THE UNIVERSITY OF CHICAGO

HOW THE PHYSICAL ENVIRONMENT INFLUENCES THOUGHT CONTENT: THE ROLE OF NATURALNESS AND VISUAL FEATURES

A DISSERTATION SUBMITTED TO

THE FACULTY OF THE DIVISION OF THE SOCIAL SCIENCES

IN CANDIDACY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

BY

KATHRYN ELIZABETH SCHERTZ

CHICAGO, ILLINOIS

JUNE 2022

DEDICATION

To my grandparents, Cletus & Marie Schertz and Jon & Barbara Sedgwick

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

To my entire committee, thank you for your time and effort in training me and supporting my various scholarly pursuits. Your unique viewpoints helped broaden my perspectives, in both research and teaching.

To Marc, I'm forever grateful that you replied to my cold email asking for a job at a time when I didn't even know 'environmental neuroscience' was a field, let alone the name of your lab. Thank you for giving me both guidance and space to grow.

To my family, your love and support are endless sources of strength. You're the best cheerleaders anyone could ask for.

To Omid, thanks for being my partner through this journey. You make me a better researcher and a better person.

ABSTRACT

The physical environments that people spend time in have wide ranging effects on cognitive functioning, health, and well-being. One under-studied influence of the physical environment is how it may influence thought content. Given the impact that conscious thoughts have on the behaviors and lived experience of people, thought content is important to examine to fully understand the myriad effects the external environment has on human health and well-being. In Chapter 1, I analyzed thousands of journal entries written by park visitors to examine how low-level and semantic visual features of the parks correlated with different thought topics. I then conducted an online study to experimentally manipulate exposure to specific visual features to determine if they induced thinking about the same thought topics under more generalized conditions. Results demonstrated a potential causal role for perceived naturalness and high non-straight edges on thinking about topics related to “Nature” and “Spiritual & Life Journey”. In Chapter 2, I examined whether the influence of visual features on thought content observed in Chapter 1 remained in the absence of overt semantic content, which could indicate a more fundamental mechanism for this effect. To do so, I created scrambled edge versions of images, which maintained edge content from the original images but removed scene identification. I extended previous findings by showing that non-straight edges retain their influence on the selection of a “Spiritual & Life Journey” topic even for the scrambled scenes. In Chapters 3 and 4, I used a randomized-control within-subject experience sampling design to examine thoughts and feelings during explorations of two public spaces, a nature conservatory and an indoor mall. This allowed me to examine the time course of affective and cognitive states as a function of short-term exploration of different environments, as well as how individual differences in personality traits interact with these environment-related thoughts and feelings. In Chapter 3 I

focus on the temporal and affective aspects of thoughts, state affect, and working memory performance while in Chapter 4 I discuss how pro-social and pro-environmental thoughts and feelings are impacted in the two settings. Taken together, these studies indicate an important role for the physical environment on individuals' cognition and affect. They demonstrate that both semantic and low-level qualities of the local environment can influence these processes over relatively short timeframes. This body of work adds to our understanding of how elements of the natural environment may be beneficial for mental health and has implications for the design and use of public spaces.

INTRODUCTION

In contemporary life, humans experience a wide variety of physical environments on a regular basis, and these environments influence how we think, feel, and act. Urban living offers many benefits (Bettencourt et al., 2007; Stier et al., 2021), however, it may also increase some stressors (Bettencourt et al., 2007; Milgram, 1970). The public spaces in cities are important places to consider as locations where individuals are spending time outside of their work and home which are likely to impact their wellbeing (Carr et al., 1992; Oldenburg & Brissett, 1982). There is evidence that public greenspace may counter some of these negative effects of urban living (Bratman et al., 2019; Hartig & Kahn, 2016), as natural environments have been shown to be salubrious for health and well-being (Berman, Stier, et al., 2019; Bratman et al., 2019; Hartig et al., 2014; Kardan, Gozdyra, et al., 2015).

City parks may be particularly useful public spaces given that park visits provide social and psychological benefits to residents (Chiesura, 2004) and support individual wellbeing (Schnell et al., 2019). Urban parks are often used for restoration, exercise, or social gatherings (Nordh & Østby, 2013). They also provide community level benefits by supporting social engagement, social capital, and place attachment (Arnberger & Eder, 2012; Jennings & Bamkole, 2019), thus increasing social ties between neighbors (Coley et al., 1997; Kaźmierczak, 2013; Peters et al., 2010; Sullivan et al., 2004).

Exposure to natural environments and stimuli can influence various cognitive and affective processes (McMahan & Estes, 2015; Stenfors et al., 2019). Acute exposure to urban greenspace, for instance, has been associated with improved working memory (Berman et al., 2008), reduced aggression (Kuo & Sullivan, 2001b), and increased pro-social behaviors and attitudes (Goldy & Piff, 2020). Some of these effects may be due to the influence that natural stimuli have on thought content (Lim et al., 2018; MacKerron & Mourato, 2013), as thoughts influence mood, behavior, and cognitive functioning (Andrews-Hanna et al., 2013; Baumeister et al., 2011; Killingsworth & Gilbert, 2010; Pennebaker & Beall, 1986). For example, exposure to nature is associated with decreased rumination (Bratman et al., 2015) and increased positive thinking (Schwartz et al., 2019). These findings suggest that the physical environment can influence specific thought content, in addition to broader cognitive functioning.

To assess environmental impacts on cognitive processes, there are different perspectives by which to quantify a physical environment. Here, I focus on visual quantification of environments which is often relied on even when a person is immersed within environments and information from other senses are available. Additionally, previous research has shown that the cognitive and affective benefits of nature are observed after simply viewing pictures of natural environments (Berman et al., 2008; Bourrier et al., 2018; Stenfors et al., 2019; Stevenson et al., 2018).

Visual features have traditionally been separated into low-level or high-level based on where they are processed in the ventral visual stream (DiCarlo & Cox, 2007). High-level features (e.g., houses, trees) may require prior knowledge to be informative, as they can be used to identify environments. These features form the semantics of an environment, which refers collectively to meaningful information or judgements about it, such as how natural or aesthetically preferred it is or what the environment is typically used for, for example. Low-level features are basic color and spatial features (e.g., hue, saturation, straight edges) that physically define objects and environments. However, the classification of these features as 'low-level' is overly simple as a substantial body of work shows that they can carry semantic information (Bar & Neta, 2006; Berman et al., 2014; Edmiston & Lupyan, 2015; Kardan, Demiralp, et al., 2015;

Kotabe et al., 2017; Lockyer & Bartram, 2012; Oliva & Torralba, 2006, 2006; Vartanian et al., 2013; Walther et al., 2009) and interact with top-down judgements of visual information (Ibarra et al., 2017; Kardan et al., 2016, 2017). For example, the number of edges in a scene is highly correlated with visual complexity (Forsythe et al., 2011), which can influence cognitive disfluency, and thus increase deep, abstract thinking (Alter, 2013). Two of the main theories about how natural environments influence cognition and affect, namely the attention restoration theory (S. Kaplan, 1995; S. Kaplan & Berman, 2010; Schertz & Berman, 2019) and the perceptual fluency account (Joye & van den Berg, 2011), have suggested that some of this influence may be the result of visual features in the environments. A venue to connect lower-level features of the environment to higher level cognition is by understanding how they may influence our spontaneous and expressed thoughts.

It is a fundamental feature of the human mind to engage in thinking (James, 1890). Our thoughts may be focused on our perceptual environment or spontaneous and unconstrained by one's current task or sensory input (Smallwood & Schooler, 2015). Spontaneous thinking may include mind wandering, daydreaming, and creative thinking, and freely unfolds over time (Mildner & Tamir, 2019). What people spend their time thinking about has direct consequences for behaviors (Baumeister et al., 2011), as well as short and long term effects on mood, mental health, and cognitive functioning (Andrews-Hanna et al., 2013; Killingsworth & Gilbert, 2010; Pennebaker & Beall, 1986; Seligman et al., 2005; Smallwood & Andrews-Hanna, 2013). Examining how thought content is influenced by the external environment will help our understanding of the numerous effects the environment has on human health and well-being, and their potential mechanisms (Berman, Kardan, et al., 2019). For example, thought patterns observed in natural environments could inform why exposure to natural environments (e.g., neighborhood parks) has mental health benefits. Shifts in thought patterns could coincide with cognitive changes, reflecting some of the restorative effects observed when spending time in nature (for reviews see (Bratman et al., 2012; S. Kaplan & Berman, 2010)).

To examine environmental effects on thought content, in addition to the quantification of the environment, thoughts also need to be operationalized. There are several methods for achieving this. One method is to record free response thoughts, either verbally or in writing, and have human raters use a coding scheme to manually classify thought content of interest using a technique such as content analysis (Stemler, 2000). Another way to analyze free response, open-ended data is to use an automated text analytic approach, such as topic modeling, which can uncover mental processes from unstructured data by automatically inferring underlying topics from text (Dehghani et al., 2014). In recent years, these have emerged as a way to analyze large corpora of data which might be prohibitively resource-intensive to do with human coders (Iliev et al., 2015). One such topic modeling approach is Latent Dirichlet Allocation (LDA), which assumes that documents are comprised of topics and topics are comprised of semantically coherent and co-occurrent words (Blei et al., 2003). LDA approaches have been used successfully with documents in several fields (Wang & Blei, 2011), including very short documents such as tweets (Hong & Davison, 2010; Ramage et al., 2010; Zhao et al., 2011).

In contrast to unstructured thought content data, ecological momentary assessment or experience sampling methods can generate structured thought content data in typical settings, in real time (Larson & Csikszentmihalyi, 2014; Stone & Shiffman, 1994). While there are many variations in experience sampling methods, they all include repeated measurements of self-report data over a defined period (Lischetzke & Könen, 2021). Structured data can allow for the investigation of specific aspects of thoughts or feelings that are of interest *a priori*.

This dissertation combines observational and experimental studies to examine how the physical features of the environment influence thought content. These studies enhance our understanding of how features of environments influence our cognitive and affective states and could advance the theories on the mechanisms through which natural environments have mental health benefits. Additionally, these results have practical implications for the design and use of public spaces within cities and neighborhoods.

CHAPTER 1: A THOUGHT IN THE PARK: THE INFLUENCE OF NATURALNESS AND LOW-LEVEL VISUAL FEATURES ON EXPRESSED THOUGHTS [1]

Abstract

Prior research has shown that the physical characteristics of one's environment have wide ranging effects on affect and cognition. Other research has demonstrated that one's thoughts have impacts on mood and behavior, and in this three-part research program we investigated how physical features of the environment can alter thought content. In one study, we analyzed thousands of journal entries written by park visitors to examine how low-level and semantic visual features of the parks correlate with different thought topics. In a second study, we validated our ecological results by conducting an online study where participants were asked to write journal entries while imagining they were visiting a park, to ensure that results from Study 1 were not due to selection bias of park visitors. In the third study, we experimentally manipulated exposure to specific visual features to determine if they induced thinking about the same thought topics under more generalized conditions. Results from Study 3 demonstrated a potential causal role for perceived naturalness and high non-straight edges on thinking about "Nature", with a significant positive interaction. Results also showed a potential causal effect of naturalness and non-straight edges on thinking about topics related to "Spiritual & Life Journey", with perceived naturalness having a negative relationship and non-straight edges having a positive relationship. We also observed a significant positive interaction between non-straight edge density and naturalness in relation to "Spiritual & Life Journey". These results have

[1] Chapter 1 has been published as:
Schertz, K. E., Sachdeva, S., Kardan, O., Kotabe, H. P., Wolf, K. L., & Berman, M. G. (2018). A thought in the park: The influence of naturalness and low-level visual features on expressed thoughts. *Cognition*, *174*, 82-93.

implications for the design of the built environment to influence human reflection and well-being.

Introduction

The physical properties of the environment that people spend their time in have wide ranging effects on cognitive functioning (Berman et al., 2008, 2012), health (Kardan, Gozdyra, et al., 2015), mental health (Mantler & Logan, 2015), and self-control behaviors (Kotabe et al., 2016). Greener surroundings in public housing developments have been associated with less crime (Kuo & Sullivan, 2001a), and nearby green spaces positively predict self-discipline scores in inner-city girls (Taylor et al., 2002). Additionally, brief exposures to nature decrease depressive rumination, a maladaptive pattern of self-referential thought (Bratman et al., 2015), suggesting that the physical features of the environment may influence an individual's specific thought content.

The valence and content of people's thoughts have also been associated with various effects on mood and cognitive functioning. For example, research on mind wandering has shown that people whose thoughts are off-topic are less happy than those whose thoughts are more on-topic (Killingsworth & Gilbert, 2010). In contrast, expressive writing evaluations have shown that thinking and writing about specific events, and one's emotional response to them, is associated with improvements in physical and mental health outcomes (Pennebaker & Beall, 1986). Similarly, writing about good things that happen each day has been associated with increased happiness and decreased depressive symptoms (Seligman et al., 2005). Thus, thoughts can have both negative and positive effects. Our studies explored how such thought patterns might change in natural environments as these understandings could shed light on why exposure to natural environments (e.g., neighborhood parks) has mental health benefits.

Urban parks are vital spaces for sustainable cities as they provide social and psychological benefits to residents (Chiesura, 2004) and are often used for restoration, exercise, or social gatherings (Nordh & Østby, 2013). Many studies have shown that park features and aesthetics can change how people feel in those parks. Park size, as well as the amount of grass, bushes, and trees, has been shown to affect the perceived restorative quality of the space (Nordh et al., 2009). Additionally, parks with more grass and water were found to positively correlate with the perceived safety of the park, while graffiti and litter were negatively correlated with perceived safety (Schroeder & Anderson, 1984). These features likely impact when, how often, and for what reason people choose to go to a park.

In addition to these semantic cues/features, recent research suggests that low-level visual features, that is basic color and spatial features, can carry semantic information (Kotabe et al., 2017; Oliva & Torralba, 2006; Walther et al., 2009), as well as interact with top-down interpretations of the visual information (Ibarra et al., 2017; Kardan et al., 2016, 2017). For instance, the amount of non-straight edges in a scene is positively correlated with the perceived naturalness (Berman et al., 2014) and preference (Kardan, Demiralp, et al., 2015) for those scenes across a wide range of urban and natural settings. Bar and Neta (Bar & Neta, 2006) found that people prefer objects with curved edges over those with straight edges, which is consistent with results from more recent studies (Kardan, Demiralp, et al., 2015; Kotabe et al., 2017). Research using computer graphics has found that both curved and jagged paths create patterns that were judged to be more organic and engaging as compared to straight paths (Lockyer & Bartram, 2012). Relatedly, recent neuroaesthetic research has provided support to the idea that contour is an important factor in aesthetic judgments (Vartanian et al., 2013) and that the curvature of paths influence how goal-oriented travel on those paths will be (Loidl & Bernard, 2014). The number of edges in a scene is also highly correlated with visual complexity (Forsythe et al., 2011), which in turn can lead to cognitive disfluency. While this is usually interpreted negatively, it has been shown that cognitive disfluency can increase deep, abstract thinking (Alter, 2013). In all, this research demonstrates that low-level visual features can influence higher level judgments and in particular that curves and edges have a direct influence on preferences and thought content.

In the first study, we analyzed thousands of informal, anonymous, written entries from park journals as a way to ascertain general mindsets and spontaneous thought patterns of park users during their visits, and investigated whether written entries were systematically connected to specific visual features of the environment. Across our research program, 'semantics,' refers collectively to *meaningful judgments* about a scene (naturalness, preference) and 'low-level visual features,' refers collectively to the basic spatial and color features of a scene (e.g., edges, hue). This method takes advantage of real-time impressions park goers are forming instead of relying on recall or mental reconstruction. Specifically, in Study 1, we conducted an ecological experiment, correlating visual features of parks with the semantic content of journal entries written by park visitors. This allowed us to understand the degree and type of correspondence between the low-level visual features of a park and the general topics of thought while visitors are in the park. Furthermore, it allowed us to assess whether these parks, founded by the TKF Foundation, were achieving their goal of being a place for respite and renewal (Wolf & Housley, 2016). Particular thought patterns may be noteworthy, in that shifts in thought patterns could coincide with cognitive changes, reflecting some of the restorative effects observed when spending time in nature (for reviews see (Bratman et al., 2012; S. Kaplan & Berman, 2010)). Results from Study 1 showed a high prevalence of topics related to religion, attention to place, and time. In particular the prevalence of the topic of "Spiritual & Life Journey" was correlated with increased numbers of non-straight edges, while the topic of “Nature” was correlated with high naturalness.

Due to the ecological nature of Study 1, we wanted to ensure that our topic modeling results which emphasized positive reflection were not due to selection bias, in that people who chose to write in park journals are generally more reflective. To address this concern, we conducted an online study where participants from across the United States were shown images of the TKF parks, asked to imagine they were visiting the parks, and then write about how visiting that park would make them think or feel. While the topics modeled from this study were unique, we again saw evidence that people were positive and reflective about life, nature and other people. We found two topics that positively correlated with both the “Spiritual & Life Journey” topic from Study 1 and non-straight edges. We also found two topics that correlated with both the “Nature” topic from Study 1 and high naturalness. These results support the validity of our ecological results from Study 1.

In Study 3, we extended our findings by experimentally manipulating exposure to different visual features using the SUN database (Xiao et al., 2010), a large independent set of images from different physical environments, to assess the causal relationship between low-level and semantic visual features and thought patterns. That is, could the low-level features of an environment cause participants to think about similar topics such as those contained within the journals from TKF parks? In Study 3, we manipulated the amount of non-straight edges and naturalness of the images and found that those features induced thinking about nature, life, and spirituality under more generalized conditions. These results have implications for the design of built spaces to manipulate the reflections and thoughts for people using those spaces.

TKF Images and Journals (Study 1)

Method and Materials

TKF Parks

The TKF Foundation, based in Annapolis, MD, USA, has supported the creation of more than 120 small parks, mainly located in cities in the mid-Atlantic coastal region of the United States. These parks are designed and constructed using collaborative approaches, and are typically located in association with hospitals, museums, churches, or city neighborhoods, but installations are also in prisons, schools, college campuses and rehab centers. The parks differ from other urban parks in several ways. First, the TKF Foundation is dedicated to a mission of creating spaces that encourage spiritual connections with nature (http://naturesacred.org/our-approach/elements-of-an-open-space/). Each of the parks has four physical design elements—'portal', 'path', 'destination', and 'surround'—which were chosen to "support moments of contemplation and respite" (Wolf & Housley, 2016). The portal is a clearly marked entryway into the park, to delineate movement into the space. The path is a device to focus one's attention. Destination features, such as art pieces or water fountains, draw a person into a space, while the surround creates a "sense of boundary, safety" (http://naturesacred.org/our-approach/elements-of-an-open-space/).

The resulting park designs generally align with the spatial characteristics proposed by attention restoration theory (ART) (R. Kaplan & Kaplan, 1989; S. Kaplan, 1995). ART proposes that certain types of environments can be "restorative", in that they can help recover top-down directed attention resources that have been fatigued. Kaplan (1995) proposes that these environments are high in compatibility, extent, being away and soft fascination. Soft fascination is provided by natural environments in that they capture bottom-up involuntary attention without being overwhelming (S. Kaplan & Berman, 2010). Think of a waterfall that is interesting to look at, which captures involuntary attention, but does not do so in an all-consuming way, i.e., one still has attentional resources to think about other things. This differs from stimuli that harshly capture attention, such as loud noises, bright lights, etc., which capture attention, but do so in an all-consuming way. Most natural parks in urban areas do not place demands on directed attention, while simultaneously having softly fascinating stimulation that capture involuntary attention (Berman et al., 2008; S. Kaplan & Berman, 2010). The TKF parks meet many of these criteria and in addition, often contain other features such as labyrinths to encourage reflection (for review of labyrinth use, see (Artress, 1996). A signature element of each park is a bench where a visitor can access a journal. Visitors are encouraged to write their thoughts and reflections. According to the TKF Foundation website, the benches are carefully located to be "[a] place of respite that invites one to pause and reflect" (http://naturesacred.org/our-approach/elements-of-an-open-space/). While the parks all align with the TKF Foundation's mission, there are individual differences in how the design elements are incorporated, taking into account the size of the park, the surrounding environment, user needs, and unique inputs by community members during participatory design process.

Journal entries

Park managers are required to submit copies of journal entries to the foundation offices on a routine basis. Journal entries from 33 parks were provided by the TKF Foundation. The dataset for this research was a total of 11,771 journal entries, with individual parks contributing a range of journal entries from 4 to 1478 entries (median = 281). Table S1 in the Supplemental Material presents additional data on the parks and distribution of journal entries. The average number of words per journal entry was 43.8. The total number of tokens (unique words) was 19,979. About

10% of the entries had over 100 words, while 6% of the entries had fewer than five words. No information is known about the individuals writing the journal entries. After receiving copies of journal pages from garden managers, the entries were manually transcribed from handwritten entries to digital text. Entry length typically ranged from several words up to several sentences. Original transcription included notation about the garden history and verbal descriptions of drawings. In a second review of the entries, edits were made for format consistency and to screen out non-English language entries, call outs of names (such as “I ‘heart’ Susan”), and call outs of sports teams (such as “Go Patriots”). The discarded entries represented a small portion of the total content (~5%). The final collection was provided to the study team as a text file.

Topic Modeling

Automated text analytic approaches, such as topic modeling, are emerging as a valuable way of inferring mental and social processes from unstructured, user-generated data (Dehghani et al., 2014). These new tools enable analysis of vast amounts of open-ended data which might not be possible by relying on more resource-intensive, manual human coding (Iliev et al., 2015). Statistical topic models, such as Latent Dirichlet Allocation (LDA), are one such approach which allow for rich underlying topics to be automatically inferred from text (Blei et al., 2003) and have been applied to meaningfully grouped documents in a number of fields (e.g. (Wang & Blei, 2011). The basic assumption in LDA-based topic models is that each document (i.e., any discrete piece of text) is composed of a distribution of topics and each topic is made up of a distribution of words. A topic, then, is essentially a list of semantically-coherent and co-occurrent words, and a document is comprised of one or several of these topics. The model estimates the most probable topic structure to explain the collection of documents (Chen, n.d.). Although unsupervised topic modeling approaches are more challenging to employ with shorter texts, several recent works have suggested that LDA is a useful approach even for noisy short texts such as tweets (Hong & Davison, 2010; Ramage et al., 2010; Zhao et al., 2011). Our confidence in the validity of the topics extracted by LDA modeling is further bolstered by the fact that the entries within the journals often contained heartfelt messages and required some degree of writer effort and introspection. Therefore, even though entries were often short, they contained meaningful information, which tends to improve the ability of topic models to detect structural signals.

The topic model in the current study was built using MALLET's implementation of LDA (Mccallum, 2002). MALLET is a Java-based package for natural language processing and other machine learning applications to unstructured data. The data, i.e., journal entries, were minimally processed for topic modeling. We removed stop-words, punctuation and converted all letters to lower case but otherwise did not alter the text in any way to avoid modifying the spontaneous content of people's journal entries.

A model with 10 topics was generated for the 11,771 journal entries in the corpus. Qualitative (i.e., discussion among the analytic group) and quantitative analyses revealed that a model with 10 topics, relative to models with 5, 15 or 20 topics, yielded the best fit of the data. The topics in this model were granular enough to indicate the predominant themes in the journal entries while not being mired by idiosyncratic linguistic differences. We also calculated optimization metrics proposed by Deveaud et al. (Deveaud et al., 2014) for the evaluation of LDA models using the 'ldatuning' package (Murzintcev, 2014) within the R environment (R Core Team, 2014). This analysis showed that the 10-topic model was an appropriate fit for the data. Table S2 in the Supplemental Materials provides these evaluation metrics and details about each metric's meaning.

Topic Labels

To apply unbiased labels to the topics in our model, we conducted an Amazon Mechanical Turk (AMT) study in which we asked participants to provide labels for each topic.

Participants. 100 US-based adults (62 male, 37 female, 1 other) were recruited from the online labor market AMT. Ages ranged from 21 to 70 (M=35.1, SD=11.1). 74 participants identified primarily as White/Caucasian, 7 identified as Black/African American, 6 identified as Hispanic/Latino, 11 identified as Asian/Asian American, and 2 identified as multiple ethnicities. The median experiment duration was 7 minutes 17 seconds and participants were compensated $1.00 for participating. Informed consent was administered by the Institutional Review Board (IRB) of the University of Chicago.

Procedure. Participants first received instructions that told them they would be presented with 10 groups of words, and for each group of words they were to pick three to five labels that best described the group. The topics were presented as word clouds, which were created based on the topic-word proportions generated by the model in Study 1 using the "wordcloud" package in R (Fellows, 2014) (see Figure 1). Within each word cloud, the top ten most prevalent words for the topic are shown and the relative size of the word displayed corresponds proportionally to its prevalence in the topic. Only complete words were used in the word cloud; there was one word fragment in the top ten words for both Time & Memories and Life & Emotions which were not included in their respective word clouds. See Table S3 in Supplemental Material for word loading weights within each word cloud. Participants were required to list at least three labels and there were blank spaces for up to five labels. The word clouds were presented in a random order for each participant with one word cloud per page. The timing was self-paced and all participants saw all ten topics.

Figure 1. Word clouds generated from topic-word proportions, as displayed to participants for labeling, and resultant descriptors: a. Family; b. World & Peace; c. Life & Emotions; d. Nature; e. Celebration; f. Park; g. Time & Memories; h. Art; i. Religion; j. Spiritual & Life Journey.

Results. Frequency analysis was conducted on all listed labels, see Table 1. We chose the final label based on the most frequently listed word, but also selected modifiers from the top choices for clarity and nuance.

Table 1

Labels and Frequency of Response

Chosen Label	1st Label and Frequency		2nd Label and Frequency		3rd Label and Frequency		4th Label and Frequency		5th Label and Frequency	
Art	Art	55	Draw	20	Emotion	16	Love	16	Doodle	15
Life & Emotions	Life	32	Emotion	30	Family	28	Love	26	Feel	24
Family	Family	92	Love	35	Celebrate	14	Home	12	Life	11
Nature	Nature	76	Outdoor	29	Earth	21	Beach	14	Outside	14
Celebration	Celebrate	40	Holiday	34	Day	26	Memories	18	Party	13
Park	Park	26	Nature	25	Beauty	18	Outdoor	16	Peace	16
Religion	Religion	74	Christian	29	Church	29	Faith	26	God	23
Spiritual & Life Journey	Journey	23	Religion	23	Spiritual	20	Life	19	Maze	15
Time & Memories	Time	35	Memories	33	Life	20	History	17	Past	14
World & Peace	World	28	Peace	22	Earth	21	Life	21	Nature	21

Note. 1st Label refers to the most common word listed as a response to each word cloud, 2nd Label is the second most listed word, and so on. Frequency is the total number of times each word was listed as a response.

Images

Eighty-seven images of the parks, provided by the TKF Foundation were utilized[2]. If we did not have at least three images for a given park, we excluded that park from our analysis, as relying on too few representative pictures may not provide an analogue to the actual experience of being in the park. Four of the 33 parks were excluded based on lack of photographs. Quantitative image analysis of nine low-level visual features was conducted using the MATLAB image processing toolbox built-in functions (*MATLAB and Image Processing Toolbox*, 2014).

Color and spatial properties

Color features for the images were based on the standard Hue-Saturation-Value model. The mean and standard deviations of **hue** (average color appearance of an image), saturation (**Sat**, how intense or pure the colors in the image are), and brightness (**Bright**, i.e., value, average luminance of an image) were calculated. The spatial features used were straight edge density (**SED**, how many straight edges are in an image), non-straight edge density (**NSED**, how many non-straight edges are in an image) and entropy (average information or uncertainty content of an image). See Figure 2 for a sample image of SED and NSED. SED, NSED, Sat, Bright, SDsat, and SDbright were quantified from their respective maps created as in (Berman et al., 2014; Kardan, Demiralp, et al., 2015). Since hue of a pixel is an angular value, hue and SDhue of image pixels were aggregated using circular mean and standard deviation (Berens, 2009) as in (Kardan, Demiralp, et al., 2015). All of these features were normalized to the number of pixels in the image. Naturalness and preference ratings that were collected for images during Kardan, Demiralp et al. (2015) were utilized. In Kardan, Demiralp et al. (2015), participants were instructed to rate how natural versus man-made each scene was on a Likert scale from 1 to 7, with 1 being very made-made and 7 being very natural. The quantitative features of each park's

[2] Park images can be seen at https://github.com/kschertz/TKF_Park_Images

images, as well as the naturalness and preference ratings, were averaged to determine the value for each park used in analysis. A correlation matrix of these features is included in the supplementary materials.

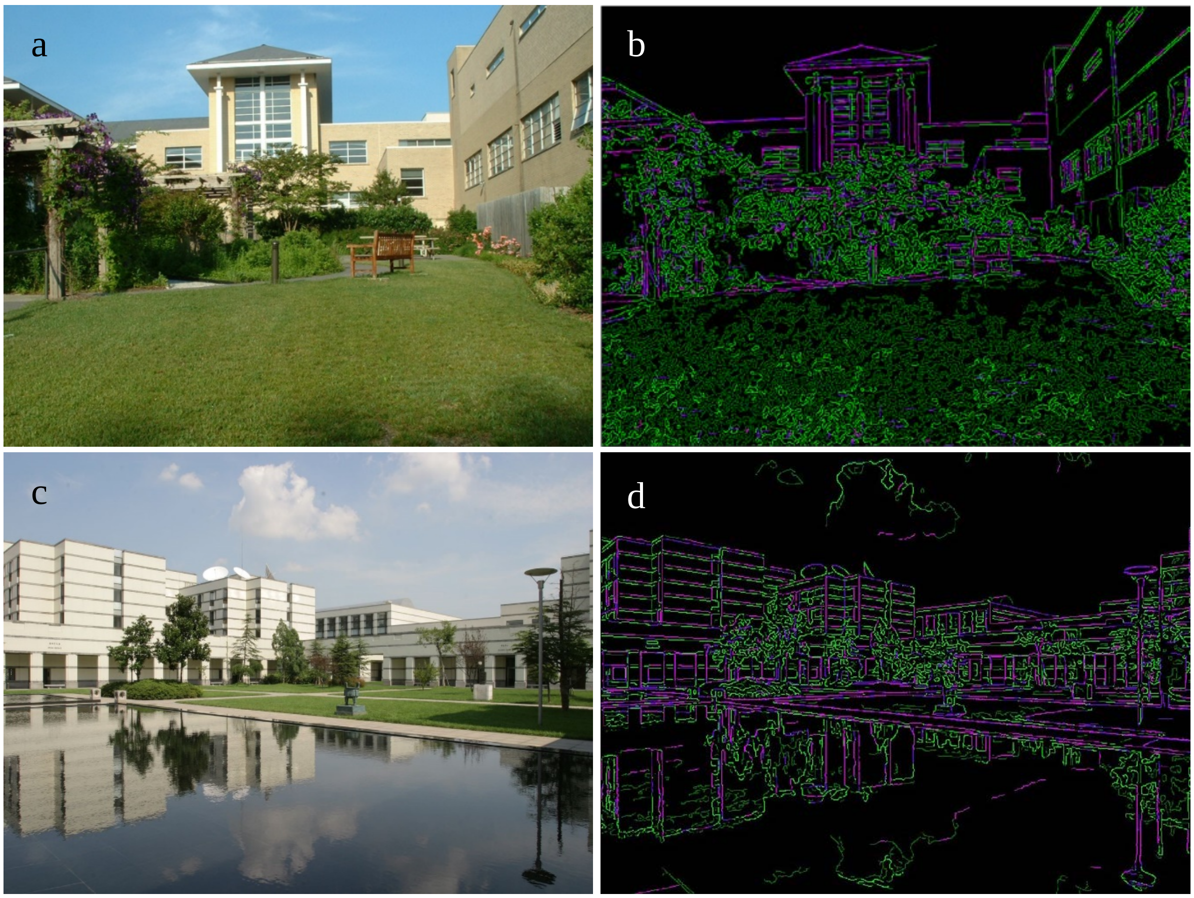

Figure 2. a. Sample image from Study 1 b. Edge composition with straight edges in purple and non-straight edges in green for image (a) c. Sample image from Study 3 d. Edge composition for image (c)

Results

Topic Modeling

The top 15 words within each topic are presented in Table 2. Topical prevalence refers to what percentage of a document (i.e., journal entry) is associated with a topic. Averaging a topic across all documents gives us the measurement of overall topic prevalence across the whole corpus. The topic labeled, “Religion” was the most predominant in the corpus, appearing in about 22.4% of journal entries. It was comprised of words such as “god”, “love”, “lord”, “Jesus”, etc. This is not unexpected as 14 of the 33 parks were located at a church or hospital, which may have driven the number of religious sentiments. Additionally, “Spiritual & Life Journey,” independent of religion, also appeared as a topic in the model (comprised of words such as “labyrinth”, “peace”, “path”). Topics such as those labeled “World & Peace”, “Time & Memories” or “Life & Emotions” also indicated that people felt contemplative as they enjoyed these park spaces and were mindful of their surroundings. The “Art” topic consisted of words that had been transformed from actual hand-drawn images, such as smiley faces, in the paper journals to linguistic representations in the digital entries. Finally, aspects of nature were also highlighted in approximately 8.8% of documents, with words such as “water”, “sun”, and “trees”. We used valence ratings from Warriner, Kuperman, & Brysbaert (Warriner et al., 2013) to quantify how positive each topic was. Averaging the valence rating for the top 15 words in each topic, we found that all topics in the model were on average positive, with a range of 6.22 to 6.97. The scale goes from 1-9 with 1 being unhappy, 5 being neutral, and 9 being most happy. The valence ratings for individual topics can be seen in Supplemental Materials Table S4. This model suggests that the TKF parks are achieving their designed purpose, as the underlying topics align with the foundation’s stated mission, that being to provide the opportunity for a deeper human experience by supporting the creation of public green spaces that offer a temporary place of sanctuary, encourage reflection, provide solace, and engender peace.

Table 2

Topic labels, topic prevalence, and top 15 words for Study 1

Topic Label	Prevalence	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10	Word 11	Word 12	Word 13	Word 14	Word 15
Religion	22.4 %	god	love	lord	dear	jesus	life	bless	pray	family	peace	father	give	day	good	amen
Park	18.4 %	place	beautiful	day	garden	great	wonderful	peaceful	nice	bench	spot	enjoy	lovely	today	sit	annapolis
Time & Memories	12.1 %	time	book	ve	back	life	years	day	today	good	year	ll	people	write	school	hope
Life & Emotion	10.0 %	love	don	life	feel	time	things	people	make	hope	hard	person	thing	good	ll	ve
Nature	8.8 %	water	sun	trees	beautiful	birds	sky	day	breeze	wind	blue	spring	leaves	cold	green	warm
Spiritual & Life Journey	7.5 %	labyrinth	peace	path	walk	life	place	center	walked	god	feel	time	journey	walking	open	moment
Family	6.9 %	love	mom	happy	dad	miss	age	birthday	sister	baby	fun	hope	brother	today	dog	dear
World & Peace	6.7 %	world	life	people	love	live	peace	earth	nature	find	place	words	human	lives	beauty	hope
Art	4.4 %	drawing	heart	face	smiley	love	drawings	written	flower	hearts	entry	inside	arrow	sun	star	girl
Celebration	2.9 %	day	today	birthday	year	house	memorial	people	ride	great	america	bike	live	drink	american	happy

Note. Topic labels are the names of each topic. Topic prevalence is what percent of the corpus covers each topic. Words 1-15 are the most common occurring words for each topic.

Image to Topic Correlations

A correlation matrix was calculated between the visual features of the park images and the document-topic weights for the journal entries. Each park had three entries, one per image. The average document-topic weighting, derived from all of the journal entries for that park, was assigned to each of the entries. We used the Holm-Bonferroni method to adjust for multiple comparisons, protecting the experiment-wise error at $\alpha = .05$. We found that the topic "Spiritual & Life Journey" positively correlated with NSED. In addition, and not surprisingly, the topic of "Nature" positively correlated with naturalness (see Table 4), which was a good validation check. Our main analysis focuses on NSED and naturalness due to the prior research discussed in the introduction, suggesting that NSED may have a particularly interesting influence on various types of cognition. See Table S5 in the Supplemental Material for correlations of other visual features as well as inter-topic correlations, however no other correlations between visual features and topics survived multiple comparison correction. Next, we conducted Study 2, to replicate our ecological findings in an experimental setting.

