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A thought in the park: The influence of naturalness and low-level visual features on expressed thoughts

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

1. Introduction

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

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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, Hartig, Hagerhall, & Fry, 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, Kardan, & Berman, 2016b; Oliva & Torralba, 2006; Walther, Caddigan, Fei-Fei, & Beck, 2009), as well as interact with top-down interpretations of the visual information (Ibarra et al., 2017; Kardan, Henderson, Yourganov, & Berman, 2016; Kardan et al., 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 (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, Kardan, & Berman, 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, Nadal, Sheehy, Cela-Conde, & Sawey, 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, Hamilton, & Daily, 2012, and 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, Hays, Ehinger, Oliva, & Torralba, 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.

2. TKF images and journals (Study 1)

2.1. Method and materials

2.1.1. 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, Kaplan, 1995; Kaplan & Kaplan, 1989). 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 (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

Fig. 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.

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.

attention, while simultaneously having softly fascinating stimulation that capture involuntary attention (Berman et al., 2008; 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, 1995). 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.

2.1.2. 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.

2.1.3. 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, Sagae, Sachdeva, & Gratch, 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, Dehghani, & Sagi, 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, Ng, & Jordan, 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, 2011). 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, Dumais, & Liebling, 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

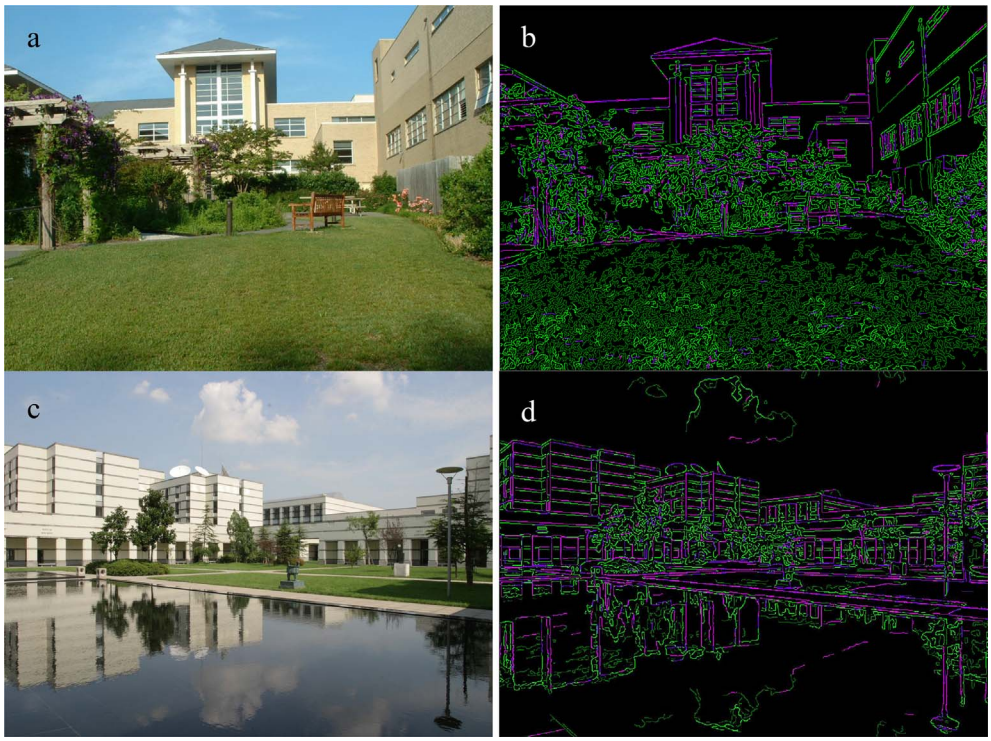

Fig. 2. a. Sample image from Study 1 b. Edge composition with straight edges in purple and non-straight edges in green for image (a) c. Sample image from Study 3 d. Edge composition for image (c).

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, SanJuan, and Bellot (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.

2.1.4. 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.

2.1.4.1. 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 min 17 s and participants were compensated $1.00 for participating. Informed consent was administered by the Institutional Review Board (IRB) of the University of Chicago.

2.1.4.2. 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 Fig. 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.

2.1.4.3. 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.

2.1.5. 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 Release 2014b, The MathWorks, Inc., Natick, Massachusetts, United States).

2.1.6. Color and spatial properties

Color features for the images were based on the standard Hue-

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

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.

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 Fig. 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) and 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 (Circular Statistics Toolbox for MATLAB, Berens, 2009) as in Kardan et al. (2016). 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 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.

