The aesthetic preference for nature sounds depends on sound object recognition

Stephen C. Van Hedger ^{1,2}
Howard C. Nusbaum ^{1,2}
Shannon L. M. Heald ^{1,2}
Alex Huang ^{1,2}
Hiroki P. Kotabe ³
Marc G. Berman ^{1,2}

¹*Department of Psychology, University of Chicago*

²*Center for Practical Wisdom, University of Chicago*

³*SKK Graduate School of Business, Sungkyunkwan University*

Corresponding author:
Stephen Van Hedger
svanhedger@uchicago.edu

Number of Tables: 1
Number of Figures: 6

Abstract

People across the world seek out beautiful sounds in nature, such as a babbling brook or a nightingale song, for positive human experiences. However, it is unclear whether this positive aesthetic response is driven by a preference for the perceptual features typical of nature sounds versus a higher-order association of nature with beauty. To test these hypotheses, participants provided aesthetic judgments for nature and urban soundscapes that varied on ease of recognition. Results demonstrated that the aesthetic preference for nature soundscapes was eliminated for the sounds hardest to recognize, and moreover the relationship between aesthetic ratings and several measured acoustic features significantly changed as a function of recognition. In a follow-up experiment, requiring participants to classify these difficult-to-identify sounds into nature or urban categories resulted in a robust preference for nature sounds and a relationship between aesthetic ratings and our measured acoustic features that was more typical of easy-to-identify sounds. This pattern of results was replicated with computer-generated artificial noises, which acoustically shared properties with the nature and urban soundscapes but by definition did not come from these environments. Taken together, these results support the conclusion that the recognition of a sound as either natural or urban dynamically organizes the relationship between aesthetic preference and perceptual features.

Keywords: *audition, aesthetics, nature, categorization, perception, concepts*

207 words

1 Compared to our experiences with manmade structures and urban environments, interacting with
2 nature provides a range of cognitive, affective, and health benefits. Experiences with nature can improve
3 directed attention (Berman et al., 2012; Berman, Jonides, & Kaplan, 2008), reduce perceived pain (Kline,
4 2009) and stress (Alvarsson et al., 2010), and generally increase well-being (Marselle, Irvine, & Warber,
5 2014). Benefits of nature have also been documented in studies that use greenspace as a quasi-
6 independent variable, suggesting that one's ability to engage with nature on a day-to-day basis may have
7 critical implications for academic and professional performance (cf. Berto, 2005; Raanaas, Evensen, Rich,
8 Sjostrom, & Patil, 2011), cognitive development (Dadvand et al., 2015), and general health (Kardan et al.,
9 2015).

10 An important consideration in any discussion of the mechanisms through which nature confers
11 these benefits is the aesthetic preference of naturalistic experiences. Aesthetic preference has been defined
12 as a "like-dislike" affective response (Zajonc, 1980), and the restorative potential of nature has been
13 clearly associated with a strong aesthetic preference for nature stimuli (Han, 2010; Hartig & Staats, 2006;
14 Purcell, Peron, & Berto, 2001; van den Berg, Koole, & van der Wulp, 2003). In particular, the aesthetic
15 valuing of nature may directly improve affect and reduce stress (cf. Alvarsson et al., 2010), which in turn
16 could improve cognitive performance (e.g., Tennessen & Cimprich, 1995) and general health (e.g.,
17 Kardan et al., 2015). However, many studies find dissociations between changes in affect and cognitive
18 performance (Berman et al., 2008; 2012; Stenfors et al., 2018) and enjoying the nature interaction is not
19 required to obtain the cognitive benefit (Berman et al., 2008).

20 A fundamental question within this area of research is whether the perceptual features that
21 differentiate nature from urban environments ground this aesthetic preference. In addition, it is unclear
22 which perceptual features differentiate nature from urban soundscapes, as well as how these features
23 relate to aesthetic preference. One possibility is that nature sounds are aesthetically valued because they
24 are thought to provide a quiet respite from typically loud urban noises (Mace, Bell, & Loomis, 2004).
25 Indeed, urban noises in the context of noise pollution (e.g., Cohen & Weinstein, 1981) are reported as

highly annoying (Basner et al., 2014), which may have subsequent consequences for measures of health and well-being.

The association between loudness and preference, however, may not completely explain individuals' aesthetic preference for nature sounds. When aesthetically rating nature and urban soundscapes presented at the same normalized amplitude, listeners still exhibit a robust preference for nature soundscapes (Van Hedger et al., 2018). Furthermore, many individuals seek out the sounds of nature in situations where loudness can be rapidly adjusted (e.g., through websites or apps), and recent research has demonstrated that such presentations of nature sounds can lead to improvements in mood and workplace productivity (e.g., DeLoach, Carter, & Braasch, 2015). This, in turn, suggests that the aesthetic preference for such stimuli may exist independently of loudness cues and may not be entirely tied to the experience of these sounds in their real-world environments.

Why might nature be preferred in situations where loudness is controlled? One possibility, which we refer to as the *inherent-organization hypothesis*, is that listeners inherently prefer the acoustic features (such as spectral centroid, or entropy) that are typically found in nature soundscapes. This kind of explanation suggests that even in situations where a sound is not identified as coming from nature, listeners may still show an aesthetic preference if the sound is acoustically reminiscent of nature. A second possibility, which we refer to as the *dynamic-organization hypothesis*, is that the aesthetic preference for nature depends on the extent to which sounds can be recognized and conceptually associated with nature (e.g., birdsong). Under the *dynamic-organization hypothesis*, the relationship between listeners' aesthetic preferences and acoustic features should critically depend on the extent to which a sound can be recognized and associated with nature. Furthermore, listeners may not aesthetically prefer sounds that are, acoustically speaking, reminiscent of nature but not recognized as coming from nature.

1 To adequately test these hypotheses, one must vary the degree to which a sound can be
2 recognized while also preserving the general perceptual features within each sound. This is accomplished
3 in the present paper using two complementary approaches. In Experiments 1-2, nature and urban
4 soundscapes are manipulated such that identification of the sound-producing object (e.g., bird) is difficult
5 but several key acoustic features of each sound are generally preserved. In Experiment 3, we generate
6 noises that acoustically overlap with these nature and urban soundscapes but, by definition, do not contain
7 objective conceptual ties to either nature or urban sound-objects.

8 Assessing the degree to which the aesthetic preference for nature sounds is acoustically versus
9 conceptually based will inform our understanding of several benefits associated with nature sounds,
10 including perceived attention restoration and stress recovery (Ratcliffe, Gatersleben, & Sowden, 2013),
11 improved post-operation recovery (Bauer et al., 2011), and neural connectivity changes reflecting an
12 increase in parasympathetic activity (Gould van Praag et al., 2017), as all of these benefits could be
13 argued to have an aesthetic component.

14

15

Experiment 1

Experiment 1 assessed the degree to which participants could identify the sound-objects contained within stereotypic nature and urban environments. The sounds were either unaltered in presentation, time-domain scrambled, or presented as a thin-slice (100ms). These two manipulations were chosen because they were hypothesized to impair the recognition of sound-objects. Scrambling has been used previously in visual paradigms to obscure the recognition of objects but maintain lower-level perceptual features (Berman et al., 2014). Thin-slicing has been used previously in audition (e.g., Krumhansl, 2010) to demonstrate that object-level information is greatly attenuated (e.g., identifying the title or artist from 300ms of a popular recording), though thin slicing sound “textures” such as typical nature and urban soundscapes should not, in theory, substantially change the spectral profiles of these sounds (cf. McDermott & Simoncelli, 2011).

The primary goal of Experiment 1 was to assess whether sound-object recognition – that is, identifying whether a particular sound came from a bird, waterfall, car, etc. could be dissociated from the spectro-temporal profiles of each sound, as this is a necessary condition for testing the *inherent-organization* and *dynamic-organization hypotheses*. We predicted that participants would have greater difficulty identifying sound objects for manipulated soundscapes, conceptually replicating prior research. Moreover, we predicted that the spectral properties of the manipulated and non-manipulated sounds would largely overlap. Such findings would suggest that spectral properties of a sound are, to an extent, dissociable from recognizing the object that produced a sound.