Table 3

Correlations between TKF journal topics and visual features

Feature	Family	Park	Life & Emotion	Time & Memories	Art	Nature	Religion	World & Peace	Celebration	Spiritual & Life Journey
NSED	-.19	-.12	.22	-.04	-.12	.02	-.05	.28	.08	.44**
	[-.39, .02]	[-.32, .09]	[.01, .41]	[-.25,.17]	[-.32, .09]	[-.19, .23]	[-.26, .16]	[.07, .46]	[-.13, .28]	[.25, .60]
Naturalness	-.20	.22	.10	.19	-.22	.52**	-.28	.06	-.05	.23
	[-.39, .01]	[.01, .41]	[-.30, .11]	[-.02,.39]	[-.41, .01]	[.35, .66]	[-.46, .07]	[-.15, .26]	[-.26, .16]	[.02, .42]

Note. N = 87. Test is Pearson correlations, 95% CI shown in brackets.
** Holm-Bonferroni Adjusted p < .05

Thought Content Online Study of TKF Parks (Study 2)

Methods and Materials

Participants

843 US-based adults (362 male, 477 female, two other, two no response) were recruited from the online labor market Amazon Mechanical Turk (AMT). The number of subjects was chosen to create a corpus of journal entries that was similar in size to the original TKF park journal corpus. Ages ranged from 18 to 77 (M=37, SD=11.6). 655 participants identified primarily as White/Caucasian, 61 identified as Black/African American, 50 identified as Hispanic/Latino, 49 identified as Asian/Asian American, 19 identified as multiple ethnicities, three identified as other, two identified as Native Hawaiian/Pacific Islander, two identified as Native American/Alaska Native, and two provided no response. The median experiment duration was 27 min 30 seconds and participants were compensated $3.00 for participating. Informed consent was administered by the Institutional Review Board (IRB) of the University of Chicago.

Images

We used the same 87 images of the TKF parks from Study 1, which included 3 images for each of the 29 parks.

Procedure

Participants first received instructions that they would see images of fifteen parks and for each park, they were asked to write freely about their thoughts and feelings while imagining themselves in the park. We specified that “gut reaction” and “train of thought” entries were acceptable, and that they were not required to write cohesive entries. For each park, participants were shown the three images representing the TKF park and a text entry box below. Participants saw a random selection of 15 of the 29 parks. The parks were presented in random order and the three images for each park were also presented in random order above the text entry box. They were asked to write for one minute for each park. After one minute, participants were allowed to advance the page or continue writing to finish their entry. There was no maximum time enforced to require participants to go to the next page.

Results

Topic Modeling

The text corpus was composed of 12,645 entries for 29 parks. Based on random sampling, the number of entries from each park ranged from 410 to 462 (median = 438). The average entry length was 36.4 words. The total number of tokens (unique words) was 10,212. The maximum entry length was 151 words, while about 1% of the entries had fewer than 5 words. We used the same method and implementation of topic modeling as in Study 1 to generate a ten topic model. The top 15 words within each topic are presented in Table 4. As this data was collected for topic comparison to Study 1, we did not run an additional online study as we had in Study 1 to create names for the topics, thus these topics are referred to as Topics 1 through 10. The most prevalent topic, Topic 1, seen in 16.9% of the corpus, showed that people were generally positive and relaxed, with words such as “happy”, “calm”, “peaceful”, and “life.” Topic 2 seems to reflect individual differences in park preference, as it may represent entries from parks that a participant would not have chosen to visit in real life. Topic 4 seems similar to the Nature topic from Study 1, where people are more literally describing the surroundings using words such as “trees”, “plants”, “flowers”, but also maintaining positivity, as the topic also includes the words “love” and “beautiful.” The public art seen in many of the parks was also highlighted, in Topic 7. Again using the Warriner et al. (2013) valence ratings, all topics had a mean word rating that was positive, with a range of 5.61 to 6.95. The valence ratings for individual topics can be seen in Supplemental Materials Table S6. One of the differences seen between topics in this corpus and the corpus in Study 1 included the lack of a Religion topic. We speculate that this was not due to a lack of religiosity of our participants, as over half identified as religious, but rather that this topic may be more salient when visiting a park that you know is at a church or hospital, as opposed to the semi-anonymous location of a park when viewed online. Participants in this online study were not told where the parks were located and their attention was focused to the park aspect of the images. Another difference seen was a general confusion about the prevalence, and purpose, of labyrinths, as seen in Topic 8. This is likely another artifact of an online study where participants do not necessarily have enough information to understand all aspects of the location they are viewing.

While there are differences in the corpus’ of Study 1 and Study 2, overall the topic modeling shows that the positive, reflective nature of journal entries in Study 1 was not due to a sampling bias of more reflective people being the only contributors to the corpus, but rather it seems to be the result of the park experience, whether experienced through photographs or in real life. Thus, in the following experiment, we tested whether NSED and naturalness had a causal role in the frequency with which people thought about the topics of “Spiritual & Life Journey” and “Nature”, respectively.

Table 4

Topic labels, topic prevalence, and top 15 words for Study 2

Topic Label	Prevalence	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10	Word 11	Word 12	Word 13	Word 14	Word 15
Topic 1	16.9 %	feel	park	make	happy	nature	relaxed	calm	peace	life	thoughts	makes	enjoy	place	peaceful	things
Topic 2	15.8 %	park	feel	don't	it's	place	wouldn't	feels	kind	building	i'd	doesn't	bit	time	long	makes
Topic 3	15.6 %	place	nice	sit	park	good	relax	time	enjoy	people	area	day	great	walk	lunch	read
Topic 4	14.6 %	park	nice	trees	plants	flowers	love	walk	beautiful	path	bench	grass	area	sit	enjoy	nature
Topic 5	9.8 %	water	sit	bench	boats	love	watch	enjoy	sitting	view	birds	sounds	watching	day	relaxing	sound
Topic 6	9.4 %	park	city	it's	area	nice	small	people	space	place	urban	close	buildings	street	nature	middle
Topic 7	5.6 %	art	park	interesting	fountain	artwork	made	i'd	enjoy	unique	cool	love	curious	kids	fun	children
Topic 8	5.1 %	circle	maze	grass	open	kids	play	park	walk	space	circles	design	place	middle	fun	benches
Topic 9	3.9 %	reminds	college	feel	thinking	campus	people	park	sad	school	back	memorial	makes	home	lost	life
Topic 10	3.2 %	i'm	garden	yard	back	it's	stones	backyard	someone's	kind	rocks	reminds	cemetery	house	bit	i'll

Note. Topic labels are the names of each topic. Topic prevalence is what percent of the corpus covers each topic. Words 1-15 are the most common occurring words for each topic.

Topic Correlations

Given our significant results from Study 1, we first calculated correlations between the topics in Study 2 and the topics of Nature and Spiritual & Life Journey from Study 1 (see Table 5) to identify which topics in Study 2 corresponded to those topics. Using the same analysis as in Study 1, we calculated the document-topic weight for each entry and averaged the scores by park to determine the average document-topic weight for each park. We had three entries per park. Each entry corresponded to the visual features of one image and was assigned the average document-topic weighting derived from all journal entries for that park. We found that Topic 1 ($r = .42$, 95% CI [.23, .58], $p < .001$) and Topic 4 ($r = .48$, 95% CI [.30, .63], $p < .001$) positively correlated with Spiritual & Life Journey. We then calculated the correlation between these two topics and non-straight edges. Topic 1 ($r = .22$, 95% CI [.01, .41], $p = .04$) and Topic 4 ($r = .25$, 95% CI [.04, .44], $p = .02$) were both positively correlated with non-straight edges. In an analysis same as above, we found that Topic 1 ($r =.37$, 95% CI [.17, .54], $p <.001$) and Topic 5 ($r =.53$, 95% CI [.36, .67], $p <.001$) positively correlated with the Nature topic from Study 1. We then calculated the correlation between these topics and naturalness. Topic 1 ($r=.62$, 95% CI [.47, .73], $p < .001$) and Topic 5 ($r=.27$, 95% CI [.07, .46], $p =.01$) were both positively correlated with naturalness. Correlations between all other visual features, the 10 Study 2 topics and the 10 Study 1 topics are shown in Supplementary Materials, Tables S7 and S8, however no other correlations between Study 2 topics and low-level visual features survived multiple comparison correction. By showing that our experimental data correlated with those of the ecological data, both through topic modeling and visual features, we provide evidence that our ecological data provided a representative sample of park visitors' experiences.

Table 5

Significant correlations between Study 1 journal topics, Study 2 journal topics and visual features

	Spiritual & Life Journey	Nature	NSED	Naturalness
Topic 1	.42 [.23, .58]***	.37 [.17,.54]***	.22 [.01, .41]*	.62 [.47,.73]***
Topic 4	.48 [.30, .62]***		.25 [.05, .44]*	
Topic 5		.53 [.36, .67]***		.27 [.07, .46]**

Note. N = 87. Test is Pearson correlations, 95% CI shown in brackets.
* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Testing the Causality of NSED and Naturalness on Thought Content (Study 3)

Method and Materials

Participants

105 US-based adults (56 male, 49 female) were recruited from the online labor market Amazon Mechanical Turk (AMT). We did not have an a priori estimation for the effect size but as we planned to analyze the data using mixed logistic regression, we determined we would need 96 subjects to detect a small effect size (f=0.15) with power of .90 (using G*Power, version 3.1.9.2) (Faul et al., 2007). Ages ranged from 19 to 69 (M=33.2, SD=10.8). 77 participants identified primarily as White/Caucasian, 10 identified as Black/African American, 9 identified as Hispanic/Latino, 7 identified as Asian/Asian American, and 2 identified as multiple ethnicities. The median experiment duration was 10 min 31 seconds and participants were compensated

$1.00 for participating. Informed consent was administered by the Institutional Review Board (IRB) of the University of Chicago.

Images

A subset of the SUN image database (Xiao et al., 2010) comprising 1,105 scene images was downloaded and run through the same quantitative image analysis as conducted in Experiment 1. This subset of 1,105 scene images had been originally selected in (Kotabe et al., 2017). We were restricted to that study's subset of images as we needed scenes that were already rated for naturalness and preference. The original subset was selected to cover a wide range of outdoor environments with different semantics and perspectives. We were not limited by the number of candidate images in the SUN database. Four groups (High/Low NSED x High/Low Naturalness) of 20 images (80 total) were selected[3] to best match NSED, naturalness and preference. Although we did not have a prediction for an interaction between naturalness and NSED, this design ensured both features would be tested across a wide range of scenes. Figure 3 shows the distribution of NSED and naturalness across studies. As NSED and naturalness are often correlated across different scenes (Berman et al., 2014), we wanted to ensure that any effects found for each were specific to that feature, which is possible with this 2 x 2 design. See Table 6 for summary statistics of group visual features. Although we tried to hold preference constant between all four groups, a single factor ANOVA showed there were significant differences between groups, $F(3,76) = 7.81$, $p < .001$. Pairwise t-tests with Bonferroni correction showed that preference for high naturalness + low NSED images was significantly higher than both low naturalness + high NSED ($p=.001$) and low naturalness + low NSED ($p<.001$), but did not differ from high naturalness + high NSED ($p=.19$). Preference for the high naturalness + high NSED

[3] Our stimuli can be downloaded at https://github.com/kschertz/TKF_MTurk

group, while numerically higher than both low naturalness groups, was not significantly different from preference for either group. Holding preference constant was not feasible likely because preference for high naturalness environments over built environments is so strong that often distributions for preference ratings between these two kinds of environments hardly overlap (S. Kaplan et al., 1972). There was a significant difference of naturalness rating between high and low naturalness groups (t = 45.48, p < .001), but there was not a significant difference for naturalness between the low and high NSED groups (t = -.18, p=.86). Naturalness and preference ratings were collected as part of Kotabe et al. (2017). Naturalness and preference were both rated on 7 point Likert scales, where in the naturalness condition, participants were asked to rate how natural versus man-made each scene was, and in the preference condition participants were asked to rate how much they liked the scene on a scale of 1 to 7. Figure 4 shows example images for each category.

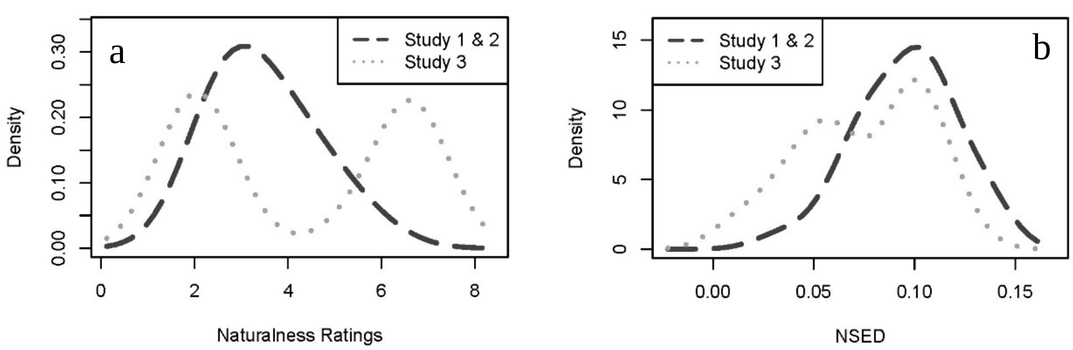

Figure 3. a. Distribution of NSED for Studies 1-2 and Study 3 image sets. b. Distribution of Naturalness Ratings for Studies 1-2 and Study 3 image sets. Note. Study 3 has bimodal distribution due to creating a 2 x 2 block design (i.e., the distributions should be bimodal as that was our experimental manipulation).

Table 6

Summary of Means and Standard Deviations of Image Group Visual Features used in Study 3

	Low Naturalness		High Naturalness	
NSED	**Low**	**High**	**Low**	**High**
Naturalness Rating	1.94 (0.25)	2.20 (0.39)	6.53 (0.49)	6.45 (0.50)
Preference Rating	4.79 (0.53)	4.81 (0.69)	5.59 (0.67)	5.32 (0.57)
NSED	0.046 (0.02)	0.101 (0.01)	0.049 (0.02)	0.104 (0.01)

Note. Naturalness and Preference are rated on a 7-point Likert scale.

Figure 4. Sample images for each stimuli group a. High Naturalness + High NSED b. High Naturalness + Low NSED c. Low Naturalness + High NSED d. Low Naturalness + Low NSED

Procedure

Participants first received instructions that they would be presented a series of 80 images, and for each scene they were to pick a set of words that best went with the image. For each image, participants were presented a forced choice condition with 10 word clouds. The word clouds presented were the same stimuli as used in the topic labeling study. Images were 800x600 and presented on a white background. Word clouds were presented below the image, with the question “What set of words do you think best goes with this image?” The order of presentation of word clouds was randomized for every image to avoid participants simply selecting the same topics and to force them to read the topics carefully. A sample screen from the experiment is shown in Figure 5. After a word cloud was selected, the survey automatically proceeded to the next image. Images were presented in random order, and all participants viewed every image.

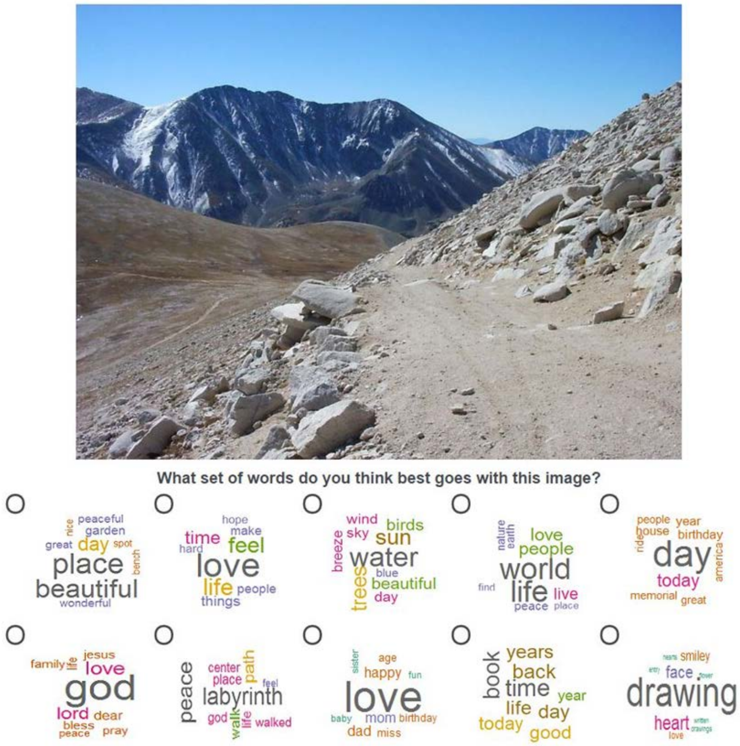

Figure 5. Example screen presentation from AMT study.

Regression Analysis

We conducted a mixed logistic regression analysis. Logistic regression was designed to analyze binomial categorical data (McCullagh, 2018). Mixed logistic regression is a type of Generalized Linear Mixed Model (Breslow & Clayton, 1993) that is flexible for binary or continuous predictors. In mixed models, outcomes are defined as the linear combination of fixed effects and random effects. In this study, it allowed us to account for subject level differences for topic selection, making it a better approach than a chi-square test. By using a mixed logistic regression, we took advantage of the benefits of ordinary logistic regression, while gaining the ability to model random effects. All models were run using R's glmer function from the lme4 library (Bates et al., 2014).

Results

Guided by the significant correlations in Study 1, we ran logistic regression models predicting the selection of "Spiritual & Life Journey" and "Nature" topics. For each model, NSED and naturalness were the independent variables and subject was a random intercept, in order to control for baseline individual differences in topic selection. For both the "Nature" and "Spiritual & Life Journey" topics as the dependent variables, there were significant main effects of NSED and naturalness ratings, as well as a significant interaction (See Table 7). As predicted by the correlations in Study 1, participants were 1.99 times, 95% CI [1.68, 2.36], more likely to choose the "Nature" topic for images with high naturalness ratings. High NSED also positively predicted the "Nature" topic, and the interaction was significant, such that the effect was largest for the high naturalness/high NSED images. Also in line with our predictions from Study 1, "Spiritual & Life Journey" was 1.60 times, 95% CI [1.22, 2.12], more likely to be chosen for images with high NSED independent of naturalness. Naturalness was a negative predictor, and there was a significant interaction such that the "Spiritual & Life Journey" was chosen the most often for images high in both NSED and naturalness. See Figure S1 in Supplementary Materials for overall topic selection frequency and Table S9 in Supplementary Materials for logistic regression models on the other topics.

Table 7

Logistic Regression Models predicting Spiritual & Life Journey and Nature topics using Naturalness and NSED

	Spiritual & Life Journey				**Nature**			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.70	.10	-28.02	<.001	-1.39	.08	-17.49	<.001
Naturalness	-0.29	.12	-2.50	.012	0.69	.09	7.89	<.001
NSED	0.47	.14	3.39	<.001	0.50	.08	5.95	<.001
Naturalness*NSED	0.84	.17	4.81	<.001	0.36	.13	2.82	.004
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=105)	0.13		0.36		0.34		0.58	
AIC	4529.8				6767.8			
Log Likelihood	-2259.9				-3378.9			
Observations	8400				8400			
Δ AIC	-88.9				-99.4			
$X^2(3)$	94.8				105.4			

Note. Δ AIC and X^2 values are based on comparison of full model to null model with grand mean and random intercepts for subjects as predictors (DV ~ 1 + (1|Subject))

Discussion

This study found a relationship between the low-level features and the semantic visual features in one's external environment with the content of symbolic thoughts as expressed by free writing and word-cloud choice. In Study 1 we used text records from urban parks, a commonly experienced community space, to explore what people are thinking about while in those spaces. Topic modeling results of the journal entries provided from urban parks in Baltimore, Washington D.C., and other mid-Atlantic U.S. metropolitan centers showed that people are often thinking about topics of spirituality, family, world, and peace – in line with the goals of the designers and the TKF Foundation that sponsored the parks. We found evidence that within even small parks in dense, urban areas people often reflect positively about nature, their relationships, and their surroundings. Prior research has shown that people are happiest while in natural environments (MacKerron & Mourato, 2013) and this current research extends this idea to show that a state of happiness while outdoors may be heightened by engaging in positive reflection.

Over one-third of our parks were located at hospitals, which may reasonably be associated with worry or sadness, but that was not conveyed by our topic modeling. Instead we observed reflections that are mostly positive and thoughtful. Study 1 also provided socio-ecologically valid, correlational data between specific thought topics and low-level and semantic features which laid the groundwork for experimental manipulations of Study 3. Study 2 provided validation of our ecological journal data by showing that the positivity and reflectiveness of our topics modeled in Study 1 were not driven by a selection bias of people who chose to write in the journals, nor were the correlations with visual features idiosyncratic to this corpus. Topic modeling in Study 2 resulted in two topics that were positively correlated with the Spiritual & Life Journey topic from Study 1 and importantly, those topics also correlated with NSED. We also replicated the intuitive finding of having nature-related thought topics correlating with naturalness ratings of the images. By combining the external validity and richness of correlational data in Study 1 with the rigor and control of experimental research in Studies 2 and 3, we are able to provide a balanced perspective via convergent results.

In Study 3, while not surprising, we find that exposure to high naturalness images increased thoughts about nature. The images used in Study 3 were more extreme in terms of their naturalness ratings than the TKF park images from Study 1. By replicating the effect of naturalness on nature thoughts, we see that through a wide variety of physical environments, similar cues may be used to reflect on one's surroundings. More interestingly, we find potentially causal evidence for the effect of NSED on symbolic thought about spirituality & life journeys. Like most of the modeled topics, this one is positive and reflective. Similar to how non-linear motion is associated with positive and calm affect (Bartram & Nakatani, 2010), non-straight shapes may evoke those types of emotions and thoughts. Given prior research showing that curved edges are seen as less aggressive than straight edges (Bar & Neta, 2006), a high level of NSED may also allow a person to relax and reflect. In a rather different mechanism, it could be that non-straight edges are increasing the visual complexity (Forsythe et al., 2011), which in turn increases cognitive disfluency, which can lead to increased deep and abstract thoughts (Alter, 2013). Labyrinth is the first word in this topic, and as several TKF parks in our study included labyrinths, it is not surprising that they were often written about in the journals. Additionally, as labyrinths have curved borders, that could have added to how correlated the topic was with NSED. However, this correlation alone would not have led to significant results in Study 3, as there were no labyrinths in those images. The significant interaction between naturalness and NSED seen in both models indicate that low-level features may have different influences depending on the overall semantic content of environment. While this may be a causal mechanism, it is possible that naturalness and NSED are both confounded with mediating semantic factors. Therefore, future research could use abstract images with little to no semantic content (Kotabe et al., 2016) and examine how exposure to those images affects the relationship between NSED and thoughts related to Spiritual & Life Journey.

This study has several implications related to the design of parks and to public health generally. While it is possible that some of the topics found in this study are unique to TKF parks, our results lend support to the idea that modest investments in small urban parks can provide residents a place for restorative experiences. In addition to the features previous research has identified as preferred in parks, here we identified visual features that could be manipulated to shift people's park experience and mental state. For example, water and non-veiling vegetation were both recently shown to be positive predictors of perceived naturalness (Ibarra et al., 2017). These could be increased in parks for a deeper engagement with nature. Additionally, Ibarra et al. (2017) showed that built structures were negatively correlated with non-straight edges, thus minimizing built structures could increase non-straight edges, which in turn could increase spiritual reflections. Given the public health burden of mental illness (Ferrari et al., 2013), there is potential for parks to be a shared, and relatively inexpensive, community health intervention.

Future research could investigate if low-level visual features and semantic features of indoor spaces influence thought in similar ways as these features in outdoor spaces by analyzing journals and images taken from within buildings. Prior consumer marketing research demonstrated an effect of ceiling height on item processing (Meyers-Levy & Zhu, 2007), with higher ceilings leading to relational and abstract processing of items and lower ceilings leading to concrete, item-specific processing, which supports the idea that indoor built environment features can also affect cognition. Future research could also look at how changes within a park throughout the year affect thoughts and their correlations with visual features, as visual features often change depending on the season. In addition, researchers could also employ experience sampling methods to obtain free-response thought content from a wide variety of locations.

Taken together, these experiments suggest that low-level visual features can actually change the content of people's thoughts. Prior research with low-level visual features showed that they can influence judgments such as preference (Kardan, Demiralp, et al., 2015) and naturalness (Berman et al., 2014), but the present study shows a more nuanced influence of low-level features interacting with semantic features on thought. Importantly, here we demonstrate a causal role of naturalness and NSED on thought content. As more of the natural environment is being replaced by designed and built physical environments, and given the importance that thoughts have on behavior and well-being, influences of low-level visual features must be taken into account to better align designed spaces with their intended purposes.

CHAPTER 2: VISUAL FEATURES INFLUENCE THOUGHT CONTENT IN THE ABSENCE OF OVERT SEMANTIC INFORMATION [1]

Abstract

It has recently been shown that the perception of visual features of the environment can influence thought content. Both low-level (e.g., fractalness) and high-level (e.g., presence of water) visual features of the environment can influence thought content, in real-world and experimental settings where these features can make people more reflective and contemplative in their thoughts. It remains to be seen, however, if these visual features retain their influence on thoughts in the absence of overt semantic content, which could indicate a more fundamental mechanism for this effect. In this study, we removed this limitation, by creating scrambled edge versions of images, which maintain edge content from the original images but remove scene identification. Non-straight edge density is one visual feature which has been shown to influence many judgements about objects and landscapes, and has also been associated with thoughts of spirituality. We extend previous findings by showing that non-straight edges retain their influence on the selection of a "Spiritual & Life Journey" topic after scene identification removal. These results strengthen the implication of a causal role for the perception of low-level visual features on the influence of higher-order cognitive function, by demonstrating that in the absence of overt semantic content, low-level features, such as edges, influence cognitive processes.

[1] Chapter 2 has been published as:
Schertz, K.E., Kardan, O. & Berman, M.G. Visual features influence thought content in the absence of overt semantic information. (2020) *Attention, Perception, & Psychophysics*.

Introduction

A person's surrounding physical environment can influence various affective and cognitive processes, such as working memory and mood (McMahan & Estes, 2015; Stenfors et al., 2019). It has recently been shown that the physical environment can also influence thought content and valence (Lim et al., 2018; MacKerron & Mourato, 2013; Schertz et al., 2018). This may be one pathway for these effects, as thoughts in turn can influence mood and behavior (Killingsworth & Gilbert, 2010; Pennebaker & Beall, 1986). Interacting with natural environments, specifically, has been shown to have mental health benefits which may be related to changes in thought patterns (Mantler & Logan, 2015; Schwartz et al., 2019). For example, brief exposures to nature are associated with decreased rumination, a maladaptive pattern of self-referential thought associated with depression (Bratman et al., 2015). Several theories about the influence of different environments on cognition and affect, such as attention restoration theory (S. Kaplan, 1995) and the perceptual fluency account (Joye & van den Berg, 2011), have suggested that some of this influence may be the result of visual features in the environments.

Traditionally, visual features have been separated into high-level and low-level features based on the organization of the visual stream where low-level features are processed more posteriorly in the ventral visual stream, and more high-level features are processed more anteriorly in the ventral visual stream (DiCarlo & Cox, 2007). In this schema, high-level visual features (e.g., water, trees, houses, etc.) allow you to identify a scene or object in a meaningful way, and may require prior knowledge to be informative. Certain features of this type could apply to whole scenes, such as judgments of naturalness and aesthetic preference. Low-level visual features, on the other hand, can be color features (e.g. hue, saturation) or spatial features (e.g. edges), which physically define scenes and objects. Various domains of research, however, support the idea that “low-level” features may also convey semantic information (Berman et al., 2014; Edmiston & Lupyan, 2015; Kotabe et al., 2016; Oliva & Torralba, 2006). This is also supported by imaging research showing that activity in areas thought to be responsible for high-level processing can be partially accounted for by low- or mid-level features (Long et al., 2018).

Low-level features have also been shown to interact with higher-level visual information to influence interpretations of scenes (Ibarra et al., 2017; Kardan et al., 2016). Non-straight edges in particular have been shown to influence various types of cognition. For example, people prefer objects and scenes with a greater number of non-straight edges compared to straight edges (Bar & Neta, 2006; Kardan, Demiralp, et al., 2015). Non-straight paths are also rated to be more organic and engaging, and less goal-oriented than straight paths (Lockyer & Bartram, 2012; Loidl & Bernard, 2014).

A recent set of studies (Schertz et al., 2018) found that perceiving different visual features was associated with changes in thought content. The visual features investigated were perceived naturalness and non-straight edge density (NSED). The first study was an ecological topic-modeling study which analyzed journal entries from park visitors in order to correlate the topics expressed with the visual features of the parks. A ten topic model was found to be appropriate for the corpus of journal entries. It was found that visiting parks which contained higher NSED was correlated with people expressing more thoughts related to spirituality and one’s life journey. Not surprisingly, it was also found that visiting parks with higher rated naturalness was correlated with more thoughts about a topic related to “Nature”. The eight other topics generated in the topic model were not correlated with either of these visual features. Thus, an experimental follow-up study was conducted where participants were shown a broad range of environmental images that independently varied on perceived naturalness and NSED to see if thoughts of Nature and “Spiritual & Life Journey” were associated with these visual features, respectively. When viewing each image participants were asked which of the topics from the ecological study, operationalized as word clouds, best fit with the image. By utilizing these word clouds, it allowed for direct comparison to the first study. Additionally, it provided participants a way to think more abstractly about the images, instead of requiring a free-response, which might have encouraged more literal interpretations of the images. As hypothesized, it was found that the topic of Spiritual & Life Journey was chosen more for images higher in NSED, and the Nature topic was chosen more often for images high in perceived naturalness.

One limitation of the prior studies is that naturalness and NSED could be confounded by mediating semantic features, which could be responsible for the observed effects, meaning these effects may only be observed when NSED are viewed within a recognizable context. The studies we present here investigate this possibility by using abstract images with little to no semantic content. We created these stimuli with an edge scrambling procedure developed by Kotabe and colleagues (2016). Using these abstract stimuli, we could then examine if NSED, in the absence of overt semantic information, maintains its influence on the topic of Spirituality & Life Journey. This would demonstrate a more fundamental mechanism for “low-level” visual features influencing cognitive processes, while adding to the body of work showing that low-level features are constitutive of our semantic knowledge (Kiefer & Pulvermüller, 2012; Pulvermüller, 2013). Additionally, this work may lead to further insights into the mechanisms through which physical environments (such as natural spaces) may produce cognitive and affective benefits via the perception of visual information (Joye & van den Berg, 2011; Schertz & Berman, 2019).

We kept the experimental protocol as close to the original study as possible in order to allow for direct comparisons of effects for intact and scrambled images. Importantly, we were not interested in baseline topic selection, but rather how topics were selected differentially for different image categories. Thus, in accordance with the results of Schertz et al. (2018), we predicted that images with higher NSED would lead to a higher selection of the Spiritual & Life Journey topic, and that images with higher naturalness would lead to less selection of the Spiritual & Life Journey topic. We also predicted that the Nature topic would be chosen more under both conditions of high naturalness and high NSED.

General Method and Materials

Original Stimuli

We started with the 80 images that had been used as stimuli in Study 3 of Schertz et al. (2018). These images were from the SUN image database (Xiao et al., 2010), and were chosen to include a large range of outdoor locations. Original intact images are available at https://github.com/kschertz/TKF_MTurk. There were four groups of 20 images each (High/Low NSED x High/Low Naturalness), which were selected to best match on NSED and naturalness between groups while having naturalness and NSED be independent. Naturalness ratings had been previously collected as part of (Kotabe et al., 2017). The original groups of images, formed using intact image ratings, were used as the basis of analysis for all studies, after ensuring they remained valid by conducting the "Stimuli Rating Procedure" described below. Table 8 shows summary statistics for the four image groups. Naturalness and NSED were uncorrelated across all 80 images (r=0.06, p=0.58, 95% CI [-0.16, 0.27]).

Table 8

Summary of Means and Standard Deviations of Original Image Group Visual Features

	Low Naturalness		**High Naturalness**	
NSED	**Low**	**High**	**Low**	**High**
Naturalness	1.94 (0.25)	2.20 (0.39)	6.53 (0.49)	6.45 (0.50)
NSED	0.046 (0.02)	0.101 (0.01)	0.049 (0.02)	0.104 (0.01)

Note. Naturalness was rated on a 7-point Likert scale.

Scrambled Stimuli

For the current study, we used an edge scrambling process to create unidentifiable versions of the original images [as in (Kotabe et al., 2016)]. This process scrambles the edge map of an image by performing transformations that have no effect on the straightness or non-straightness of the edges, thus preserving the edge density of the original image to a high degree while the semantic content (e.g., objects) becomes unidentifiable. The correlation between the edge density of original images and generated scrambled versions in the current study was $r = .923$, $p <.001$ (95% CI [.88, .95]). The scrambled edge stimuli are available at https://osf.io/acvdz/.

The method of scrambling is described in (Kotabe et al., 2016); here we summarize the procedure in four steps (indicated by numbered process arrows in Figure 6). In Process 1, we started with an original image (Figure 6a) and created the edge map (Figure 6b). In parallel to this, we created two random matrices (Figure 6c) of the same size of the images (600x800) with each element (i.e., pixel) drawn from a binary random distribution of 0 or 1. These matrices were convolved (Figure 6, Process 2) with a median filter of size 30x40 pixels. Median filters replace values of individual pixels with the median value of all pixels inside the filter window (Pratt, 1978). Thus, this convolution creates larger patches of zeros and ones, placed at random locations across the matrices (henceforth referred to as random masks, depicted in Figure 6d). The size of the median filter (5% of image dimensions = 30x40) was selected through trial and error in a previous experiment to maximize the correlation between scrambled and original image edge density while also rendering objects unidentifiable (Kotabe et al., 2016). The edge map was then multiplied (dot product) with each of the random masks (Figure 6, Process 3). This creates two stimuli, each with half of the original edges on average (Figure 6e). One of the resulting images was flipped on the x-axis, and then the two images were overlaid on each other (Figure 6, Process 4). The final result is a stimulus with approximately the same amount of edges as the original image and with no change in straightness of the edge components (Figure 6f). Afterward, we had the generated scrambled stimuli re-rated for naturalness by new participants. We obtained these new ratings to determine if naturalness and NSED remained uncorrelated, as they were in the original study with intact scenes.

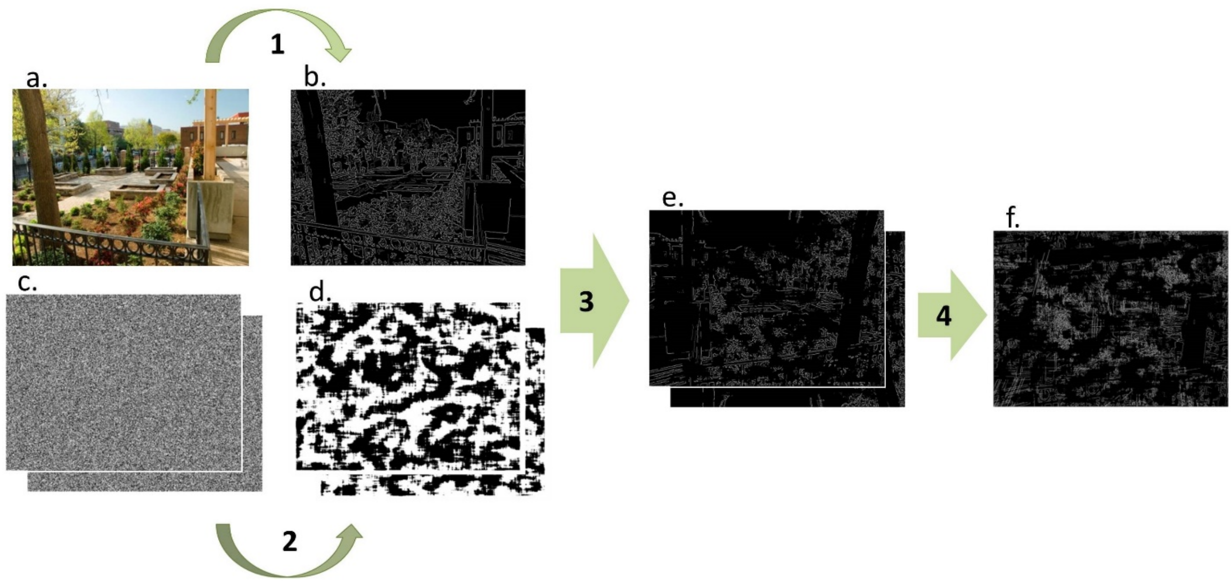

Figure 6. Stimuli creation process. Process 1: Edge map created from original image. Process 2: Two random masks created having on average half a surface of 1s and half a surface of 0s. Process 3: Edge map is multiplied (dot product) with the two masks. Process 4: One image is flipped over the x-axis; the two images are overlaid on each other. a) Original Image; b) Edge map; c) Random matrices of 0s and 1s; d) Random masks; e) Two images, each with half of the total edges; f) Final scrambled stimulus.

Stimuli Rating Procedure

Naturalness ratings were obtained for the scrambled stimuli using Amazon Mechanical Turk, through the TurkPrime platform (Litman et al., 2017). Fifty participants rated all 80 of the images, using a 7-point Likert scale, in accordance with the original naturalness rating procedure.