2.2. Results

2.2.1. 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, and Brysbaert (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 6.22–6.97. The scale goes from 1 to 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.

2.2.2. 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-

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	−0.19 [−0.39, 0.02]	−0.12 [−0.32, 0.09]	0.22 [0.01, 0.41]	−0.04 [−0.25, 0.17]	−0.12 [−0.32, 0.09]	0.02 [−0.19, 0.23]	−0.05 [−0.26, 0.16]	0.28 [0.07, 0.46]	0.08 [−0.13, 0.28]	0.44** [0.25, 0.60]
Naturalness	−0.20 [−0.39, 0.01]	0.22 [0.01, 0.41]	0.10 [−0.30, 0.11]	0.19 [−0.02, 0.39]	−0.22 [−0.41, 0.01]	0.52** [0.35, 0.66]	−0.28 [−0.46, 0.07]	0.06 [−0.15, 0.26]	−0.05 [−0.26, 0.16]	0.23 [0.02, 0.42]

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

wise error at $\alpha = 0.05$. 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 3), 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.

3. Thought content online study of TKF parks (Study 2)

3.1. Methods and materials

3.1.1. 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 s and participants were compensated $3.00 for participating. Informed consent was administered by the Institutional Review Board (IRB) of the University of Chicago.

3.1.2. Images

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

3.1.3. 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.

3.2. Results

3.2.1. 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 5.61–6.95. 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.

3.2.2. 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 ($r = 0.42$, 95% CI [0.23, 0.58], $p < .001$) and Topic 4 ($r = 0.48$, 95% CI [0.30, 0.63], $p < .001$) positively correlated with Spiritual & Life Journey. We then calculated the correlation between these two topics and non-straight edges. Topic 1 ($r = 0.22$, 95% CI [0.01, 0.41], $p = .04$) and Topic 4 ($r = 0.25$, 95% CI [0.04, 0.44], $p = .02$) were both positively correlated with non-straight edges. In an analysis same as above, we found that Topic 1 ($r = 0.37$, 95% CI [0.17, 0.54], $p < .001$) and Topic 5 ($r = 0.53$, 95% CI [0.36, 0.67], $p < .001$) positively correlated with the Nature topic from Study 1. We then calculated the correlation between these topics and naturalness. Topic 1 ($r = 0.62$, 95% CI [0.47, 0.73], $p < .001$) and Topic 5 ($r = 0.27$, 95% CI [0.07, 0.46], $p = .01$) 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.

4. Testing the causality of NSED and naturalness on thought content (Study 3)

4.1. Method and materials

4.1.1. 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 0.90 (G*Power, 3.1.9.2). 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 s and participants were compensated $1.00 for participating. Informed consent was administered by the Institutional Review Board (IRB) of the University of Chicago.

4.1.2. Images

A subset of the SUN image database (Xiao et al., 2010) comprising 1105 scene images was downloaded and run through the same quantitative image analysis as conducted in Experiment 1. This subset of 1105 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 × High/Low Naturalness) of 20 images (80 total) were selected[3] to best match NSED, naturalness and preference. Although we

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

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. Fig. 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 × 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 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 (Kaplan, Kaplan, & Wendt, 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 ($t = -0.18$, $p = .86$). 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 1–7. Fig. 4 shows example images for each category.

4.1.3. 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 800 × 600 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 Fig. 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.

4.1.4. Regression analysis

We conducted a mixed logistic regression analysis. Logistic regression was designed to analyze binomial categorical data (McCullagh & Nelder, 1989). 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, Maechler, Bolker, & Walker, 2015).

4.2. 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 Fig. S1 in Supplementary Materials for overall topic selection frequency and Table S9 in Supplementary Materials for logistic regression models on the other topics.

Table 5
Significant correlations between Study 1 journal topics, Study 2 journal topics and visual features.

	Spiritual & life journey	Nature	NSED	Naturalness
Topic 1	0.42 [0.23, 0.58]***	0.37 [0.17, 0.54]***	0.22 [0.01, 0.41]*	0.62 [0.47, 0.73]***
Topic 4	0.48 [0.30, 0.62]***		0.25 [0.05, 0.44]*	
Topic 5		0.53 [0.36, 0.67]***		0.27 [0.07, 0.46]**