Method

Participants

We recruited 150 participants on Amazon's Mechanical Turk (MTurk), and 145 participants completed the task. Participants were randomly assigned to condition in a between-subjects design: 49 participants (28 male, 20 female, 1 no response) heard soundscapes that had not been altered (Unaltered Group), 48 participants (29 male, 19 female) heard soundscapes that had been time-domain scrambled (Scrambled Group), and 48 participants (29 male, 19 female) heard soundscapes that had been thin sliced (Thin-Sliced Group). Participants had to have a minimum 90% positive rating from prior MTurk assignments, had to have completed a minimum of 10 previous assignments, and had to be residing in the United States to qualify. All participants consented to voluntary participation via the guidelines established by the Institutional Review Board at The University of Chicago, and all participants were compensated for their participation in the experiment.

Materials

We tested 80 soundscapes, which were downloaded from an online video sharing website. Half of the sounds were selected by the authors to represent typical soundscapes of nature, while the remaining sounds were selected to represent typical soundscapes of urban environments. The full database of sounds can be accessed through Open Science Framework. It should be noted that both the nature and urban soundscapes were not necessarily limited to a single sound-object (e.g., a single nature soundscape could contain sounds of insects, running water, and wind). We sampled multiple sources of nature and urban sounds, as we wanted to increase the potential for our analyses to generalize beyond specific sound classes (e.g., just birdsong).

The time-domain scrambled sounds were manipulated using the "scramble" toolbox in Matlab (Mathworks: Natick, MA). Each sound file was chopped into a set of short (25ms) windows with a 50%

1 overlap and was tapered with a raised cosine window. The 25ms windows were then shuffled and re-
2 overlapped within a 250ms radius. This process preserved the long-term spectral features of each sound
3 but effectively destroyed the spectro-temporal transitions within each soundscape. The thin-sliced sounds
4 were taken from the beginning of each full 5-second sound clip with the exception of some birdsong
5 stimuli, in which there was no audible birdsong at the beginning of the clip. All sounds were root mean
6 square (RMS) normalized and digitized at a 44.1 kHz sampling rate with a 16-bit depth. The experiment
7 was coded in jsPsych (de Leeuw, 2015).

8 *Acoustic Analyses*

9 For each sound we calculated five acoustic features: (1) spectral entropy, (2) spectral flatness, (3) spectral
10 skewness, (4) spectral centroid, and (5) dominant frequency. These features were calculated with the
11 *seewave* package in R (Sueur, Aubin, & Simonis, 2008). These features were not specifically selected
12 with respect to the hypotheses of the experiment. Rather, the features were meant to represent the spectral
13 profiles of our sounds in a non-redundant manner.

14 The spectral centroid represents the spectral center of gravity and is perceptually related to the
15 “brightness” of a sound. Spectral flatness is obtained by comparing the geometrical mean and the
16 arithmetical mean of the spectrum and can be thought to represent the extent to which a sound is heard as
17 “noisy” versus “tonal.” Spectral entropy is also a “noisiness” measure ranging from zero to one but is
18 calculated differently (assessing Shannon entropy) and thus is not redundant with spectral flatness.
19 Spectral skewness is a measure of asymmetry, with negative values indicating left skew (lower
20 frequencies), values of zero indicating no skew, and positive values indicating right skew (higher
21 frequencies). Dominant frequency represents the frequency with the greatest power at the particular
22 sampled time window. We averaged across all time windows to obtain a single value for each sound.

23

24

1 *Procedure*

2 After providing informed consent, participants were presented with a 10-second sample of pink noise
3 (RMS normalized to the same level as the soundscapes) and were instructed to adjust their computer
4 volume to a comfortable listening level. Once this calibration had been completed, participants received
5 instructions that they would hear 80 five-second sounds (Unaltered and Time-Domain Scrambled Groups)
6 or 80 one hundred millisecond-sounds (Thin-Sliced Group). Participants were additionally instructed that
7 they would be asked to type, in a few words, what they thought made each sound. Thus, the particular
8 wording of the task encouraged participants to respond with specific sound-objects (e.g., “bird”) rather
9 than the broad distinction of “nature” or “urban” or descriptive terms such as “buzzing.” The 80 sounds
10 were presented in a random order.

11

12

Results

Sound-Object Identification Accuracy

To assess sound-object identification accuracy, we used participant responses in the Unaltered Group to establish correct responses for each sound file. The main stipulation was that each response had to appear more than once in order to be included as a correct response. Typos were manually corrected. We adopted this particular method of determining correct answers because our stimuli were recorded from, real-world environments, and thus we did not want to limit artificially the number of acceptable answers. Rather, through looking at consistency of word use among participants, we were able to obtain a comprehensive yet consistent set of answers.

Using this method of determining correct answers, participants in the Unaltered Group correctly identified 83.6% ($SD = 10.0\%$) of objects within soundscapes. Participants were more accurate at identifying unaltered nature soundscapes ($M = 89.3\%$, $SD = 10.4\%$) compared to unaltered urban soundscapes ($M = 77.9\%$, $SD = 12.0\%$; $t(48) = 7.75$, $p < .001$). As hypothesized, sound-object identification in the Scrambled Group ($M = 54.3\%$, $SD = 8.7\%$) was significantly worse than identification in the Unaltered Group ($t(95) = 15.33$, $p < .001$). Even though time-domain scrambling significantly impaired sound-object identification for both nature and urban soundscapes independently, we found an unexpected asymmetry in that scrambling appeared to impair urban sound-object identification more than nature sound-object identification. Compared to unaltered soundscape identification, accuracy for scrambled nature soundscapes dropped 17.1 percentage points to 72.2% ($t(95) = 7.78$, $p < .001$) while accuracy for scrambled urban soundscapes dropped 41.6 percentage points to 36.3% ($t(95) = 18.05$, $p < .001$). Finally, we observed poorest sound-object identification performance in the Thin-Sliced Group, with participants only accurately identifying 31.5% ($SD = 14.8\%$) of sound-objects. This overall level of performance was significantly worse than sound-object identification in both the Unaltered ($t(95) = 20.32$, $p < .001$) and Scrambled ($t(94) = 9.18$, $p < .001$) groups. The pattern of

nature soundscapes being easier to identify than urban soundscapes was present in the thin-sliced sounds but was only marginally supported (nature: $M = 33.3\%$, $SD = 15.8\%$; urban: $M = 29.6\%$, $SD = 16.6\%$; $t(47) = 1.92$, $p = .06$).

Acoustic Differences between Nature and Urban Soundscapes

For unaltered soundscapes, we found that our nature soundscapes had higher spectral centroids, greater spectral entropy, higher dominant frequencies, greater spectral flatness, and less spectral skew compared to urban soundscapes. These findings were generally consistent across both scrambling and thin slicing (see Table 1), with the sole exception being spectral skew, which did not significantly differ between scrambled nature and urban soundscapes.

Unaltered				
<i>Feature</i>	<i>M ± SE</i> (Nature)	<i>M ± SE</i> (Urban)	<i>t</i>	<i>Cohen's d</i>
Centroid	4.16 ± 0.24	2.08 ± 0.17	7.10***	1.59
Entropy	0.74 ± 0.02	0.64 ± 0.02	4.17***	0.93
Skew	9.62 ± 1.52	28.29 ± 5.49	-3.28**	-0.73
Flatness	0.16 ± 0.01	0.09 ± 0.01	3.70***	0.83
DomHz	1.47 ± 0.26	0.32 ± 0.05	4.42***	0.99
Scrambled				
<i>Feature</i>	<i>M ± SE</i> (Nature)	<i>M ± SE</i> (Urban)	<i>t</i>	<i>Cohen's d</i>
Centroid	4.16 ± 0.24	1.92 ± 0.16	7.86***	1.76
Entropy	0.75 ± 0.02	0.64 ± 0.02	4.24***	0.95
Skew	7.62 ± 5.64	11.10 ± 1.94	-1.62	-0.36
Flatness	0.18 ± 0.02	0.09 ± 0.01	4.05***	0.91
DomHz	1.49 ± 0.26	0.32 ± 0.05	4.41***	0.99
Thin-Sliced				
<i>Feature</i>	<i>M ± SE</i> (Nature)	<i>M ± SE</i> (Urban)	<i>t</i>	<i>Cohen's d</i>
Centroid	3.97 ± 0.24	1.81 ± 0.15	7.74***	1.73
Entropy	0.73 ± 0.02	0.63 ± 0.02	3.54***	0.79
Skew	8.52 ± 0.97	11.37 ± 0.89	-2.16*	-0.48
Flatness	0.15 ± 0.02	0.08 ± 0.01	4.38***	0.98
DomHz	1.27 ± 0.23	0.28 ± 0.04	4.31***	0.96

Table 1: Summary and comparison of acoustic features for nature and urban soundscapes.