We first measured inter-rater reliability, as a prior study found that inter-rater reliability of perceived naturalness ratings for scrambled edge images were not high enough to be usable (Kotabe et al., 2017). Here, inter-rater consistency was determined using Shrout and Fleiss' (1979) Case 2 intraclass correlation (ICC), and was found to be ICC = 0.45, 95% CI [0.37, 0.53]. This estimate is considered "fair" by conventional standards (Cicchetti, 1994) and could be used. The naturalness ratings of the scrambled stimuli were significantly correlated with the naturalness ratings of the original images ($r = 0.82$, $p < 0.001$, 95% CI [0.74, 0.88]). However, the factors naturalness and NSED were no longer uncorrelated ($r = 0.40$, $p < 0.001$, 95% CI [0.20, 0.57]). Figure 7 shows the distribution of original and new ratings by group.

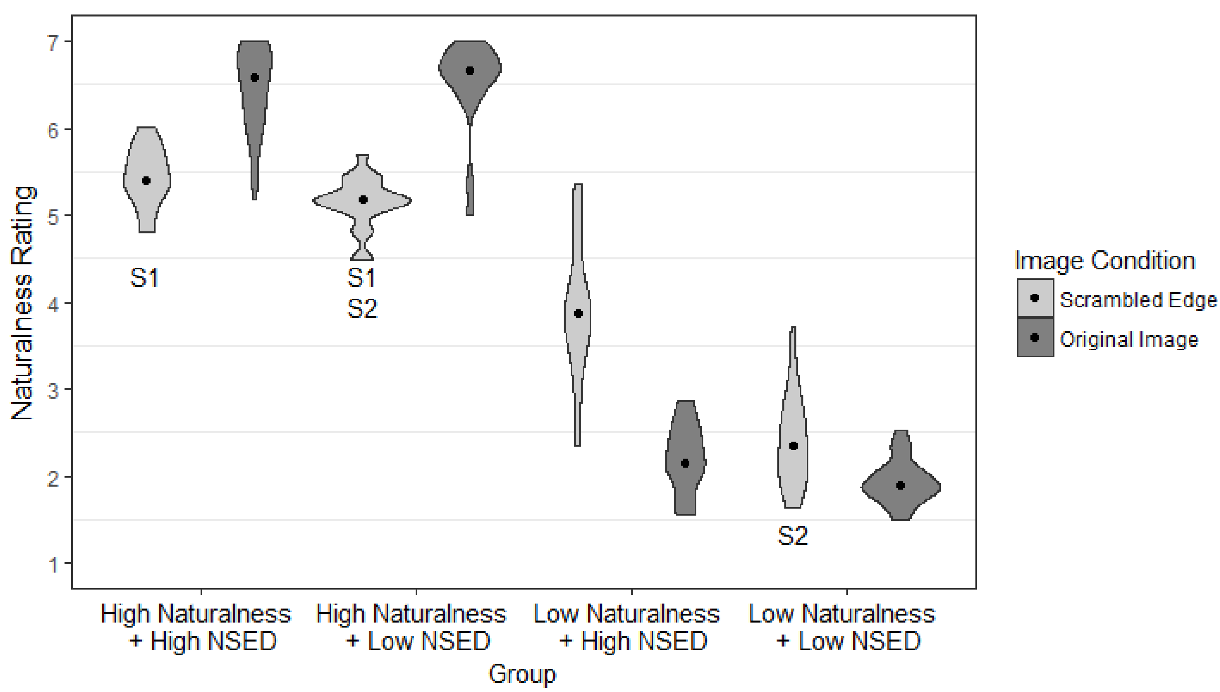

Figure 7. Violin plot of original and scrambled edge naturalness ratings by group. Black dots represent the median rating of each group. S1 indicates image groups used in Study 1 and S2 indicates image groups used in Study 2.

As naturalness and NSED were correlated in the new ratings, presenting all 80 images in the identical procedure, and using the same logistic regression, as Study 3 in Schertz et al. (2018) (Topic ~ Naturalness*NSED + (1|Subject)) would not accurately determine independent effects of these two features on thought content. Thus, we had to depart from our pre-registered analysis plan, in which we planned to present all images together and conduct one logistic regression. We decided to conduct two studies, each using two of the original four image groups, to investigate the main effects of a) NSED and b) naturalness on thought content separately. Our hypotheses regarding the independent influences of NSED and naturalness on thought content remain as proposed in the pre-registration.

In the first study, to determine the influence of NSED, participants saw the 'high naturalness + high NSED' and 'high naturalness + low NSED' image groups. Due to the range of new ratings, the perceived naturalness of these groups *is statistically* different ($t = 3.0$, $p = .004$). However, we do not believe that there is a *meaningful* difference in naturalness between the groups. That is, on the 7-point Likert scale, the 'high naturalness + high NSED' group mean for naturalness is 5.4, while the 'high naturalness + low NSED' group mean for naturalness is 5.1, and the group distributions greatly overlap (see Figure 2). However, to ensure this statistical difference did not influence the results, we repeated the analysis on a subset of images which did not statistically differ in perceived naturalness. To create these subsets, we removed the three highest rated images from the 'high naturalness + high NSED' group and the three lowest rated images from the 'high naturalness + low NSED' group. This created the largest subset of images that did not statistically differ in perceived naturalness ($t = 1.5$, $p = .14$). Images removed from analysis were: NL05, NL15, NL17, NH11, NH15, and NH19 (images available with online materials).

In the second study, to determine the influence of naturalness, participants saw the ‘high naturalness + low NSED’ images and the ‘low naturalness + low NSED’ images. With these two groups, NSED is not significantly different, and naturalness ratings do not overlap (see Figure 7). With this design we were able to look separately at main effects for NSED (Study 1) and naturalness (Study 2).

Thought Content Topics

Although we only have a priori hypotheses about two topics (Nature and Spiritual & Life Journey), in order to maintain experimental control and the ability to directly compare the results of scrambled images to intact images, we used the same topics as in Schertz et al. (2018) which were generated from the topic modeling of Study 1 from Schertz et al. (2018). That study used Latent Dirichlet Allocation (LDA), which infers underlying topics from textual documents. A ten-topic model was generated from approximately 12,000 journal entries written by park visitors. To determine how positive or negative each topic was, we used valence ratings from (Warriner et al., 2013), which vary from one (most negative) to nine (most positive) with five being neutral. Using the top ten words in each topic, we found that the mean valence rating was positive for all topics ($M= 6.60$, $SD=0.92$), with no significant differences in valence across topics, $F(1,9)=1.22$, $p=.29$ (see Table S2.1 for valence ratings for each topic). These 10 topics were displayed as word cloud visualizations (see Figure 8). The word clouds show the ten most prevalent words for each topic with the relative size of each word being proportional to its prevalence in the topic. As these word clouds are data-driven, they could not be equated for how frequently each of their constituent words is used or experienced in daily life (see Table S2.1). As such, we conducted an exploratory analysis to investigate whether word frequency correlated with topic selection for both Study 1 and Study 2. These word clouds were used in the forced-choice task of Study 3 of the same paper, i.e., Schertz et al., 2018. Labels for each topic were provided by participants in a separate study who saw each of the word clouds, in random order, and were asked to provide 3-5 labels for each one. We used a simple frequency analysis to choose the final label for each word based on the most frequently listed word, and selected modifiers from the top choices for clarity. See Schertz et al. (2018) for further details on LDA, parks included in the topic modeling, and participant information.

Figure 8. Word clouds as displayed to participants. Topic were labeled as the following: a. Family; b. World & Peace; c. Life & Emotions; d. Nature; e. Celebration; f. Park; g. Time & Memories; h. Art; i. Religion; j. Spiritual & Life Journey. (Re-print from Schertz et al. (2018)).

Transparency & Openness

The data and materials (i.e. images) for this manuscript are available at https://osf.io/acvdz/. Original intact images are available at https://github.com/kschertz/TKF_MTurk. Studies 1 and 2 were pre-registered (https://osf.io/s49ru).

Testing the effect of NSED on thought content (Study 1)

Method and materials

Participants

100 US-based adults (64 male, 35 female, 1 other) were recruited from the online labor market Amazon Mechanical Turk, using TurkPrime (Litman et al., 2017). Sample size was

selected to match Study 3 in (Schertz et al., 2018), which had originally been calculated as sufficient to detect a small effect. Ages ranged from 21 to 72 (M = 35.6, SD = 9.9). The median experiment duration was 8.6 minutes and participants were compensated for their participation. All participants consented to voluntary participation using guidelines established by the Institutional Review Board of the University of Chicago.

Procedure

Participants were first given instructions for the task. They were told there would be 40 images shown, and that for each image they were to pick a set of words that best went with the image. They were also told there would be attention checks during the task. For each trial, a participant saw one image and 10 word clouds. Images were 800 x 600 and presented in the center of the screen on a white background. See Figure S2.1 for a sample presentation screen. The participants were allowed to select only one word cloud per image. Each trial lasted for at least 6 seconds; after 6 seconds, the image and word clouds remained on-screen until the participant made a response. Images were presented in random order, and all participants saw every image. Word cloud location was not randomized, due to feedback from participants in the previous study who expressed frustration over difficulty in finding their desired word cloud as they are not simple labels. For each attention check, a word cloud was shown in place of an image and participants were instructed to choose that word cloud as their selection for the trial. As described above, participants in this study saw the 20 images from ‘high naturalness + high NSED’ category and the 20 images from ‘high naturalness + low NSED’ category.

Regression Analysis

We conducted a mixed logistic regression analysis, which allows us to take advantage of the benefits of ordinary logistic regression (McCullagh, 2018) for binomial data while also being able to model random effects. Mixed logistic regression is a type of Generalized Linear Mixed

Model (Breslow & Clayton, 1993) which allows for binary dependent variables, and binary or continuous independent variables. In mixed models, dependent variables are predicted with a linear combination of fixed and random effects. Here, we accounted for subject level differences in topic selection by modeling subject as a random effect, which makes it more suitable than a chi-square test. We also account for images as a random effect, to ensure results were generalizable beyond the specific images used. All models were run in R, using the glmer function from the lme4 library (Bates et al., 2014).

Results

Average topic selection is shown in Figure 9. Guided by the results of Schertz et al. (2018) Study 3, we ran logistic regression models predicting the selection of the "Spiritual & Life Journey" and "Nature" topics. In each model, NSED was the independent variable, with subject as a random intercept. For the "Spiritual & Life Journey" topic, NSED had a significant effect, while results were not significant for the "Nature" topic (see Table 9). Participants were 1.5 times more likely to choose "Spiritual & Life Journey" for images high in NSED (Odds Ratio (OR) 95% CI [1.2, 1.8]). These results held when we repeated the analysis using the naturalness-matched subset of images (see Table 10). See Table S2.2 for logistic regression for all other topics. We did not find a significant correlation between word frequencies and topic selection ($r=-0.47$, $p=0.16$, 95% CI [-0.85, 0.22]).

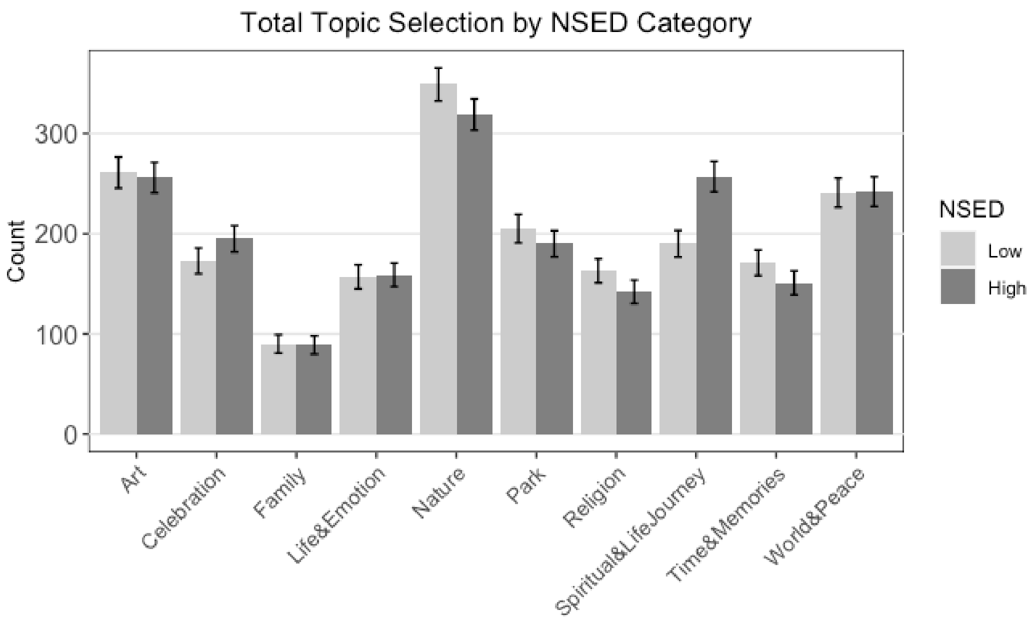

Figure 9. Total topic selection across all participants by images' NSED category for Study 1. Note. Error bars represent bootstrapped standard deviation.

Table 9

Logistic Regression Models predicting Spiritual & Life Journey and Nature topics using NSED

	Spiritual & Life Journey				**Nature**			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.56	.14	-17.91	<.001	-1.77	.09	-20.44	<.001
NSED	0.38	.15	2.45	.01	-0.11	.09	-1.30	.19
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.64		0.80		0.32		0.57	
Image (n=40)	0.13		0.36		0.03		0.16	
AIC	2626.3				3547.9			
Log Likelihood	-1309.2				-1770.0			
Observations	4000				4000			
Δ AIC	-3.6				0.7			
X^2(1)	5.52				1.22			

Note. Δ AIC and X^2 values are based on comparison of full model to null model with grand mean and random intercepts for subjects and images as predictors (DV ~ 1 + (1|Subject) + (1|Image))

Table 10

Logistic Regression Models predicting Spiritual & Life Journey and Nature topics using NSED on Naturalness-matched subset of images

	Spiritual & Life Journey				**Nature**			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.57	.15	-17.31	<.001	-1.67	.10	-16.31	<.001
NSED	0.39	.16	2.38	.017	-0.11	.11	-.939	.35
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.65		0.81		0.37		0.61	
Image (n=34)	0.11		0.34		0.03		0.18	
AIC	2211.6				3025.5			
Log Likelihood	-1101.8				-1508.8			
Observations	3400				3400			
Δ AIC	-3.1				1.2			
$X^2(1)$	5.17				0.86			

Note. Δ AIC and X^2 values are based on comparison of full model to null model with grand mean and random intercepts for subjects and images as predictors (DV ~ 1 + (1|Subject) + (1|Image))

Testing the effect of Naturalness on thought content (Study 2)

Methods and materials

Participants

100 US-based adults (65 male, 35 female) were recruited from the online labor market Amazon Mechanical Turk, using TurkPrime (Litman et al., 2017). Sample size was selected to match Study 3 in Schertz et al. (2018), which had been calculated as being sufficient to observe a small effect. Ages ranged from 21 to 70 (M = 37.8, SD = 11.1). The median experiment duration was 8.9 minutes and participants were compensated for their participation. All participants consented to voluntary participation using guidelines established by the Institutional Review Board of the University of Chicago.

Procedure

The same procedure was used as in Study 1. In this study, the two groups of images used were the ‘low naturalness + low NSED’ category (20 images) and the ‘high naturalness + low NSED’ category (20 images), for a total of 40 images. As shown above (Figure 7), these groups are matched on NSED but differ on perceived naturalness ratings, which allowed us to test for the independent effect of naturalness on topic selection.

Regression Analysis

The same mixed logistic regression analysis was conducted as in Study 1.

Results

Average topic selection is shown in Figure 10. As in Study 1, we ran logistic regression models predicting the selection of the “Spiritual & Life Journey” and the “Nature” topics. Naturalness was the independent variable and subject was a random intercept. For both topics, naturalness had a significant effect, in the predicted direction (see Table 11). For the topic “Nature”, naturalness had a significant positive effect. Participants were 3.7 times more likely to choose the “Nature” topic for images with high rated naturalness (OR 95% CI [3.1, 4.6]). Naturalness also had a significant effect for the “Spiritual & Life Journey” topic, whereby participants were 2.4 less likely to choose “Spiritual & Life Journey” for images with high naturalness (OR 95% CI [2.0, 3.0]). See Table S2.3 for logistic regression for all other topics. As in Study 1, we did not find a significant correlation between word frequencies and topic selection (r=-0.30, p=0.38, 95% CI [-0.78, 0.40]).

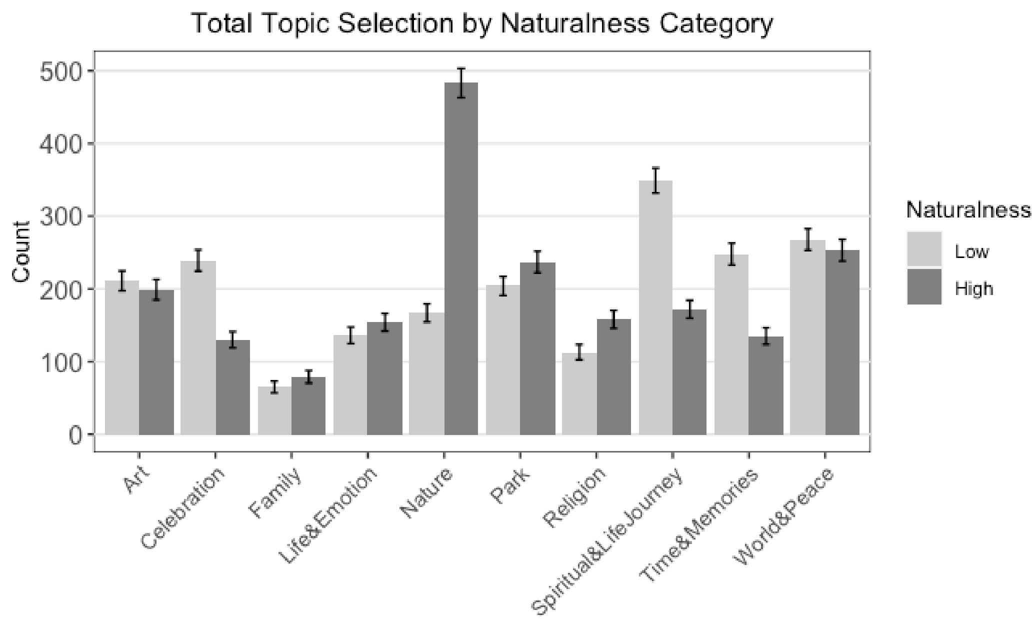

Figure 10. Total topic selection across all participants by images' Naturalness category for Study 2. Note. Error bars represent bootstrapped standard deviation.

Table 11

Logistic Regression Models predicting Spiritual & Life Journey and Nature topics using Naturalness

	Spiritual & Life Journey				**Nature**			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-1.72	.12	-14.61	<.001	-2.60	.12	-21.48	<.001
Naturalness	-0.89	.14	-6.48	<.001	1.34	.12	11.04	<.001
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.55		0.74		0.46		0.67	
Image (n=40)	0.08		0.29		0.05		0.22	
AIC	2877.4				3261.3			
Log Likelihood	-1434.7				-1626.6			
Observations	4000				4000			
Δ AIC	-74.8				-200.8			
X^2(1)	29.2				204.8			

Note. Δ AIC and X^2 values are based on comparison of full model to null model with grand mean and random intercepts for subjects and images as predictors (DV ~ 1 + (1|Subject) + (1|Image))

Testing words within 'Spiritual & Life Journey' (Study 3)

After finding significant results for the Spiritual & Life Journey topic in Study 1 and Study 2, we wanted to ensure that these results were not driven solely by the word 'labyrinth', which is the largest and potentially easiest to read word in the world cloud, as well as one of the more concrete words in this generally abstract concept. To test this, we ran a follow up study following a similar procedure to Study 1 and Study 2, however participants chose between the words within the Spiritual & Life Journey topic. We then calculated the odds ratio for each word being chosen between the two groups of images. This is an exploratory study that was conducted as part of the peer-review process and not pre-registered.

Methods and materials

Participants

100 US-based adults were recruited from the online labor market Amazon Mechanical Turk, using TurkPrime (Litman et al., 2017). Participants were pseudo-randomly assigned to see images from Study 1 (Testing NSED) or Study 2 (Testing naturalness). Participants from Study 1 and Study 2 were excluded from participating. Data collection failed for one participant, leaving 99 participants (42 female, 56 male, 1 other). Ages ranged from 21 to 68 ($M = 38.0$, $SD = 11.4$). For race/ethnicity, 66 identified as White, 17 identified as Black/African American, 7 identified as Asian/Asian American, 4 identified as Hispanic/Latino, 3 identified as multiple ethnicities, and 2 chose not to respond. The median experiment duration was 13 minutes and participants were compensated for their participation. All participants consented to voluntary participation using guidelines established by the Institutional Review Board of the University of Chicago.

Procedure

The procedure was similar to the procedure used in Study 1 and Study 2. Participants saw 40 images total, either 'high naturalness + high NSED' category (20 images) and 'high naturalness + low NSED' category (20 images), as in Study 1, or 'low naturalness + low NSED' category (20 images) and 'high naturalness + low NSED' category (20 images), as in Study 2. For each trial, the image was seen for four seconds before the answer options appeared below. For the answer options, they saw the nine words within the Spiritual & Life Journey topic: center, feel, god, labyrinth, life, path, peace, place, and walk. Of note, the word cloud also contains the word 'walked.' It was decided that including both 'walk' and 'walked' would be confusing. Words were displayed in random order for each trial. Participants were asked to choose which of the words best went with the image. They were allowed to choose as many as they wanted, with the requirement that they pick at least one. After choosing their answers, they could proceed to the next trial.

Odds Ratio Analysis

As we were interested in the differential selection of words between image groups, we determined the Odds Ratio (OR) for each word being selected for one category of images compared to the other category of images. This was calculated by first counting the number of times each word was selected for each image group. For images from Study 1, we then divided this count for 'high naturalness + high NSED' by the count for 'high naturalness + low NSED.' For images from Study 2, we divided the count for 'low naturalness + low NSED' by the count for 'high naturalness + low NSED.' In this way, an OR greater than 1 would indicate that the word was chosen more in the same direction as our effects seen in Study 1 and Study 2. For each word, we then conducted a one-tailed permutation test to determine if the OR was significantly higher than a null distribution.

Results

Study 1 Images

Table 12 shows the calculated Odds Ratios for each of the nine words within the Spiritual & Life Journey topic for high NSED images compared to low NSED images. Feel and labyrinth were chosen significantly more for images with high NSED compared to low NSED, while life was marginally significant (p=.056).

Table 12

Odds Ratios for selection of words within 'Spiritual & Life Journey' for high NSED images compared to low NSED images

Word	Total Number of Times Chosen	Odds Ratio†	p-value
Center	286	0.62	1
Feel	228	1.4	0.004 **
God	177	0.77	0.961
Labyrinth	229	1.57	0.0005 **
Life	360	1.14	0.056 •
Path	374	0.78	0.998
Peace	229	1.04	0.336
Place	405	1.05	0.270
Walk	284	0.91	0.803

Notes. † Odds Ratio is selection for high NSED images divided by selection for low NSED images. Alpha values: • indicates significant at .1, ** indicates significant at .01 in permutation test.

Study 2 Images

Table 13 shows the calculated Odds Ratios for each of the nine words within the Spiritual & Life Journey topic for low naturalness images compared to high naturalness images. Center, labyrinth, and place were chosen significantly more for images with low naturalness compared to high naturalness.

Table 13

Odds Ratios for selection of words within 'Spiritual & Life Journey' for low naturalness images compared to high naturalness images

Word	**Total Number of Times Chosen**	**Odds Ratio†**	**p-value**
Center	412	1.42	0.0005**
Feel	323	0.68	0.999
God	209	0.46	1
Labyrinth	327	1.75	0.0005**
Life	356	0.65	1
Path	371	0.90	0.836
Peace	374	0.53	1
Place	579	1.87	0.0005**
Walk	317	0.87	0.906

Notes. † Odds Ratio is selection for low naturalness images divided by selection for high naturalness images. Alpha values: • indicates significant at .1, ** indicates significant at .01 in permutation test.

Discussion

This study found a significant relationship between viewing low-level visual features, in the absence of overt semantic content, on thought content, as operationalized through the selection of topically organized word clouds. We found that participants were more likely to select the Nature topic for images previously rated as highly natural (but that contain no overt nature content). More interestingly, we also found that participants were more likely to select the Spirituality & Life Journey topic for images with high NSED (compared to low NSED), even when there is no overt semantic content. Participants were also less likely to select Spiritual & Life Journey for images with high rated naturalness (compared to low naturalness). The only effect from Study 3 of Schertz et al. (2018) that we did not replicate was the positive association of NSED and the Nature topic in the forced-choice task; here, the results were not significant. However, this is not inconsistent with the ecological study of Schertz et al. (2018, Study 1), where there was also a non-significant relationship between NSED and thoughts about nature.

The odds ratio for NSED effect on Spiritual & Life Journey (OR = 1.5, 95% CI [1.2, 1.8]) was similar to the original study (OR = 1.6, 95% CI [1.2, 2.1]) which indicates a context-independent effect of NSED on this topic. On the other hand, the effect for perceived naturalness on the selection of Nature had a much larger odds ratio (OR = 3.7, 95% CI [3.1, 4.6]) than the original study (OR = 2.0, 95% CI [1.7, 2.4]) (Schertz et al., 2018, Section 4.2). This might be an effect due to the lack of other semantic information, and perhaps perceived naturalness becoming a more salient cue. Supporting this idea, the Nature topic in Study 2 was the most chosen topic overall, whereas in the original study it was the third most chosen.

There are several lines of research providing ideas for why we have now observed the association between the Spiritual & Life Journey topic and the perception of NSED in several studies. Forysthe and colleagues proposed that visual complexity (which can be caused by high NSED, for example see (K. Van Hedger et al., 2019)) can increase cognitive disfluency (Forsythe et al., 2011), which in turn can increase deep and abstract thinking (Alter, 2013). From a separate lens, as straight edges are viewed as more aggressive than non-straight edges (Bar & Neta, 2007), images with higher NSED may become associated with more calm and relaxed thoughts. This is also supported by the associations between the perception of non-linear motion and increases in calming affect (Bartram & Nakatani, 2010).

It is also important to consider the words that make up the topic word cloud, as participants were not told the names of the word clouds (e.g., Spiritual & Life Journey, Family, World & Peace, etc.). As non-straight paths are generally viewed as more organic and engaging than straight paths (Lockyer & Bartram, 2012), connections to words from the Spiritual & Life Journey word cloud such as *life*, *path*, *walk*, and *feel* may have been evoked for these images. Likewise, the maze-like structures that appear in images with high NSED may be responsible for thoughts of *labyrinths* (Artress, 1996), another word in the Spiritual & Life Journey word cloud. The results from Study 3 showed that particular individual words from the Spiritual & Life Journey word cloud, such as *feel*, *life*, and *labyrinth* were chosen more often for the high NSED images, which supports these ideas.

This study adds to the body of work showing that viewing features of different environments can influence behavior, thoughts, and cognition (Kotabe et al., 2016; Kuo & Sullivan, 2001a). Additionally, it provides evidence that low-level visual features, and the information that those visual features convey, could be a mechanism for this influence on thought (Schertz & Berman, 2019). These results also challenge the notion of a strict separation between visual information and semantic knowledge. The naturalness information that remains in images containing only edges seems to be sufficient to induce thoughts about nature. Likewise, isolated edges also retain their influence on thoughts about spirituality and life journey. To further investigate this mechanism, future work could examine free responses to these images, as well as how other low-level features in isolation influence other thought topics. As the utility of low-level visual features in designing psychologically salubrious interiors and exteriors are becoming more relevant in architecture and urban planning (Coburn et al., 2019), expanding this literature will also have immediate applications.

There are several limitations to this study. The first is that we could not investigate the interactions between naturalness and NSED, as based on the naturalness ratings of our scrambled stimuli, these features were no longer uncorrelated. Given that these features are often correlated in real-world stimuli (Berman et al., 2014; Ibarra et al., 2017), and that NSED is almost necessarily used to judge naturalness when edges are the only feature remaining in an image, it may be difficult to create a set of scrambled-edge stimuli where NSED and perceived naturalness are uncorrelated. Additionally, this was a forced-choice task using topics from the original study (i.e., Schertz et al., 2018). By operationalizing thought content in this manner, the task does not ask participants to generate their own thoughts per se. It does, however, have the strength of providing a framework for participants to think more abstractly about these images, which is not trivial because tapping into these potential thoughts via open-ended free-responding would likely yield very literal descriptions. However, it would be important for future research to employ free response tasks to investigate the influence of these features on self-generated thoughts. Future research could also investigate how these isolated low-level visual features influence other cognitive effects observed due to different physical environments, such as the benefits seen in working memory after short exposures to pictures of nature (Berto, 2005; Stenfors et al., 2019).

In conclusion, this study provides an important step in understanding the influence of perceiving low-level visual features on higher-level cognitive processes. We found that scrambled-edge images were consistently rated for perceived naturalness and that these ratings significantly correlated with the original images' naturalness ratings. We also found that these scrambled-edge stimuli maintained their influence on thought content in the absence of overt semantic information. Thus, the mere perception of low-level visual features of an environment is important to consider when evaluating the cognitive influence of both natural and urban spaces on behavior, thought, and cognition.

CHAPTER 3: ENVIRONMENTAL INFLUENCES ON AFFECT AND COGNITION: A STUDY OF NATURAL AND COMMERCIAL SEMI-PUBLIC SPACES

Abstract

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

Introduction

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

As much of the world is industrialized and urbanized, the public and semi-public spaces in cities are important places to consider as locations where individuals are spending time outside of their work and home and thus may impact their wellbeing (Carr et al., 1992; Oldenburg & Brissett, 1982). These spaces, however, belong to a variety of categories and have been designed for a multitude of more specific purposes. Public places include outdoor locations such as plazas, parks, and playgrounds, as well as indoor locations such as transit stations, nature conservatories, and shopping malls. In this paper we focus on how various measures of thoughts, affect, and cognitive performance varied between two indoor semi-public spaces, a nature conservatory and a large indoor mall.

One important feature that public spaces might have is their ability to improve or alter thought content. Thought content is an important part of everyone's daily lived experience

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

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

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

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

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

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

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

In this study we found that during walks in the conservatory participants felt more positive and creative, while also reporting thought content that was more positive and exciting and more about the past. After participants walked in the mall they reported higher feelings of impulsivity and more thoughts about the future. There was also evidence of improvements in cognitive performance after the conservatory walk compared to the mall walk, which replicates prior work (Berman et al., 2008; Bourrier et al., 2018; Stevenson et al., 2018; S. C. Van Hedger et al., 2018). Lastly, there were some relationships between trait personality measures and changes in thought content. Overall, these results show that a brief walk in a conservatory versus a commercial mall yielded benefits in thought content, mood, and cognitive processing.

Methods

Participants

A total of 99 participants participated in the study from October 2018 through April 2019. The participants were either University of Chicago students or adults from the surrounding communities, recruited through Facebook or the University's SONA Research Participation System. Participants ranged in age from 18 to 39, with a mean age of 22. There were 39 men, 58 women, and 2 participants who selected 'other' for gender. 31 participants identified as white/Caucasian, 31 identified as Asian/Asian American, 16 identified as Hispanic, Latino, or Chicano, 15 identified as Black/African American, 5 identified as multiple ethnicities and 1 participant identified as another race/ethnicity. Data collection issues resulted in the loss of three subjects' data and 10 participants did not return for the second session of the two-part study. This resulted in full analyzable data for 86 participants. This research was approved by the Institutional Review Board of the University of Chicago. Sample size was determined primarily through resource constraints (e.g., time, money) but is similar to other studies examining the effects of nature exposure on affect (McMahan & Estes, 2015).

Locations

The conservatory study location was the Garfield Park Conservatory (referred to as 'conservatory' throughout) located in the Garfield Park neighborhood of Chicago (https://garfieldconservatory.org). The mall location was the Water Tower Place mall (referred to as 'mall' throughout) located in the Near North neighborhood of Chicago (https://www.shopwatertower.com/en.html). See Figure 11 for a sample scene from each location.

Figure 11. Example images of Garfield Park Conservatory (left) and Water Tower Place mall (right). Images from Wikimedia Commons (Jrissman, 2010; Kenraiz, 2016).

Procedure

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

When participants arrived at the laboratory building for each session, they were met by research assistants and directed to a shuttle bus. Research assistants collected participants’ personal mobile devices (so that they would not be distracted by their own mobile devices during the walks) and distributed the experimental cell phones (Moto G5 Androids). All tasks during the study sessions were completed on these experimental phones. Participants completed the baseline survey and working memory task (dual n-back) on the bus while it was stationary at the laboratory building. Headphones were distributed for use during the working memory task. The bus then drove participants and research assistants to one of the study locations, which were both approximately 30 minutes away from the laboratory. Upon arrival at the study location, participants were instructed to explore the environments and answer survey questions on the experimental cell phone when prompted. Participants were prompted by a timer on the cell phone to complete the ambulatory survey after 20 minutes (Survey 1), 40 minutes (Survey 2), and 60 minutes (Survey 3). After completing the third survey, participants were directed to meet the research assistants at the entrance. They were then instructed to complete the working memory task again, which was completed in the lobby area of the locations. Finally, the shuttle bus drove everyone back to the laboratory building. Each session lasted approximately 2-2.5 hours. Figure 12 shows a diagram representation of the study procedure.

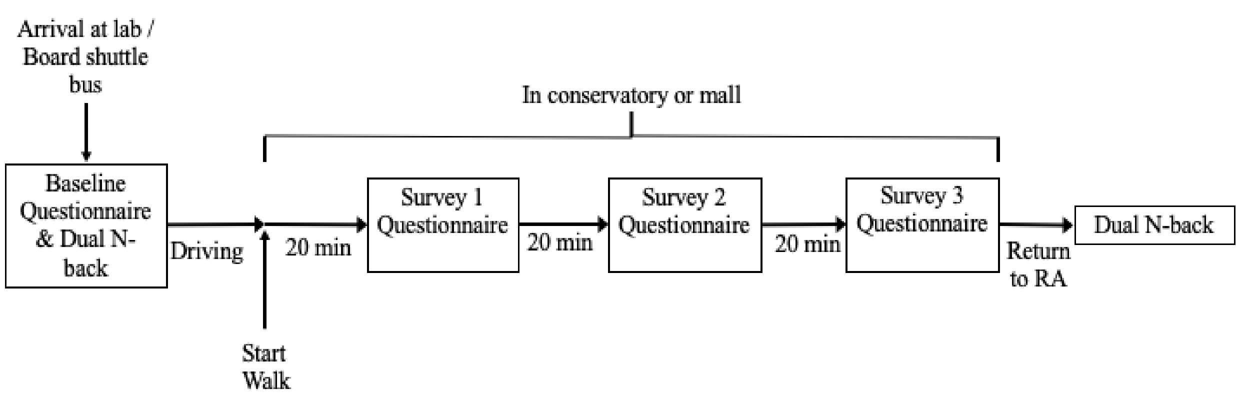

Figure 12. Study Procedure.

Survey Questions

Trait Questionnaire

In addition to providing demographic information, participants responded to a short form Big Five inventory (mini-IPIP) (Donnellan et al., 2006), the Reflection-Rumination Questionnaire (RRQ) (Trapnell & Campbell, 1999), the Subjective Vitality Score (SVS) (Ryan & Frederick, 1997), the Valuing Emotions (VE) scale (Mangelsdorf & Kotabe, 2017), the Trait Rash Impulsivity Scale (TRIS) (Mayhew & Powell, 2014), and the 3-question loneliness scale (Hughes et al., 2004).

Baseline Questionnaire

Upon arrival to each study session, before being transported to the study locations, participants filled out the baseline questionnaire. Participants were asked questions about their most recent thought including its valence (e.g., was it exciting, negative), and when in time it was focused (e.g., focused in the past, present, or future). They also answered questions about their general affective state (i.e., positive affect and negative affect), feelings of boredom and creativity, and impulsive buying. The questions about impulsive buying were taken from the Buying Impulsiveness Scale (Rook & Fisher, 1995), but framed as state rather than trait measures (see Supplemental Table 1 for exact wording). Other questions were also asked that are not analyzed in this manuscript. The full list of questions and possible answers is shown in Supplemental Table 1. Due to a coding error, Likert scales in the baseline questionnaire went from 0-7 while Likert scales in the ambulatory questionnaire went from 0-10. For all analyses, baseline responses were rescaled to 0-10.

Ambulatory Questionnaire

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

Cognitive Task

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

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

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

Statistical Analyses

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

All models had regularizing priors. Regularizing priors prevent models from overfitting to the sample by slowing the model’s rate of learning from the data. Full specification of the models, including their priors, is shown the Results section for each variable. Every model was run with 10,000 draws and 1,000 warmup draws in four Markov Chain Monte Carlo (MCMC) chains, for a total posterior distribution of 36,000 post-warmup draws. We summarize the posterior distributions by reporting the 89% percentile intervals (PI). PIs may also be referred to as quantile intervals and indicate the probability mass centered around the mean of the posterior distributions. Since PIs are not the same as frequentist confidence intervals, the 89th percentile interval was chosen to avoid both conscious and subconscious attempts at hypothesis testing that may occur if presented with a conventional 95% interval, as suggested by McElreath (McElreath, 2020).