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

5. 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

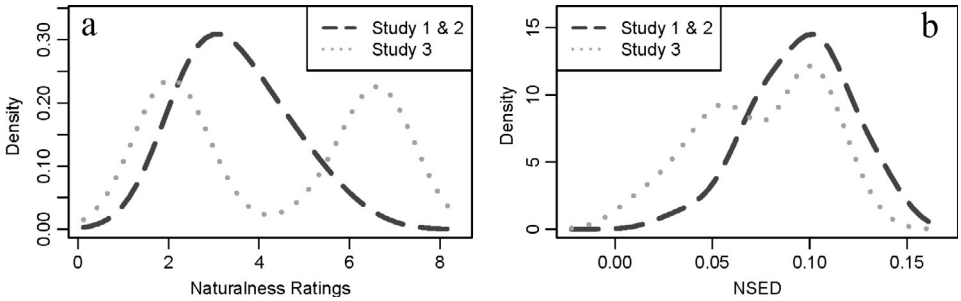

Fig. 3. a. Distribution of NSED for Studies 1–2 and Study 3 image sets. b. Distribution of Naturalness Ratings for Studies 1–2 and Study 3 image sets.

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.

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

Fig. 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.

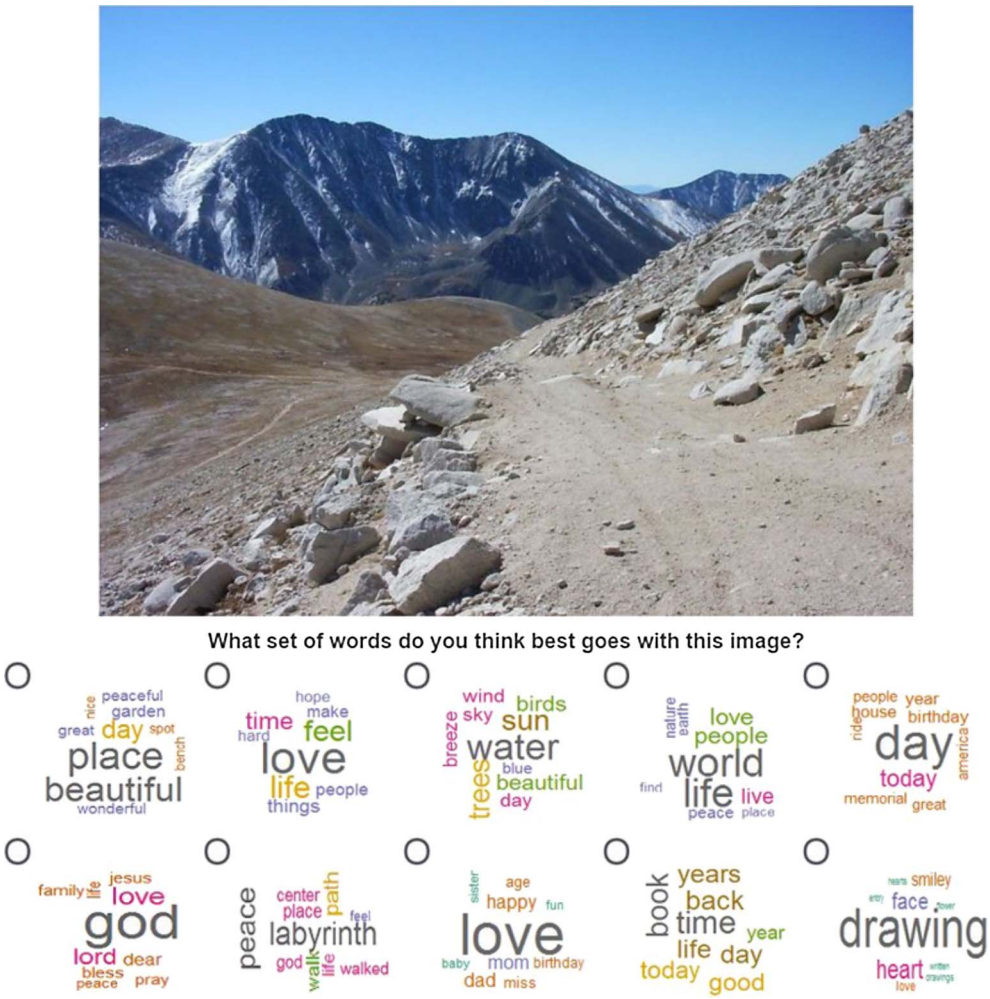

Fig. 5. Example screen presentation from AMT study.

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	0.10	−28.02	< .001	−1.39	0.08	−17.49	< .001
Naturalness	−0.29	0.12	−2.50	.012	0.69	0.09	7.89	< .001
NSED	0.47	0.14	3.39	< .001	0.50	0.08	5.95	< .001
Naturalness * NSED	0.84	0.17	4.81	< .001	0.36	0.13	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)).

abstract images with little to no semantic content (Kotabe et al., 2016a) 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.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2018.01.011.

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