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Visual features influence thought content in the absence of overt semantic information

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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. Nonstraight edge density is one visual feature that 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 nonstraight 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.

Keywords Environmental effects · Thought content · Visual features

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, Dodds, O'Neil-Dunne, Danforth, & Ricketts, 2019). For example, brief exposures to nature are associated with decreased rumination, a maladaptive pattern of self-referential thought associated with depression (Bratman, Hamilton, Hahn, Daily, & Gross, 2015). Several theories about the influence of different environments on cognition and affect, such as attention restoration theory (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) 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

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information (Berman et al., 2014; Edmiston & Lupyan, 2015; Kotabe, Kardan, & Berman, 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-level or mid-level features (Long, Yu, & Konkle, 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). Nonstraight edges in particular have been shown to influence various types of cognition. For example, people prefer objects and scenes with a greater number of nonstraight edges compared to straight edges (Bar & Neta, 2006; Kardan et al., 2015). Nonstraight 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 nonstraight edge density (NSED). The first study was an ecological topic-modeling study that analyzed journal entries from park visitors to correlate the topics expressed with the visual features of the parks. A 10-topic model was found to be appropriate for the corpus of journal entries. It was found that visiting parks that 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 et al. (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 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, Hays, Ehinger, Oliva, & Torralba, 2010) and were chosen to include a large range of outdoor locations. Original intact images are available (https://github.com/kschertz/TKF_MTurk). There were four groups of 20 images each (High/Low NSED × 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, Kardan, & Berman, 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 1 shows summary statistics for the four image groups. Naturalness and NSED were uncorrelated across all 80 images ($r = .06$, $p = .58$, 95% CI [−0.16, 0.27]).

Table 1 Summary of means and standard deviations of original image group visual features

	Low naturalness		High naturalness	
	Low NSED	High NSED	Low NSED	High NSED
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. NSED = nonstraight edge density

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 nonstraightness 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 (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 Fig. 1). In Process 1, we started with an original image (Fig. 1a) and created the edge map (Fig. 1b). In parallel to this, we created two random matrices (Fig. 1c) of the same size of the images (600 × 800) with each element (i.e., pixel) drawn from a binary random distribution of zero or one. These matrices were convolved (see Fig. 1, Process 2) with a median filter of size 30 × 40 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 Fig. 1d). The size of the median filter (5% of image dimensions = 30 × 40) 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 (Fig. 1, Process 3). This creates two stimuli, each with half of the original edges on average (Fig. 1e). One of the resulting images was flipped on the *x*-axis, and then the two images were overlaid on each other (Fig. 1, Process 4). The 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 (Fig. 1f). Afterward, we had the generated scrambled stimuli rerated 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.

