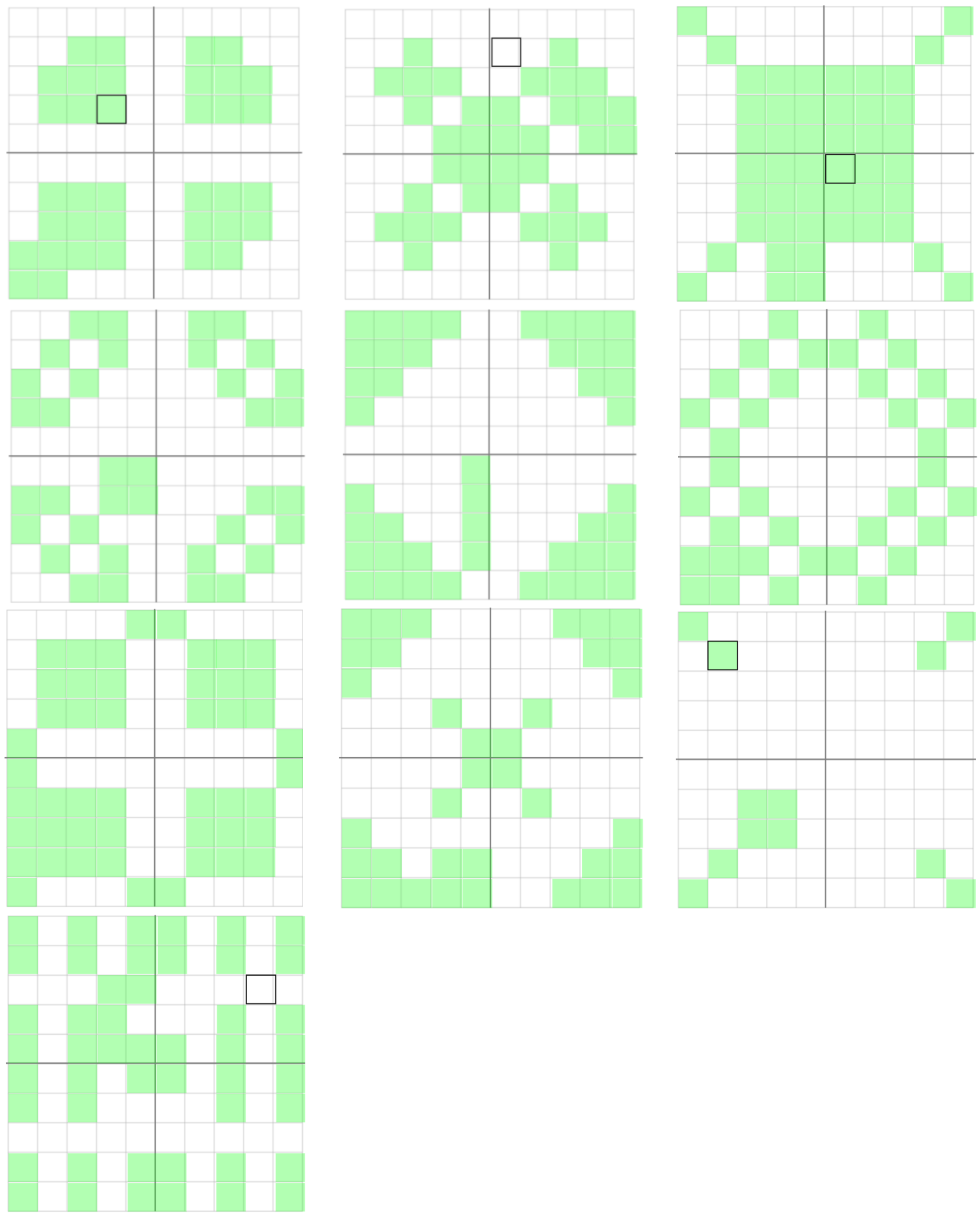
Pre Image Viewing	***Post Image Viewing***
926	741
574	658
9728	8537
8694	5862
34856	94713
68451	69598
814735	454153
658427	236975
2639418	5275914
8269374	8257365
81267349	13572869
34651827	65754313
659871179	646945335
974674874	541334651