*** $p < .001$ ** $p < .01$ * $p < .05$

Discussion

There are two primary conclusions to draw from Experiment 1. First, the manipulations significantly impaired sound-object identification, with thin slicing disrupting identification by over 50 percentage points. Second, despite this decrease in sound-object identification, the measured acoustic features of these soundscapes remained relatively stable across all conditions (i.e., the features that differentiated unaltered nature and urban soundscapes also differentiated scrambled and thin-sliced soundscapes). These points, taken together, suggest (1) that our nature sounds were acoustically differentiable from our urban sounds, and (2) it is generally possible to preserve the spectral properties of a sound while increasing the difficulty of explicitly recognizing the object that produced the sound.

As such, Experiment 1 demonstrates that these sounds are well suited for testing the *inherent-organization* and *dynamic-organization hypotheses*. By reducing sound-object recognition but maintaining the general spectral properties of each sound, the *inherent-organization hypothesis* would predict that listeners should display an aesthetic preference for nature sounds across all sound manipulations (e.g., listeners should exhibit positive relationships between aesthetic ratings and spectral entropy, as nature sounds were consistently higher on entropy across all sound manipulations). In contrast, the *dynamic-organization hypothesis* would predict that the relationship between aesthetic ratings and acoustic features should change as a function of sound-object identification – that is, the overall aesthetic valuing of nature (and the association between aesthetic ratings and acoustic properties) should change across sound manipulations.

Experiment 2A

Experiment 2A tests whether listeners' aesthetic valuing of the nature and urban sounds from Experiment 1 can be better explained under the *inherent-organization hypothesis* versus the *dynamic-organization hypothesis*. Under the *inherent-organization hypothesis*, we would predict that listeners should aesthetically prefer nature sounds even when the sounds are scrambled and thin-sliced (i.e. when the sounds are more difficult to recognize). Moreover, the relationship between aesthetic ratings and acoustic features should remain invariant regardless of sound condition, as this would suggest that the acoustic features that differentiate nature and urban sounds are driving this aesthetic preference. Conversely, under the *dynamic-organization hypothesis*, we would predict that listeners' aesthetic preference for nature sounds might be attenuated for scrambled and thin-sliced sounds, as these sounds are more difficult to recognize and associate with nature and urban environments. Moreover, the relationship between aesthetic ratings and acoustic features should vary across sound manipulation, as this would suggest that the relationship between aesthetic ratings and acoustic features is dynamic.

Method

Participants

We recruited 150 individuals from MTurk to participate in the experiment, and 149 completed the task. Of the 149 participants, 50 (24 male, 26 female) listened to Unaltered Sounds, 50 (28 male, 22 female) listened to Scrambled Sounds, and 49 (30 male, 17 female, 2 no response) listened to Thin-Sliced Sounds. Similar to Experiment 1, participants had to have a minimum 90% positive rating from prior MTurk assignments, had to have completed a minimum of 10 previous assignments, and had to be residing in the United States to qualify. All participants consented to voluntary participation via the guidelines established by the Institutional Review Board at The University of Chicago, and all participants were compensated for their participation in the experiment.

Materials

The sounds were identical to those used in Experiment 1. The experiment was coded in jsPsych (de Leeuw, 2015).

Procedure

The consent procedure and volume calibration were identical to Experiment 1. After volume calibration, participants received instructions that they would hear 80 five-second sounds (Unaltered and Scrambled Sounds) or 80 one hundred millisecond-sounds (Thin-Sliced Sounds). Participants were also instructed that they would rate how much they liked each sound. The 80 sounds were presented in a random order. Participants provided their aesthetic judgments on a 7-point scale, with “1” representing “strongly dislike,” “4” representing “neither dislike nor like,” and “7” representing “strongly like.” Once participants heard and rated all 80 sounds, they were asked to provide basic demographic information.

Results

Aesthetic Ratings

To assess how the aesthetic ratings for nature and urban soundscapes changed as a function of sound manipulation, we constructed a 2 x 3 mixed ANOVA. Mean aesthetic rating was the dependent variable, while soundscape category (nature vs. urban) was a within-participant factor and sound-manipulation type (Unaltered vs. Scrambled vs. Thin-Sliced) was a between-participant factor.

In this analysis, we found a significant main effect of sound-manipulation type ($F(2, 146) = 7.50$, $p < .001$), in which overall aesthetic ratings decreased as a function of sound identification (i.e., unaltered soundscapes were higher than scrambled soundscapes, which in turn were higher than thin-sliced soundscapes). We also found a significant main effect of soundscape category ($F(1, 146) = 290.1$, $p < .001$), meaning that participants on average rated nature soundscapes higher than urban soundscapes. While this finding seems to support the *inherent-organization hypothesis*, we also found a significant interaction between soundscape category and sound-manipulation condition ($F(2, 146) = 115.8$, $p < .001$), whereby the nature-related aesthetic preference was robustly observed in the Unaltered Group (Nature $M \pm SE$: 5.40 ± 0.11 ; Urban $M \pm SE$: 3.18 ± 0.11) attenuated in the Scrambled Group (Nature $M \pm SE$: 4.34 ± 0.10 ; Urban $M \pm SE$: 3.49 ± 0.09), and not present in the Thin-Sliced Group (Nature $M \pm SE$: 3.82 ± 0.11 ; Urban $M \pm SE$: 3.81 ± 0.11). This interaction (see Figure 1) strongly supports the *dynamic-organization hypothesis*, as the relative aesthetic preference for nature soundscapes was reduced as sound identification was reduced.

From these analyses, however, it is difficult to tell whether the observed attenuation in aesthetic ratings between nature and urban soundscapes is truly a result of increasing the difficulty of sound identification, as opposed to an artifact of the acoustic manipulations themselves. Put another way, time-domain scrambling and thin slicing recordings may render aesthetic judgments meaningless, with participants responding arbitrarily (which, when averaged, would result in mean ratings close to the mid-point of the scale) because aesthetic judgments of such sounds might be difficult. If this were the case,

then we would predict an attenuation of any relationship between our acoustic features and aesthetic judgments as a function of soundscape identification. This is assessed in the next section.

Figure 1: Mean plots of aesthetic ratings across soundscape type (nature or urban) for each of the sound conditions. While participants had clear aesthetic preferences for unaltered (U) nature soundscapes compared to urban soundscapes, this preference was attenuated for scrambled (S) soundscapes and not present for thin-sliced (TS) soundscapes. Given the graded conceptual identification from Experiment 1, this pattern of results is what would be expected under the *dynamic-organization hypothesis*. In further support of this hypothesis, encouraging participants to think about the thin-sliced soundscapes in terms of nature or urban categories restored the nature-related aesthetic preference (TS-2B).

1 *Correlations of Acoustic Features with Aesthetic Ratings*

2 Based on the *inherent-organization hypothesis*, we would expect positive relationships between aesthetic
 3 ratings and (1) spectral centroid, (2) spectral entropy, (3) dominant frequency, and (4) spectral flatness, as
 4 well as a negative relationship between aesthetic ratings and spectral skew. Critically, these relationships
 5 would need to persist across all sound conditions, as this would support the argument that inherent
 6 aesthetic preferences are tied to these acoustic properties, regardless of the ease with which a sound can
 7 be identified as coming from nature.

8 Unaltered Sounds: As depicted in Figure 2A, we found significant positive correlations between
 9 aesthetic ratings and (1) median spectral centroid ($r = .53, p < .001$), (2) spectral entropy ($r = .31, p =$
 10 $.005$), (3) dominant frequency ($r = .45, p < .001$), and (4) spectral flatness ($r = .37, p < .001$). Spectral
 11 skew was significantly negatively correlated with aesthetic ratings ($r = -.31, p = .006$). Scrambled Sounds:
 12 As depicted in Figure 2B, we did not find a significant correlation between aesthetic ratings and any of
 13 our acoustic features. Thin-Sliced Sounds: As depicted in Figure 2C, we found *negative* correlations
 14 between aesthetic ratings and (1) spectral entropy ($r = -.72, p < .001$), (2) spectral centroid ($r = -.30, p =$
 15 $.008$), and (3) spectral flatness ($r = -.27, p = .016$). Spectral skew was positively associated with aesthetic
 16 ratings ($r = .47, p < .001$).