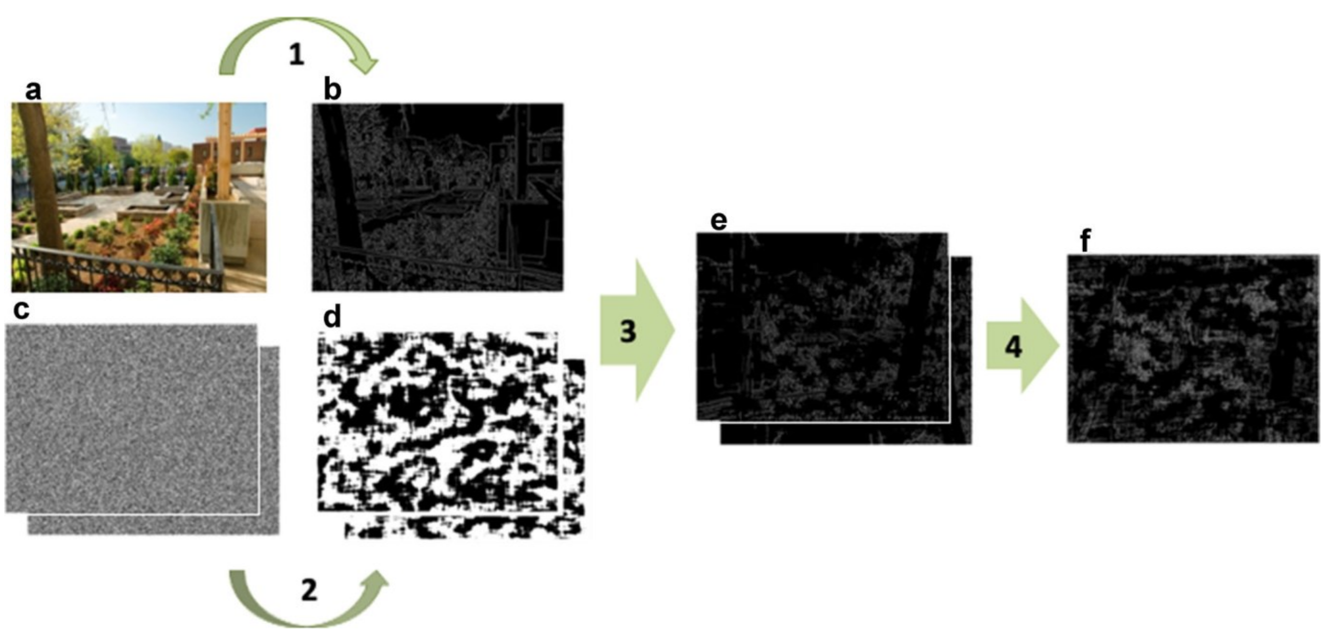

Fig. 1 Stimuli creation process. Process 1: Edge map created from original image. Process 2: Two random masks created having on average half a surface of 1 s and half a surface of 0 s. Process 3: Edge map is multiplied (dot product) with the two masks. Process 4: One image is flipped over the *x*-axis; the two images are overlaid on each other. a Original image. b Edge map. c Random matrices of 0 s and 1 s. 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, Robinson, & Abberbock, 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 interrater reliability, as a prior study found that interrater reliability of perceived naturalness ratings for scrambled edge images were not high enough to be usable (Kotabe et al., 2017). Here, interrater 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 ($r = .82$, $p < .001$, 95% CI [0.74, 0.88]). However, the factors naturalness and NSED were no longer uncorrelated ($r = .40$, $p < .001$, 95% CI [0.20, 0.57]). Figure 2 shows the distribution of original and new ratings by group.

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 preregistered 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 pro- posed in the preregistration.

In the first study, to determine the influence of NSED, participants saw the "high naturalness + high NSED" and "high naturalness + low NSED" image groups. Because of 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 Fig. 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 Fig. 2). With this design, we were able to look separately at main effects for NSED (Study 1) and naturalness (Study 2).

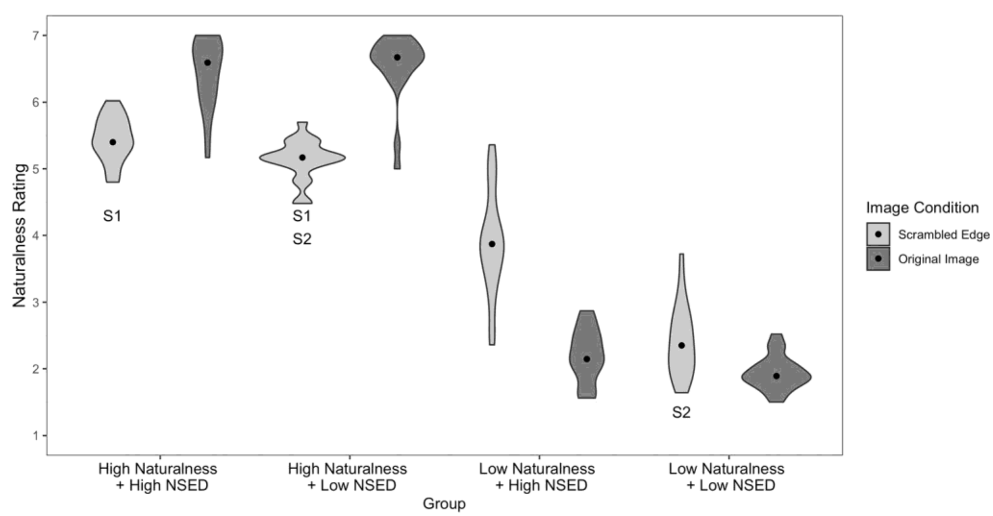

Fig. 2 Violin plot of original and scrambled edge naturalness ratings by group. Black dots represent the median rating of each group. S1 indicates image groups used in Study 1 and S2 indicates image groups used in Study 2. NSED = nonstraight edge density