Transparency and Openness

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. All data and analysis code are available at https://osf.io/npwrj/. Data were analyzed using R, version 3.6.3 (R Core Team, 2017) using the 'brms' package (Bürkner, 2017). This study's design and its analysis were not pre-registered. Additional dependent measures were collected during this study that are not reported here; these variables were not the focus of this manuscript and will be analyzed in the future. The full list of dependent measures is shown in Table S3.1.

Results

Thought Content

Temporal Aspects of Thought

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

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

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

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

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

There was no evidence of interactions between surveys and condition for reporting thoughts about the present or thoughts with no time aspect, see Figure 13 and Table S3.2.

Although able to, participants did not often select more than one choice for the time aspect; the multi-choice models are presented in the supplementary materials (Table S3.3).

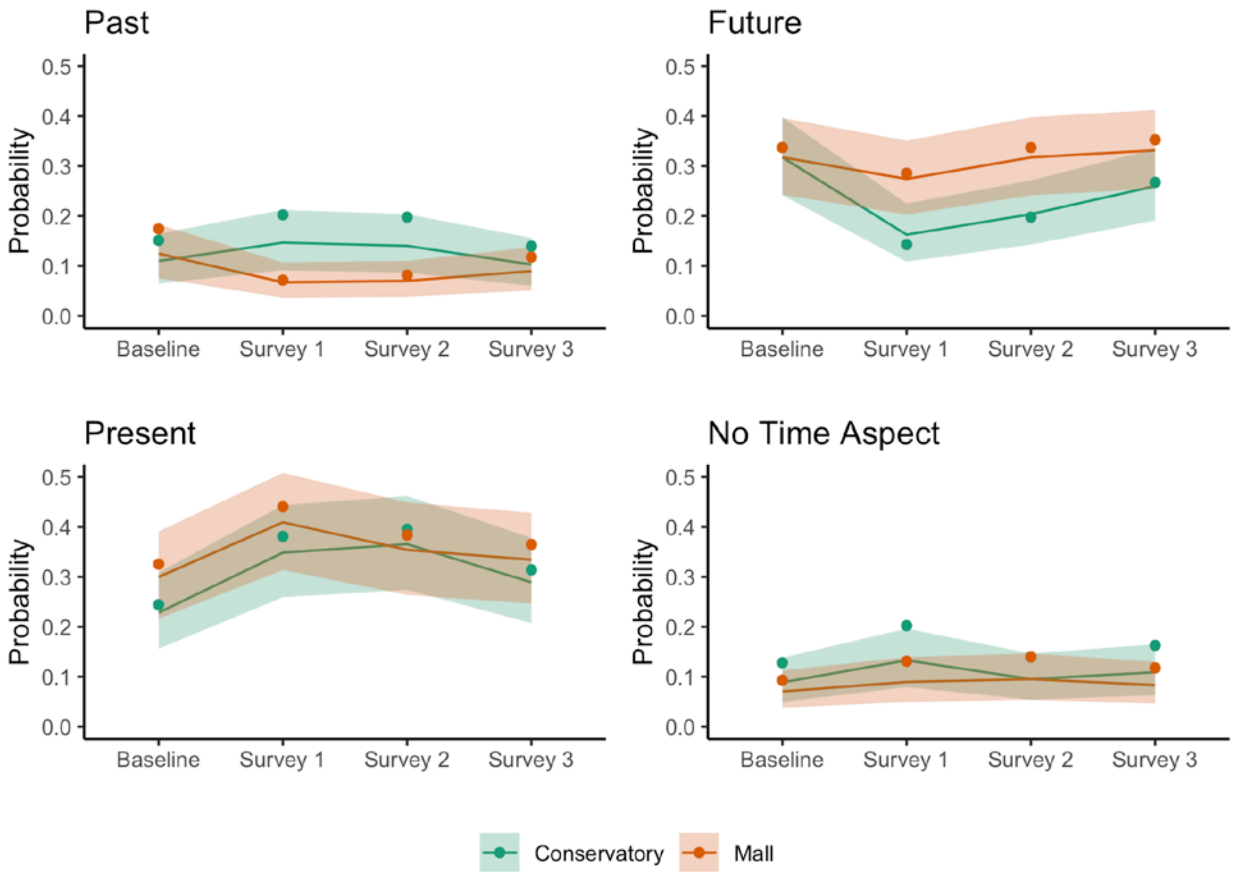

Figure 13. Observed and modeled selection of temporal aspect of thoughts. Points are observed probabilities from the raw data. The fitted line is the logistic regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Valence of Thought

Participants rated their thoughts on seven dimensions – deep, exciting, imaginative, negative, positive, spontaneous, and stressful. After using principal component analysis for data reduction, we used the first and second principal components (PC) as the dependent variables in our linear regression models. The first PC accounted for 40% of the variance across the seven dimensions. Ratings of exciting and positive showed the strongest loadings overall, with imaginative, deep, and spontaneous also loading positively, and negative and stressful loading negatively. We refer to this first PC as positive/exciting thinking. The second principal component accounted for 25% of the variance in the seven dimensions. This PC mostly reflected highly negative and stressful ratings of thoughts, with deep, imaginative and spontaneous also loading positively. We refer to this second PC as negative/stressful thinking. Loadings of the seven dimensions onto these two PCs are shown in Figure 14.

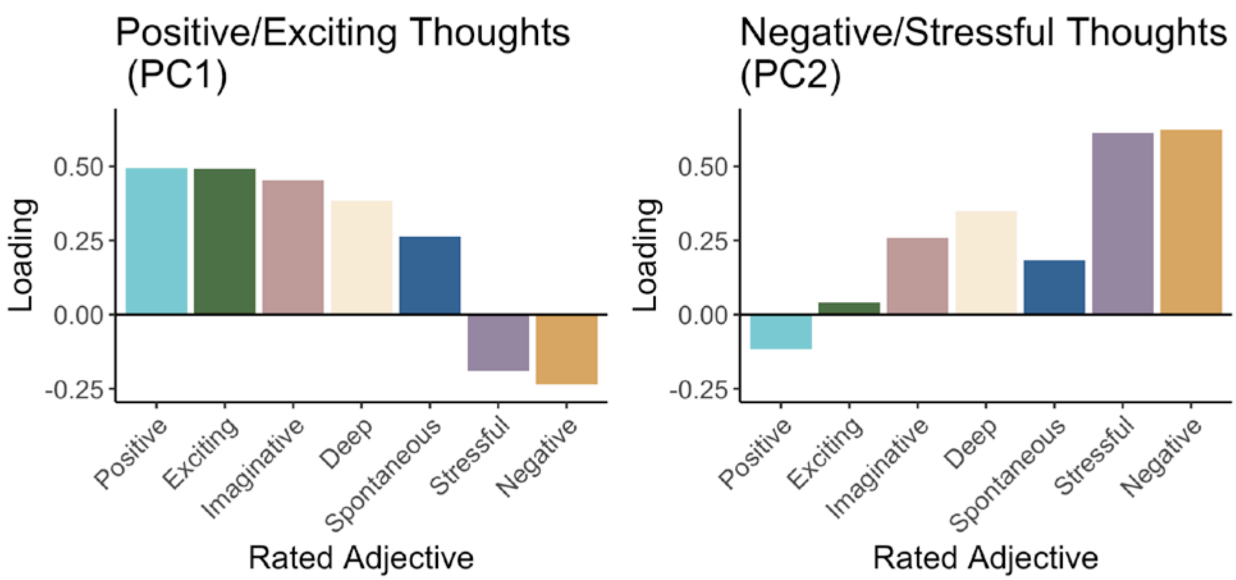

Figure 14. Loadings of thought valence onto the first and second principal components.

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

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

$\sigma \sim \text{Exponential}(1)$
$\sigma_\alpha \sim \text{Exponential}(1)$

Compared to baseline, thoughts were rated as higher on exciting/positive thinking while on both walks (see Figure 15), but there was also a time by condition interaction, such that thoughts were reported as more exciting/positive in the conservatory compared to the mall at survey 1 and survey 2. As the ratings were standardized for the principal component analysis, differences in the posterior distribution are in standard deviations (SD). At survey 1, thoughts were 0.51 SD higher (89% PI [0.19, 0.84] for exciting/positive thinking in the conservatory compared to the mall, with 99.5% of MCMC chains showing a difference greater than 0. At survey 2, thoughts were also 0.51 SD higher (89% PI [0.19, 0.82] for exciting/positive thinking in the conservatory compared to the mall, with 99.4% of MCMC chains showing a difference greater than 0. There was weaker evidence of a difference in these thought ratings at survey 3, with a mean difference of 0.24 SD (89% PI [-0.08, 0.55]) and 88.3% of MCMC chains showing a positive difference between conditions. Although baseline thoughts were reported before participants were taken to the study locations, there was an observed baseline difference for this PC. Thus, we repeated the analysis after subtracting the baseline reported valence in each condition. The results were similar, but weaker (see Table S3.5 and Figure S3.1).

For negative/stressful thinking, we found a reduction in ratings for this PC through the walk in both conditions, with no evidence of an interaction between time and condition (see Figure 15). Full models are shown in Table S3.4.

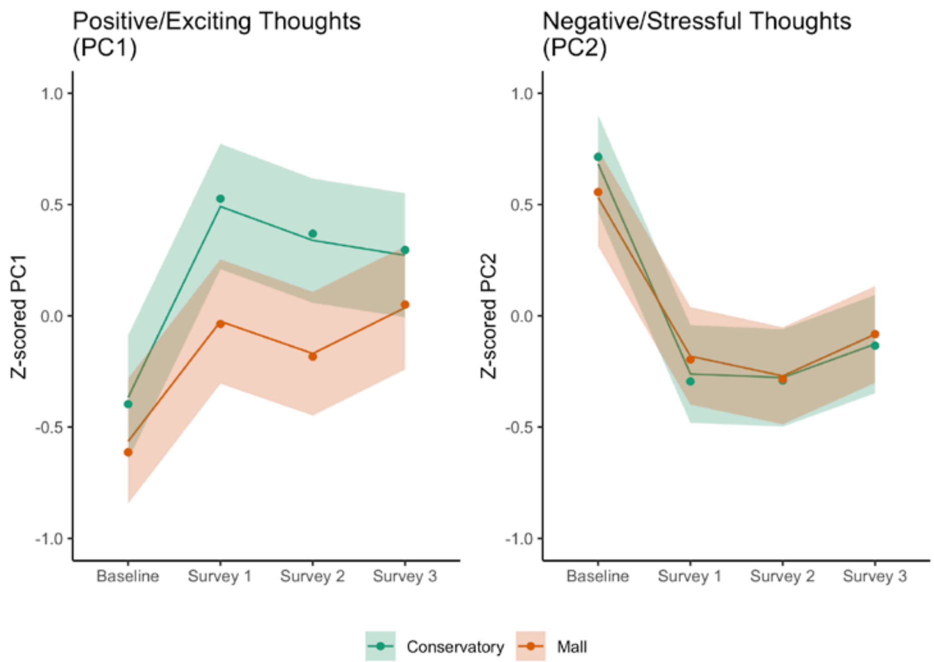

Figure 15. Observed and modeled thought valence for PC1 (exciting/positive thinking) and PC2 (negative/stressful thinking). Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

State Level Affect

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

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

Participants reported higher levels of positive affect at all three surveys in the conservatory compared to the mall (Figure 16). On a 10-point scale, the posterior distribution showed that positive affect was 1.34 points higher (89% PI [0.99, 1.7]) in the conservatory compared to the mall at Survey 1, 1.18 points higher (89% PI [0.83, 1.54]) at Survey 2, and 1.08 points higher (89% PI [0.73, 1.43]) at Survey 3. All MCMC chains showed a difference greater than 0 for all three interactions.

For the negative affect, we found participants reported lower levels throughout the walk in both conditions, with no evidence of an interaction between time and condition (see Figure 16). Full models are shown in Table S3.6.

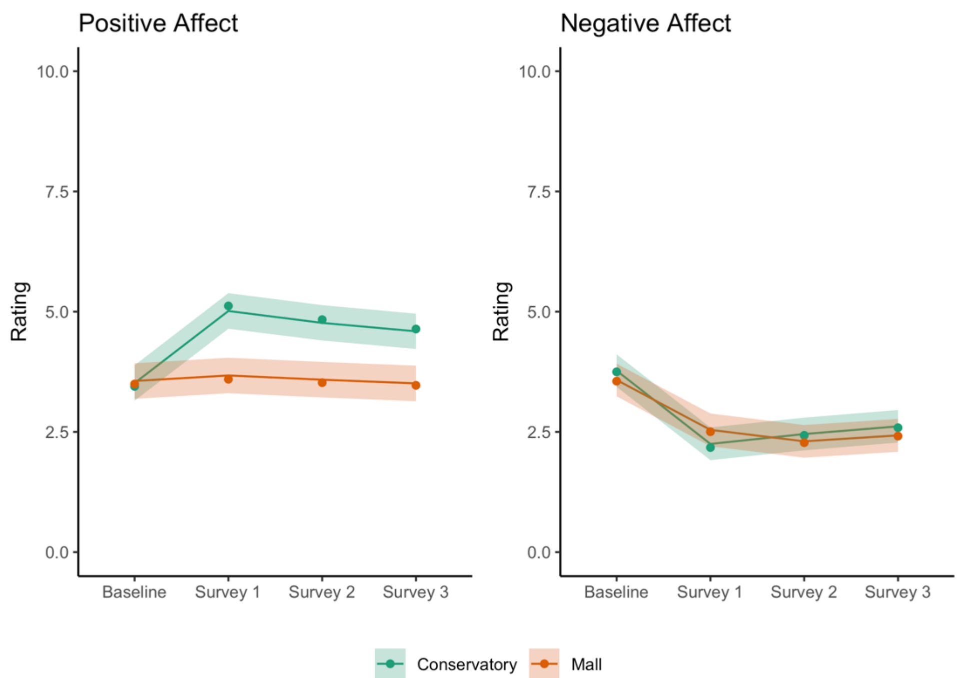

Figure 16. Observed and modeled levels of positive and negative affect. Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

In addition to positive and negative affect, participants reported how impulsive, creative, and bored they were feeling (see Figure 17). Participants reported higher levels of creativity in the conservatory compared to the mall at all three surveys (Figure 17). On a 10-point scale, the posterior distribution showed mean difference at Survey 1 was 1.18 (89% PI [0.73, 1.64]). The mean difference was 1.21 (89% PI [0.76, 1.67]) at Survey 2, and 0.94 (89% PI [0.5, 1.39]) at Survey 3. All MCMC chains showed a difference greater than 0 at all three surveys.

Participants reported lower levels of impulsivity in the conservatory compared to the mall at all three surveys (Figure 17). On a 10-point scale, the posterior distribution showed a mean difference at Survey 1 of -1.84 (89% PI [-2.31, -1.38]). The mean difference was -1.59 (89% PI [-2.05, -1.12]) at Survey 2, and -1.42 (89% PI [-1.88, -0.96]) at Survey 3. All MCMC chains showed a difference less than 0 for all three surveys.

Participants showed a reduction in feelings of boredom from baseline to Survey 1, with weak evidence of an interaction between conditions at Survey 1 (Figure 17). The posterior distribution showed that boredom was -0.37 points lower (89% PI [-0.86, 0.11]) in the conservatory compared to the mall at Survey 1, with 89.3% of MCMC chains showing a difference less than 0. There was no evidence of a difference in boredom between conditions at Survey 2 or 3. Full models for all state-level reports are shown in Table S3.7.

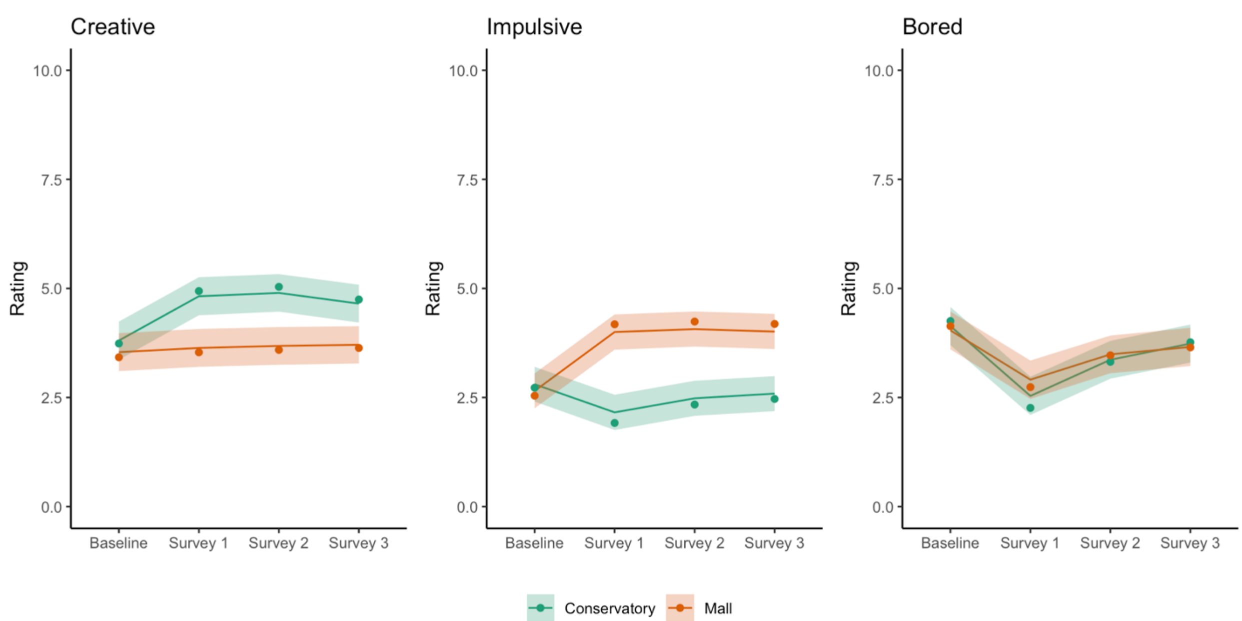

Figure 17. Observed and modeled feelings of creativity, impulsivity, and boredom. Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Impulsive Buying

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

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

We found that at Survey 3, impulsive buying was 0.82 standard deviations higher in the mall compared to the conservatory, 89% PI [0.62, 1.01], with all MCMC chains showing a difference greater than 0. See Figure 18. Full model is shown in Table S3.8.

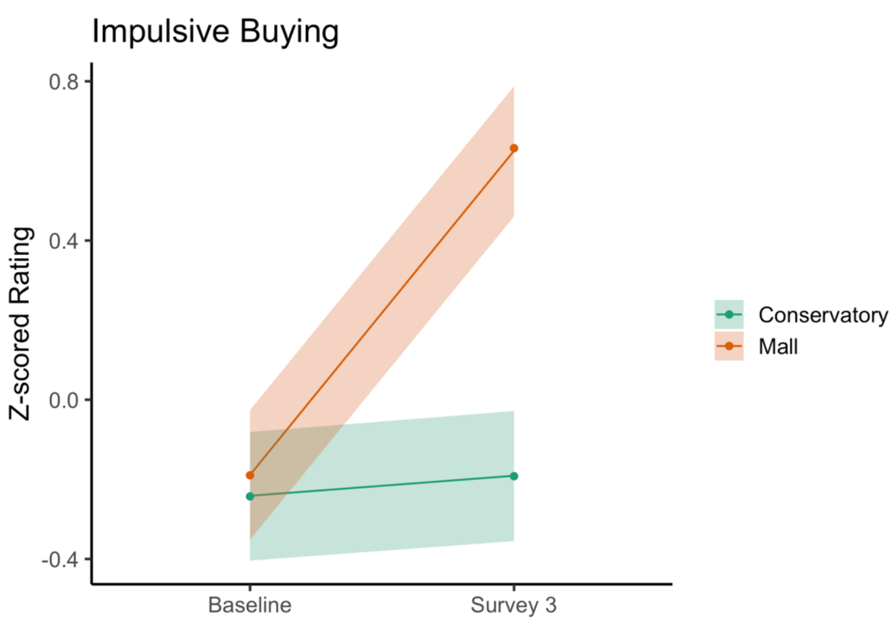

Figure 18. Observed and modeled feelings of impulsive buying. Points are mean observed standardized ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Working Memory

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

$Response_i$ ~ Normal(μ, σ)
μ_i = 1 + β*condition*pre_post*session$_{[j]}$ + $\alpha_{participant[i]}$
β_j ~ Normal(0, 0.2) , for j=1 – 8
$\alpha_i \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha)$, for $i = 1 - 86$
$\overline{\alpha} \sim \text{Normal}(0.5,1)$
σ ~ Exponential(1)
σ_α ~ Exponential(1)

We found evidence of a small main effect of time (b = 0.03, 89% PI [0.00, 0.06], 96.5% MCMC chains greater than 0), and a main effect of session (b = 0.06, 89% PI [0.01, 0.11], 98.8% MCMC chains greater than 0) but no effect of interactions between environment, session, and time on performance (see Figure S3.2). Performance on 3-back trials for our participants was very poor as overall hit rate was under 50% (HR = 0.39, SD = 0.20) and mean A' on 3-back was 0.67 (SD = 0.19), suggesting that there was a lot of noise in the 3-back data. As such, we ran an additional analysis, which only included the 2-back blocks where mean performance was much higher; A' on the 2-back blocks was 0.85. This model showed a main effect of session, such that scores were higher in the second session (beta = 0.04, 89% PI [0.00, 0.08], with 94.9% of MCMC chains showing a beta greater than 0). Importantly, we also found an interaction between time and environment, such that performance change scores were higher after the walk in the conservatory compared to after the walk in the mall (beta = 0.04, 89% PI [0.01, 0.08] with 97.1% of MCMC chains showing a beta more than 0), indicating more improvement after the conservatory walk compared to the mall walk (Figure 19). See Table S3.9 for the full models.

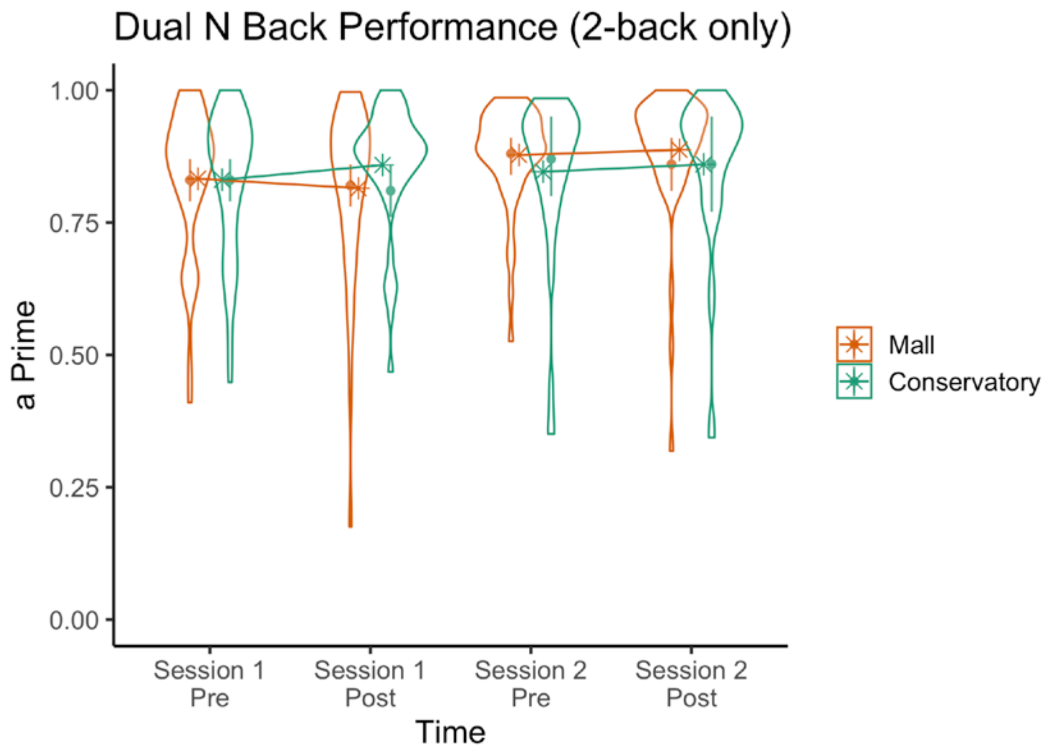

Figure 19. Modeled and observed Dual N-back performance on 2-back blocks. Dots represent the mean and lines represent the 89% percentile interval of the model's posterior distribution. Violin plot represents the distribution of observed performance. Stars represent the observed mean performance.

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

We computed Bayesian bivariate linear correlation estimates (rho) between participant trait measures (e.g., Agreeableness) and the dependent variables (e.g., state positive affect) that had shown time by environment interactions in the main analyses (Figure 20). Each participant's reported ratings within each environment were averaged (i.e., responses at Surveys 1-3). For dual n-back, we used the change in 2-back performance (post score – pre score).

Trait intellect (also called "openness to experience") was positively correlated with positive thoughts, positive affect, and feelings of creativity in the conservatory but did not show strong relationships with outcomes in the mall. Trait reflection was also positively correlated with creativity in the conservatory. Although in general, participants were more likely to think about the past in the conservatory, trait intellect and reflection were both negatively correlated with past thinking in the conservatory. This means that participants high on trait intellect and reflection were less likely to think about the past in the conservatory. We did not find evidence of a correlation between trait impulsivity and the difference in positive affect between the conservatory and mall (r = -.05, 89% PI [-.24, .16]), a relationship that had previously been reported (Bakolis et al., 2018). Within each condition separately, there was a negative correlation between trait impulsivity and positive affect.

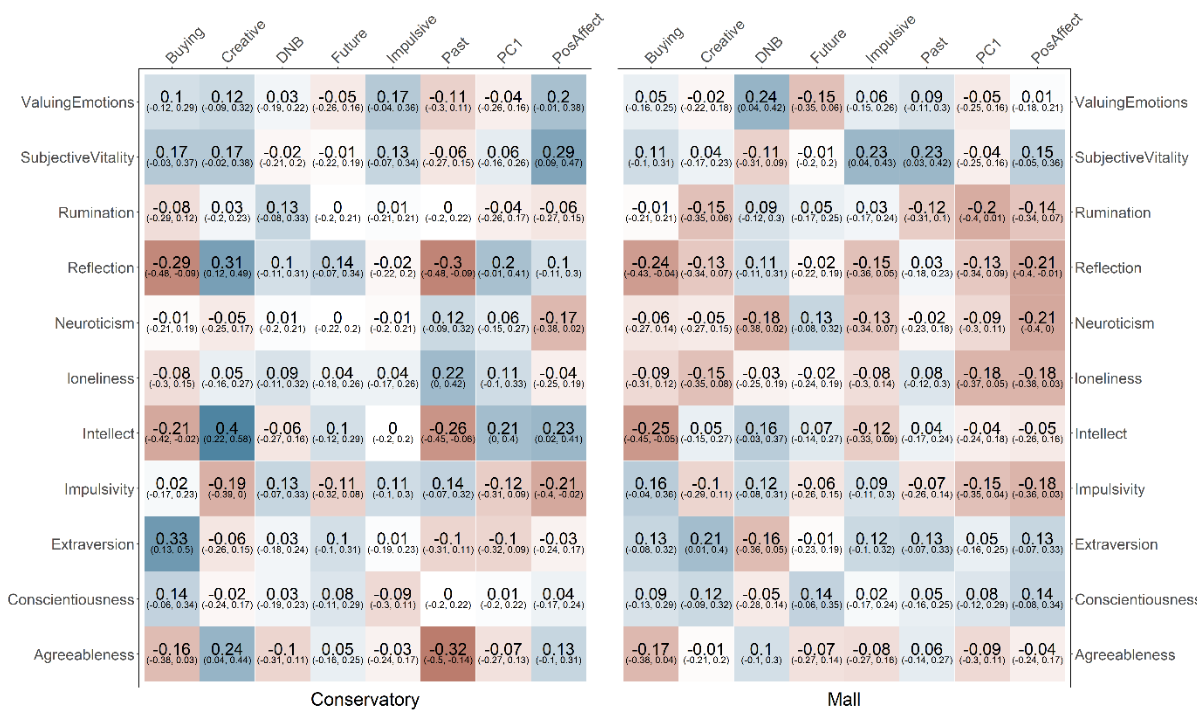

Figure 20. Bivariate linear correlations between individual trait measures (rows) and dependent variables (columns) in the conservatory (left) and mall (right). PC1 is positive/exciting thoughts. DNB is change in dual n-back performance. Positive correlations are shown in blue and negative correlations are shown in red. 89% confidence intervals are shown in paratheses.

Correlations between Dependent Variables

Bayesian bivariate linear correlations between dependent variables were calculated as well, see Figure 21. Positive affect, positive/exciting thoughts and creativity all positively correlated with each other in both the conservatory and the mall. Improvements in dual n-back performance was positively correlated with positive thinking, positive affect, state impulsivity, and creativity in the conservatory, but those relationships were not seen in the mall. Future thinking was positively correlated with state impulsivity in the mall but was negatively correlated with state impulsivity in the conservatory. Broadly, the patterns between past and future thinking with the other dependent variables is different between the two environments.

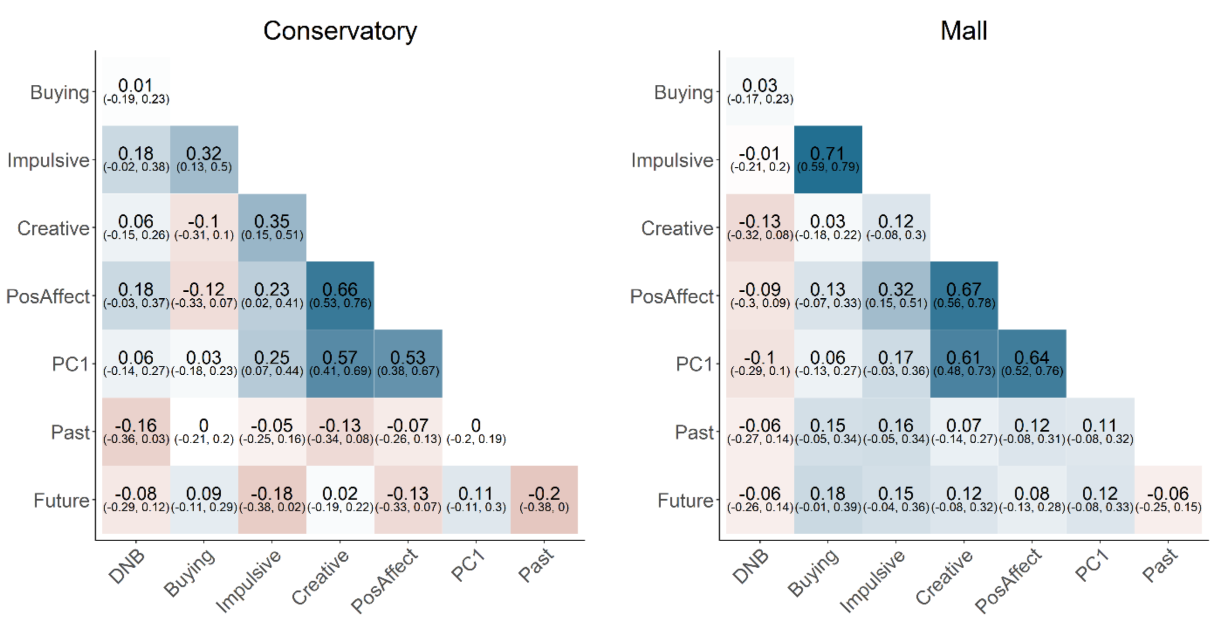

Figure 21. Bivariate linear correlations between dependent measures in the conservatory (left) and mall (right). PC1 is positive/exciting thoughts. DNB is change in dual n-back performance. Positive correlations are shown in blue and negative correlations are shown in red. 89% confidence intervals are shown in parentheses.

Discussion

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

Some of the results can be grouped in terms of similar patterns. For instance, feelings of positive affect and creativity both increased in the conservatory and stayed unchanged from baseline in the mall. Another group of dependent variables showing a similar pattern was negative thoughts, negative mood, and boredom; these all decreased from baseline during the walks without showing an interaction by condition.

Many of these results are in accordance with previous research. For example, the finding of increased creativity in the conservatory is in line with previous research showing increases in creative performance following exposure to images, sounds, and immersive experiences of natural environments (Chulvi et al., 2020; McCoy & Evans, 2002). While those studies all tested creative performance, here participants were asked directly how creative they were feeling at the time. We also replicated previous findings that spending time in natural environments, either wild or manicured, can increase positive affect (McMahan & Estes, 2015). Our findings are also in line with previous work which found that in open-ended free response people described “an experience in nature" more positively than they did "an experience shopping" (Craig et al., 2018). Recent research has found that changes in affect after viewing nature stimuli are associated with individual preferences for those images (Meidenbauer et al., 2020). Unfortunately, here we do not have preference ratings of the environments so we cannot investigate this pathway with the data from this study. While it is possible that the conservatory is more preferred over the mall, it is our sense that both environments would be relatively high on preference for most people.

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

While we can only speculate about the small effect size and lack of interaction effect when modeling 3-back and 2-back together, it should be noted that testing was not done under ideal experimental conditions. Logistics of the study led to post-environment testing to be conducted on cell phones in the lobby/entry way of the locations, which was likely distracting for participants. These may also be reasons for worse overall performance by these participants compared to Van Hedger et al. (2018), which included participants from a similar population. Additionally, there may have been reduced potential for improvement given that participants were pinged on cell phones and required to take multiple surveys throughout their walk. Previous research has found that using portable electronic devices while in a natural environment diminished attention restoration (Jiang et al., 2019).

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

Other interesting individual differences were observed. In particular, it appears that individuals who scored higher on trait reflection seemed to attain more of the benefits from interacting with nature, given that this trait was positively correlated with positive/exciting thinking, and creativity, with some evidence of improvement in general positive affect as well, while exploring the conservatory. However, these individuals also showed negative correlations with positive affect and creativity in the mall, which may indicate a general sensitivity to environmental context. Participants scoring high on extraversion, on the other hand, were more likely to show higher positive affect in the mall, but not in the conservatory. Further research linking personality traits and outcomes from environmental exposures is needed and will be important for both theoretical understanding and real-world applications.

Many of the differences in affect and thought content were present at all three surveyed timepoints. Any difference between the two environments that was observed was evident by the first survey. This indicates that approximately 20 minutes in an environment is sufficient to induce differences in affect and cognition. Some aspects though, such as past and future directed thoughts which showed an interaction with environment, were only observed at Surveys 1 and 2, thus not seeming to last the entire hour long walk. With these data, we do not know why some differences last longer than others. Given the size of the particular environments that were used in this study, it is possible that participants had fully explored the spaces by the end of one hour, which attenuated some of the differences later in the survey. This may be reflected in reported feelings of boredom becoming closer to baseline levels by Survey 3. It would be useful to replicate this study in larger spaces to see how the extent of the space is related to the time course of thought content, especially as Kaplan (S. Kaplan, 1995) theorized that environments with greater extent would lead to greater psychological benefits. Findings like this indicate the importance of repeated measurements *during* exploration of different environments.

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

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

There are also several limitations for the generalizability of this study. While the study was conducted in an ecologically valid manner, with participants visiting the locations during normal operating hours with other visitors present, and using mobile devices, participants visited these locations without companions. How these environments may shape conversation (and thus thoughts) for people visiting with others should be researched. This study was also limited to one natural and one commercial space in one North American city. The design and amenities at conservatories and malls around the world may lead to other types of thought content. Cultural differences in the purposes of, and comfort in, these types of public spaces may also influence the results. These particular locations were chosen in part because they were free to enter, accessible year-round, similar in size to each other, desirable, frequently visited, and approximately equal driving time from our research lab. Replicating this study in additional locations will be informative in determining more universal impacts of environments on thought content and affect.

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

CHAPTER 4: NATURE'S PATH TO THINKING ABOUT OTHERS AND THE SURROUNDING ENVIRONMENT

Abstract

Research has shown differences in pro-social and pro-environmental behaviors after exposure to different physical environments. In this within-subject design, we used repeated surveys to measure social and environmental thought content throughout one-hour environmental explorations of a nature conservatory and an indoor mall. At each survey, participants (N = 86, undergraduates and community members) reported whom they were thinking about and how connected they felt to the physical and social environment. Using Bayesian multi-level models, we found that while visiting the conservatory, participants were less likely to think about themselves, felt closer to people nearby and around the world, and felt higher connectedness to their social and physical environment. These differences persisted throughout the walk and were differentially affected by the number of people in the surrounding environment. This study furthers our understanding of the ways in which natural environments influence thoughts and feelings about the social and physical environment.