17 These correlations, as a whole, suggest that participants did not merely respond randomly in the
 18 scrambled and thin-sliced conditions. Rather, it appears that participants underwent a strategic shift when
 19 determining aesthetic qualities for nature and urban soundscapes, based on the degree to which the objects
 20 within a soundscape could be identified. In fact, the strongest relationship between aesthetic ratings and
 21 an acoustic feature was observed in the thin-sliced condition, and moreover the direction of these
 22 relationships was the *opposite* of what we would expect under the *inherent-organization hypothesis*. For
 23 example, the relationship between entropy and aesthetics reverses in direction for difficult-to-identify thin
 24 slices, providing evidence that features alone are not predictive of aesthetic preference, but contribute

differentially based on the ability to recognize and associate a sound with either a nature or urban environment.

Figure 2: Correlation matrices for aesthetic ratings and acoustic properties. Panels A - C represent unaltered, scrambled, and thin-sliced sounds, respectively (Experiment 2A). Panel D represents the same thin-sliced sounds as those plotted in C, with the only difference being that the aesthetic ratings were explicitly framed in terms of nature and urban categories (Experiment 2B). *** $p < .001$ ** $p < .01$ * $p < .05$

Discussion

The results from Experiment 2A strongly support the *dynamic-organization hypothesis*. For thin-sliced sounds, which were the hardest to recognize as containing nature or urban sound-objects (Experiment 1), participants did not display an aesthetic preference for nature sounds. This elimination of aesthetic preference, moreover, was accompanied by a shift in the relationship between acoustic features and aesthetic ratings. More specifically, aesthetic ratings were negatively associated with spectral centroid, entropy, and flatness, despite the fact that our nature sounds were significantly higher on these features compared to urban sounds, and aesthetic ratings were positively associated with spectral skew, despite the fact that our nature sounds were significantly lower on skew compared to urban sounds.

This dynamic relationship between acoustic features and aesthetic ratings suggests that the conceptual identification of a sound as either natural or urban fundamentally alters the way in which a listener uses acoustic cues to arrive at an aesthetic judgment. If this is the case, then encouraging listeners to conceptually identify these thin-sliced sounds should not only change aesthetic ratings, but also change the relationship between acoustic features and aesthetics to look more like unaltered soundscapes, which by definition have high conceptual identification.

Experiment 2B

Experiment 2B was identical to the Thin-Sliced Condition of Experiment 2A with the exception that listeners classified each sound as either natural or urban prior to providing an aesthetic rating. We hypothesized that participants' aesthetic ratings would be influenced by framing these sounds into nature/urban categories, such that nature sounds would become aesthetically preferred over urban sounds, despite the fact that this was not the case for these same sounds in Experiment 2A.

Importantly, participants were never provided with feedback as to whether the sound came from a nature or urban source. Rather, this classification was simply meant to encourage listeners to interpret these difficult-to-identify sounds in a nature/urban framework. As such, we expected considerable variance in accuracy (i.e. correctly labeling a sound as nature or urban). According to the *dynamic-organization hypothesis*, we would expect that the extent to which a sound is categorized as nature or urban should directly relate to its subsequent aesthetic ratings (such that sounds heard more as coming from nature should receive higher aesthetic ratings and sounds heard more as coming from urban environments should receive lower aesthetic ratings).

Method

Participants

We recruited 49 individuals (34 male, 15 female) on MTurk to participate in the experiment, as this was our sample size for the Thin-Sliced Group from Experiment 2A. Similar to the previous experiments, participants had to have a minimum 90% positive rating from prior MTurk assignments, had to have completed a minimum of 10 previous assignments, and had to be residing in the United States to qualify. All participants consented to voluntary participation via the guidelines established by the Institutional Review Board at The University of Chicago, and all participants were compensated for their participation in the experiment.

Materials

The sounds were identical to those used in the Thin-Sliced Group in Experiment 2A. The experiment was coded in jsPsych (de Leeuw, 2015).

Procedure

The consent and volume calibration were identical to Experiments 1 and 2A. After volume calibration, participants received instructions that they would hear 80 one hundred millisecond-sounds. Importantly, participants were told that these short sounds were sampled from longer soundscapes that either came from nature or urban environments. Additionally, prior to making an aesthetic rating, participants made a forced-choice judgment without feedback as to whether they believed each thin slice came from a nature or urban environment (by pressing the “n” or “u” key). Participants rated how much they liked each sound on the same 7-point scale used in Experiment 2A. Once participants heard and rated all 80 sounds, which were presented in a random order, they were asked to provide basic demographic information.

Results

Aesthetic Ratings

Participants displayed a robust aesthetic preference for nature soundscapes compared to urban soundscapes ($t(48) = 7.44, p < .001, d = 1.06$), which is notable given that the same sounds did not exhibit a nature-related aesthetic preference in Experiment 2A. The mean rating for nature soundscapes was 4.27 ($SE: 0.10$) while the mean rating for urban soundscapes was 3.40 ($SE: 0.14$). The aesthetic ratings for nature and urban sounds are plotted in Figure 1 (far right).

Category Accuracy

Participants were significantly above chance at determining whether a thin-slice came from a nature or urban environment ($M = 70.6\%, SD = 11.0\%, t(48) = 13.09, p < .001$). This result is not surprising given the results from Experiment 1, which demonstrated that the recognition of specific sound-objects was greatly attenuated but not entirely eliminated for our thin-sliced sounds. However, it is important to note that this level of accuracy is also well below ceiling performance. As such, these results lend support to the conjecture that participants in the Thin-Sliced Group from Experiment 2A – who were not told anything about the nature or urban origin of the sounds – were likely making aesthetic judgments without explicit awareness that the sounds came from nature or urban environments.

We additionally assessed how category accuracy – split by nature and urban sounds – related to aesthetic preference ratings. Under the *dynamic-organization hypothesis*, we would predict that category accuracy should positively relate to aesthetic ratings for nature sounds (as the less ambiguous sounds should be more aesthetically preferred), whereas category accuracy should negatively relate to aesthetic ratings for urban sounds (as the less ambiguous sounds should be less aesthetically preferred). These predictions were strongly confirmed. Category accuracy was strongly and positively related to aesthetic ratings for nature sounds ($r(38) = .91, p < .001$), whereas category accuracy was strongly and negatively

related to aesthetic ratings for urban sounds ($r(38) = -.67, p < .001$). This relationship is plotted in Figure 3A.

This strong relationship between category accuracy and aesthetic ratings, however, may have been driven by response bias – that is, participants who just labeled a sound as coming from nature may provide a high aesthetic rating simply because of this categorization outcome, not necessarily because the nature/urban framework provided participants with an insight into the identity of the sound (e.g., bird song) which then made the nature stimuli actually *sound* more aesthetically pleasing. This is a subtle but important distinction. In order to test whether this relationship could be explained by response bias, we examined the relationship between aesthetic ratings in the present experiment and aesthetic ratings from the unaltered soundscapes from Experiment 2A, which by definition had high levels of recognition. If the rank-ordering of these two sound sets in terms of aesthetic ratings is similar, this would suggest that participants were not simply responding with an arbitrarily higher or lower aesthetic rating after labeling a sound as nature or urban, respectively; rather, such a relationship would suggest that the provided nature/urban framework allowed participants to better understand the identity of the sounds, which was then used to make an aesthetic judgment.

We used a Spearman's Rank-Order Correlation to assess the relationship between aesthetic ratings from Experiment 2A and the present experiment. The correlation was positive and significant ($\rho(38) = .77, p < .001$), suggesting that the nature/urban framing of the present experiment resulted in aesthetic ratings that were rank-ordered in a highly similar manner as the easy-to-identify, unaltered soundscapes. In contrast, the aesthetic ratings for the thin-sliced sounds from Experiment 2A (which received no nature/urban framing) were not significantly related to the unaltered soundscape ratings ($\rho(38) = .14, p = .213$). As such, these results suggest that introducing the nature/urban framework in the present experiment allowed participants to accurately interpret the sound-objects in the thin slices, which then largely determined participants' aesthetic ratings. This in turn suggests that the aesthetic preference for nature sounds in the present experiment was likely driven by recognizing and associating particular

sounds with nature and urban objects, not simply rating a sound higher aesthetically because of the categorization process.