Thought content topics

Although we only have a priori hypotheses about two topics (Nature and Spiritual & Life Journey), 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 10-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, Kuperman, and Brysbaert (2013), which vary from 1 (*most negative*) to 9 (*most positive*), with 5 being neutral. Using the top 10 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 S1 in the Supplementary Material for valence ratings for each topic). These 10 topics were displayed as word cloud visualizations (see Fig. 3). The word clouds show the 10 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 (Brysbaert & New, 2009) (see Table S1). 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 three to five 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.

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

Method and materials

Participants

A total of 100 U.S.-based adults (64 males, 35 females, one 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 years ($M = 35.6$ years, $SD = 9.9$ years). 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

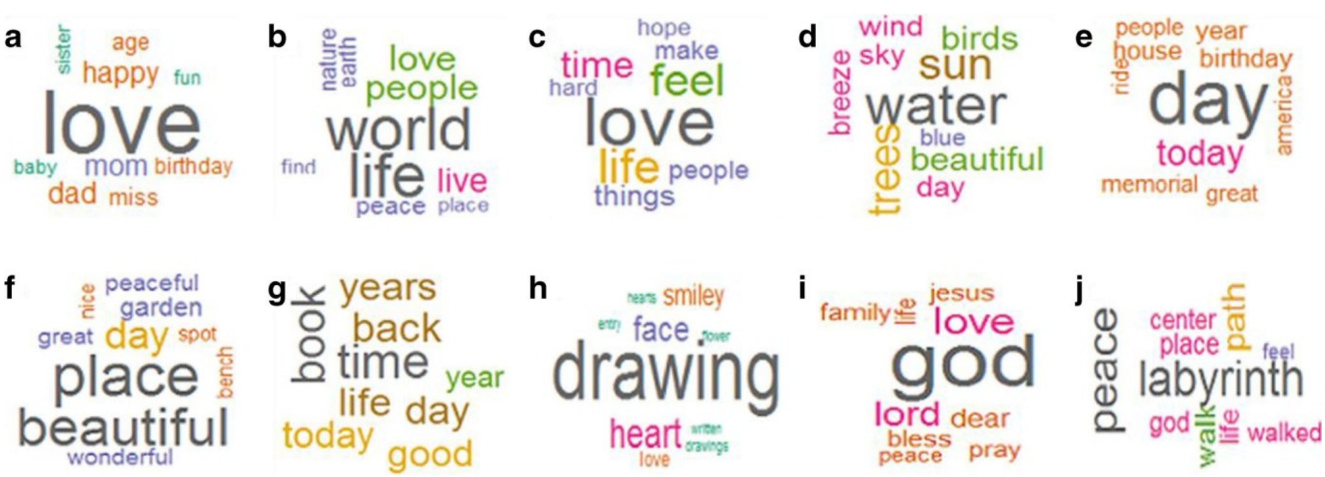

Fig. 3 Word clouds as displayed to participants. Topic were labeled as the following: a Family. b World & Peace. c Life & Emotions. d Nature. e Celebration. f Park. g Time & Memories. h Art. i Religion. j Spiritual & Life Journey. Reprinted from "A thought in the park: The influence of naturalness and low-level visual features on expressed thoughts," by Schertz, et al., 2018, Cognition, 174, 82–93. Copyright (2018), by Elsevier. Reprinted with permission

during the task. For each trial, a participant saw one image and 10 word clouds. Images were 800 × 600 pixels and presented in the center of the screen on a white background. See Supplemental Fig. S1 for a sample presentation screen. The participants could 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, because feedback from participants in the previous study 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 the "high naturalness + high NSED" category and the 20 images from the "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, Mächler, Bolker, & Walker, 2014).

Results

Average topic selection is shown in Fig. 4. Guided by the results of Schertz et al.'s (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 and image as random intercepts. For the Spiritual & Life Journey topic, NSED had a significant effect, while results were not significant for the Nature topic (see Table 2). 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 3). See Table S2 in the Supplementary Material for logistic regression for all other topics. We found no significant correlation between word frequencies and topic selection ($r = -.47$, $p = .16$, 95% CI [−0.85, 0.22]).