Introduction

Public spaces, such as parks, plazas, and community centers, are important and highly influential places in contemporary human social life. These spaces are composed of social and physical elements that can influence physical and mental health, cognitive and affective states, and overall well-being (Benita et al., 2019; Cattell et al., 2008; Francis et al., 2012; Giles-Corti et al., 2005). Within the realm of physical environments, natural environments and stimuli have been shown to be especially salubrious for health and well-being (Berman, Kardan, et al., 2019, 2019; Bratman et al., 2019; Hartig et al., 2014; Kardan et al., 2015; Schertz & Berman, 2019). For example, urban greenspaces provide benefits at the community level by supporting social engagement, social capital, and place attachment (Arnberger & Eder, 2012; Jennings & Bamkole, 2019)**.** Urban greenspaces also provide places for neighbors to meet and establish social ties (Coley et al., 1997; Peters et al., 2010; Sullivan et al., 2004).

There is a robust literature on the psychological effects of being in natural environments. One category of effects focuses on pro-social orientation. Exposure to natural environments, on both acute and long-term bases, has been shown to positively influence pro-social behaviors and attitudes (Goldy & Piff, 2020). For example, a study in which people were directed to either notice natural or human-built elements of their environment found that those in the nature group reported greater pro-social orientation and connection to others at the end of a two-week period (Passmore & Holder, 2017). In another study, people who viewed nature scenes, compared to human-made scenes, reported stronger prosocial and other-focused values (Weinstein et al., 2009).

In addition to pro-social orientation, increased pro-environmental behaviors have also been associated with exposure to natural environments. In an observational study, participants who visited nature more often were more likely to engage in household pro-environmental behaviors, a relationship which was moderated by nature connectedness (Martin et al., 2020). Another study found that use of natural environments for psychological restoration was associated with self-reported improved ecological behavior, even when controlling for concern for the environment (Hartig et al., 2007).

In the current study, we sought to investigate how environmental effects on social and environmental orientation might be reflected in conscious thoughts and feelings while exploring a nature conservatory and a large indoor mall. What people spend their time thinking about forms an important part of their lived experience (Baumeister et al., 2020; Larson & Csikszentmihalyi, 2014; Sripada & Taxali, 2020), and thought content is important to examine to fully understand the myriad effects of the external environment on human health and well-being (Berman, Kardan, et al., 2019; Berman, Stier, et al., 2019). Previous work has found relationships between thought content and the visual features in one's physical environment (Schertz et al., 2018, 2020), suggesting that the surrounding environment can influence conscious thoughts.

Examining thought content directly may show if people consciously have more pro-social or pro-environmental thoughts when in natural environments. In terms of thought content and feelings, pro-social attitudes and orientation towards others may manifest in several ways. First, people may think less about themselves, and more about other people, or more about themselves together with other people, in a natural environment. Second, they may feel more connected to their social environment. And third, they may feel closer to others, such as family and friends, people in the surrounding environment, or even people around the world. Increased environmental orientation may result in feeling closer to the surrounding physical environment as well as having more thoughts about the physical surroundings, when in a natural environment.

In this study, we used a within-person design and experience sampling methodology to measure differences in thought content throughout a one-hour environmental exploration of a nature conservatory and a large indoor mall. Experience sampling methods such as ecological momentary assessment generate structured reports about what people are thinking and feeling throughout the day by asking them in real-time (Larson & Csikszentmihalyi, 2014; Stone & Shiffman, 1994). Short-term experience sampling studies, for example, covering one to two hours, have been used to get more intensive reports of thoughts in specific environments (Doherty et al., 2014). Given recent findings showing that social context influences social thinking (Mildner & Tamir, 2021), we also investigated how the number of people in the surroundings interacted with the influence of the environments on social thought.

We found that during walks in the nature conservatory participants thought less about themselves, more about themselves in a relational sense (that is, together with others), felt closer to people nearby and around the world, and felt more connected to the social environment compared to the walk in the mall. This was true even when controlling for the number of people that could be seen in the environment. Additionally, people felt more connected to the physical environment in the nature conservatory. Overall, these results demonstrated that a brief walk in a conservatory compared to a mall yielded many benefits for socially and environmentally engaged thinking.

Methods

Participants

A total of 99 participants participated in the study from October 2018 through April 2019. Ten participants did not return for the second session of the two-part study. Data collection issues resulted in the loss of three participants' data, leaving full analyzable data for 86 participants. Participants (mean age = 21.57 years, SD = 3.79 years, Range 18-39) were either University of Chicago students or adults from the surrounding communities recruited through Facebook, flyers posted in the community, and the university's research participation system. There were 39 men, 58 women, and 2 participants who selected 'other' for gender. In terms of ethnicity, 31 participants identified as white/Caucasian, 31 identified as Asian/Asian American, 16 identified as Hispanic, Latino, or Chicano, 15 identified as Black/African American, 5 identified as multiple ethnicities and 1 participant identified as another race/ethnicity. Sample size was determined primarily through resource constraints (e.g., time, money) and is similar to other studies examining the effects of nature exposure (McMahan & Estes, 2015). This research was approved by the Institutional Review Board of the University of Chicago.

Locations

The nature conservatory study location was the Garfield Park Conservatory (referred to as 'conservatory' throughout) located in the Garfield Park neighborhood of Chicago (https://garfieldconservatory.org). The mall location was the Water Tower Place mall (referred to as 'mall' throughout) located in the Near North neighborhood of Chicago (https://www.shopwatertower.com/en.html). Figure 22 shows example images from the spaces.

Figure 22. Example images of Garfield Park Conservatory (left) and Water Tower Place mall (right). Images from Wikimedia Commons (Jrissman, 2010; Kenraiz, 2016).

Procedure

The study was conducted over two sessions, spaced one week apart. The order of environments (i.e., conservatory, mall) was counter-balanced across participants. There was a maximum of 12 participants in each study session, due to practical limitations in transporting participants to the testing locations and the need to maintain a manageable ratio of participants to research assistants. Participants completed the trait questionnaires online via before arriving to the first session. All tasks during the study sessions were completed on Moto G5 Android cell phones.

When participants arrived at the laboratory building for each session, they were met by research assistants and directed to a shuttle bus. Research assistants collected participants' personal mobile devices and distributed the experimental cell phones. Participants then completed the baseline survey and working memory task on the bus while it was stationary at the laboratory building. The shuttle bus then drove participants and research assistants to one of the study locations. Both study locations were approximately 30 minutes away from the laboratory.

Upon arrival at the study location, participants were instructed to explore the environments and answer survey questions on the experimental cell phone when indicated. Participants were prompted by a timer on the cell phone to complete the ambulatory survey after 20 minutes (Survey 1), 40 minutes (Survey 2), and 60 minutes (Survey 3). When they completed the third survey, they were prompted to meet the research assistants at the entrance. They were then directed to complete the working memory task again. The shuttle bus then drove everyone back to the laboratory building. Each session lasted approximately 2-2.5 hours. Figure 23 shows a diagram representation of the study procedure.

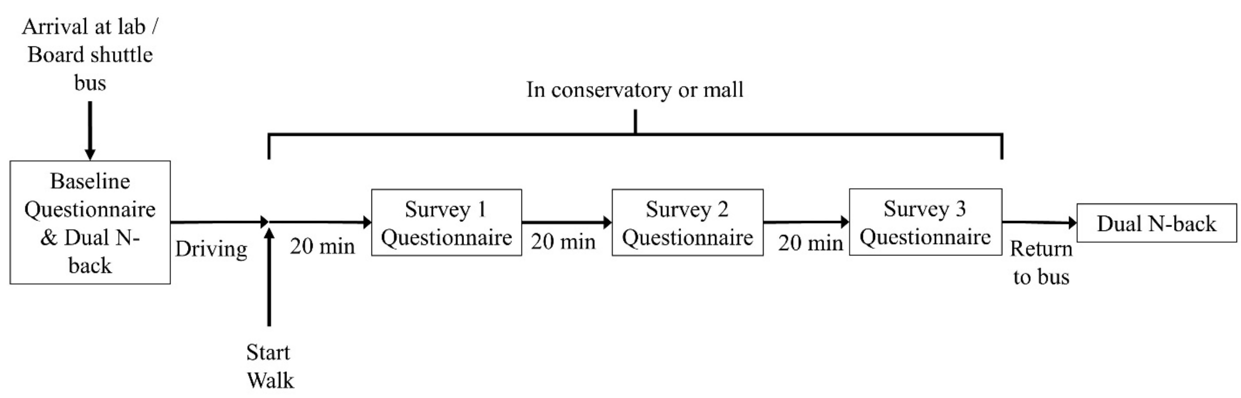

Figure 23. Study Procedure.

Survey Questions

Trait Questionnaires

Trait questionnaires were completed at home by participants when they signed up for the study. In addition to providing demographic information, participants responded to a short form Big Five inventory (mini-IPIP) (Donnellan et al., 2006), the Reflection-Rumination Questionnaire (RRQ) (Trapnell & Campbell, 1999), the Subjective Vitality Score (SVS) (Ryan & Frederick, 1997), the Valuing Emotions (VE) scale (Mangelsdorf & Kotabe, 2017), the Trait Rash Impulsivity Scale (TRIS) (Mayhew & Powell, 2014), and the 3-question loneliness scale (Hughes et al., 2004).

Baseline Questionnaire

Upon arrival to each study session, before being transported to the study locations, participants completed the baseline questionnaire regarding their recent thoughts and feelings. Participants reported whether their most recent thought was about themselves, other people, both themselves and other people, or something other than people. They also answered questions about how close they felt to their friends and family, people in their surroundings, and people around the world, as well as how connected they felt to their physical and social environments. Due to a coding error, Likert scales in the baseline questionnaire went from 0-7 while Likert scales in the ambulatory questionnaire went from 0-10. For all analyses, baseline responses were rescaled to 0-10. The participants were allowed to define each term in the questions for themselves, as we did not further define any of the concepts.

Ambulatory Questionnaire

While walking around the study locations, participants completed the ambulatory survey three times. These surveys included the same questions as the baseline questionnaire, with an additional question that asked how many people were visible around them.

Statistical Analyses

Statistical analyses were conducted in a Bayesian framework using multi-level models, with participant as a random/varying intercept. Continuous dependent variables were analyzed using linear regression. Categorical dependent variables (i.e., self/other focus of thought) were analyzed using logistic regressions. In all models, the independent variables were the interaction term between condition (i.e., conservatory and mall) and survey/timepoint (i.e., Baseline, Survey 1-3). Main effects for condition were not included as the baseline survey for each condition was taken before participants were transported to the two environments.

Regularizing priors were used for all models. Regularizing priors prevent models from overfitting to the sample by slowing the rate of learning from the data. Full specifications of the models, including their priors, are shown in the Results section for each variable. Each model was run with 10,000 draws and 1,000 warmup draws for four Markov Chain Monte Carlo (MCMC) chains, for a total posterior distribution of 36,000 post-warmup draws. Posterior distributions have been summarized by reporting the 89% percentile intervals (PI). PIs are also referred to as quantile intervals and indicate the probability mass centered around the mean of the posterior distributions. Since PIs are not the same as frequentist confidence intervals, the 89th percentile interval was chosen to avoid both conscious and subconscious attempts at hypothesis testing that may occur if presented with a conventional 95% interval, as suggested by McElreath (McElreath, 2020). Bivariate correlations between dependent measures are reported in Supplemental Figure 1.

Transparency and Openness

Data and analysis code are available at https://osf.io/cu6jr/. Models were run in R 4.1.1 (R Core Team, 2017) using the ‘brms’ package (Bürkner, 2017). This study’s design and its analysis were not pre-registered. Additional dependent measures were collected during this study that are not reported here. The full list of dependent measures is shown in Table S4.1. Some of the additional dependent measures are reported in (Schertz et al., 2021), which uses data from the same study.

Results

Thoughts of Self and Others

Socially focused thinking was assessed in several ways, one of which was by measuring thoughts about the self and/or others. Participants responded to the question "Was [your most recent] thought mostly about yourself, mostly about others, about yourself and others, or not about people?" These responses are mutually exclusive; thus, participants could only select one response. Each of the four response options (i.e. 'myself', 'other people', 'myself and other people', 'something other than people') was modeled as a logistic regression in the form:

$Response_i \sim \text{Binomial}(1, p_i)$	Likelihood
$\text{logit}(p_i) = 1 + \beta_{\text{condition*survey[j]}} + \alpha_{\text{participant[i]}}$	Logistic Regression Model
$\beta_j \sim \text{Normal}(0, 0.5)$, for j=1-8	Prior for betas (8 survey by condition combinations, 2 conditions and 4 time points)
$\alpha_{participant[i]} \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha)$, for $i = 1 - 86$	Adaptive prior for each participant
$\overline{\alpha} \sim \text{Normal}(0, 1.5)$	Prior for Average Participant
$\sigma_\alpha \sim \text{Exponential}(1)$	Prior for SD of participant

Participants were less likely to report thoughts about themselves in the conservatory compared to the mall during all ambulatory surveys, see Figure 24a. After being in the environment for ~20 minutes (i.e., at Survey 1), the odds ratio between the two settings was 2.05 (i.e., participants were 2.05 times more likely to think about themselves in the mall vs. the conservatory), 89% PI [1.42, 2.85], with 99.9% of the MCMC samples showing an odds ratio greater than one. In probability terms, this was a difference of 24% probability of self-focused thoughts in the conservatory and 47% probability of self-focused thoughts in the mall. At Survey

2 (~40 minutes), the probability of self-focused thoughts was 29% in the conservatory and 38% in the mall, with a modeled odds ratio of 1.39 (89% PI [0.96, 1.91]), with 92.3% of the MCMC samples showing an odds ratio greater than one. At Survey 3 (~60 minutes), the probability of self-focused thoughts was 27% in the conservatory and 54% in the mall, with an odds ratio of 2.03 (89% PI [1.46, 2.76]), with 100% of the MCMC samples showing a positive difference.

When participants did think about themselves in the conservatory, it was often as part of a social relationship. That is, there was also evidence, though weaker, that participants reported more thoughts about 'themselves and others' throughout the conservatory walk compared to the mall walk (Figure 24b). At Survey 1, the odds ratio between conservatory and mall was 1.40 (89% PI [0.93, 2.00]) with 90.2% of the MCMC samples showing an odds ratio greater than one. At Survey 2, the odds ratio was 1.27 (89% PI [0.82, 1.83]), with 79.6% of the MCMC samples showing an odds ratio greater than one. At Survey 3, the odds ratio was 1.47 (89% PI [0.99, 2.07]), with 94% of the MCMC samples showing an odds ratio greater than one.

There was no evidence of a conditional difference for reporting thoughts about only other people at any survey (Figure 24c). At Survey 1, the odds ratio was 1.10 (89% PI [0.54, 1.80]. At Survey 2, the odds ratio was 0.76 (89% PI [0.42, 1.24], and at Survey 3, the odds ratio was 1.32 (89% PI [0.69, 2.20]).

The results thus far showed that when in the nature conservancy, compared to the mall, people thought less about themselves as well as more about themselves together with others (with no difference in thinking about other people). The remaining option was non-social thoughts ("focused on things other than people"), which also were more prevalent during walks in the conservatory compared to the mall at all survey time points (Figure 24d). After ~20 minutes, (i.e., at Survey 1), the odds ratio between the two settings for these non-interpersonal thoughts was 2.12 (i.e., 2.12 times more likely to think about things other than people in the conservatory vs. the mall), 89% PI [1.24, 3.35], with 99% of the MCMC samples showing an odds ratio greater than one. The probability of non-interpersonal thoughts was 23% in the conservatory and 11% in the mall. At Survey 2, the probability of non-interpersonal thoughts was 21% in the conservatory and 14% in the mall. The odds ratio was 1.68 (89% PI [1.00, 2.59]), with 94.4% of the MCMC samples showing an odds ratio greater than one. At Survey 3, the probability of non-interpersonal thoughts was 15% in the conservatory and 7% in the mall, with an odds ratio of 2.26 (89% PI [1.20, 3.77]), and 98.4% of the MCMC samples showing a positive difference. See Table S4.2 for full regression models.

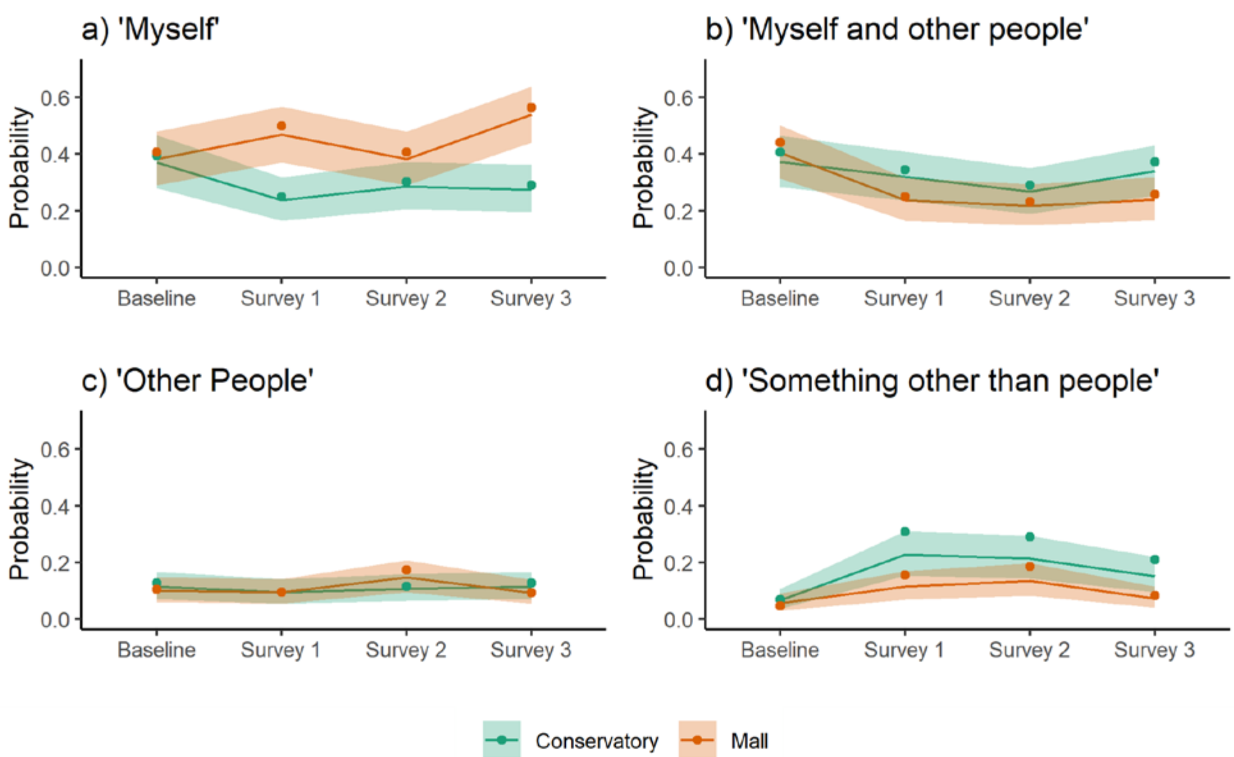

Figure 24. Observed and modeled selection of a) self, b) self and others, c) others, and d) non-interpersonal focused thinking. Points are observed probabilities from the raw data. The fitted line is the logistic regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Feelings of closeness to others

Sociality was also examined through feelings of closeness to various social groups, ranging from people in general to those with whom they have personal relationships. Specifically, they rated feelings of closeness to their family and friends, people in their surroundings, and people all over the world (0 = not at all close; 10 = very close). Responses were modeled as linear regressions of a continuous variable in the form:

$Response_i \sim \text{Normal}(\mu, \sigma)$
$\mu_i = 1 + \beta_{\text{condition*survey[j]}} + \alpha_{\text{participant[i]}}$
$\beta_j \sim \text{Normal}(0, 0.5)$, for j=1 – 8
$\alpha_{participant[i]} \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha)$, for $i = 1 - 86$
$\sigma \sim \text{Exponential}(1)$
$\overline{\alpha} \sim \text{Normal}(5, 1.5)$
$\sigma_\alpha \sim \text{Exponential}(1)$

Participants reported feeling closer to people around the world while in the conservatory compared to the mall at all three survey timepoints, Figure 25a. On a 10-point scale, the posterior distribution was 1.08 points (89% PI [0.71,1.45]) higher at Survey 1 in the conservatory compared to the mall. At Survey 2, the difference was 0.90 points (89% PI [0.53,1.26]), and at Survey 3, the difference was 0.91 points (89% PI [0.55,1.28]). 100% of MCMC chains showed a difference greater than 0 at all three time points.

Participants also reported feeling closer to people in their surroundings while in the conservatory compared to the mall at all three survey timepoints, Figure 25b. On a 10-point scale, the posterior distribution was 1.15 points (89% PI [0.72,1.59]) higher at Survey 1 in the conservatory compared to the mall with 100% of MCMC chains showing a difference greater than 0. At Survey 2, the difference was 0.93 points (89% PI [0.51,1.35]) with 100% of MCMC chains showing a difference greater than 0, and at Survey 3, the difference was 0.51 points (89% PI [0.09,0.94]), with 97.4% of MCMC chains showing a difference greater than 0.

Feelings of closeness to friends and family showed an unexpected baseline difference, despite ratings taking place before going to the conditional locations (Figure 25c). Therefore, we subtracted baseline scores in each condition. In this adjusted model, there was no evidence of an interaction between conditions (Survey 1: difference = 0.14, 89% PI [-0.28, 0.57]; Survey 2: difference = 0.02, 89% PI [-0.40, 0.43]; Survey 3: difference = -0.09, 89% PI [-0.51, 0.33]). See Table S4.3 for full regression models.

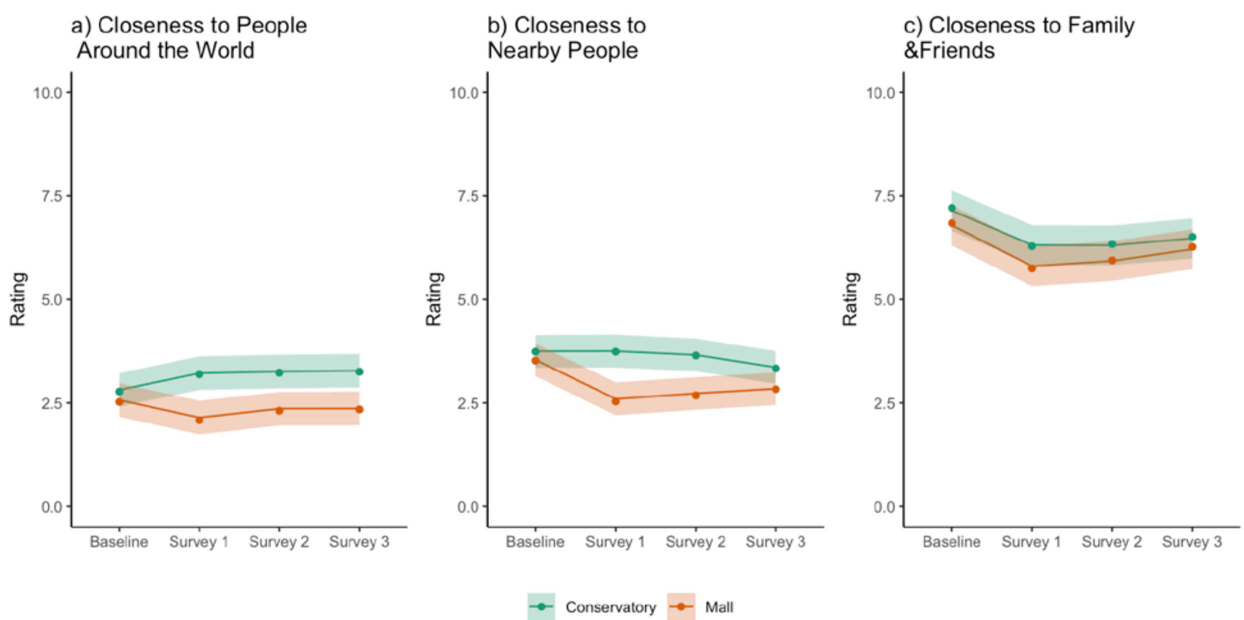

Figure 25. Observed and modeled ratings for feelings of closeness to a) people around the world, b) people in the surroundings, and c) friends and family. Points are mean observed ratings from the raw data. The fitted line is the linear model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Feelings of connection to the social and physical environment

As a final indicator of sociality, participants responded to the question "How much do you feel connected to the social environment around you?" on a scale from 0 (not at all) to 10 (very much). To assess feelings about the physical environment, participants also indicated how connected they felt to the physical environment. These two responses were modeled as linear regressions of a continuous variable in the form:

$$Response_i \sim \text{Normal}(\mu, \sigma)$$
$$\mu_i = 1 + \beta_{\text{condition*survey[j]}} + \alpha_{\text{participant[i]}}$$
$$\beta_j \sim \text{Normal}(0, 0.5) \text{ , for } j=1-8$$
$$\alpha_{participant[i]} \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha) \text{ ,for } i = 1 - 86$$
$$\sigma \sim \text{Exponential}(1)$$
$$\overline{\alpha} \sim \text{Normal}(5, 1.5)$$
$$\sigma_\alpha \sim \text{Exponential}(1)$$

Similar to the results for interpersonal thoughts and feelings, there was a condition by survey interaction for feelings of connection to the social environment (Figure 26a). Participants felt more connection to their social environment when walking in the nature conservatory. On a 10-point scale, the posterior distribution showed that connection to the social environment was 0.43 points higher (89% PI [0.00, 0.86]) in the conservatory compared to the mall at Survey 1, with 94.5% of MCMC chains showing a difference greater than 0. At Survey 2, connection was rated 0.60 points higher (89% PI [0.17, 1.02]) with 98.8% of MCMC chains showing a difference greater than 0. At Survey 3, connection was rated 0.52 points higher (89% PI [0.10, 0.94]), with 97.5% of MCMC chains showing a difference greater than 0.

Expanding beyond the social environment, the results showed that participants reported higher levels of connection to the physical environment in the conservatory compared to the mall at all three surveys (Figure 26b). On a 10-point scale, the posterior distribution showed that connection to the physical environment was 2.47 points higher (95% CI [1.93, 3.02]) in the conservatory compared to the mall at Survey 1, 2.38 points higher (95% CI [1.82, 2.93]) at

Survey 2, and 2.35 points higher (95% CI [1.79, 2.91]) at Survey 3. All MCMC chains showed a difference greater than 0 for all three interactions. See Table S4.4 for full regression models.

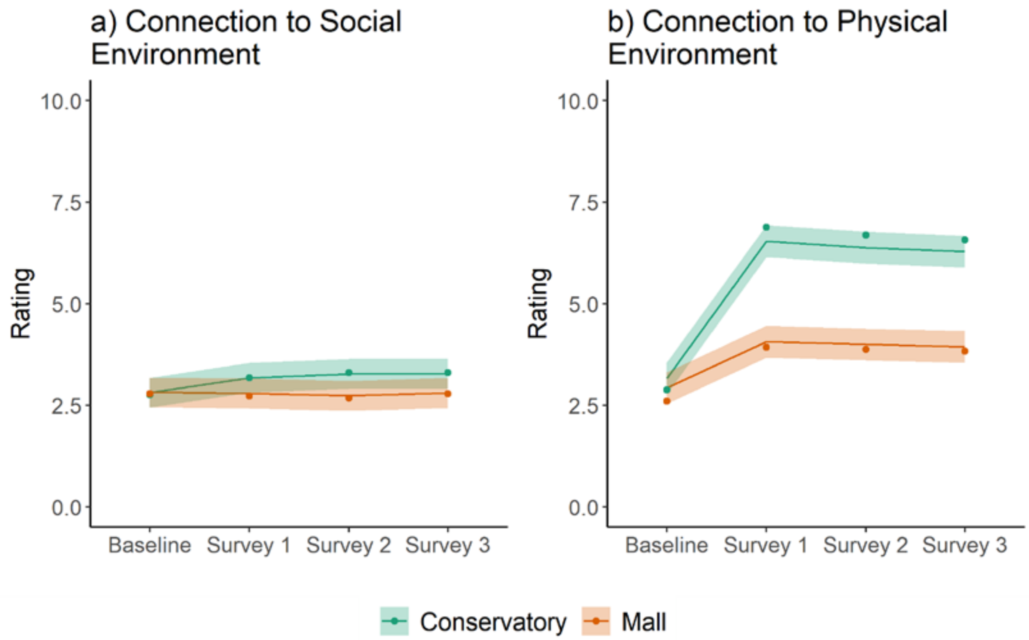

Figure 26. Observed and modeled ratings for feelings of connection to a) the social environment, and b) the physical environment. Points are mean observed ratings from the raw data. The fitted line is the linear model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Influence of reported number of people in sight on thoughts and feelings

The reported differences in thought content by condition could potentially be explained by the presence of different numbers of people at the time of responding. Thus, we analyzed all our dependent variables as a function of environment, number of people in sight at time of response, and their interaction. Descriptively, it was more likely for there to be zero or one to six people in sight in the conservatory and more likely for there to be six to 10 people in sight in the mall. There were many reports of having 11-20 or 21 or more people in sight in both locations. See Supplemental Figure S4.2 for a histogram of number of people in sight by condition.

For the responses to the question “Who was your most recent thought about?”, the logistic model took this form:

$Response_i \sim \text{Binomial}(1, p_i)$
$\text{logit}(p_i) = 1 + \alpha_{\text{participant}[i]} + \beta 1_{condition[j]} + \beta 2_{people\_around[k]} + \beta 3_{\text{condition*people\_around}[l]}$
$\beta 1_j \sim \text{Normal}(0, 0.5)$, for j = 1-2 (conservatory, mall)
$\beta 2_k \sim \text{Normal}(0, 0.5)$, for k = 1-5 (levels of people in sight)
$\beta 3_l \sim \text{Normal}(0, 0.5)$, for l = 1-10 (interaction of condition x people in sight)
$\alpha_{participant[i]} \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha)$, for $i = 1 - 86$
$\overline{\alpha} \sim \text{Normal}(0, 1.5)$
$\sigma_\alpha \sim \text{Exponential}(1)$

There was a main effect of number of people around on participants reporting thoughts about just themselves (see Figure 27), but this did not interact with condition. Participants reported less thoughts about just themselves when there were more people in their surroundings in both locations. For example, the proportion of self-focused thoughts when surrounded by 21 or more people was 0.30 (89% PI [0.03, 0.54]) less than when there was no one in sight at the mall, and 0.28 (89% PI [0.12, 0.44]) less in the conservatory. Thoughts about others, myself & others, and non-interpersonal thoughts were not associated with the number of people in the surrounding area (see Figure S4.3 and Table S4.5).

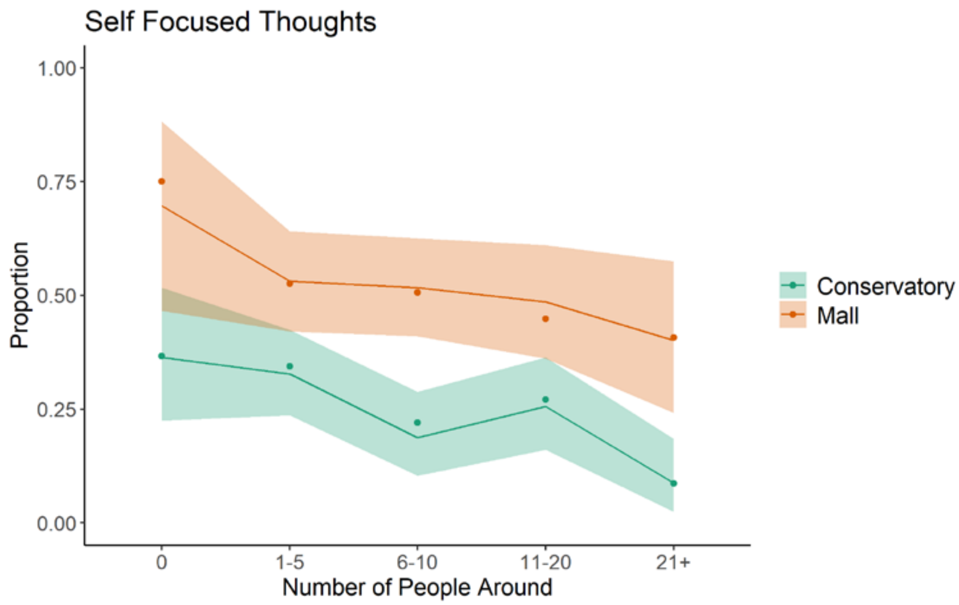

Figure 27. Observed and modeled selection of self-focused thoughts, as related to the number of people in sight. Points are observed probabilities from the raw data. The fitted line is the logistic regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

For questions asking about closeness to different groups of people and feelings of connection to the physical and social environment, the model linear model took the following form:

$$Response_i \sim \text{Normal}(\mu, \sigma)$$
$$\mu_i = 1 + \alpha_{\text{participant[i]}} + \beta 1_{condition\text{[j]}} + \beta 2_{people\_around\text{[k]}} + \beta 3_{\text{condition*people\_around[l]}}$$
$$\beta 1_{\text{j}} \sim \text{Normal}(0, 2) \text{ , for j = 1-2 (conservatory, mall)}$$
$$\beta 2_{\text{k}} \sim \text{Normal}(0, 2) \text{ , for k = 1-5 (levels of people in sight)}$$
$$\beta 3_{\text{l}} \sim \text{Normal}(0, 2) \text{ , for l = 1-10 (interaction of condition x people in sight)}$$
$$\alpha_{participant[i]} \sim \text{Normal}(\overline{\alpha}, \sigma_\alpha) \text{ , for } i = 1 - 86$$
$$\sigma \sim \text{Exponential}(1)$$
$$\overline{\alpha} \sim \text{Normal}(5, 1.5)$$
$$\sigma_\alpha \sim \text{Exponential}(1)$$

Feelings of closeness to nearby people interacted between condition and number of people around (Figure 28a). Feelings of closeness to nearby people was higher with a greater number of people around in the conservatory but was lower with a greater number of people around in the mall. For example, when there were 21 or more people around closeness to nearby people was rated 0.87 (89% PI [0.07, 1.68]) points higher than when there was no one in sight at the conservatory. When in the mall, closeness to nearby people was rated highest when in sight of no one and rated lowest when surrounded by 11-20 people, with a 0.87 (89% PI [-0.08, 1.81]) point difference between the two.

Feelings of closeness to people around the world also interacted with number of people around (Figure 28b). While ratings were relatively stable across different numbers of people around in the mall, there was a drop in closeness to people around the world in the conservatory when participants saw 11-20 people around them. Closeness to people around the world when surrounded by 11-20 people was 0.83 (89% PI [0.25, 1.42]) points lower than no one in sight and 0.93 (89% PI [0.26, 1.60]) points lower than when there were 21 or more people around. Closeness to family and friends did not interact with number of people in the surroundings. See Table S4.6 for full models.

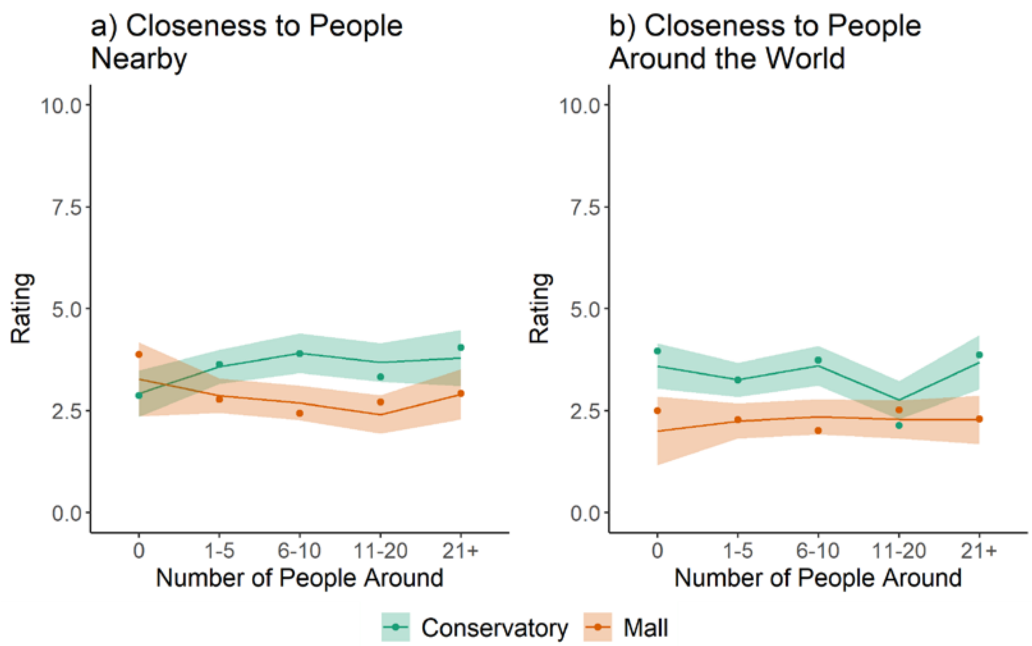

Figure 28. Observed and modeled ratings for feelings of closeness to people in the surroundings and people around the world, as related to the number of people in sight at time of survey.