Figure 3: Relationship between category identification accuracy and aesthetic ratings in the present experiment, split by nature (N) and urban (U) sounds (Panel A). Panel B (left) demonstrates that the aesthetic ratings from the present experiment are highly related to the aesthetic ratings from the unaltered soundscapes from Experiment 2A. This relationship does not hold when using the thin-sliced sounds from Experiment 2A (Panel B, right).

Correlations of Acoustic Features with Aesthetic Ratings

The framing our thin-sliced soundscapes in terms of nature or urban category membership significantly influenced the relationship between our acoustic features and aesthetic ratings. Most notably, the relationship between spectral entropy and aesthetic ratings – which was strongly negative in Experiment 2A ($r = -.71, p < .001$) – was attenuated in the present experiment such that the relationship was no longer significant ($r = -.14, p = .21$). Moreover, this change in correlation strength between experiments was significant ($z = -4.76, p < .001$).

1 We additionally found evidence that aesthetic ratings were positively related to both median
2 spectral centroid ($r = .34, p = .002$) and dominant frequency ($r = .57, p < .001$), which is notable for two
3 reasons. First, these positive relationships were not significantly present for thin-sliced sounds in
4 Experiment 2A (centroid: $r = -.30$; dominant frequency: $r = .13$), and the correlations in the present
5 experiment marked a significant increase from these values (centroid: $z = 4.21, p < .001$; dominant
6 frequency: $z = 3.21, p = .001$). Second, these acoustic features – which differentiated our nature and urban
7 soundscapes – were significantly and positively related to aesthetic ratings for our unaltered soundscapes
8 in Experiment 2A, which by definition had high conceptual identification.

9
10

Discussion

Experiment 2B further supports the *dynamic-organization hypothesis* by demonstrating that relatively small changes to task instructions and experimental design, meant to encourage the framing of soundscapes as either natural or urban, led to an aesthetic preference for thin-sliced nature sounds as well as shifted the relationship between aesthetic ratings and acoustic features. These findings also did not appear to be driven by a response bias (e.g., participants giving a sound a high aesthetic rating solely because they had just provided a “nature” label), as rank-ordering the sounds of the present experiment on their aesthetic rating strongly mapped onto the aesthetic ratings of the unaltered soundscapes from Experiment 2A. As such, the most parsimonious explanation of the results is that categorizing the thin-sliced sounds into nature or urban categories provided listeners with a framework to for interpretation. This framework allowed listeners to better understand the source of each sound, which resulted in (1) higher aesthetic ratings for nature sounds, (2) shifted relationships between aesthetic ratings and acoustic features, and (3) similar rank-orderings of sounds on aesthetic ratings compared to easy-to-identify (i.e., unaltered) soundscapes.

One concern with the results thus far is that the support for the *dynamic-organization hypothesis* rests on a stimulus set that, despite the manipulations of scrambling and thin-slicing, have objective ties to nature or urban environments. As such, a stronger test of the *dynamic-organization* and *inherent-organization hypotheses* is to use a novel sound set with no objective ties to nature. If aesthetic ratings of these sounds correlate with acoustic features in a manner similar to the unaltered soundscapes from Experiment 2A, this would support the *inherent-organization hypothesis*. If, however, aesthetic ratings of these sounds correlate with acoustic features in a manner similar to the thin-sliced soundscapes from Experiment 2A, this would support the *dynamic-organization hypothesis*.

Experiment 3A

In Experiment 3A, listeners aesthetically rated a set of computer-generated aperiodic noises. These noises were not generated by sound-objects typically associated with nature or urban environments, and as such, allow for a more construct-valid test of the *dynamic-organization* and *inherent-organization hypotheses*. More specifically, if the acoustic features that differentiate our nature and urban sounds (e.g., higher spectral centroid, higher spectral entropy) positively relate to aesthetic ratings, in a similar manner to the unaltered soundscapes from Experiment 2A, this would suggest that these features may relate to aesthetic preference independently of a nature/urban framework. Such a pattern of results would be consistent with the *inherent-organization hypothesis*. If, however, the acoustic features that differentiate our nature and urban sounds negatively relate to aesthetic ratings, in a similar manner to the thin-sliced soundscapes from Experiment 2A, this would suggest that nature sounds may be aesthetically preferred *in spite of* their acoustic features, which, outside of a nature/urban framework, are judged to be less aesthetically pleasing. Such a pattern of results would be consistent with the *dynamic-organization hypothesis*.

Method

Participants

We recruited 50 participants from MTurk for the experiment, and 48 individuals (24 male, 23 female, 1 no response) completed the task. The recruitment and treatment of participants was identical to Experiments 1-2, in that participants had to have a minimum 90% positive rating from prior MTurk assignments, had to have completed a minimum of 10 previous assignments, and had to be residing in the United States to qualify. All participants consented to voluntary participation via the guidelines established by the Institutional Review Board at The University of Chicago, and all participants were compensated for their participation in the experiment.

Materials

We generated 75 variants of white, pink, and brown noise. Each noise was one second in duration. We chose brown, pink, and white noises, as opposed to another class of sounds (e.g., complex tones) for two reasons. First, these noises by definition include variability on the acoustic dimensions of interest (see Figure 4 for a comparison of noise and soundscape stimuli). Second, aperiodic noises are found in both nature and urban settings (e.g., wind rustling through trees, television static). Of the 75 noise stimuli, 54 were generated in Adobe Audition (Adobe Systems: San Jose, CA) using the “generate noise” function (18 brown, 18 pink, and 18 white). We applied six kinds of permutations to these noise stimuli (unaltered, high-pass filter of frequencies greater than 500 Hz, low-pass filter of frequencies less than 500 Hz, band-pass filter of frequencies between 500 and 5000 Hz, band-stop filter of frequencies between 500 and 5000 Hz, and a comb filter with peaks at octaves of 50 Hz up to 9500 Hz). This resulted in six versions of each of the noise types. We then frequency modulated these sounds by 0 Hz, 0.5 Hz, or 0.2 Hz, resulting in 54 total sounds (three noise types * six filters * three modulations). These permutations were chosen to

1 generate acoustic diversity among the classes of noise; they were not hypothesized to make the noises
2 sound particularly natural or urban.

3 The remaining 21 noises were generated using Java source code that created a continuum of pink
4 noise. Given that canonical pink noise can be described as containing a power spectrum density (PSD) of
5 $1/f$, multiplying f by an exponent allows for different variations of pink noise (i.e., different PSDs).
6 Specifically, we generated 9 intermediary noises between pink and white noise, 9 intermediary noises
7 between pink and brown noise, as well as the three canonical versions of each noise (white, pink, and
8 brown). These 21 noise stimuli were not altered in any way (i.e., using any of the filters or modulations
9 that were applied to the Adobe Audition noises). All stimuli were RMS normalized. Additionally, all
10 noise stimuli were presented in stereo at a 44.1 kHz sampling rate and 16-bit depth. The experiment was
11 coded in jsPsych (de Leeuw, 2015).

12

13

1 *Acoustic Analyses*

2 We analyzed each of the 75 sounds using the same procedures as described in Experiment 1. Thus, each
3 sound had the following five attributes: spectral centroid, dominant frequency, spectral entropy, spectral
4 flatness, and spectral skew.

5

6 *Procedure*

7 The procedure was identical to Experiment 2A, with the exception that participants were told that they
8 would be hearing 75 one-second sounds.

9

10

Figure 4: Mean, standard error, and individual stimuli plotted across all sound conditions (Unaltered, Scrambled, and Thin-Sliced of Experiments 1-2, and Generated from Experiment 3) for (A) spectral centroid, (B) spectral entropy, (C) dominant frequency, (D) spectral skew, and (E) spectral flatness.