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

Methods and materials

Participants

A total of 100 U.S.-based adults (65 males, 35 females) 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 years ($M = 37.8$ years, $SD = 11.1$ years). 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 in Fig. 2, 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 Fig. 5. 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 and image were random intercepts. For both topics, naturalness had a significant effect, in the predicted direction (see Table 4). 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,

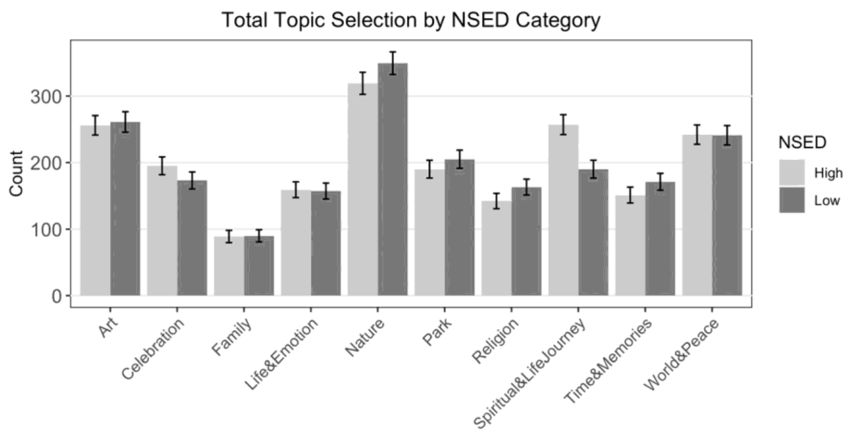

Fig. 4 Total topic selection across all participants by images' nonstraight edge density (NSED) category for Study 1. *Note.* Error bars represent bootstrapped standard deviation

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 S3 in the Supplementary Material for logistic regression for all other topics. As in Study 1, we found no significant correlation between word frequencies and topic selection ($r = -.30$, $p = .38$, 95% CI [−0.78, 0.40]).

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 preregistered.

Methods and materials

Participants

A total of 100 U.S.-based adults were recruited from the online labor market Amazon Mechanical Turk, using TurkPrime (Litman et al., 2017). Participants were pseudorandomly 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

Table 2 Logistic regression models predicting Spiritual & Life Journey and Nature topics using NSED

	Spiritual & Life Journey				Nature			
Fixed effects	*B*	*SE*	*z*	*p*	*B*	*SE*	*z*	*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	*SD*			Variance	*SD*		
Subject ($n = 100$)	0.64	0.80			0.32	0.57		
Image ($n = 40$)	0.13	0.36			0.03	0.16		
AIC	2,626.3				3,547.9			
Log likelihood	−1,309.2				−1,770.0			
Observations	4,000				4,000			
ΔAIC	−3.6				0.7			
$\chi^2(1)$	5.52				1.22			

Note. ΔAIC and χ^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)). NSED = nonstraight edge density

Table 3 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*	*SE*	*z*	*p*	*B*	*SE*	*z*	*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	*SD*			Variance	*SD*		
Subject (n = 100)	0.65	0.81			0.37	0.61		
Image (n = 34)	0.11	0.34			0.03	0.18		
AIC	2,211.6				3,025.5			
Log likelihood	−1,101.8				−1,508.8			
Observations	3,400				3,400			
ΔAIC	−3.1				1.2			
$\chi^2(1)$	5.17				0.86			

Note. ΔAIC and χ^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)). NSED = nonstraight edge density

failed for one participant, leaving 99 participants (42 females, 56 males, one other). Ages ranged from 21 to 68 years (M = 38.0 years, SD = 11.4 years). For race/ethnicity, 66 identified as White, 17 identified as Black/African American, seven identified as Asian/Asian American, four identified as Hispanic/Latino, three identified as multiple ethnicities, and two 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 the “high naturalness + high NSED” category (20 images) and “high naturalness + low NSED” category (20 images), as in Study 1, or the “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 4 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 could 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