Grid Task Patterns

Pre Image Viewing



Post Image Viewing



Appendix C: Supplementary Analyses

Table C1

ANOVA Summary Table, Backward Digit Span Task

	Sum of Squares	*df*	Mean Square	*F*	*p*	$\eta^2 p$
Within-subjects effects						
Pre_Post	6.12	1.00	6.12	0.70	0.40	0.00
Pre_Post × Natural_Built	1.49	1.00	1.49	0.17	0.68	0.00
Pre_Post × BDS_Grid	2.63	1.00	2.63	0.30	0.58	0.00
Pre_Post × PRO_DPU	8.43	1.00	8.43	0.97	0.33	0.00
Pre_Post × Natural_Built × BDS_Grid	2.78	1.00	2.78	0.32	0.57	0.00
Pre_Post × Natural_Built × PRO_DPU	26.84	1.00	26.84	3.09	0.08	0.01
Pre_Post × BDS_Grid × PRO_DPU	0.44	1.00	0.44	0.05	0.82	0.00
Pre_Post × Natural_Built × BDS_Grid × PRO_DPU	0.10	1.00	0.10	0.01	0.92	0.00
Residual	1912.33	220.00	8.69			
Between-subjects effects						
Natural_Built	19.81	1.00	19.81	0.97	0.33	0.00
BDS_Grid	1.32	1.00	1.32	0.07	0.80	0.00
PRO_DPU	175.45	1.00	175.45	8.60	0.00	0.04
Natural_Built × BDS_Grid	17.73	1.00	17.73	0.87	0.35	0.00
Natural_Built × PRO_DPU	0.10	1.00	0.10	0.00	0.94	0.00
BDS_Grid × PRO_DPU	4.54	1.00	4.54	0.22	0.64	0.00
Natural_Built × BDS_Grid × PRO_DPU	34.69	1.00	34.69	1.70	0.19	0.01
Residual	4488.33	220.00	20.40			

Note. Type 3 Sum of Squares.

Table C2

ANOVA Summary Table, Grid Task

	Sum of Squares	*df*	Mean Square	*F*	*p*	$\eta^2 p$
Within-subjects effects						
Pre_Post	147.08	1.00	147.08	51.06	<.001	0.19
Pre_Post × Natural_Built	0.00	1.00	0.00	0.00	0.99	0.00
Pre_Post × BDS_Grid	0.51	1.00	0.51	0.18	0.68	0.00
Pre_Post × PRO_DPU	0.00	1.00	0.00	0.00	0.99	0.00
Pre_Post × Natural_Built × BDS_Grid	6.21	1.00	6.21	2.16	0.14	0.01
Pre_Post × Natural_Built × PRO_DPU	4.88	1.00	4.88	1.69	0.20	0.01
Pre_Post × BDS_Grid × PRO_DPU	0.14	1.00	0.14	0.05	0.83	0.00
Pre_Post × Natural_Built × BDS_Grid × PRO_DPU	8.15	1.00	8.15	2.83	0.09	0.01
Residual	633.70	220.00	2.88			
Between-subjects effects						
Natural_Built	3.40	1.00	3.40	0.17	0.68	0.00
BDS_Grid	26.08	1.00	26.08	1.27	0.26	0.01
PRO_DPU	40.97	1.00	40.97	1.99	0.16	0.01
Natural_Built × BDS_Grid	2.77	1.00	2.77	0.13	0.71	0.00
Natural_Built × PRO_DPU	3.39	1.00	3.39	0.16	0.69	0.00
BDS_Grid × PRO_DPU	4.22	1.00	4.22	0.21	0.65	0.00
Natural_Built × BDS_Grid × PRO_DPU	0.47	1.00	0.47	0.02	0.88	0.00
Residual	4518.21	220.00	20.54			

Note. Type 3 Sum of Squares.