Results

Correlations of Acoustic Features with Aesthetic Ratings

As displayed in Figure 5A, there was a negative relationship between aesthetic ratings and (1) spectral entropy ($r = -.84, p < .001$), (2) spectral centroid ($r = -.67, p < .001$), spectral flatness ($r = -.66, p < .001$), and dominant frequency ($r = -.30, p = .009$). There was a positive relationship between aesthetic ratings and spectral skew ($r = .65, p < .001$). For comparison, the direction of these correlations was identical to the thin-sliced soundscapes without a conceptual label from Experiment 2A (Figure 2C), with the exception of dominant frequency which was negative in the present experiment and weakly positive in Experiment 2A.

Figure 5: Matrices displaying the correlation between aesthetic ratings and acoustic features from the tested generated noises. In Experiment 3A (A), participants were given no conceptual framework for understanding the noises. In Experiment 3B, in which participants labeled each noise as natural or urban prior to providing an aesthetic rating, correlations are split based on whether the noise was labeled as urban (B) or natural (C). *** $p < .001$ ** $p < .01$ * $p < .05$

Discussion

Are novel sounds, not specifically modeled after nature or urban sound environments, aesthetically judged based on similar acoustic features as actual sounds from nature and urban environments? The results from the present experiment suggest that the acoustic features found to differentiate actual nature and urban sounds were *inversely* related to aesthetic ratings for generated noises. Put another way, this means that the generated noises that were more acoustically similar to our nature sounds from Experiments 1-2 were given lower aesthetic ratings. This pattern of results is similar to what was observed for thin-sliced sounds in Experiment 2A, which were also the hardest sounds to recognize.

As such, the present experiment provides additional evidence that the acoustic features that may be indicative of nature identification need an appropriate framework for interpretation. Without a nature/urban framework, we paradoxically observe that the acoustic features that differentiate nature from urban sounds are less aesthetically preferred. Of course, in the present experiment such a framework would not clearly map onto the tested sounds (as no sound is truly from a nature or urban environment). Nevertheless, introducing such a nature/urban framework may encourage participants to weight acoustic features dynamically in service of making an aesthetic judgment. Specifically, sounds labeled as coming from nature should be aesthetically preferred compared to sounds labeled as urban. Moreover, sounds labeled as nature should display a fundamentally different relationship between acoustic features and aesthetic ratings compared to sounds labeled as urban.

Experiment 3B

The fact that the computer-generated noises from Experiment 3A acoustically overlapped with our nature and urban soundscapes suggests that listeners may aesthetically judge these noises in similar fashion to natural or urban sounds when encouraged to do so. Thus, Experiment 3B was identical to Experiment 3A with the exception that listeners classified the sounds into nature or urban categories prior to making an aesthetic judgment.

Despite the fact that this kind of classification cannot be analyzed in terms of “correct” and “incorrect” responses (as no sound is objectively from a nature or urban environment), it still can provide an important framework for interpreting our prior results. Specifically, if the nature/urban framework of the present experiment changes the relationship between acoustic features and aesthetic ratings, such that sounds classified as nature have a distinct relationship between aesthetic ratings and acoustic features compared to sounds classified as urban, this would suggest that this framework may change the way in which specific acoustic properties are factored into an aesthetic response, which would support the *dynamic-organization hypothesis*.

Method

Participants

We recruited 48 individuals (23 male, 24 female, 1 no response) on MTurk to participate in the experiment, as this was our sample size for Experiment 3A. Participant recruitment and treatment was identical to the previous experiments, in that participants had to have a minimum 90% positive rating from prior MTurk assignments, had to have completed a minimum of 10 previous assignments, and had to be residing in the United States to qualify. All participants consented to voluntary participation via the guidelines established by the Institutional Review Board at The University of Chicago, and all participants were compensated for their participation in the experiment.

Materials

The sounds were identical to those used in Experiment 3A. The experiment was coded in jsPsych (de Leeuw, 2015).

Procedure

The consent and volume calibration were identical to the previous experiments. After volume calibration, participants received instructions that they would hear 75 one-second sounds. Similar to Experiment 2A, participants were told that these sounds were sampled from longer soundscapes that either came from nature or urban environments. Additionally, prior to making an aesthetic rating, participants made a forced-choice judgment without feedback as to whether they believed each sound came from a nature or urban environment (by pressing the “n” or “u” key). Participants rated how much they liked each sound on the same 7-point scale as used previously. Once participants heard and rated all 75 sounds, which were presented in a random order, they were asked to provide basic demographic information.

Results

Categorization of Noises as Natural or Urban

Given that the computer-generated noises did not have objective origins in natural or urban sound-objects, we first assessed the general distribution of category responses across our sounds. In particular, we measured the overall frequency of responding with a “nature” versus “urban” category label, as well as the distribution of these category judgments across our stimuli.

Overall, participants were approximately equally likely to classify sounds into nature (47.6%) and urban (52.4%) categories. These category judgments, moreover, appeared to be normally distributed across our stimuli (Shapiro-Wilk: $W = 0.987$, $p = .623$), with the 25th percentile corresponding to labeling a sound as natural 37.5% of the time and the 75th percentile corresponding to labeling a sound as natural 58.3% of the time. These results highlight the variability in classification judgments (i.e., relatively few sounds were consistently classified as nature or urban), which is perhaps not surprising considering that our stimuli did not actually originate from nature or urban environments.

Aesthetic Ratings

The approach to analyzing aesthetic ratings was informed by the ambiguity of the sound set. Specifically, given that the tested sounds were not consistently heard as natural or urban, we assessed how aesthetic ratings *for identical sounds* changed as a function of classification. For each sound, we calculated separate mean aesthetic ratings for when it was heard as natural (as opposed to urban). Noises that were classified as natural received an average aesthetic rating of 4.47 (SD: 0.39), whereas the same noises – classified as urban – received an average aesthetic rating of 3.19 (SD: 0.59), which represented a highly significant difference ($t(74) = 17.27$, $p < .001$). In fact, as represented in Figure 6, virtually all of the noises (74 of 75) were rated aesthetically higher when classified as natural versus urban.

Figure 6: Noises that were classified as coming from nature (green, left) were almost exclusively given higher aesthetic ratings compared to when the same noise was classified as urban (grey, left). The dashed lines link each individual noise sample.

Relationship to Acoustic Features

In assessing how aesthetic ratings related to our measured acoustic features, we used the same nature-averaged and urban-averaged aesthetic response for each sound as described in the previous section. This approach allows for a causal test of the hypothesis that classifying a sound as nature will attenuate the strong negative relationship between spectral entropy, spectral centroid, and spectral flatness, which was found in Experiment 2.

1 When the noises were classified as urban (Figure 5B), the relationship between aesthetic ratings
2 and acoustic features was virtually identical to what was observed in Experiment 3A (i.e., when no
3 nature/urban framework was provided). Specifically, we found negative relationships between aesthetic
4 ratings and spectral entropy ($r = -.72, p < .001$), spectral centroid ($r = -.56, p < .001$), spectral flatness ($r =$
5 $-.60, p < .001$), and dominant frequency ($r = -.26, p = .024$). Spectral skew was positively related to
6 aesthetic ratings ($r = .59, p < .001$).

7 When the noises were classified as nature (Figure 5C), these negative relationships were
8 attenuated. While we still observed a significant negative relationship between aesthetic ratings and
9 spectral entropy ($r = -.37, p = .001$), this relationship was significantly attenuated compared to when the
10 noises were labeled as urban ($z = 3.12, p = .002$). We did not find a significant relationship between
11 aesthetic ratings and spectral centroid ($r = -.11, p = .347$), spectral flatness ($r = .03, p = .798$), or dominant
12 frequency ($r = -.02, p = .865$). This attenuated relationship, moreover, was significant for spectral centroid
13 ($z = 3.13, p = .002$) and spectral flatness ($z = 4.34, p < .001$) but not for dominant frequency ($z = 1.48, p =$
14 $.139$). Spectral skew remained significantly positively related to aesthetic ratings ($r = .41, p < .001$), and
15 the correlation strength was not significantly different from what was observed when the noises were
16 heard as urban ($z = 1.45, p = .147$).

17

General Discussion

The present results strongly suggest that nature sounds have high aesthetic ratings only when they can be recognized and associated with nature - not because the acoustic features that differentiate nature and urban sounds are inherently preferred. In fact, when difficult-to-identify or completely ambiguous sounds were not given a nature/urban framework for interpretation (Experiments 2A and 3A), the relationship between identified acoustic features and aesthetic preference was the opposite of what one would expect under the *inherent-organization hypothesis* – that is, the acoustic features that were higher among nature sounds were negatively related to aesthetic ratings (and vice versa). This observation supports the *dynamic-organization hypothesis* and also draws a notable parallel to a conceptually related study using nature images (Kotabe, Kardan, & Berman, 2017).