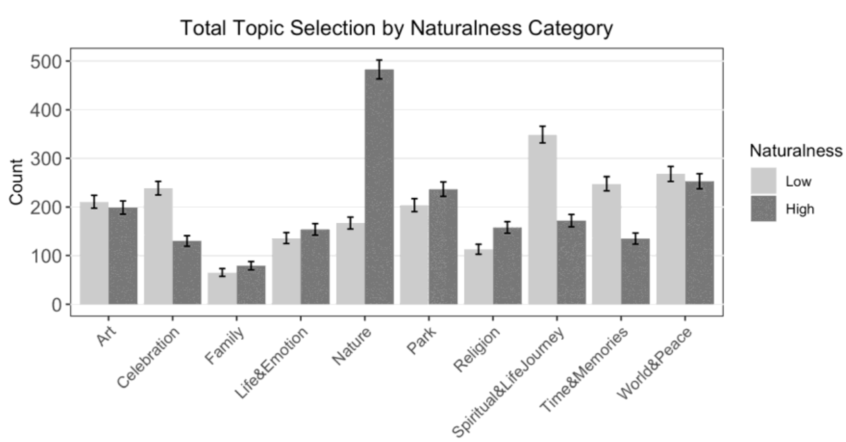

Fig. 5 Total topic selection across all participants by images’ Naturalness category for Study 2. *Note*. Error bars represent bootstrapped standard deviation.

Table 4 Logistic regression models predicting Spiritual & Life Journey and Nature topics using naturalness

	Spiritual & Life Journey				Nature			
Fixed Effects	*B*	*SE*	*z*	*p*	*B*	*SE*	*z*	*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	*SD*			Variance	*SD*		
Subject ($n = 100$)	0.55	0.74			0.46	0.67		
Image ($n = 40$)	0.08	0.29			0.05	0.22		
AIC	2,877.4				3,261.3			
Log likelihood	−1,434.7				−1,626.6			
Observations	4,000				4,000			
ΔAIC	−74.8				−200.8			
$\chi^2(1)$	29.2				204.8			

Note. ΔAIC and χ^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))

each word being selected for one category of images compared with 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 the "high naturalness + high NSED" group by the count for the "high naturalness + low NSED" group. For images from Study 2, we divided the count for the "low naturalness + low NSED" group by the count for the "high naturalness + low NSED" group. In this way, an odds ratio 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 odds ratio was significantly higher than a null distribution.

Results

Study 1 images

Table 5 shows the calculated odds ratios for each of the nine words within the Spiritual & Life Journey topic for high NSED images compared with low NSED images. Feel and labyrinth were chosen significantly more for images with high NSED compared with low NSED, while life was marginally significant ($p = .056$).

Study 2 images

Table 6 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.

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 with 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 with low naturalness). The only effect from Study 3 of Schertz et al. (2018) that we did not replicate was the positive

Table 5 Odds ratios for selection of words within Spiritual & Life Journey for high nonstraight edge density (NSED) images compared with low NSED images

Word	Total number of times chosen	Odds ratio†	*p*
Center	286	0.62	1
Feel	228	1.4	.004 **
God	177	0.77	.961
Labyrinth	229	1.57	.0005 **
Life	360	1.14	.056 •
Path	374	0.78	.998
Peace	229	1.04	.336
Place	405	1.05	.270
Walk	284	0.91	.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

Table 6 Odds ratios for selection of words within Spiritual & Life Journey for low naturalness images compared with high naturalness images

Word	Total number of times chosen	Odds ratio†	*p*
Center	412	1.42	.0005**
Feel	323	0.68	.999
God	209	0.46	1
Labyrinth	327	1.75	.0005**
Life	356	0.65	1
Path	371	0.90	.836
Peace	374	0.53	1
Place	579	1.87	.0005**
Walk	317	0.87	.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

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 nonsignificant 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; e.g., see Van Hedger, Keedy, Schertz, Berman, & de Wit, 2019) can increase cognitive disfluency (Forsythe, Nadal, Sheehy, Cela-Conde, & Sawey, 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 nonstraight 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 nonlinear 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). As nonstraight 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, 2001). 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 is 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.

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Compliance with ethical standards

Declarations of Interest None.

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Open practice statement The data, analysis code, and materials (i.e., images) for this manuscript are available (https://osf.io/acvdz/). Original intact images are available (https://github.com/kschertz/TKF_MTurk). Studies 1 and 2 were preregistered (https://osf.io/s49ru).