Figure 28, continued. Points are mean observed ratings from the raw data. The fitted line is the linear model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Feelings of connection to the social environment showed no main effect of number of people around but had an interaction between condition and number of people around, such that connection to the social environment was higher in the mall than conservatory when there were no people in sight but dropped to be lower than the conservatory with any number of people around (Figure 29a). For example, connection to the social environment when there were 21 or more people around was rated 0.92 (89% PI [-0.1, 1.96]) points lower than when there was no one in sight at the mall. See Table S4.7 for full model.

There was a main effect of number of people around on feelings of connection to the physical environment (Figure 29b), but this did not interact with condition. Participants reported less connected to the physical environment when there were more people in their surroundings in both environments. For example, connection to the physical environment when surrounded by 21 or people was 1.08 (89% PI [-0.05, 2.22]) points lower than when there was no one in sight at the mall, and 0.90 (89% PI [-0.01, 1.80]) points lower in the conservatory. See Table S4.7 for full model.

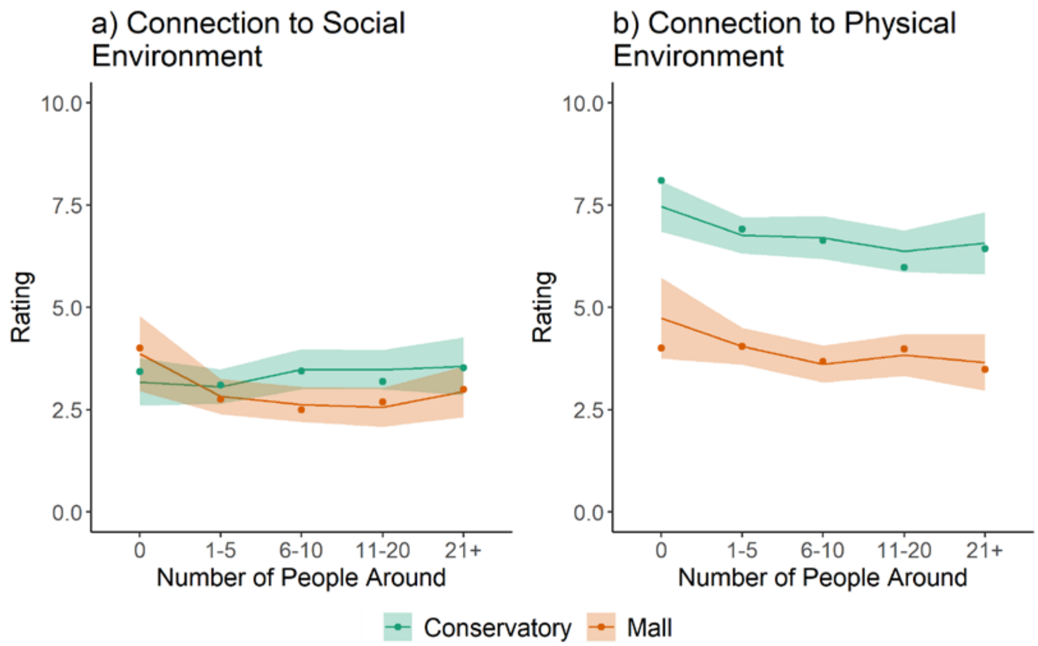

Figure 29. Observed and modeled ratings for feelings of connection to the physical and social environment, as related to the number of people in sight at time of survey. Points are mean observed ratings from the raw data. The fitted line is the linear model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Relationships between personality measures and thought content

We computed Bayesian bivariate linear correlation estimates (rho) between participant trait measures (e.g., Agreeableness) and dependent variables (e.g., closeness to nearby people) that had shown time by environment interactions in the main analyses. Each participant's reported ratings within each environment (i.e., responses at Surveys 1-3) were averaged and correlations were conducted separately for each environment. There were not many strong correlations between the trait measures and dependent variables. Trait intellect (sometime referred to as openness to experience) was positively correlated with feelings of connection to the physical environment in the conservatory (rho = .29, 89% PI [.10, .48]). Subjective vitality was positively correlated with feeling closer to nearby people and people around the world in both environments (close nearby, conservatory rho = .28, 89% PI [.08, .47], mall rho = .25, 89%

PI [.05, .44]; closeness around the world, conservatory rho = .44, 89% PI [.26, .59], mall rho = .27, 89% PI [.07, .46]. See Figure S4.4 for all other correlations. Overall, the results were not substantially moderated by individual differences and thus were fairly consistent across the measured personality types.

Discussion

Across numerous measures we observed that being around natural elements led to a greater emphasis on social and environmental thoughts and feelings compared to being in a retail environment. Participants had less self-focused thoughts in the conservatory and had more thoughts about themselves in a relational sense (that is, themselves with other people), as well as more non-interpersonal thoughts (i.e., thoughts about things other than people). Participants reported feeling closer to people all over the world, as well as people in their surrounding environment, when in the conservatory compared to the mall. They also felt more connected to both social and physical elements of their environment while walking in the conservatory. These findings are in line with previous work showing that exposure to natural environments may increase orientation towards others (Goldy & Piff, 2020). Broadly, these results suggest a pattern of thoughts and feelings while in a natural space that is less self-focused and instead more focused on, and connected to, both people and other things in the surrounding environment.

We did not define the term “social environment” for participants, which meant they were allowed to interpret what the construct meant for them. There were similar patterns of results for connection to the social environment and closeness to people nearby, as well as closeness to people around the world. The ratings on these questions all showed large, positive correlations as well, with connection to the social environment correlating more strongly with closeness to nearby people than people around the world. This may reflect participants using similar cues from their surroundings to answer these questions.

By having participants report thought content repeatedly while in the two environments, we were able to measure how differences in thought changed over time with increasing amounts of exposure. All observed differences were present at the first surveyed timepoint, indicating that spending approximately 20 minutes in these environments was sufficient to induce differences in thoughts and feelings. Additionally, all differences in thought content were present at all three time points, indicating the strong persistence of these effects. Findings like this indicate the importance of repeated measurements *during* explorations of different environments.

It remains unknown how persistent these thought content differences would be after participants left the respective environments. For example, at the end of the hour walk in the nature conservatory, participants were less likely to be thinking about themselves, but we do not know if this bias away from self-focused thinking would persist for another hour after leaving the conservatory. Doing so would require new studies that continue to monitor thoughts after participants leave different environments, which could be conducted using our ecological momentary assessment procedure. Additionally, given the causal impact of conscious thoughts on behavior (Baumeister et al., 2011), studies that examine social thinking with pro-social behavior, or environmentally focused thinking with pro-environmental behavior, could elucidate links between thought content and behavior in these domains. For instance, conscious feelings of connection to others may mediate the occurrence of pro-social behavior that has been observed after exposure to natural environments. Given that nature connectedness is associated with pro-environmental behaviors (Geng et al., 2015), having access and opportunity to visit safe, urban greenspace may be helpful for environmental conservation efforts (Maurice et al., 2021).

The number of people in sight while taking the survey had a complex effect that often interacted with the environment. More people in sight was generally associated with increased feelings of closeness to nearby people and connection to the social environment in the conservatory but, interestingly, decreased those effects in the mall. Importantly, the number of people that were around was similar in both environments but had different effects on feelings of connection to the social environment and feelings of closeness to nearby people. For other types of thoughts, the number of people around had similar effects independent of environment type (e.g., connectedness to the physical environment and proportion of self-focused thoughts). More people in sight was associated with a decrease in self-focused thoughts in both environments, however the main effect of the mall was such that the proportion of self-focused thoughts with 21 or more people around in the mall was similar to that of having zero people around in the conservatory. In other words, a crowded mall was associated with a similar proportion of self-focused thoughts as an empty conservatory. Thinking about oneself is not inherently bad, however orientation towards others and prosocial purpose may improve health and reduce loneliness (Bains & Turnbull, 2019).

There are several limitations for the generalizability of this study. This study was limited to two locations in one large US city. The design and amenities at conservatories and malls, as well as other natural and commercial spaces more broadly, around the world may influence thoughts about the social and physical environments. Cultural differences in the purposes of, and comfort in, these public spaces may also have an influence. Our study locations were chosen in part because they were accessible year-round, similar in size to each other, free to enter, desirable and frequently visited, and approximately equal distance from our lab. It will be informative to replicate this study in additional locations to determine universal effects. We attempted to conduct the study in an ecologically valid manner by having participants visit the locations during normal operating hours throughout the week with other visitors present, while using mobile devices. One aspect that may be different from typical environmental exposure, however, is that participants visited these locations without companions. How these environments may shape conversation (and thus thoughts) for people visiting with others should be researched.

In conclusion, this study further informs the immediate impact of our surrounding physical environment on conscious thoughts and feelings, through the use of public space. Being able to use public spaces in general can increase feelings of belonging (Trawalter et al., 2021). Access to public greenspace, in particular, seems to be particularly beneficial for increasing feelings of connection to others, particularly to those nearby. Although living in large cities can increase exposure to large social networks (Stier et al., 2021), having accessible urban greenspace within those cities may help to create environments that engender particularly positive social engagement.

GENERAL DISCUSSION

Overall, the findings of the previous chapters indicate that a person's surrounding physical environment can influence their thoughts in systematic ways. Thus, in addition to the well-studied effects of environmental features on general cognition and affect, there is now evidence that specific thought patterns can be influenced by one's environment. This work also adds to the body of work demonstrating that low-level features are constitutive of semantic knowledge (Kiefer & Pulvermüller, 2012; Pulvermüller, 2013). Specifically, I found that scrambled edge images, which did not contain overt semantic information, maintained the influence of naturalness and non-straight edges on thought content that had been seen with intact images. Additionally, my findings could lead to insights into the mechanisms through which physical environments produce cognitive and affective benefits via the perception of visual information (Joye & van den Berg, 2011; Schertz & Berman, 2019).

How the environment influences thought content has largely been ignored, despite a substantial body of work looking at various aspects of spontaneous thought, which is also called mind wandering, undirected thought, or self-generated thought (Christoff, 2012; Sripada & Taxali, 2020). This is partly due to the fact that spontaneous thought, by definition, is not highly constrained by the surrounding environment, as spontaneous thought is typically defined by the types of thought it is not – it is not goal-directed, governed by cognitive control, or fully determined by salient stimuli (Mildner & Tamir, 2019). Therefore, research looking into how context influences thoughts has, for the most part, focused on factors such as one's current task (Nyklíček et al., 2021), or its difficulty (Smallwood & Andrews-Hanna, 2013), as contextual factors, rather than the features of the environment. The studies included in this dissertation suggest that environmental factors influence many different aspects of thought content including valence, sociality, temporality, and environmental focus, among other features.

There are several lines of work that follow from these studies. One line could examine how locations might be "generators" versus "attractors" of certain thought patterns. Places may be attractors of certain thought patterns, by drawing in people who are already having those thoughts. Places may also be generators of thought content, by influencing what people think about whenever they happen to go there. The distinction of places as attractors or generators has been used in other social sciences fields, such as criminology (Brantingham & Brantingham, 1995; for an example see Kurland et al., 2014). Most of the studies included here provide evidence that urban greenspaces can act as generators of certain types of thoughts. The within-subject designs of Chapters 1 (Study 3), 2, 3, and 4 all strengthen this argument. However, natural environments could be thought attractors as well. Do people choose to visit parks when they are already thinking about certain topics? Some of the journal entries from Chapter 1 (Study 1) imply this could be the case. For instance, one visitor to the park at Govens Presbyterian Church wrote, "A cold day, hard to write, but I have been thinking often of the labyrinth and felt it calling me. This is very much a time of new beginning and going forward into the unknown and letting go of the old. I call forth a spirit of adventure and summon my visions of faith. My meditation, go forth in joy, look back in peace." To examine how thoughts might be generated by or attracted to a space, it will be necessary to examine thought content over longer periods of time with geolocated data, potentially through experience sampling studies or the use of social media posts. Studies of these types may also show how thoughts and feelings more generally "move" through larger environments, as well as how they may become more similar or different across individuals in certain locations.

Across all studies, the theme of positively valenced affect or thought content was observed in natural environments. This was determined either by self-reported thought, self-reported affect or by utilizing valence ratings of words. Given that previous findings have found that preferences for natural images accounts for positive affect improvements from viewing images of nature (Meidenbauer et al., 2020), future work should examine how preference interacts with environments to influence thought content. Another line of work should attempt to integrate with or update the theories that have already been posited about the restorative effects of natural environments with the changes in thought content found across these studies. For instance, shifts in thought content may mediate previously observed cognitive and affective benefits of natural environments, which could further elucidate the mechanisms of these effects. For example, attention restoration theory hypothesizes that environments are restorative for working-memory processes when they are softly fascinating, have sufficient extent, induce feelings of being away, and are compatible with one's goals (R. Kaplan & Kaplan, 1989). If we observe that either conscious thoughts or latent topics related to these components correlate with improved working-memory performance, it might lend support to the hypothesis that these features are important for cognitive restoration.

In addition to these theoretical questions, this body of work has implications for urban planning and the design of built spaces. Urban greenspaces offer city dwellers a location to engage in positive, reflective thought, and connect to their surrounding social and physical environment. In addition to the ecosystems services that natural areas within cities provide, the mental health benefits of nature should be considered as a reason for their necessity (Bratman et al., 2019). The design of the built environment should also account for the low-level visual features which make up its components, as these contribute to the thoughts and feelings a space engenders. Equitable access to safe and maintained urban greenspace should be a goal for sustainable and healthy communities.

REFERENCES

Alter, A. L. (2013). The Benefits of Cognitive Disfluency. *Current Directions in Psychological Science*, *22*(6), 437–442. https://doi.org/10.1177/0963721413498894

Andrews-Hanna, J., Kaiser, R., Turner, A., Reineberg, A., Godinez, D., Dimidjian, S., & Banich, M. (2013). A penny for your thoughts: Dimensions of self-generated thought content and relationships with individual differences in emotional wellbeing. *Frontiers in Psychology*, *4*. https://www.frontiersin.org/article/10.3389/fpsyg.2013.00900

Arnberger, A., & Eder, R. (2012). The influence of green space on community attachment of urban and suburban residents. *Urban Forestry & Urban Greening*, *11*(1), 41–49. https://doi.org/10.1016/j.ufug.2011.11.003

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

Artress, L. (1996). *Walking a Sacred Path: Rediscovering the Labyrinth as a Spiritual Practice*. Penguin.

Bakolis, I., Hammoud, R., Smythe, M., Gibbons, J., Davidson, N., Tognin, S., & Mechelli, A. (2018). Urban Mind: Using Smartphone Technologies to Investigate the Impact of Nature on Mental Well-Being in Real Time. *BioScience*, *68*(2), 134–145. https://doi.org/10.1093/biosci/bix149

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, *17*(8), 645–648.

Bar, M., & Neta, M. (2007). Visual elements of subjective preference modulate amygdala activation. *Neuropsychologia*, *45*(10), 2191–2200. https://doi.org/10.1016/j.neuropsychologia.2007.03.008

Bartram, L., & Nakatani, A. (2010). *What Makes Motion Meaningful? Affective Properties of Abstract Motion*. 468–474. https://doi.org/10.1109/PSIVT.2010.85

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting Linear Mixed-Effects Models using lme4. *ArXiv:1406.5823 [Stat]*. http://arxiv.org/abs/1406.5823

Baumeister, R. F., Hofmann, W., Summerville, A., Reiss, P. T., & Vohs, K. D. (2020). Everyday Thoughts in Time: Experience Sampling Studies of Mental Time Travel. *Personality and Social Psychology Bulletin*, *46*(12), 1631–1648. https://doi.org/10.1177/0146167220908411

Baumeister, R. F., Masicampo, E. J., & Vohs, K. D. (2011). Do Conscious Thoughts Cause Behavior? *Annual Review of Psychology*, *62*(1), 331–361. https://doi.org/10.1146/annurev.psych.093008.131126

Berens, P. (2009). **CircStat**: A *MATLAB* Toolbox for Circular Statistics. *Journal of Statistical Software*, *31*(10). https://doi.org/10.18637/jss.v031.i10

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), e114572. https://doi.org/10.1371/journal.pone.0114572

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

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

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

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

Berry, M. S., Repke, M. A., Nickerson, N. P., Iii, L. G. C., Odum, A. L., & Jordan, K. E. (2015). Making Time for Nature: Visual Exposure to Natural Environments Lengthens Subjective Time Perception and Reduces Impulsivity. *PLOS ONE*, *10*(11), e0141030. https://doi.org/10.1371/journal.pone.0141030

Berry, M. S., Sweeney, M. M., Morath, J., Odum, A. L., & Jordan, K. E. (2014). The Nature of Impulsivity: Visual Exposure to Natural Environments Decreases Impulsive Decision-Making in a Delay Discounting Task. *PLOS ONE*, *9*(5), e97915. https://doi.org/10.1371/journal.pone.0097915

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology*, *25*, 249–259.

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

Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent Dirichlet Allocation. *Journal of Machine Learning Research*, *3*(Jan), 993–1022.

Bourrier, S. C., Berman, M. G., & Enns, J. T. (2018). Cognitive Strategies and Natural Environments Interact in Influencing Executive Function. *Frontiers in Psychology*, *9*, 1248. https://doi.org/10.3389/fpsyg.2018.01248

Brantingham, P., & Brantingham, P. (1995). Criminality of place. *European Journal on Criminal Policy and Research*, *3*(3), 5–26. https://doi.org/10.1007/BF02242925

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

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

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

Breslow, N. E., & Clayton, D. G. (1993). Approximate Inference in Generalized Linear Mixed Models. *Journal of the American Statistical Association*, *88*(421), 9–25. https://doi.org/10.1080/01621459.1993.10594284

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*, *41*(4), 977–990. https://doi.org/10.3758/BRM.41.4.977

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01
Carr, S., Francis, M., Rivlin, L. G., & Stone, A. M. (1992). *Public Space*. Cambridge University Press.
Chen, E. (n.d.). *Introduction to Latent Dirichlet Allocation*. Retrieved February 19, 2019, from http://blog.echen.me/2011/08/22/introduction-to-latent-dirichlet-allocation/
Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning*, *68*(1), 129–138. https://doi.org/10.1016/j.landurbplan.2003.08.003
Christoff, K. (2012). Undirected thought: Neural determinants and correlates. *Brain Research*, *1428*, 51–59. https://doi.org/10.1016/j.brainres.2011.09.060
Chulvi, V., Agost, M. J., Felip, F., & Gual, J. (2020). Natural elements in the designer's work environment influence the creativity of their results. *Journal of Building Engineering*, *28*, 101033. https://doi.org/10.1016/j.jobe.2019.101033
Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological Assessment*, *6*(4), 284–290.
Coburn, A., Kardan, O., Kotabe, H., Steinberg, J., Hout, M. C., Robbins, A., MacDonald, J., Hayn-Leichsenring, G., & Berman, M. G. (2019). Psychological responses to natural patterns in architecture. *Journal of Environmental Psychology*, *62*, 133–145. https://doi.org/10.1016/j.jenvp.2019.02.007
Coley, R. L., Sullivan, W. C., & Kuo, F. E. (1997). Where Does Community Grow?: The Social Context Created by Nature in Urban Public Housing. *Environment and Behavior*, *29*(4), 468–494. https://doi.org/10.1177/001391659702900402
Craig, T. P., Fischer, A., & Lorenzo-Arribas, A. (2018). Shopping versus Nature? An Exploratory Study of Everyday Experiences. *Frontiers in Psychology*, *0*. https://doi.org/10.3389/fpsyg.2018.00009
Dehghani, M., Sagae, K., Sachdeva, S., & Gratch, J. (2014). Analyzing Political Rhetoric in Conservative and Liberal Weblogs Related to the Construction of the "Ground Zero Mosque." *Journal of Information Technology & Politics*, *11*(1), 1–14. https://doi.org/10.1080/19331681.2013.826613
Deveaud, R., SanJuan, E., & Bellot, P. (2014). Accurate and effective latent concept modeling for ad hoc information retrieval. *Document Numérique*, *17*(1), 61–84. https://doi.org/10.3166/dn.17.1.61-84
DiCarlo, J. J., & Cox, D. D. (2007). Untangling invariant object recognition. *Trends in Cognitive Sciences*, *11*(8), 333–341. https://doi.org/10.1016/j.tics.2007.06.010
Doherty, S. T., Lemieux, C. J., & Canally, C. (2014). Tracking human activity and well-being in natural environments using wearable sensors and experience sampling. *Social Science & Medicine*, *106*, 83–92. https://doi.org/10.1016/j.socscimed.2014.01.048
Donnellan, M. B., Oswald, F. L., Baird, B. M., & Lucas, R. E. (2006). The Mini-IPIP Scales: Tiny-yet-effective measures of the Big Five Factors of Personality. *Psychological Assessment*, *18*(2), 192–203. https://doi.org/10.1037/1040-3590.18.2.192
Edmiston, P., & Lupyan, G. (2015). Visual interference disrupts visual and only visual knowledge. *Journal of Vision*, *15*(12), 10–10. https://doi.org/10.1167/15.12.10
El Hedhli, K., Chebat, J.-C., & Sirgy, M. J. (2013). Shopping well-being at the mall: Construct, antecedents, and consequences. *Journal of Business Research*, *66*(7), 856–863. https://doi.org/10.1016/j.jbusres.2011.06.011

Farren, L., Belza, B., Allen, P., Brolliar, S., Brown, D. R., Cormier, M. L., Janicek, S., Jones, D. L., King, D. K., Marquez, D. X., & Rosenberg, D. E. (2015). Mall Walking Program Environments, Features, and Participants: A Scoping Review. *Preventing Chronic Disease*, *12*. https://doi.org/10.5888/pcd12.150027

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

Fellows, I. (2014). *Wordcloud* [R].

Ferrari, A. J., Charlson, F. J., Norman, R. E., Patten, S. B., Freedman, G., Murray, C. J. L., Vos, T., & Whiteford, H. A. (2013). Burden of Depressive Disorders by Country, Sex, Age, and Year: Findings from the Global Burden of Disease Study 2010. *PLoS Medicine*, *10*(11), e1001547. https://doi.org/10.1371/journal.pmed.1001547

Forsythe, A., Nadal, M., Sheehy, N., Cela-Conde, C. J., & Sawey, M. (2011). Predicting beauty: Fractal dimension and visual complexity in art. *British Journal of Psychology*, *102*(1), 49–70. https://doi.org/10.1348/000712610X498958

Goldy, S. P., & Piff, P. K. (2020). Toward a social ecology of prosociality: Why, when, and where nature enhances social connection. *Current Opinion in Psychology*, *32*, 27–31. https://doi.org/10.1016/j.copsyc.2019.06.016

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

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health*, *35*(1), 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hong, L., & Davison, B. D. (2010). Empirical Study of Topic Modeling in Twitter. *Proceedings of the First Workshop on Social Media Analytics*, 80–88. https://doi.org/10.1145/1964858.1964870

Hughes, M. E., Waite, L. J., Hawkley, L. C., & Cacioppo, J. T. (2004). A Short Scale for Measuring Loneliness in Large Surveys. *Research on Aging*, *26*(6), 655–672. https://doi.org/10.1177/0164027504268574

Ibarra, F. F., Kardan, O., Hunter, M. R., Kotabe, H. P., Meyer, F. A. C., & Berman, M. G. (2017). Image Feature Types and Their Predictions of Aesthetic Preference and Naturalness. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00632

Iliev, R., Dehghani, M., & Sagi, E. (2015). Automated text analysis in psychology: Methods, applications, and future developments. *Language and Cognition*, *7*(02), 265–290. https://doi.org/10.1017/langcog.2014.30

James, W. (1890). *The principles of psychology, vol. 1*. Dover Publications.

Jennings, V., & Bamkole, O. (2019). The Relationship between Social Cohesion and Urban Green Space: An Avenue for Health Promotion. *International Journal of Environmental Research and Public Health*, *16*(3), 452. https://doi.org/10.3390/ijerph16030452

Jiang, B., Schmillen, R., & Sullivan, W. C. (2019). How to Waste a Break: Using Portable Electronic Devices Substantially Counteracts Attention Enhancement Effects of Green Spaces. *Environment and Behavior*, *51*(9–10), 1133–1160. https://doi.org/10.1177/0013916518788603

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

Joye, Y., & van den Berg, A. (2011). Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research. *Urban Forestry & Urban Greening*, *10*(4), 261–268. https://doi.org/10.1016/j.ufug.2011.07.004

Jrissman. (2010). *English: This is a photograph of the Water Tower Place mall in Chicago, IL. It has eight levels and opened in 1975.* Own work. https://commons.wikimedia.org/wiki/File:WaterTowerPlaceMall.JPG

Kaplan, R., & Kaplan, S. (1989). *The Experience of Nature: A Psychological Perspective*. CUP Archive.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182.

Kaplan, S., & Berman, M. G. (2010). Directed Attention as a Common Resource for Executive Functioning and Self-Regulation. *Perspectives on Psychological Science*, *5*(1), 43–57. https://doi.org/10.1177/1745691609356784

Kaplan, S., Kaplan, R., & Wendt, J. S. (1972). Rated preference and complexity for natural and urban visual material. *Perception & Psychophysics*, *12*(4), 354–356. https://doi.org/10.3758/BF03207221

Kardan, O., Demiralp, E., Hout, M. C., Hunter, M. R., Karimi, H., Hanayik, T., Yourganov, G., Jonides, J., & Berman, M. G. (2015). Is the preference of natural versus man-made scenes driven by bottom–up processing of the visual features of nature? *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00471

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

Kardan, O., Henderson, J. M., Yourganov, G., & Berman, M. G. (2016). Observers' cognitive states modulate how visual inputs relate to gaze control. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(9), 1429–1442. https://doi.org/10.1037/xhp0000224

Kardan, O., Layden, E., Choe, K. W., Lyu, M., Zhang, X., Beilock, S. L., Rosenberg, M. D., & Berman, M. G. (2020). *Scale-invariance in brain activity predicts practice effects in cognitive performance* (p. 2020.05.25.114959). https://doi.org/10.1101/2020.05.25.114959

Kardan, O., Shneidman, L., Krogh-Jespersen, S., Gaskins, S., Berman, M. G., & Woodward, A. (2017). Cultural and Developmental Influences on Overt Visual Attention to Videos. *Scientific Reports*, *7*(1), 11264. https://doi.org/10.1038/s41598-017-11570-w

Kaźmierczak, A. (2013). The contribution of local parks to neighbourhood social ties. *Landscape and Urban Planning*, *109*(1), 31–44. https://doi.org/10.1016/j.landurbplan.2012.05.007

Kenraiz, K. Z. (2016). *English: Garfield Park Conservatory in Chicago*. Own work. https://commons.wikimedia.org/wiki/File:Garfield_Park_Conservatory_kz16.jpg

Kiefer, M., & Pulvermüller, F. (2012). Conceptual representations in mind and brain: Theoretical developments, current evidence and future directions. *Cortex*, *48*(7), 805–825. https://doi.org/10.1016/j.cortex.2011.04.006

Killingsworth, M. A., & Gilbert, D. T. (2010). A Wandering Mind Is an Unhappy Mind. *Science*, *330*(6006), 932–932. https://doi.org/10.1126/science.1192439

Kotabe, H. P., Kardan, O., & Berman, M. G. (2016). The order of disorder: Deconstructing visual disorder and its effect on rule-breaking. *Journal of Experimental Psychology: General*, *145*(12), 1713–1727. https://doi.org/10.1037/xge0000240

Kotabe, H. P., Kardan, O., & Berman, M. G. (2017). The nature-disorder paradox: A perceptual study on how nature is disorderly yet aesthetically preferred. *Journal of Experimental Psychology: General*, *146*(8), 1126–1142. https://doi.org/10.1037/xge0000321

Kuo, F. E., & Sullivan, W. C. (2001a). Environment and Crime in the Inner City: Does Vegetation Reduce Crime? *Environment and Behavior*, *33*(3), 343–367. https://doi.org/10.1177/0013916501333002

Kuo, F. E., & Sullivan, W. C. (2001b). Aggression and Violence in the Inner City: Effects of Environment via Mental Fatigue. *Environment and Behavior*, *33*(4), 543–571. https://doi.org/10.1177/00139160121973124

Kurland, J., Johnson, S. D., & Tilley, N. (2014). Offenses around Stadiums: A Natural Experiment on Crime Attraction and Generation. *Journal of Research in Crime and Delinquency*, *51*(1), 5–28. https://doi.org/10.1177/0022427812471349

Larson, R., & Csikszentmihalyi, M. (2014). The Experience Sampling Method. In M. Csikszentmihalyi (Ed.), *Flow and the Foundations of Positive Psychology: The Collected Works of Mihaly Csikszentmihalyi* (pp. 21–34). Springer Netherlands. https://doi.org/10.1007/978-94-017-9088-8_2

Layden, E. A. (2017). *N-Back Memory Training* [Android]. https://play.google.com/store/apps/details?id=science.eal.n_backmemorytraining&hl=en

Lim, K. H., Lee, K. E., Kendal, D., Rashidi, L., Naghizade, E., Winter, S., & Vasardani, M. (2018). The Grass is Greener on the Other Side: Understanding the Effects of Green Spaces on Twitter User Sentiments. *Companion Proceedings of the The Web Conference 2018*, 275–282. https://doi.org/10.1145/3184558.3186337

Lischetzke, T., & Könen, T. (2021). Daily Diary Methodology. In F. Maggino (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 1–8). Springer International Publishing. https://doi.org/10.1007/978-3-319-69909-7_657-2

Litman, L., Robinson, J., & Abberbock, T. (2017). TurkPrime.com: A versatile crowdsourcing data acquisition platform for the behavioral sciences. *Behavior Research Methods*, *49*(2), 433–442. https://doi.org/10.3758/s13428-016-0727-z

Lockyer, M., & Bartram, L. (2012). Affective motion textures. *Computers & Graphics*, *36*(6), 776–790. https://doi.org/10.1016/j.cag.2012.04.009

Loidl, H., & Bernard, S. (2014). *Open(ing) Spaces: Design as Landscape Architecture*. Walter de Gruyter.

Long, B., Yu, C.-P., & Konkle, T. (2018). Mid-level visual features underlie the high-level categorical organization of the ventral stream. *Proceedings of the National Academy of Sciences*, *115*(38), E9015–E9024. https://doi.org/10.1073/pnas.1719616115

MacKerron, G., & Mourato, S. (2013). Happiness is greater in natural environments. *Global Environmental Change*, *23*(5), 992–1000. https://doi.org/10.1016/j.gloenvcha.2013.03.010

Mangelsdorf, H. H., & Kotabe, H. P. (2017, April). *Psychological consequences of valuing emotions*. University of Chicago Cognitive Brown Bag, Chicago, IL, US.

Mantler, A., & Logan, A. C. (2015). Natural environments and mental health. *Advances in Integrative Medicine*, *2*(1), 5–12. https://doi.org/10.1016/j.aimed.2015.03.002

MATLAB and Image Processing Toolbox (Version 2014b). (2014). [Matlab]. The MathWorks Inc.

Mayhew, M. J., & Powell, J. H. (2014). The development of a brief self-report questionnaire to measure 'recent' Rash Impulsivity: A preliminary investigation of its validity and

association with recent alcohol consumption. *Addictive Behaviors*, *39*(11), 1597–1605. https://doi.org/10.1016/j.addbeh.2014.03.022
Mccallum, A. (2002). *MALLET: A Machine Learning for Language Toolkit*.
McCoy, J. M., & Evans, G. W. (2002). The Potential Role of the Physical Environment in Fostering Creativity. *Creativity Research Journal*, *14*(3–4), 409–426. https://doi.org/10.1207/S15326934CRJ1434_11
McCullagh, P. (2018). *Generalized Linear Models*. Routledge.
McElreath, R. (2020). *Statistical Rethinking: A Bayesian Course with Examples in R and STAN*. CRC Press.
McMahan, E. A., & Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *The Journal of Positive Psychology*, *10*(6), 507–519. https://doi.org/10.1080/17439760.2014.994224
Meidenbauer, K. L., Stenfors, C. U. D., Bratman, G. N., Gross, J. J., Schertz, K. E., Choe, K. W., & Berman, M. G. (2020). The affective benefits of nature exposure: What's nature got to do with it? *Journal of Environmental Psychology*, *72*, 101498. https://doi.org/10.1016/j.jenvp.2020.101498
Meyers-Levy, J., & Zhu, R. (2007). The Influence of Ceiling Height: The Effect of Priming on the Type of Processing That People Use. *Journal of Consumer Research*, *34*(2), 174–186. https://doi.org/10.1086/519146
Mildner, J. N., & Tamir, D. I. (2019). Spontaneous Thought as an Unconstrained Memory Process. *Trends in Neurosciences*, *42*(11), 763–777. https://doi.org/10.1016/j.tins.2019.09.001
Milgram, S. (1970). *The experience of living in cities: A psychological analysis* (p. 173). American Psychological Association. https://doi.org/10.1037/10042-011
Murzintcev, N. (2014). *Ldatuning* [R]. https://cran.r-project.org/web/packages/ldatuning/index.html
Nordh, H., Hartig, T., Hagerhall, C. M., & Fry, G. (2009). Components of small urban parks that predict the possibility for restoration. *Urban Forestry & Urban Greening*, *8*(4), 225–235. https://doi.org/10.1016/j.ufug.2009.06.003
Nordh, H., & Østby, K. (2013). Pocket parks for people – A study of park design and use. *Urban Forestry & Urban Greening*, *12*(1), 12–17. https://doi.org/10.1016/j.ufug.2012.11.003
Nyklíček, I., Tinga, A. M., & Spapens, S. (2021). The relation between thinking and mood in daily life: The effects of content and context of thought. *Consciousness and Cognition*, *95*, 103193. https://doi.org/10.1016/j.concog.2021.103193
Oldenburg, R., & Brissett, D. (1982). The third place. *Qualitative Sociology*, *5*(4), 265–284.
Oliva, A., & Torralba, A. (2006). Building the gist of a scene: The role of global image features in recognition. *Progress in Brain Research*, *155*, 23–36.
Pennebaker, J. W., & Beall, S. K. (1986). Confronting a traumatic event: Toward an understanding of inhibition and disease. *Journal of Abnormal Psychology*, *95*(3), 274.
Peters, K., Elands, B., & Buijs, A. (2010). Social interactions in urban parks: Stimulating social cohesion? *Urban Forestry & Urban Greening*, *9*(2), 93–100. https://doi.org/10.1016/j.ufug.2009.11.003
Plambech, T., & Konijnendijk van den Bosch, C. C. (2015). The impact of nature on creativity – A study among Danish creative professionals. *Urban Forestry & Urban Greening*, *14*(2), 255–263. https://doi.org/10.1016/j.ufug.2015.02.006
Pratt, W. K. (1978). *Digital Image Processing*. Wiley.