Importantly for the *dynamic-organization hypothesis*, relatively simple changes to the experiment, in which participants had to classify these difficult-to-identify and ambiguous sounds as nature or urban prior to aesthetically rating the sounds, was sufficient to shift the way in which aesthetic responses related to acoustic features of the sounds. These findings are conceptually similar to a recent study (Haga, Halin, Holmgren, & Sörqvist, 2016) demonstrating that an ambiguous noise was rated higher on restorative potential if participants were told it came from a waterfall (as opposed to urban machinery or no label). While Haga and colleagues demonstrate that an identical sound can be heard as either natural or urban, which then has implications for how the sound is evaluated, the present set of experiments expand upon these findings in three critical ways.

First, by using a sound set that had objective ties to natural and urban environments (Experiments 1-2), the present experiments provide compelling evidence that acoustically *unambiguous* nature sounds (i.e., clearly differentiated from urban soundscapes on several acoustic features) that are difficult to recognize as coming from nature are not aesthetically preferred over urban sounds. This observation strengthens the argument that the preference for nature sounds is not driven by the acoustic features that

1 differentiate nature and urban sounds on broad spectral properties (e.g., spectral entropy). Second,
2 through testing more than one auditory stimulus, we were able to assess how category knowledge shifted
3 the relative weighting between acoustic features and aesthetic preferences. These findings are perhaps
4 most critical as we found, somewhat paradoxically, that the sounds that were more “nature-like” were *less*
5 aesthetically preferred when the sound could not be appropriately framed as either natural or urban. Third,
6 the way in which category-level information was introduced subtly but importantly differed. Rather than
7 provide listeners with a particular framing (e.g., “this is the sound of rainfall”), category judgments in the
8 present experiments were participant-driven. This design choice provides the benefit of assessing the
9 distributional properties of participants’ nature and urban categorizations. In the case of Experiment 3B,
10 in which there was no correct nature or urban label, responses were normally distributed around 50%,
11 suggesting these classes of noises are equally likely to be heard by a listener as natural or urban.

12 The dynamic interplay between perceptual and conceptual information in forming aesthetic
13 preferences, observed in the present experiments, is paralleled in other aesthetic domains such as music
14 and visual art. While there are particular, sensory-based foundations for aesthetic reactions to musical
15 events (e.g., Terhardt, 1974) as well as conceptual foundations, the interplay between perceptual and
16 conceptual factors can lead to “paradoxical” situations, in which, for example, the aesthetic appraisal of
17 music does not match the sensory pleasurableness (Brattico, 2015). Moreover, sounds that are
18 consistently judged as unpleasant, presumably due to acoustic features (e.g., fingernails on a chalkboard),
19 are judged as less unpleasant when given an alternative conceptual framing, such as being a part of
20 contemporary music (Reuter & Oehler, 2011). In visual art, understanding the context in which a
21 particular work was produced can change its aesthetic value. In *Ways of Seeing*, John Berger presents
22 readers with a painting of a cornfield with birds flying out of it, asking readers to take a moment to
23 observe. Then, when readers turn the page, the painting is reprinted with a new framework – the last
24 painting Vincent Van Gogh painted before he killed himself. Berger writes, “It is hard to define exactly
25 how the words have changed the image but undoubtedly they have. The image now illustrates the

1 sentence” (p.28). This example demonstrates that context changes aesthetic reactions at multiple levels –
2 that is, the new framework does not necessarily change the recognition of the objects in the painting, yet it
3 presumably changes the interpretation of the meaning of those objects and consequently the aesthetic
4 response.

5 The present results can also be interpreted in a framework of preference formation more
6 generally. Specifically, the present results suggest that identical stimuli – at least from a sensory or “low-
7 level” point of view – are valued in fundamentally different ways based on the frameworks in which they
8 are interpreted. This pattern of results can be integrated into a broader body of literature on how frames
9 influence preferences and decision-making. In economics, “reference levels” have been shown to
10 significantly influence decision making (Tversky & Kahneman, 1991), in that changes of reference level
11 can fundamentally change (and even reverse) preference. For example, the valuing of a choice is defined
12 by the framework of gains and losses relative to a specific reference level, with losses demonstrating a
13 steeper function than gains (i.e., *loss aversion*).

14 Aesthetic reactions to nature have been discussed in science, philosophy, and urban planning for
15 well over a century (e.g., Muir, 1894; Olmsted, 1952). Understanding how nature can elicit aesthetic
16 reactions from individuals, moreover, makes up an important part of the contemporary study of empirical
17 aesthetics (e.g., Leder & Nadal, 2014). Taken together, the present results highlight that listeners’
18 aesthetic responses to nature sounds cannot be effectively modeled by the acoustic properties of nature
19 sounds alone. Rather, it is essential to incorporate the relevant framework (i.e., that the sounds originate
20 from nature), as this framework dynamically reorganizes the relationship between aesthetic ratings and
21 acoustic properties, as well as drives the aesthetic preference for nature sounds. In this sense, the present
22 results can be incorporated into existing frameworks of the psychology of aesthetics. In particular,
23 Bergeron and Lopes (2012) argue that aesthetic experiences require the evaluation of an object, possess
24 an affective dimension (i.e., it is subjectively felt), and *contain a semantic dimension* (i.e., are not
25 captured by mere sensation). This final point is particularly important for understanding the present

1 results, as it suggests that aesthetic reactions, as a construct, may not exist independently of a semantic
2 framework for interpretation.

3 Overall, the present results demonstrate that aesthetic responses to nature sounds are integrally
4 tied to the recognition and association of sounds with nature environments. Manipulating this recognition
5 process – either through acoustic permutations that impaired sound-object recognition (Experiments 1-2)
6 or through generating novel sounds that did not originate from nature (Experiment 3) – results in a
7 fundamentally different relationship between aesthetic ratings and acoustic features, supporting our
8 *dynamic-organization hypothesis*. These findings can be integrated in a broader framework of preference
9 formation, as well as within recent theoretical accounts of empirical science, which state that aesthetics
10 are not mere sensations and require a semantic understanding. The dynamic interplay between acoustic
11 features and aesthetic judgments in the present paper may help provide a framework for understanding
12 how nature sounds may provide a range of affective benefits through its aesthetic valuing.

1 Acknowledgments

2 This work was supported by a grant from the TKF Foundation to Marc G. Berman, two grants from the
3 John Templeton Foundation (the University of Chicago Center for Practical Wisdom) to Howard
4 Nusbaum (PI) and Marc G. Berman (co-PI) and the Virtue, Happiness, and Meaning of Life Scholars
5 Group, and a grant from the National Science Foundation (BCS-1632445) to Marc G. Berman, as well as
6 an internal grant from the University of Chicago to Marc G. Berman.

7

8 Data Availability

9 The data from all of the experiments, in addition to the experimental materials, are available on the Open
10 Science Framework (<https://osf.io/4wb27/>).

11

12 Author Contributions

13 SCVH and MGB designed the experiments. AH coded the experiments as well as assisted in data
14 processing. SCVH analyzed the data and prepared a first draft, after which all authors provided comments
15 until the manuscript reached its final form.