Pulvermüller, F. (2013). How neurons make meaning: Brain mechanisms for embodied and abstract-symbolic semantics. *Trends in Cognitive Sciences*, *17*(9), 458–470. https://doi.org/10.1016/j.tics.2013.06.004

R Core Team. (2017). *R: A language and environment for statistical computing.* (3.3.3) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Ramage, D., Dumais, S., & Liebling, D. (2010, May 16). Characterizing Microblogs with Topic Models. *Fourth International AAAI Conference on Weblogs and Social Media*. Fourth International AAAI Conference on Weblogs and Social Media. https://www.aaai.org/ocs/index.php/ICWSM/ICWSM10/paper/view/1528

Rook, D. W., & Fisher, R. J. (1995). Normative Influences on Impulsive Buying Behavior. *Journal of Consumer Research*, *22*(3), 305–313. https://doi.org/10.1086/209452

Ryan, R. M., & Frederick, C. (1997). On Energy, Personality, and Health: Subjective Vitality as a Dynamic Reflection of Well-Being. *Journal of Personality*, *65*(3), 529–565. https://doi.org/10.1111/j.1467-6494.1997.tb00326.x

Schertz, K. E., & Berman, M. G. (2019). Understanding Nature and Its Cognitive Benefits: *Current Directions in Psychological Science*, *28*(5), 496–502. https://doi.org/10.1177/0963721419854100

Schertz, K. E., Kardan, O., & Berman, M. G. (2020). Visual features influence thought content in the absence of overt semantic information. *Attention, Perception, & Psychophysics*. https://doi.org/10.3758/s13414-020-02121-z

Schertz, K. E., Sachdeva, S., Kardan, O., Kotabe, H. P., Wolf, K. L., & Berman, M. G. (2018). A thought in the park: The influence of naturalness and low-level visual features on expressed thoughts. *Cognition*, *174*, 82–93. https://doi.org/10.1016/j.cognition.2018.01.011

Schertz, K. E., Saxon, J., Cardenas-Iniguez, C., Bettencourt, L. M. A., Ding, Y., Hoffmann, H., & Berman, M. G. (2021). Neighborhood street activity and greenspace usage uniquely contribute to predicting crime. *Npj Urban Sustainability*, *1*(1), 1–10. https://doi.org/10.1038/s42949-020-00005-7

Schnell, I., Harel, N., & Mishori, D. (2019). The benefits of discrete visits in urban parks. *Urban Forestry & Urban Greening*, *41*, 179–184. https://doi.org/10.1016/j.ufug.2019.03.019

Schroeder, H. W., & Anderson, L. M. (1984). Perception of Personal Safety in Urban Recreation Sites. *Journal of Leisure Research*, *16*(2), 178–194. https://doi.org/10.1080/00222216.1984.11969584

Schwartz, A. J., Dodds, P. S., O'Neil-Dunne, J. P. M., Danforth, C. M., & Ricketts, T. H. (2019). Visitors to urban greenspace have higher sentiment and lower negativity on Twitter. *People and Nature*, *1*(4), 476–485. https://doi.org/10.1002/pan3.10045

Seligman, M. E. P., Steen, T. A., Park, N., & Peterson, C. (2005). Positive Psychology Progress: Empirical Validation of Interventions. *American Psychologist*, *60*(5), 410–421. https://doi.org/10.1037/0003-066X.60.5.410

Smallwood, J., & Andrews-Hanna, J. (2013). Not all minds that wander are lost: The importance of a balanced perspective on the mind-wandering state. *Frontiers in Psychology*, *4*. https://www.frontiersin.org/article/10.3389/fpsyg.2013.00441

Smallwood, J., & Schooler, J. W. (2015). The Science of Mind Wandering: Empirically Navigating the Stream of Consciousness. *Annual Review of Psychology*, *66*(1), 487–518. https://doi.org/10.1146/annurev-psych-010814-015331

Sripada, C., & Taxali, A. (2020). Structure in the stream of consciousness: Evidence from a verbalized thought protocol and automated text analytic methods. *Consciousness and Cognition*, *85*, 103007. https://doi.org/10.1016/j.concog.2020.103007

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers*, *31*(1), 137–149. https://doi.org/10.3758/BF03207704

Stemler, S. (2000). An overview of content analysis. *Practical Assessment, Research, and Evaluation*, *7*(1). https://doi.org/10.7275/z6fm-2e34

Stenfors, C. U. D., Van Hedger, S. C., Schertz, K. E., Meyer, F. A. C., Smith, K. E. L., Norman, G. J., Bourrier, S. C., Enns, J. T., Kardan, O., Jonides, J., & Berman, M. G. (2019). Positive Effects of Nature on Cognitive Performance Across Multiple Experiments: Test Order but Not Affect Modulates the Cognitive Effects. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.01413

Stevenson, M. P., Schilhab, T., & Bentsen, P. (2018). Attention Restoration Theory II: A systematic review to clarify attention processes affected by exposure to natural environments. *Journal of Toxicology and Environmental Health, Part B*, *21*(4), 227–268. https://doi.org/10.1080/10937404.2018.1505571

Stier, A. J., Schertz, K. E., Rim, N. W., Cardenas-Iniguez, C., Lahey, B. B., Bettencourt, L. M. A., & Berman, M. G. (2021). Evidence and theory for lower rates of depression in larger US urban areas. *Proceedings of the National Academy of Sciences*, *118*(31). https://doi.org/10.1073/pnas.2022472118

Stone, A. A., & Shiffman, S. (1994). Ecological Momentary Assessment (Ema) in Behavioral Medicine. *Annals of Behavioral Medicine*, *16*(3), 199–202. https://doi.org/10.1093/abm/16.3.199

Sullivan, W. C., Kuo, F. E., & DePooter, S. F. (2004). The fruit of urban nature—Vital neighborhood spaces. *Environment and Behavior*, *36*, 678.

Taylor, A. F., Kuo, F. E., & Sullivan, W. C. (2002). Views of nature and self-discipline: Evidence from inner city children. *Journal of Environmental Psychology*, *22*(1), 49–63. https://doi.org/10.1006/jevp.2001.0241

Trapnell, P. D., & Campbell, J. D. (1999). Private self-consciousness and the five-factor model of personality: Distinguishing rumination from reflection. *Journal of Personality and Social Psychology*, *76*(2), 284–304. https://doi.org/10.1037/0022-3514.76.2.284

Van Hedger, K., Keedy, S. K., Schertz, K. E., Berman, M. G., & de Wit, H. (2019). Effects of methamphetamine on neural responses to visual stimuli. *Psychopharmacology*, *236*(6), 1741–1748. https://doi.org/10.1007/s00213-018-5156-5

Van Hedger, S. C., Nusbaum, H., Clohisy, L., Jaeggi, S. M., Buschkuehl, M., & Berman, M. G. (2018). Of cricket chirps and car horns: The effect of nature sounds on cognitive performance. *Psychonomic Bulletin & Review*. https://doi.org/10.3758/s13423-018-1539-1

Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L. B., Leder, H., Modrono, C., Nadal, M., Rostrup, N., & Skov, M. (2013). Impact of contour on aesthetic judgments and approach-avoidance decisions in architecture. *Proceedings of the National Academy of Sciences*, *110*(Supplement_2), 10446–10453. https://doi.org/10.1073/pnas.1301227110

Walther, D. B., Caddigan, E., Fei-Fei, L., & Beck, D. M. (2009). Natural Scene Categories Revealed in Distributed Patterns of Activity in the Human Brain. *Journal of Neuroscience*, *29*(34), 10573–10581. https://doi.org/10.1523/JNEUROSCI.0559-09.2009

Wang, C., & Blei, D. M. (2011). Collaborative topic modeling for recommending scientific articles. *Proceedings of the 17th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 448–456. http://dl.acm.org/citation.cfm?id=2020480

Warriner, A. B., Kuperman, V., & Brysbaert, M. (2013). Norms of valence, arousal, and dominance for 13,915 English lemmas. *Behavior Research Methods*, *45*(4), 1191–1207. https://doi.org/10.3758/s13428-012-0314-x

Wolf, K. L., & Housley, E. (2016). *The Sacred and Nearby Nature in Cities* (p. 59). The TKF Foundation.

Xiao, J., Hays, J., Ehinger, K., Oliva, A., & Torralba, A. (2010). *SUN database: Large-scale scene recognition from abbey to zoo*. 3485–3492.

Zhao, W. X., Jiang, J., Weng, J., He, J., Lim, E.-P., Yan, H., & Li, X. (2011). Comparing Twitter and Traditional Media Using Topic Models. In P. Clough, C. Foley, C. Gurrin, G. J. F. Jones, W. Kraaij, H. Lee, & V. Mudoch (Eds.), *Advances in Information Retrieval* (pp. 338–349). Springer Berlin Heidelberg.

Appendix A: Supplementary Materials for Chapter 1

Table S1. 1

TKF Foundation Park locations and journal entry distribution

Name	**Location/ Metropolitan Area**	**Location Type**	**# of Entries**
4th Street City Park	Annapolis, MD	Park	575
American Visionary Art Museum	Baltimore, MD	Museum	702
Annapolis Maritime Museum	Annapolis, MD	Museum	665
Annapolis Waterworks Park	Annapolis, MD	Park	129
Anne Arundel Medical Center	Annapolis, MD	Hospital	498
Baltimore Clayworks	Baltimore, MD	Park	177
Baltimore Washington Medical Center	Baltimore, MD	Hospital	276
Chesapeake Bay Foundation Headquarters	Annapolis, MD	Park	707
Childrens' Peace Center	Baltimore, MD	Church	142
Crispus Attucks Development Corporation	Washington, D.C.	Park	32
Franklin Square Hospital	Baltimore, MD	Hospital	56
Frederick Douglass Gardens	Washington, D.C.	Park	31
Govans Presbyterian Church	Baltimore, MD	Church	341
Memorial Groves, Congressional Cemetery, Embassy Row	Washington, D.C.	Park	390
Juvenile Auxiliary Volunteer Agency	Baltimore, MD	Park	74
Jeremy's Way Street End Park	Annapolis, MD	Park	579
Johns Hopkins Bayview Medical Center	Baltimore, MD	Hospital	432
Kernan Hospital	Baltimore, MD	Hospital	58
Marian House	Baltimore, MD	Hospital	12
Maryland Hall for Creative Arts	Annapolis, MD	Museum	287
Georgetown Waterfront Park	Washington, D.C.	Park	573
Newborn Holistic Ministries – Martha's Place	Baltimore, MD	Church	154
Providence Hospital	Washington, D.C.	Hospital	496
St. Anthony's of Padua Church-Falls Church	Washington, D.C.	Church	61
Stadium Place-Thanksgiving Place Labyrinth	Baltimore, MD	Park	191
UMBC-Joseph Beuys Project	Baltimore, MD	Park	1478
University of Penn Museum of Archeology and Anthropology	Philadelphia, PA	Museum	231
Village Learning Place	Baltimore, MD	Museum	4
Whitman Walker Clinic of Northern Virginia	Washington, D.C.	Hospital	306

Table S1. 2

LDA Topic Model Evaluation Metrics

# of Topics in Model	Held-out Likelihood	Residuals	Exclusivity of Topics (Avg.)	Semantic Coherence (Avg.)	Iterations to Model Convergence
5	-6.89	17.85	9.10	-90.68	339
10	-6.78	12.89	9.78	-118.62	282
15	-6.81	13.23	9.74	-116.88	366
20	-6.82	15.96	9.57	-104.27	500

Note. Semantic coherence (Mimno, Wallach, Talley, Leenders, & McCallum, 2011; Newman, Lau, Grieser, & Baldwin, 2010) is a criterion, which closely mimics human judgments of topic quality and is maximized when the most likely words of a topic frequently co-occur. Exclusivity is a measure of topic content which evaluates whether a word is exclusive to a given topic or if it is relatively common across topics (Bischof & Airoldi, 2012). Nonexclusive topics are less likely to carry semantic weight. Held-out likelihood is calculated by applying the probabilities of a model to a test set and assessing how well the probability model applies. This criterion has been found to be relatively uncorrelated with human judgments of topic quality (Chang, Gerrish, Wang, Boyd-Graber, & Blei, 2009). Residuals are goodness-of-fit measures of the model performance as described by Taddy (2012).

Table S1. 3

Word weights within topic word clouds for Study 1

Family		**Park**		**Life & Emotions**		**Time & Memories**		**Art**	
Words	Weights	Words	Weights	Words	Weights	Words	Weights	Words	Weights
love	0.077	place	0.057	love	0.039	time	0.019	drawing	0.175
mom	0.021	beautiful	0.051	life	0.026	book	0.018	heart	0.07
happy	0.018	day	0.036	feel	0.024	back	0.016	face	0.061
dad	0.018	garden	0.02	time	0.019	life	0.015	smiley	0.041
miss	0.012	great	0.017	things	0.014	years	0.015	love	0.026
age	0.012	wonderful	0.017	people	0.011	day	0.015	drawings	0.01
birthday	0.011	peaceful	0.017	make	0.011	today	0.014	written	0.01
sister	0.009	nice	0.014	hope	0.01	good	0.014	flower	0.008
baby	0.009	bench	0.014	hard	0.01	year	0.011	hearts	0.007
fun	0.009	spot	0.013					entry	0.007

Nature		**Religion**		**World & Peace**		**Celebration**		**Spiritual & Life Journey**	
Words	Weights	Words	Weights	Words	Weights	Words	Weights	Words	Weights
water	0.022	god	0.087	world	0.027	day	0.028	labyrinth	0.03
sun	0.018	love	0.039	life	0.027	today	0.011	peace	0.028
trees	0.016	lord	0.034	people	0.015	birthday	0.007	path	0.02
beautiful	0.012	dear	0.02	love	0.015	year	0.007	walk	0.017
birds	0.012	jesus	0.019	live	0.013	house	0.007	life	0.015
sky	0.01	life	0.019	peace	0.009	memorial	0.006	place	0.015
day	0.01	bless	0.018	earth	0.008	people	0.006	center	0.014
breeze	0.01	pray	0.018	nature	0.008	ride	0.006	walked	0.014
wind	0.01	family	0.018	find	0.007	great	0.006	god	0.014
blue	0.008	peace	0.014	place	0.007	america	0.006	feel	0.011

Table S1. 4

Valence Ratings for Study 1 Topics

Topic	Mean Valence Rating of Top 15 Words
Religion	6.97
Park	6.82
Time & Memories	6.24
Life & Emotion	6.27
Nature	6.75
Spiritual & Life Journey	6.22
Family	6.94
World & Peace	6.92
Art	6.69
Celebration	6.67

Note. Valence ratings were calculated using values from Warriner, Kuperman, & Brysbaert (2013).

Table S1. 5

Visual Feature and Intra-topic correlation matrix for Study 1

Feature/Topic	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1. Hue	-----																			
2. Sat	-.32**	-----																		
3. Bright	.08	-.33**	-----																	
4. sdHue	.54**	-.62**	.39**	----																
5. sdSat	-.3**	.35**	-.17	-.24*	----															
6. sdBright	.11	-.18	.10	.34**	.28**	----														
7. Entropy	-.17	.00	.31**	.05	.18	.31**	----													
8. SED	-.09	.14	.19	.04	.06	.03	.14	----												
9. NSED	.02	-.02	-.29**	-.12	-.06	-.09	.04	-.62**	----											
10. Naturalness	.28**	.29**	-.37**	-.26*	-.05	-.19	-.11	-.17	.18	----										
11. Preference	.11	.20	-.15	-.04	.08	.14	-.11	.11	-.11	.42**	----									
12. Family	.06	.05	.16	.15	.12	-.11	-.10	.11	-.19	-.20	-.13	----								
13. Park	.26*	-.09	-.09	.16	-.08	.11	-.27*	-.09	-.12	.22*	.31**	-.07	----							
14. Life & Emotions	-.09	.06	-.05	-.27*	-.10	-.09	.04	-.06	.22*	.10	.00	-.22*	-.43**	----						
15. Time & Memories	-.00	.14	-.01	-.15	-.03	.15	.17	-.02	-.04	.19	.15	-.22*	.17	.32**	----					
16. Art	-.01	-.06	.09	.04	.04	.17	-.16	.19	-.12	-.22*	-.13	.16	.26*	-.04	-.07	----				
17. Nature	.32**	.02	-.14	.04	-.09	-.06	-.22*	-.24*	.02	.52**	.16	.05	.63**	-.25*	.09	.15	----			
18. Religion	-.20	-.03	.09	.03	.09	-.06	.22*	.16	-.06	-.28**	-.19	-.10	-.68**	-.08	-.48**	-.46**	-.66**	----		
19. World & Peace	-.20	.18	-.20	-.31**	-13	-.08	-.06	-.12	.28**	.06	.18	-.21*	-.16	.62**	.32**	-.16	-.17	-.22*	----	
20. Celebration	.10	-.21	.10	.09	-.04	.02	.07	-.09	.08	-.05	.12	-.12	.33**	-.01	.18	-.03	.26*	-.38**	.18	----
21. Spiritual & Life Journey	-.05	.03	-.23*	-.15	-.07	-.04	-.00	-.33**	.44**	.22*	-.00	-.41**	-.15	.07	-.04	-.28**	-.13	.05	.27*	-.09

Notes. * p < .05, ** p < .01 (not adjusted for multiple comparisons)

Table S1. 6

Valence Ratings for Study 2 Topics

Topic	Mean Valence Rating of Top 15 Words
Topic 1	6.88
Topic 2	6.15
Topic 3	6.66
Topic 4	6.79
Topic 5	6.53
Topic 6	5.90
Topic 7	6.95
Topic 8	6.48
Topic 9	5.61
Topic 10	5.70

Note. Valence ratings were calculated using values from Warriner, Kuperman, & Brysbaert (2013).

Table S1. 7

Visual Feature and Intra-topic correlation matrix for Study 2

Feature/Topic	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1. Hue	-----																			
2. Sat	-.32**	-----																		
3. Bright	.08	-.33**	-----																	
4. sdHue	.54**	-.62**	.39**	----																
5. sdSat	-.3**	.35**	-.17	-.24*	----															
6. sdBright	.11	-.18	.10	.34**	.28**	----														
7. Entropy	-.17	.00	.31**	.05	.18	.31**	----													
8. SED	-.09	.14	.19	.04	.06	.03	.14	----												
9. NSED	.02	-.02	-.29**	-.12	-.06	-.09	.04	-.62**	----											
10. Naturalness	.28**	.29**	-.37**	-.26*	-.05	-.19	-.11	-.17	.18	----										
11. Preference	.11	.20	-.15	-.04	.08	.14	-.11	.11	-.11	.42**	----									
12. Topic 1	.11	.24*	-.37**	-.22*	-.17	-.27*	-.29*	-.26*	.22*	.62**	.37**	----								
13. Topic 2	-.05	-.21	.26*	.13	.03	.12	.14	.06	.01	-.57**	-.50**	-.71**	----							
14. Topic 3	.09	-.06	.05	.07	-.05	-.14	.06	.07	-.10	-.13	-.11	-.00	.07	----						
15. Topic 4	-.10	.34**	-.33**	-.35**	-.05	-.26*	.02	-.09	.25*	.42**	.24*	.71**	-.46**	.16	----					
16. Topic 5	.20	-.13	-.05	.12	.04	.04	-.13	-.02	-.21	.27*	.29**	.10	-.46*	-.07	-.23*	----				
17. Topic 6	-.03	-.02	.03	-.04	.16	.13	.28*	-.03	.10	-.30*	-.31*	-.50*	.43*	.06	-.25*	-.31*	----			
18. Topic 7	-.18	.03	.17	.17	.11	.16	-.04	.16	-.08	-.22*	-.03	-.20	-.03	-.42**	-.30**	-.28**	-.02	----		
19. Topic 8	-.12	-.11	.19	-.04	-.14	.00	-.01	.03	-.04	-.25*	-.15	-.10	.31**	.02	-.13	-.37**	-.23*	-.04	----	
20. Topic 9	.08	-.02	-.01	.06	-.10	-.12	-.01	-.08	.12	-.17	-.18	-.17	.38**	-.05	-.19	-.23*	.18	-.13	-.02	----
21. Topic 10	.07	.05	-.07	-.10	-.04	.12	.10	.01	.01	.30**	.13	-.01	-.03	-.29**	.13	-.13	-.05	-.04	-.11	.02

Notes. * p < .05, ** p < .01 (not adjusted for multiple comparisons)

Table S1. 8

Topic correlation matrix between Study 1 and Study 2

Topics	Family	Park	Life & Emotions	Time & Memories	Art	Nature	Religion	World & Peace	Celebration	Spiritual & Life Journey
Topic 1	-.20	.22*	.08	-.02	-.35**	.37**	-.18	.33**	-.15	.42**
Topic 2	.23*	-.38**	.09	-.02	.18	-.31**	.11	.02	.10	-.05
Topic 3	-.16	-.18	-.21	-.15	-.44**	-.12	.47**	-.08	.07	-.08
Topic 4	-.18	-.25*	.21	.14	-.46**	-.08	.12	.41**	-.21*	.48**
Topic 5	.10	.61**	-.35**	.02	-.08	.53**	-.32**	-.37**	.33**	-.27*
Topic 6	-.01	-.18	.03	.17	.05	-.30**	.15	-.18	.12	-.13
Topic 7	.14	.07	-.15	-.25*	.60**	-.13	-.05	-.07	-.22*	-.15
Topic 8	-.16	-.32**	.15	-.24	.10	-.27*	.27*	.03	-.22*	.18
Topic 9	.17	-.28**	.31**	-.02	-.18	-.10	.13	.26*	-.08	-.18
Topic 10	-.26	-.10	.61**	.66**	.02	-.04	-.29**	.34**	-.00	.04

Notes. * p < .05, ** p < .01 (not adjusted for multiple comparisons)

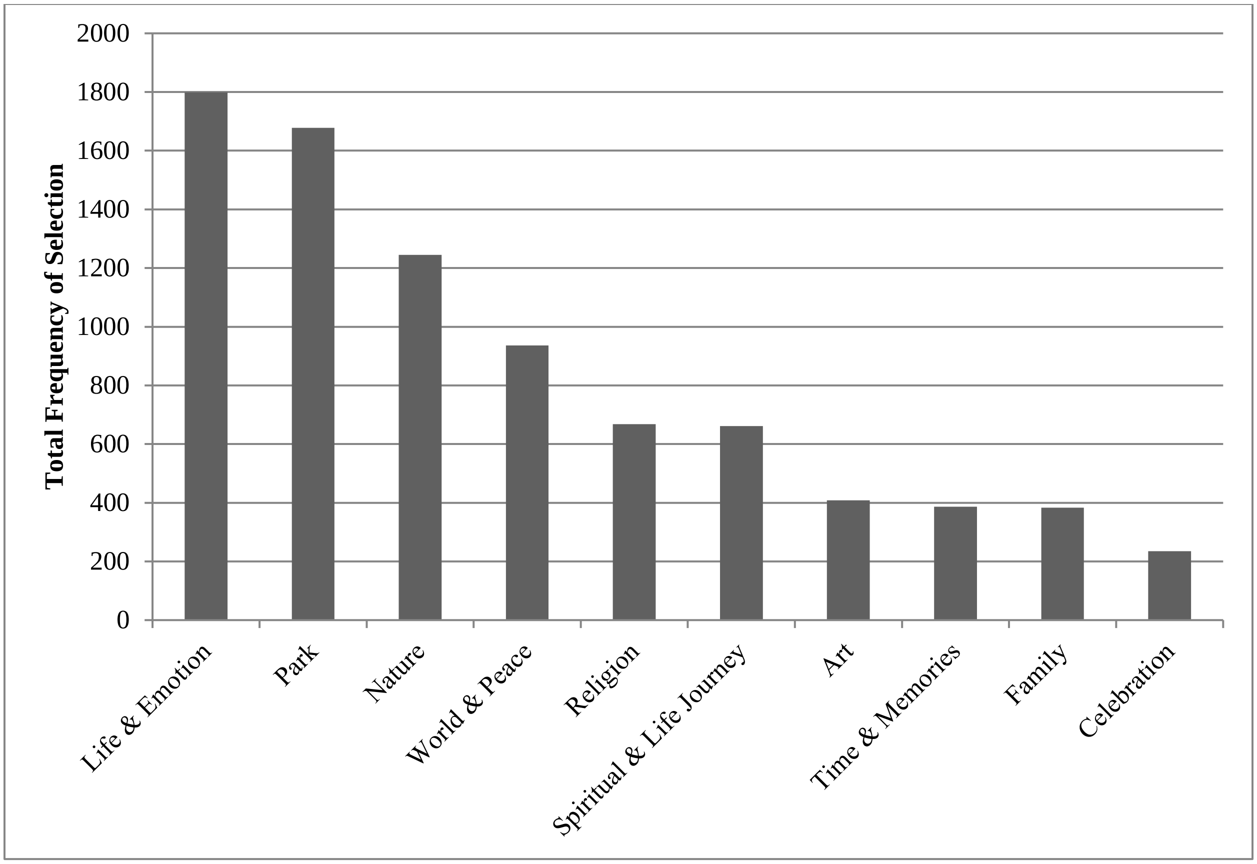

Figure S1. 1. Total Frequency of Topic Selection in Study 3

Table S1. 9

Logistic Regressions for Additional Topics in Study 3

	Life & Emotion				Time & Memories				Celebration				World & Peace			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-1.13	.07	-16.02	<.001	-3.16	.14	-21.82	<.001	-4.66	.29	-16.04	<.001	-3.28	.13	-24.70	<.001
Naturalness	0.11	.07	1.54	.12	0.74	.16	4.55	<.001	0.16	.19	0.87	>.250	-1.62	.12	-13.39	<.001
NSED	0.46	.08	5.98	<.001	0.25	.14	1.78	.076	0.16	.19	0.87	>.250	0.23	.16	1.48	.139
Naturalness*NSED	0.17	.11	1.61	.11	0.88	.22	4.02	<.001	0.35	.27	1.29	.197	0.19	.18	1.06	.29
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=105)	0.24		0.49		0.91		0.95		3.33		1.83		0.59		0.77	
AIC	8506.2				2984.8				1934.4				5214.1			
Log Likelihood	-4248.1				-1487.4				-962.2				-2602.1			
Observations	8400				8400				8400				8400			
Δ AIC	44.3				18.2				-4.4				459			
X^2	50.2				24.2				-1.6				465.0			

	Family				Park				Art				Religion			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-3.87	.18	-21.73	<.001	-1.34	.08	-16.88	<.001	-3.61	.15	-24.13	<.001	-3.30	.14	-24.40	<.001
Naturalness	-0.85	.15	-5.50	<.001	1.72	.11	15.16	<.001	-0.78	.15	-5.21	<.001	-1.18	.13	-9.32	<.001
NSED	0.31	.19	1.62	.105	-1.08	.07	-15.25	<.001	0.20	.18	1.08	>.250	0.33	.16	2.01	.044
Naturalness*NSED	0.14	.23	0.62	>.250	-0.54	.15	-3.72	<.001	0.12	.22	0.53	>.250	0.19	.19	1.00	>.250
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=105)	1.12		1.06		0.35		0.58		0.55		0.74		0.59		0.77	
AIC	2919.9				6986.4				3140.7				4329.9			
Log Likelihood	-1455.0				-3488.2				-1565.3				-2159.9			
Observations	8400				8400				8400				8400			
Δ AIC	66.5				1275.2				57.8				205.9			
X^2	72.4				1281.2				64.0				212.0			

Appendix B: Supplementary Materials for Chapter 2

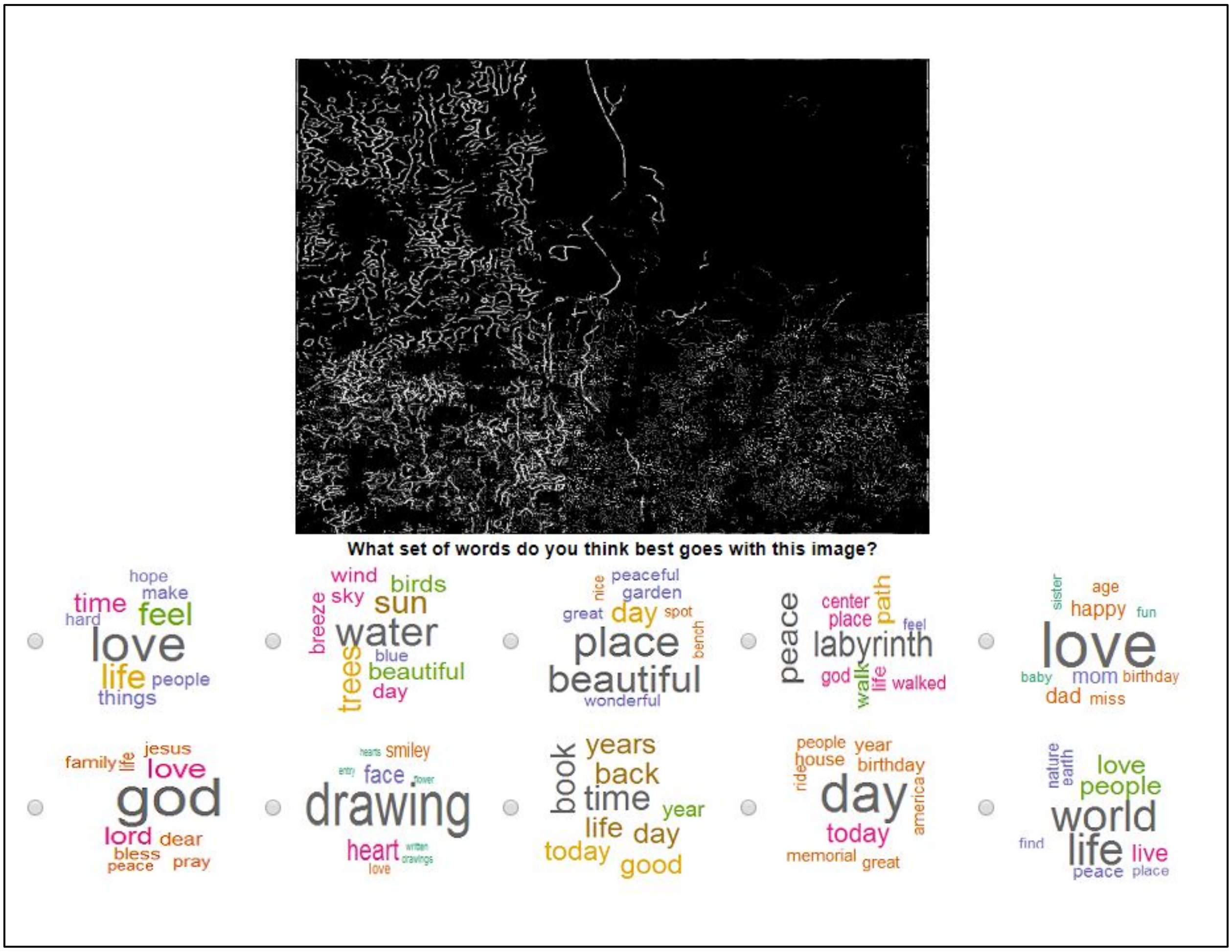

Figure S2. 1. Example screenshot of stimuli presentation.

Table S2. 1

Valence Ratings and Word Frequencies by Topic of words shown in word clouds

Topic	**Mean Valence Rating**	**Mean Word Frequency (per million words)**
Art	6.69 (0.86)	201 (341)
Celebration	6.36 (0.68)	427 (376)
Family	6.95 (1.33)	396 (301)
Life & Emotion	6.18 (1.03)	892 (550)
Nature	6.94 (0.63)	170 (238)
Park	6.76 (0.99)	343 (339)
Religion	6.84 (0.84)	383 (402)
Spiritual & Life Journey	6.21 (0.82)	350 (347)
Time & Memories	6.20 (0.88)	1038 (911)
World & Peace	6.86 (0.81)	546 (409)

Note. Standard deviations shown in parentheses. Valence ratings were calculated using values from Warriner, Kuperman, & Brysbaert (2013). Word frequencies were calculated from the SUBTLEX-US corpus (Brysbaert & New, 2009).

Table S2. 2

Logistic Regressions for Additional Topics in Study 1 (Effects of NSED on thought content)

	Art				**Celebration**				**Family**				**Life & Emotions †**			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.17	0.12	-18.20	<.001	-2.37	0.11	-21.40	<.001	-3.58	0.19	-18.41	<.001	-2.58	0.11	-23.72	<.001
NSED	-0.03	0.11	-0.24	.81	0.13	.13	1.05	.29	-0.01	0.19	-0.08	.94	0.01	0.12	0.12	.91
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.77		0.88		0.34		0.58		1.03		1.02		0.33		0.57	
Image (n=40)	0.02		0.12		0.04		0.20		0.10		0.32		-		-	
AIC	2864.2				2426.2				1373.7				2193.8			
Log Likelihood	-1428.1				-1209.1				-682.9				-1093.9			
Observations	4000				4000				4000				4000			
Δ AIC	1.9				1.0				2.0				2.0			
X^2	0.06				1.06				0.01				0.01			

	Park †				**Religion †**				**Time & Memories**				**World & Peace †**			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.43	0.11	-22.33	<.001	-2.91	0.14	-20.55	<.001	-2.68	0.13	-21.31	<.001	-2.05	0.08	-24.32	<.001
NSED	-0.09	0.11	-0.82	.41	-0.15	0.12	-1.29	.20	-0.16	0.15	-1.00	.32	0.004	0.10	0.05	.96
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.46		0.68		0.85		0.92		0.34		0.58		0.18		0.43	
Image (n=40)	-		-		-		-		0.07		0.27		-		-	
AIC	2511.9				2060.9				2209.9				2932.8			
Log Likelihood	-1253.0				-1027.4				-1101.0				-1463.4			
Observations	4000				4000				4000				4000			
Δ AIC	1.3				0.3				1.0				2.0			
X^2	0.66				1.67				0.97				0.002			

Note. We did not have a priori hypotheses for the relationship between these topics and NSED. This was because in Schertz et al. (2018), there were inconsistent results between the ecological study which generated the topics (Study 1) and the forced-choice task which mirrors the current study (Study 3). There were no significant correlations between these topics and NSED in the ecological study. However, in Study 3 of Schertz et al. (2018), where participants completed the same task as the current study with intact images, NSED was a significant predictor of Life & Emotions (B=0.46, SE=0.11, p<.001), Park (B=-1.08, SE=0.07, p<.001), and Religion (B=0.33, SE=0.16, p=.04).

† These models resulted in 'singular fits' when including Subject and Image as random intercepts, and thus were run with only Subject as a random intercept

Table S2. 3

Logistic Regressions for Additional Topics in Study 2 (Effects of Naturalness on thought content)

	Art †				Celebration †				Family †				Life & Emotions			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.41	0.11	-21.29	<.001	-2.77	0.11	-25.39	<.001	-3.38	0.15	-22.23	<.001	-2.69	0.12	-21.67	<.001
Naturalness	-0.07	0.11	-0.64	.52	-0.68	0.11	-5.93	<.001	0.21	0.17	1.20	.23	0.14	0.13	1.06	.29
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.54		0.73		0.25		0.50		0.42		0.65		0.48		0.70	
Image (n=40)	-		-		-		-		-		-		0.03		0.16	
AIC	2579.0				2411.4				1233.3				2049.1			
Log Likelihood	-1286.5				-1202.7				-613.7				-1020.5			
Observations	4000				4000				4000				4000			
Δ AIC	1.6				-34.7				0.5				1.0			
X^2	0.41				36.7				1.4				1.05			

	Park				Religion				Time & Memories				World & Peace			
Fixed Effects	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**	**B**	**Std. Err**	**z-value**	**p**
Intercept	-2.11	0.10	-21.68	<.001	-2.71	0.13	-20.42	<.001	-2.84	0.13	-22.67	<.001	-2.01	0.09	-22.76	<.001
Naturalness	0.17	0.12	1.50	0.13	0.37	0.13	2.74	.006	-0.71	0.13	-5.61	<.001	-0.07	0.10	-0.66	.51
Random Effects	**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**		**Variance**		**Std. Dev.**	
Subject (n=100)	0.25		.5		0.63		0.80		0.48		0.69		0.21		0.46	
Image (n=40)	0.03		0.17		0.02		0.15		0.03		0.17		0.01		0.12	
AIC	2752.9				1937.6				2420.2				3072.3			
Log Likelihood	-1372.5				-964.8				-1206.1				-1532.1			
Observations	4000				4000				4000				4000			
Δ AIC	-0.2				-4.7				-21.6				1.5			
X^2	2.1				6.7				23.7				0.43			

Note. We did not have a priori hypotheses for the relationship between these topics and Naturalness. This was because in Schertz et al. (2018), there were inconsistent results between the ecological study which generated the topics (Study 1) and the forced-choice task which mirrors the current study (Study 3). There were no significant correlations between these topics and NSED in the ecological study. In Study 3 of Schertz et al. (2018), where participants completed the same task as the current study with intact images, Naturalness was a significant predictor of Art (B=-0.78, SE=0.15, p<.001), Family (B=-0.85, SE=0.15, p<.001), Park (B=1.72, SE=0.11, p<.001), Religion (B=-1.18, SE=0.13, p<.001), Time & Memories (B=0.74, SE=0.16, p<.001), and World & Peace (B=-1.62, SE=0.12, p<.001).

† These models resulted in 'singular fits' when including Subject and Image as random intercepts, and thus were run with only Subject as a random intercept

Appendix C: Supplementary Materials for Chapter 3

Table S3. 1

Baseline Survey Questions

Question	Possible Responses	Measure	Analyzed in Chapter
Was your most recent thought about the past, present (within 5 min before or 5 min after right now), or future, or did it have no time aspect?	Past, Present, Future, No Time Aspect	Temporal Aspect	X
[If answered 'past'] Was your thought in the past about something that occurred ...	Earlier today, Yesterday, A few days ago, 1-4 weeks ago, 1-12 months ago, More than a year ago, More than 10 years ago, Before you were born	Temporal Aspect	
[If answered 'future'] Was your thought in the future about something that will occur ...	Later today, Tomorrow, A few days from now, 1-4 weeks from now, 1-12 months from now, More than a year from now, More than 10 years from now, More than 50 years from now, After life	Temporal Aspect	
Was the thought mostly about yourself, mostly about others, about yourself and others, or not about people?	Mostly about myself, Mostly about others, About myself and others, Something else/not about people (with free response)	Personal Aspect	
[If answered 'mostly about others' or 'mostly about myself and others'] Who was your thought about?	Significant other, Family, Friends, Acquaintances, Coworkers, People I don't know, Other (with free response)	Personal Aspect	
How positive was the thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How negative was the thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How exciting was the thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How spontaneous was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How deep was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How imaginative was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How stressful was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	X
How creative do you feel right now?	0-7; 0 = Not at all, 7 = Very much	State	X
How bored do you feel right now?	0-7; 0 = Not at all, 7 = Very much	State	X
How impulsive do you feel right now?	0-7; 0 = Not at all, 7 = Very much	State	X
How close do you feel to each of the following groups:			
My family and friends	0-7; 0 = Not at all close, 7 = Very close	Closeness to People	
People in my surroundings	0-7; 0 = Not at all close, 7 = Very close	Closeness to People	
People all over the world	0-7; 0 = Not at all close, 7 = Very close	Closeness to People	

Question	Possible Responses	Measure	Analyzed in Chapter
How much do you feel connected to the physical environment around you?	0-7; 0 = Not at all, 7 = Very much	Environmental Connectedness	
How much do you feel connected to the social environment around you?	0-7; 0 = Not at all, 7 = Very much	Environmental Connectedness	
How disorderly or orderly is the physical environment around you?	-5-5; -5 = Very disorderly, 5 = Very orderly	Environmental Disorder	
How disorderly or orderly is the social environment around you?	-5-5; -5 = Very disorderly, 5 = Very orderly	Environmental Disorder	
How much do you feel each of these emotions right now:			
Stressed	0-7; 0 = Not at all, 7 = Very much	Negative Affect	X
Mentally fatigued	0-7; 0 = Not at all, 7 = Very much	Negative Affect	X
Insignificant	0-7; 0 = Not at all, 7 = Very much	Negative Affect	X
Optimistic	0-7; 0 = Not at all, 7 = Very much	Positive Affect	X
In awe	0-7; 0 = Not at all, 7 = Very much	Positive Affect	X
Grateful	0-7; 0 = Not at all, 7 = Very much	Positive Affect	X
Energetic	0-7; 0 = Not at all, 7 = Very much	Positive Affect	X
How much do you feel like you have "gotten away" from your everyday concerns?	0-7; 0 = Not at all, 7 = Very much	Escape	
How many people can you see around you right now?	0, 1-5, 6-10, 11-20, 21+	Number of People Around	
Right now, I feel like buying something spontaneously.	0-7; 0 = Not at all, 7 = Very much	Impulsive Buying	X
I would carefully plan my purchases if I were to buy something right now.	0-7; 0 = Not at all, 7 = Very much	Impulsive Buying	X
I would buy things without thinking if I were to buy something right now.	0-7; 0 = Not at all, 7 = Very much	Impulsive Buying	X
†Over the course your walk, would you say that time has seemed to move...	Much slower than usual, Somewhat slower than usual, As usual, Somewhat faster than usual, Much faster than usual	Time Perception	

Table S3. 2

Temporal Aspect of Thoughts

	Past		**Future**		**Present**		**No Time**	
Predictors	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*
Intercept	0.11	0.07 – 0.17	0.37	0.26 – 0.50	0.49	0.33 – 0.70	0.10	0.06 – 0.15
Conservatory Baseline	1.13	0.65 – 1.76	1.32	0.83 – 1.97	0.63	0.38 – 0.95	0.98	0.56 – 1.56
Mall Baseline	1.31	0.76 – 2.04	1.32	0.83 – 1.97	0.92	0.57 – 1.38	0.76	0.42 – 1.22
Conservatory Survey 1	1.59	0.93 – 2.45	0.55	0.33 – 0.84	1.15	0.71 – 1.71	1.56	0.91 – 2.42
Mall Survey 1	0.65	0.36 – 1.05	1.07	0.67 – 1.60	1.49	0.93 – 2.23	0.99	0.56 – 1.57
Conservatory Survey 2	1.50	0.88 – 2.33	0.72	0.44 – 1.09	1.24	0.77 – 1.84	1.06	0.61 – 1.68
Mall Survey 2	0.69	0.38 – 1.10	1.32	0.82 – 1.97	1.18	0.73 – 1.76	1.07	0.61 – 1.68
Conservatory Survey 3	1.05	0.60 – 1.65	1.00	0.62 – 1.48	0.87	0.54 – 1.30	1.24	0.71 – 1.95
Mall Survey 3	0.90	0.51 – 1.42	1.41	0.89 – 2.08	1.08	0.67 – 1.61	0.91	0.52 – 1.44
Random Effects								
σ^2	3.29		3.29		3.29		3.29	
τ_{00}	1.30 $_{subject}$		0.26 $_{subject}$		1.23 $_{subject}$		1.62 $_{subject}$	
N	86 $_{subject}$		86 $_{subject}$		86 $_{subject}$		86 $_{subject}$	
Observations	683		683		683		683	

Table S3. 3

Temporal Aspect of Thoughts (Multiple Choices Together)

	Past-Present		**Past-Future**		**Present-Future**		**Past-Present-Future**	
Predictors	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*
Intercept	0.01	0.00 – 0.01	0.02	0.01 – 0.03	0.02	0.01 – 0.03	0.01	0.00 – 0.02
Conservatory Baseline	0.98	0.42 – 1.83	1.43	0.66 – 2.55	1.62	0.82 – 2.74	1.37	0.60 – 2.54
Mall Baseline	1.20	0.52 – 2.22	1.42	0.66 – 2.56	0.72	0.34 – 1.25	1.13	0.50 – 2.08
Conservatory Survey 1	1.20	0.51 – 2.26	1.01	0.46 – 1.84	0.98	0.48 – 1.70	1.14	0.50 – 2.10
Mall Survey 1	1.20	0.52 – 2.23	1.01	0.45 – 1.86	1.11	0.55 – 1.90	0.93	0.40 – 1.73
Conservatory Survey 2	0.98	0.41 – 1.84	0.84	0.37 – 1.53	1.26	0.63 – 2.17	1.14	0.50 – 2.09
Mall Survey 2	1.20	0.52 – 2.23	1.01	0.45 – 1.84	0.96	0.47 – 1.65	0.93	0.40 – 1.74
Conservatory Survey 3	0.98	0.42 – 1.84	1.42	0.66 – 2.53	1.43	0.72 – 2.43	1.13	0.50 – 2.09
Mall Survey 3	1.20	0.52 – 2.23	0.84	0.37 – 1.54	0.83	0.40 – 1.46	1.13	0.50 – 2.09
Random Effects								
σ^2	3.29		3.29		3.29		3.29	
τ_{00}	0.52 $_{subject}$		0.30 $_{subject}$		2.77 $_{subject}$		0.45 $_{subject}$	
N	86 $_{subject}$		86 $_{subject}$		86 $_{subject}$		86 $_{subject}$	
Observations	683		683		683		683	

Valence of Thoughts

Table S3. 4

Valence of Thoughts

	Positive/Exciting		Negative/Stressful	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	0.00	-0.33 – 0.34	0.00	-0.31 – 0.32
Conservatory Baseline	-0.37	-0.72 – -0.02	0.68	0.35 – 1.00
Mall Baseline	-0.57	-0.92 – -0.21	0.53	0.20 – 0.85
Conservatory Survey 1	0.49	0.13 – 0.84	-0.26	-0.59 – 0.06
Mall Survey 1	-0.03	-0.38 – 0.33	-0.18	-0.51 – 0.14
Conservatory Survey 2	0.34	-0.02 – 0.69	-0.28	-0.60 – 0.04
Mall Survey 2	-0.17	-0.52 – 0.18	-0.27	-0.60 – 0.05
Conservatory Survey 3	0.27	-0.08 – 0.62	-0.13	-0.46 – 0.19
Mall Survey 3	0.03	-0.32 – 0.39	-0.09	-0.41 – 0.24
Random Effects				
σ^2	1.85		1.02	
τ_{00}	0.89 $_{subject}$		0.61 $_{subject}$	
N	86 $_{subject}$		86 $_{subject}$	
Observations	683		683	

Table S3. 5

Positive/Exciting Thoughts - Baseline Adjusted

Predictors	*Estimates*	*CI (89%)*
Intercept	0.51	0.18 – 0.84
Conservatory Baseline	-0.46	-0.82 – -0.10
Mall Baseline	-0.46	-0.82 – -0.10
Conservatory Survey 1	0.38	0.01 – 0.74
Mall Survey 1	0.08	-0.29 – 0.45
Conservatory Survey 2	0.23	-0.13 – 0.60
Mall Survey 2	-0.07	-0.43 – 0.29
Conservatory Survey 3	0.16	-0.20 – 0.53
Mall Survey 3	0.13	-0.24 – 0.49
Random Effects		
σ^2	2.26	
$\tau_{00\ subject}$	0.72	
$N_{subject}$	86	
Observations	683	

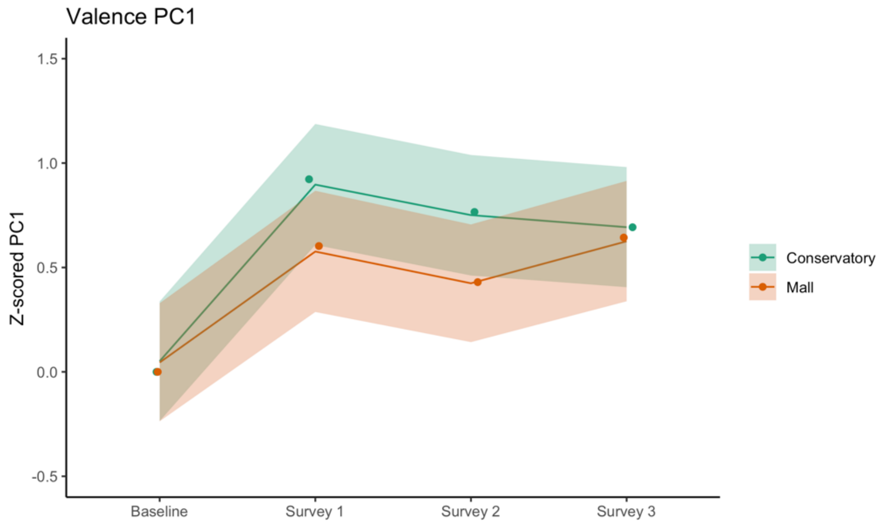

Figure S3. 1. Observed and modeled thought valence for PC1 (exciting/positive thinking) which was adjusted for baseline. Points are mean observed ratings. The fitted line is the linear regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

State Affect

Table S3. 6

Positive and Negative State Affect

	Positive Affect		**Negative Affect**	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	4.03	3.63 – 4.43	2.72	1.01 – 4.44
Conservatory Baseline	-0.51	-0.88 – -0.15	1.05	-0.66 – 2.75
Mall Baseline	-0.47	-0.84 – -0.10	0.86	-0.85 – 2.56
Conservatory Survey 1	0.99	0.61 – 1.35	-0.47	-2.18 – 1.22
Mall Survey 1	-0.35	-0.72 – 0.02	-0.18	-1.89 – 1.52
Conservatory Survey 2	0.74	0.37 – 1.11	-0.27	-1.98 – 1.45
Mall Survey 2	-0.44	-0.81 – -0.08	-0.42	-2.13 – 1.29
Conservatory Survey 3	0.57	0.20 – 0.93	-0.11	-1.81 – 1.59
Mall Survey 3	-0.52	-0.88 – -0.15	-0.30	-2.01 – 1.40
Random Effects				
σ^2	2.32		1.74	
τ_{00}	2.37 subject		2.05 subject	
N	86 subject		86 subject	
Observations	683		683	

Table S3. 7

Feelings of Creativity, Impulsivity, & Boredom

	Creativity		**Impulsivity**		**Boredom**	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	4.10	3.68 – 4.52	3.10	2.71 – 3.49	3.48	3.08 – 3.89
Conservatory Baseline	-0.29	-0.71 – 0.12	-0.29	-0.71 – 0.12	0.65	0.23 – 1.07
Mall Baseline	-0.55	-0.97 – -0.14	-0.44	-0.86 – -0.02	0.55	0.13 – 0.98
Conservatory Survey 1	0.73	0.31 – 1.14	-0.94	-1.35 – -0.52	-0.95	-1.37 – -0.52
Mall Survey 1	-0.46	-0.88 – -0.04	0.90	0.48 – 1.32	-0.57	-1.00 – -0.15
Conservatory Survey 2	0.80	0.39 – 1.21	-0.61	-1.03 – -0.20	-0.12	-0.54 – 0.31
Mall Survey 2	-0.41	-0.83 – 0.00	0.97	0.55 – 1.39	0.01	-0.42 – 0.43
Conservatory Survey 3	0.56	0.15 – 0.97	-0.51	-0.92 – -0.09	0.25	-0.17 – 0.67
Mall Survey 3	-0.39	-0.80 – 0.04	0.91	0.49 – 1.33	0.17	-0.25 – 0.60
Random Effects						
σ^2	4.10		4.33		4.63	
τ_{00}	2.73 subject		1.70 subject		2.45 subject	
N	86 subject		86 subject		86 subject	
Observations	683		683		683	

Table S3. 8

Feelings of Impulsive Buying

Predictors	*Estimates*	*CI (89%)*
Intercept	-0.00	-0.81 – 0.81
Conservatory Baseline	-0.24	-1.05 – 0.57
Mall Baseline	-0.19	-1.00 – 0.62
Conservatory Survey 3	-0.19	-1.00 – 0.61
Mall Survey 3	0.63	-0.18 – 1.44
Random Effects		
σ^2	0.61	
$\tau_{00\ subject}$	0.27	
$N_{subject}$	86	
Observations	343	

Dual N-back

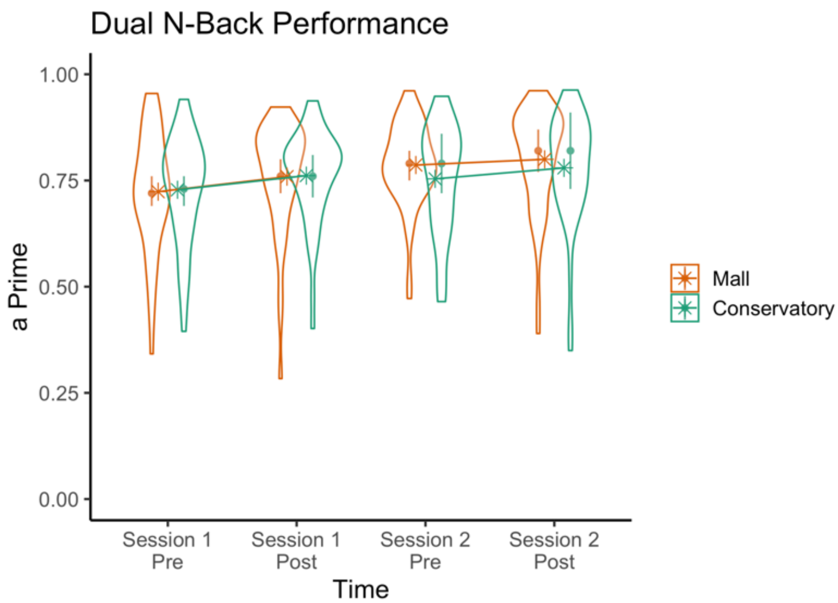

Figure S3. 2. Modeled and observed Dual N-back performance on all blocks. Dots represent the mean and lines represent the 89% percentile interval of the model's posterior distribution. Violin plot represents the distribution of observed performance. Stars represent the observed mean performance.

Table S3. 9

Dual N-back Performance

	All blocks		**2-back Only**	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	0.72	0.69 – 0.76	0.83	0.80 – 0.87
Conservatory	0.00	-0.04 – 0.04	-0.00	-0.05 – 0.04
Session 2	0.06	0.02 – 0.10	0.04	0.00 – 0.09
Post	0.03	0.00 – 0.06	-0.02	-0.05 – 0.01
Conservatory:Session 2	-0.03	-0.11 – 0.04	-0.03	-0.11 – 0.05
Conservatory:Post	-0.00	-0.04 – 0.04	0.05	0.01 – 0.08
Session 2:Post	-0.02	-0.06 – 0.02	0.03	-0.01 – 0.07
Conservatory:Session 2:Post	0.01	-0.05 – 0.07	-0.04	-0.09 – 0.01
Random Effects				
σ^2	0.03		0.01	
τ_{00}	0.01 $_{subject}$		0.01 $_{subject}$	
N	86 $_{subject}$		86 $_{subject}$	
Observations	1376		688	

Appendix D: Supplementary Materials for Chapter 4

Table S4. 1

Baseline Survey Questions

Question	Possible Responses	Measure	Analyzed in Chapter
Was the thought mostly about yourself, mostly about others, about yourself and others, or not about people?	Mostly about myself, Mostly about others, About myself and others, Something else/not about people (with free response)	Personal Aspect	X
[If answered 'mostly about others' or 'mostly about myself and others'] Who was your thought about?	Significant other, Family, Friends, Acquaintances, Coworkers, People I don't know, Other (with free response)	Personal Aspect	
How close do you feel to each of the following groups:			
My family and friends	0-7; 0 = Not at all close, 7 = Very close	Closeness to People	X
People in my surroundings	0-7; 0 = Not at all close, 7 = Very close	Closeness to People	X
People all over the world	0-7; 0 = Not at all close, 7 = Very close	Closeness to People	X
How much do you feel connected to the physical environment around you?	0-7; 0 = Not at all, 7 = Very much	Environmental Connectedness	X
How much do you feel connected to the social environment around you?	0-7; 0 = Not at all, 7 = Very much	Environmental Connectedness	X
*How many people can you see around you right now?	0, 1-5, 6-10, 11-20, 21+	Number of People Around	X
Was your most recent thought about the past, present (within 5 min before or 5 min after right now), or future, or did it have no time aspect?	Past, Present, Future, No Time Aspect	Temporal Aspect	
[If answered 'past'] Was your thought in the past about something that occurred ...	Earlier today, Yesterday, A few days ago, 1-4 weeks ago, 1-12 months ago, More than a year ago, More than 10 years ago, Before you were born	Temporal Aspect	
[If answered 'future'] Was your thought in the future about something that will occur ...	Later today, Tomorrow, A few days from now, 1-4 weeks from now, 1-12 months from now, More than a year from now, More than 10 years from now, More than 50 years from now, After life	Temporal Aspect	

Question	Possible Responses	Measure	Analyzed in Chapter
How positive was the thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How negative was the thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How exciting was the thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How spontaneous was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How deep was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How imaginative was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How stressful was your thought?	0-7; 0 = Not at all, 7 = Very much	Valence	
How creative do you feel right now?	0-7; 0 = Not at all, 7 = Very much	State	
How bored do you feel right now?	0-7; 0 = Not at all, 7 = Very much	State	
How impulsive do you feel right now?	0-7; 0 = Not at all, 7 = Very much	State	
How disorderly or orderly is the physical environment around you?	-5-5; -5 = Very disorderly, 5 = Very orderly	Environmental Disorder	
How disorderly or orderly is the social environment around you?	-5-5; -5 = Very disorderly, 5 = Very orderly	Environmental Disorder	
How much do you feel each of these emotions right now:			
Stressed	0-7; 0 = Not at all, 7 = Very much	Negative Affect	
Mentally fatigued	0-7; 0 = Not at all, 7 = Very much	Negative Affect	
Insignificant	0-7; 0 = Not at all, 7 = Very much	Negative Affect	
Optimistic	0-7; 0 = Not at all, 7 = Very much	Positive Affect	
In awe	0-7; 0 = Not at all, 7 = Very much	Positive Affect	
Grateful	0-7; 0 = Not at all, 7 = Very much	Positive Affect	
Energetic	0-7; 0 = Not at all, 7 = Very much	Positive Affect	
How much do you feel like you have "gotten away" from your everyday concerns?	0-7; 0 = Not at all, 7 = Very much	Escape	
† Right now, I feel like buying something spontaneously.	0-7; 0 = Not at all, 7 = Very much	Impulsive Buying	
† I would carefully plan my purchases if I were to buy something right now.	0-7; 0 = Not at all, 7 = Very much	Impulsive Buying	
† I would buy things without thinking if I were to buy something right now.	0-7; 0 = Not at all, 7 = Very much	Impulsive Buying	
†Over the course your walk, would you say that time has seemed to move...	Much slower than usual, Somewhat slower than usual, As usual, Somewhat faster than usual, Much faster than usual	Time Perception	

Note. * Question not asked at baseline, only Surveys 1-3. † Question only asked at Survey 3, not Surveys 1 & 2.

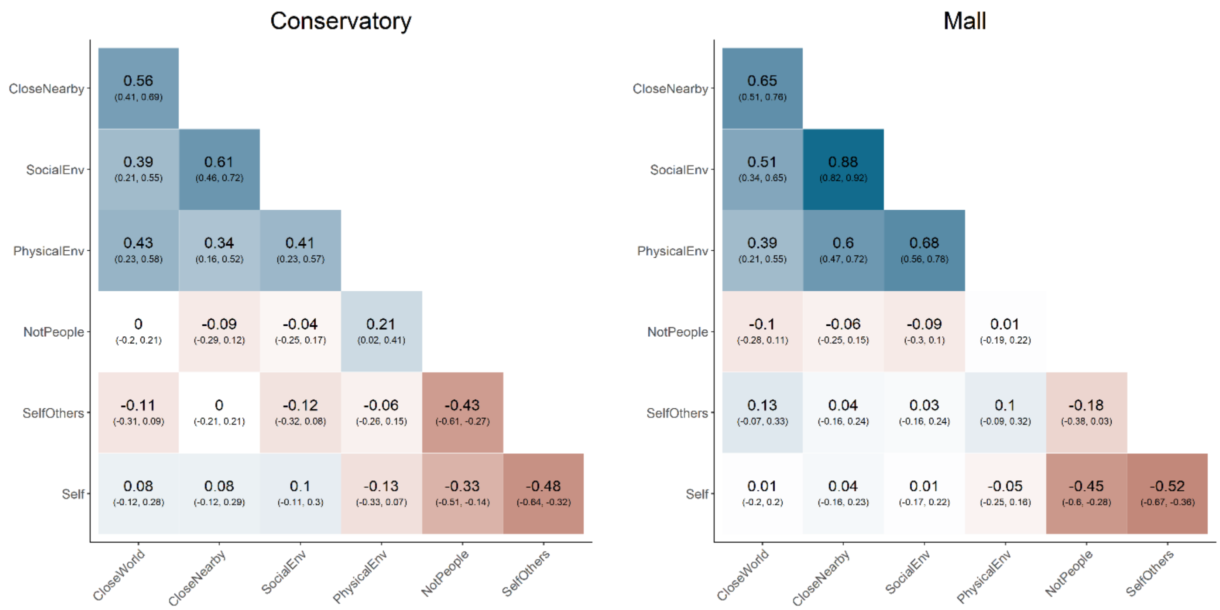

Figure S4. 1. Bivariate Bayesian linear correlation estimates between different aspects of thought content in the Nature Conservatory (left) and Mall (right). Positive correlations are shown in blue and negative correlations are shown in red. 89% confidence intervals are shown in parentheses.

Table S4. 2

Self Vs Others Aspect of Thoughts

	Self		**Not People**		**Both**		**Others**	
Predictors	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*
Intercept	0.58	0.39 – 0.82	0.13	0.08 – 0.19	0.43	0.29 – 0.60	0.12	0.08 – 0.17
Conservatory Baseline	1.07	0.67 – 1.59	0.56	0.31 – 0.90	1.47	0.92 – 2.18	1.14	0.65 – 1.79
dfMall Baseline	1.13	0.70 – 1.68	0.47	0.25 – 0.75	1.69	1.06 – 2.52	0.97	0.55 – 1.53
Conservatory Survey 1	0.56	0.34 – 0.85	2.34	1.40 – 3.55	1.16	0.71 – 1.74	0.91	0.51 – 1.45
Mall Survey 1	1.62	1.01 – 2.40	1.02	0.59 – 1.58	0.77	0.47 – 1.16	0.91	0.51 – 1.45
Conservatory Survey 2	0.72	0.45 – 1.08	2.17	1.30 – 3.32	0.90	0.55 – 1.34	1.05	0.60 – 1.65
Mall Survey 2	1.13	0.70 – 1.69	1.24	0.73 – 1.92	0.68	0.42 – 1.04	1.52	0.89 – 2.34
Conservatory Survey 3	0.69	0.42 – 1.03	1.42	0.84 – 2.19	1.27	0.79 – 1.89	1.14	0.65 – 1.79
Mall Survey 3	2.16	1.34 – 3.21	0.62	0.34 – 0.99	0.77	0.48 – 1.16	0.90	0.51 – 1.43
Random Effects								
σ^2	3.29		3.29		3.29		3.29	
τ_{00}	1.16_{intakeID}		1.31_{intakeID}		0.97_{intakeID}		0.24_{intakeID}	
N	86_{intakeID}		86_{intakeID}		86_{intakeID}		86_{intakeID}	
Observations	683		683		683		683	

Table S4. 3

Closeness to Various Groups of People

	Nearby		Around the World		Family & Friends	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	3.28	2.88 – 3.67	2.75	2.32 – 3.17	6.37	5.90 – 6.83
Conservatory Baseline	0.42	0.04 – 0.82	0.06	-0.31 – 0.42	0.69	0.29 – 1.09
Mall Baseline	0.24	-0.15 – 0.63	-0.17	-0.53 – 0.20	0.37	-0.02 – 0.77
Conservatory Survey 1	0.43	0.03 – 0.82	0.43	0.07 – 0.80	-0.05	-0.45 – 0.35
Mall Survey 1	-0.61	-1.00 – -0.22	-0.56	-0.93 – -0.19	-0.51	-0.91 – -0.10
Conservatory Survey 2	0.34	-0.05 – 0.73	0.47	0.10 – 0.84	-0.06	-0.45 – 0.34
Mall Survey 2	-0.50	-0.88 – -0.11	-0.36	-0.73 – 0.01	-0.39	-0.80 – 0.01
Conservatory Survey 3	0.07	-0.32 – 0.46	0.49	0.12 – 0.85	0.09	-0.31 – 0.49
Mall Survey 3	-0.39	-0.78 – -0.00	-0.36	-0.73 – 0.01	-0.14	-0.54 – 0.26
Random Effects						
σ^2	3.14		2.33		3.60	
τ_{00}	2.12 intakeID		3.12 intakeID		4.14 intakeID	
N	86 intakeID		86 intakeID		86 intakeID	
Observations	683		683		683	

Table S4. 4

Connection to Physical and Social Environments

	Physical		Social	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	4.67	4.29 – 5.05	2.96	2.58 – 3.34
Conservatory Baseline	-1.50	-1.91 – -1.09	-0.15	-0.54 – 0.24
Mall Baseline	-1.74	-2.15 – -1.34	-0.14	-0.53 – 0.25
Conservatory Survey 1	1.88	1.47 – 2.28	0.22	-0.17 – 0.60
Mall Survey 1	-0.59	-1.00 – -0.19	-0.17	-0.56 – 0.22
Conservatory Survey 2	1.72	1.31 – 2.12	0.31	-0.07 – 0.71
Mall Survey 2	-0.67	-1.07 – -0.26	-0.23	-0.62 – 0.16
Conservatory Survey 3	1.62	1.21 – 2.03	0.31	-0.08 – 0.71
Mall Survey 3	-0.72	-1.14 – -0.32	-0.16	-0.55 – 0.24
Random Effects				
σ^2	3.92		3.11	
τ_{00}	1.69 $_{intakeID}$		1.77 $_{intakeID}$	
N	86 $_{intakeID}$		86 $_{intakeID}$	
Observations	683		683	

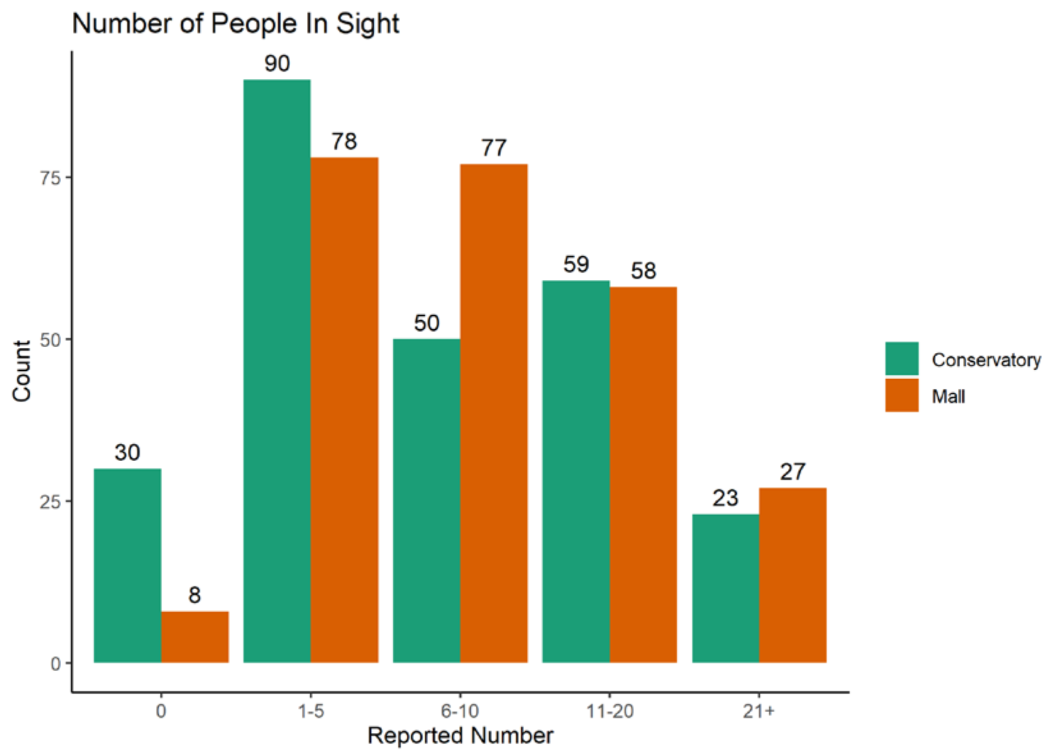

Figure S4. 2. Reported number of people in sight while in the conservatory and mall.

Table S4. 5

Associations with Number of People Around for Self vs Other focused thoughts

	Self		**Not People**		**Self & Others**		**Other People**	
Predictors	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*	*Odds Ratios*	*CI (89%)*
Intercept	0.61	0.29 – 1.07	0.29	0.17 – 0.45	0.40	0.26 – 0.58	0.12	0.07 – 0.18
Mall	5.63	1.56 – 13.27	0.51	0.30 – 0.77	0.71	0.44 – 1.05	1.06	0.63 – 1.63
1-5 People	0.95	0.41 – 1.78	1.02	0.59 – 1.59	1.03	0.62 – 1.55	0.99	0.55 – 1.58
6-10 People	0.45	0.17 – 0.91	0.94	0.53 – 1.51	1.57	0.93 – 2.43	0.98	0.52 – 1.62
11-20 People	0.68	0.26 – 1.35	0.91	0.51 – 1.46	1.11	0.65 – 1.73	1.49	0.83 – 2.40
21+ People	0.19	0.04 – 0.46	1.20	0.62 – 2.01	1.50	0.82 – 2.45	1.21	0.61 – 2.05
Mall:1-5 People	0.69	0.16 – 1.71	0.92	0.48 – 1.55	0.86	0.47 – 1.41	1.37	0.70 – 2.31
Mall:6-10 People	1.46	0.32 – 3.71	1.15	0.59 – 1.94	0.74	0.40 – 1.22	1.00	0.50 – 1.73
Mall:11-20 People	0.84	0.18 – 2.13	0.95	0.47 – 1.65	1.37	0.73 – 2.24	0.84	0.41 – 1.44
Mall:21+ People	2.92	0.42 – 8.43	0.85	0.39 – 1.53	1.23	0.60 – 2.14	1.17	0.55 – 2.09
Random Effects								
σ^2	3.29		3.29		3.29		3.29	
τ_{00}	0.93 $_{intakeID}$		1.57 $_{intakeID}$		0.53 $_{intakeID}$		0.15 $_{intakeID}$	
N	85 $_{intakeID}$		85 $_{intakeID}$		85 $_{intakeID}$		85 $_{intakeID}$	
Observations	500		500		500		500	

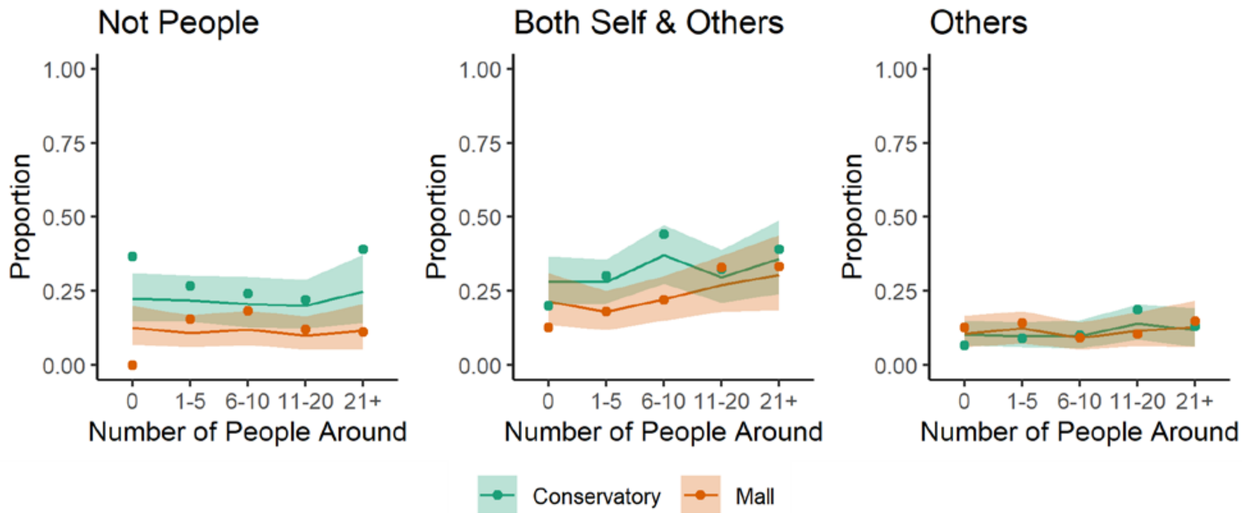

Figure S4. 3**.** Observed and modeled selection of thoughts focused on things other than people (left), both self and others (center) and just other people (right), as related to the number of people in sight. Points are observed probabilities from the raw data. The fitted line is the logistic regression model's predicted estimate. The shaded area represents the 89th percentile interval of the posterior distribution.

Table S4. 6

Associations with Number of People Around for Closeness to Other Groups of People

	People Nearby		**People Around the World**		**Family & Friends**	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	2.92	2.35 – 3.49	3.59	3.04 – 4.15	6.00	5.37 – 6.65
Mall	0.35	-0.54 – 1.24	-1.59	-2.41 – -0.77	0.22	-0.71 – 1.15
1-5 People	0.66	0.08 – 1.24	-0.34	-0.85 – 0.18	0.47	-0.15 – 1.07
6-10 People	0.99	0.34 – 1.64	0.01	-0.57 – 0.58	0.19	-0.50 – 0.86
11-20 People	0.76	0.11 – 1.41	-0.83	-1.42 – -0.25	0.35	-0.34 – 1.03
21+ People	0.87	0.07 – 1.68	0.09	-0.64 – 0.82	0.24	-0.62 – 1.11
Mall:1-5 People	-1.06	-2.04 – -0.07	0.58	-0.34 – 1.48	-0.89	-1.91 – 0.15
Mall:6-10 People	-1.57	-2.57 – -0.57	0.34	-0.59 – 1.26	-0.65	-1.69 – 0.40
Mall:11-20 People	-1.63	-2.64 – -0.60	1.12	0.18 – 2.04	-0.48	-1.53 – 0.58
Mall:21+ People	-1.25	-2.42 – -0.07	0.18	-0.90 – 1.26	-0.35	-1.57 – 0.87
Random Effects						
σ^2	2.85		2.23		3.19	
τ_{00}	2.62 intakeID		3.49 intakeID		4.84 intakeID	
N	85 intakeID		85 intakeID		85 intakeID	
Observations	500		500		500	

Table S4. 7

Associations with Number of People Around for Connection to Environment

	Physical Environment		**Social Environment**	
Predictors	*Estimates*	*CI (89%)*	*Estimates*	*CI (89%)*
Intercept	7.47	6.85 – 8.08	3.18	2.61 – 3.76
Mall	-2.74	-3.70 – -1.75	0.68	-0.21 – 1.59
1-5 People	-0.70	-1.35 – -0.05	-0.12	-0.72 – 0.48
6-10 People	-0.76	-1.49 – -0.03	0.31	-0.36 – 0.97
11-20 People	-1.10	-1.82 – -0.37	0.30	-0.37 – 0.96
21+ People	-0.90	-1.80 – 0.01	0.38	-0.45 – 1.21
Mall:1-5 People	0.02	-1.06 – 1.09	-0.92	-1.92 – 0.08
Mall:6-10 People	-0.35	-1.47 – 0.75	-1.55	-2.57 – -0.53
Mall:11-20 People	0.19	-0.93 – 1.31	-1.60	-2.64 – -0.58
Mall:21+ People	-0.18	-1.47 – 1.11	-1.31	-2.51 – -0.12
Random Effects				
σ^2	3.95		3.02	
τ_{00}	2.11 $_{intakeID}$		2.48 $_{intakeID}$	
N	85 $_{intakeID}$		85 $_{intakeID}$	
Observations	500		500	

Figure S4. 4. Bivariate linear correlations between individual trait measures (rows) and dependent variables (columns) in the conservatory (left) and mall (right). Positive correlations are shown in blue and negative correlations are shown in red. 89% confidence intervals are shown in parentheses.