References

- Alvarsson, J. J., Wiens, S., & Nilsson, M. E. (2010). Stress recovery during exposure to nature sound and environmental noise. *International Journal of Environmental Research and Public Health*, 7(3), 1036–1046. <https://doi.org/10.3390/ijerph7031036>
- Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *The Lancet*, 383(9925), 1325–1332. [https://doi.org/10.1016/S0140-6736\(13\)61613-X](https://doi.org/10.1016/S0140-6736(13)61613-X)
- Bauer, B. a, Cutshall, S. a, Anderson, P. G., Prinsen, S. K., Wentworth, L. J., Olney, T. J., ... Kelly, R. F. (2011). Effect of the combination of music and nature sounds on pain and anxiety in cardiac surgical patients: a randomized study. *Alternative Therapies in Health and Medicine*, 17(4), 16–23. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/22314630>
- Bergeron, V., & Lopes, D. M. (2012). Aesthetic theory and aesthetic science: Prospects for integration. In A. Shimamura & P. S.E. (Eds.), *Aesthetic Science: Connecting Minds, Brains, and Experience* (pp. 63– 79). New York, NY: Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780199732142.003.0024>
- Berman, M. G., Hout, M. C., Kardan, O., Hunter, M. R., Yourganov, G., Henderson, J. M., ... Jonides, J. (2014). The perception of naturalness correlates with low-level visual Features of environmental scenes. *PLoS ONE*, 9(12). <https://doi.org/10.1371/journal.pone.0114572>
- Berman, M. G., Jonides, J., & Kaplan, S. (2008). The Cognitive Benefits of Interacting With Nature. *Psychological Science*, 19(12), 1207–1212. <https://doi.org/10.1111/j.1467-9280.2008.02225.x>
- Berman, M. G., Kross, E., Krpan, K. M., Askren, M. K., Burson, A., Deldin, P. J., ... Jonides, J. (2012).

- 1 Interacting with nature improves cognition and affect for individuals with depression. *Journal of*
2 *Affective Disorders*, 140(3), 300–305. <https://doi.org/10.1016/j.jad.2012.03.012>. Interacting
- 3 Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of*
4 *Environmental Psychology*, 25(3), 249–259. <https://doi.org/10.1016/j.jenvp.2005.07.001>
- 5 Brattico, E. (2015). From pleasure to liking and back: Bottom-up and top-down enjoyment of music. In
6 *Art, Aesthetics, and the Brain*. Oxford University Press.
- 7 Cohen, S., & Weinstein, N. (1981). Nonauditory Effects of Noise on Behavior and Health. *Journal of*
8 *Social Issues*, 37(1), 36–70. <https://doi.org/10.1111/j.1540-4560.1981.tb01057.x>
- 9 Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., ...
10 Sunyer, J. (2015). Green spaces and cognitive development in primary schoolchildren. *Proceedings*
11 *of the National Academy of Sciences of the United States of America*, 112(26), 7937–7942.
12 <https://doi.org/10.1073/pnas.1503402112>
- 13 de Leeuw, J. R. (2015). jsPsych: A JavaScript library for creating behavioral experiments in a Web
14 browser. *Behavior Research Methods*, 47, 1–12. <https://doi.org/10.3758/s13428-014-0458-y>
- 15 DeLoach, A. G., Carter, J. P., & Braasch, J. (2015). Tuning the cognitive environment: Sound masking
16 with “natural” sounds in open-plan offices. *The Journal of the Acoustical Society of America*, 137,
17 2291. <https://doi.org/https://doi.org/10.1121/1.4920363>
- 18 Gould van Praag, C. D., Garfinkel, S. N., Sparasci, O., Mees, A., Philippides, A. O., Ware, M., ...
19 Critchley, H. D. (2017). Mind-wandering and alterations to default mode network connectivity when
20 listening to naturalistic versus artificial sounds. *Scientific Reports*, 7(February), 45273.
21 <https://doi.org/10.1038/srep45273>
- 22 Haga, A., Halin, N., Holmgren, M., & Sörqvist, P. (2016). Psychological restoration can depend on

- 1 stimulus-source attribution: A challenge for the evolutionary account? *Frontiers in Psychology*,
2 7(NOV), 1–8. <https://doi.org/10.3389/fpsyg.2016.01831>
- 3 Han, K. (2010). An Exploration of Relationships Among the Responses to Natural Scenes. *Environment*
4 *and Behavior*, 42(2), 243–270. <https://doi.org/10.1177/0013916509333875>
- 5 Hartig, T., & Staats, H. (2006). The need for psychological restoration as a determinant of environmental
6 preferences. *Journal of Environmental Psychology*, 26(3), 215–226.
7 <https://doi.org/10.1016/j.jenvp.2006.07.007>
- 8 Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L. J., Paus, T., & Berman, M. G. (2015).
9 Neighborhood greenspace and health in a large urban center. *Scientific Reports*, 5, 11610.
10 <https://doi.org/10.1038/srep11610>
- 11 Kline, G. A. (2009). Does a view of nature promote relief from acute pain? *Journal of Holistic Nursing*,
12 27(3), 159–66. <https://doi.org/10.1177/0898010109336138>
- 13 Kotabe, H. P., Kardan, O., & Berman, M. G. (2017). The nature-disorder paradox: A perceptual study on
14 how nature is disorderly yet aesthetically preferred. *Journal of Experimental Psychology: General*,
15 146(8), 1126–1142. <https://doi.org/10.1037/xge0000321>
- 16 Krumhansl, C. L. (2010). Plink: “Thin slices” of music. *Music Perception: An Interdisciplinary Journal*,
17 27(5), 337–354. <https://doi.org/10.1525/MP.2010.27.5.337>
- 18 Leder, H., & Nadal, M. (2014). Ten years of a model of aesthetic appreciation and aesthetic judgments:
19 The aesthetic episode - Developments and challenges in empirical aesthetics. *British Journal of*
20 *Psychology*, 105(4), 443–446. <https://doi.org/10.1111/bjop.12084>
- 21 Mace, B. L., Bell, P. A., & Loomis, R. J. (2004). Visibility and natural quiet in national parks and
22 wilderness areas: Psychological considerations. *Environment and Behavior*, 36(1), 5–31.

- 1 <https://doi.org/10.1177/0013916503254747>
- 2 Marselle, M. R., Irvine, K. N., & Warber, S. L. (2014). Examining group walks in nature and multiple
3 aspects of well-being: A large-scale study. *Ecopsychology*, 6(3), 134–147.
4 <https://doi.org/10.1089/eco.2014.0027>
- 5 McDermott, J. H., & Simoncelli, E. P. (2011). Sound texture perception via statistics of the auditory
6 periphery: Evidence from sound synthesis. *Neuron*, 71(5), 926–940.
7 <https://doi.org/10.1016/j.neuron.2011.06.032>
- 8 Muir, J. (1894). A View of the High Sierra. In *The Mountains of California*. New York: The Century
9 Company.
- 10 Olmsted, F. L. (1952). Yosemite and the Mariposa Grove: A Preliminary Report, 1865. *Landscape*
11 *Architecture*, 43(1).
- 12 Purcell, T., Peron, E., & Berto, R. (2001). Why Do Preferences Differ Between Scene Types?
13 *Environment and Behavior*, 33(1), 93–106. <https://doi.org/10.1177/00139160121972882>
- 14 Raanaas, R. K., Evensen, K. H., Rich, D., Sjostrom, G., & Patil, G. (2011). Benefits of indoor plants on
15 attention capacity in an office setting. *Journal of Environmental Psychology*, 31(1), 99–105.
16 <https://doi.org/10.1016/j.jenvp.2010.11.005>
- 17 Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2013). Bird sounds and their contributions to perceived
18 attention restoration and stress recovery. *Journal of Environmental Psychology*, 36, 221–228.
19 <https://doi.org/10.1016/j.jenvp.2013.08.004>
- 20 Sueur, J., Aubin, T., & Simonis, C. (2008). Sound analysis and synthesis with the package Seewave.
21 *Bioacoustics*, 18, 213–226.
- 22 Tennessen, C. M., & Cimprich, B. (1995). Views To Nature: Effects on Attention. *Journal of*

- 1 *Environmental Psychology*, 15, 77–85.
- 2 Terhardt, E. (1974). Pitch, consonance, and harmony. *Journal of the Acoustical Society of America*, 55(5),
3 1061–1069.
- 4 Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model.
5 *The Quarterly Journal of Economics*, 106(4), 1039–1061.
- 6 van den Berg, A. E., Koole, S. L., & van der Wulp, N. Y. (2003). Environmental preference and
7 restoration: (How) are they related? *Journal of Environmental Psychology*, 23(2), 135–146.
8 [https://doi.org/10.1016/S0272-4944\(02\)00111-1](https://doi.org/10.1016/S0272-4944(02)00111-1)
- 9 Van Hedger, S. C., Nusbaum, H. C., Clohisy, L., Jaeggi, S. M., Buschkuhl, M., & Berman, M. G.
10 (2018). Of cricket chirps and car horns: The effects of nature sounds on cognitive performance.
11 *PsyArXiv*. <https://doi.org/10.31234/osf.io/f5hcz>
- 12 Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*,
13 35(2), 151–175.
- 14