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Clustering analysis of human perceptual responses to birdsongs

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ABSTRACT

Augmenting birdsongs is a commonly used approach in soundscape design to enhance overall sound quality. However, the selection of birdsongs often tends to be arbitrary and lacks objective criteria, despite the varying acoustic characteristics that result in different perceptual experiences. To address this issue, cluster analysis of birdsongs was conducted based on their perceptual attributes. In total, 100 birdsongs from different bird species were used as stimuli. The birdsongs were evaluated using a semantic differential perceptual attribute scale. Principal component analysis (PCA) was performed to identify the key perceptual dimensions of the birdsongs, followed by hierarchical cluster analysis (HCA) to group the birdsongs accordingly. The results from the HCA identified four distinct clusters of birdsongs, while the PCA indicated that variations in sharpness and loudness over time were critical factors in differentiating between these clusters. The findings of this study could assist in selecting pleasant and appropriate birdsongs for soundscape design in various contexts.

Keywords: *soundscape, birdsongs, perception, psychoacoustics*

1. INTRODUCTION

Birdsongs have been found to alleviate stress and anxiety while also enhancing perceived environmental restorativeness [1–3]. Additionally, studies have shown that incorporating birdsongs into urban noise environments can significantly lower the perceived intensity of noise and enhance the overall soundscape quality, highlighting their potential value in soundscape design [4–6].

Although the perceptual and psychoacoustic features of water sounds have been widely explored [7–9], research focusing on birdsongs remains relatively scarce [10]. To effectively utilize birdsongs in soundscape planning, a more detailed understanding of their psychoacoustic properties and how they are perceived is crucial.

This study aims to explore both the perceptual and psychoacoustic aspects of birdsongs for use in soundscape design. Specifically, a listening test under a laboratory condition was conducted to identify the main perceptual components of birdsongs and categorize the birdsongs based on the identified components.

2. METHOD

2.1 Acoustic stimuli

In total, 100 birdsongs from various bird species were used as acoustic stimuli, with each recording lasting 10 seconds and being in monaural format. These recordings were obtained from the Macaulay Library at the Cornell Lab of Ornithology.

To ensure consistency, the A-weighted 10-second equivalent sound pressure level of the stimuli was calibrated to 65 dB. This calibration was performed using a head and torso simulator (45BB, GRAS Sound and Vibration A/S, Denmark).

2.2 Semantic differential scales

In this study, semantic differential (SD) scales with 13 pairs of bipolar adjectives were used to assess multidimensional perceptions of birdsongs as shown in Table 1. Participants

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were asked to assess the birdsongs on 7-point bipolar scale (-3 to +3).

Table 1. 13 pairs of bipolar adjective attributes

No	SD attributes	
1	Dull	Sharp
2	Low-pitched	High-pitched
3	Unmelodious	Melodious
4	Dislike	Like
5	Harsh	Gentle
6	Unpleasant	Pleasant
7	Quiet	Loud
8	Un-energetic	Energetic
9	Boring	Lively
10	Chaotic	Calm
11	Rough	Smooth
12	Uneventful	Eventful
13	Continuous	Intermittent

2.3 Procedure

In this study, 80 participants (46 males and 34 females) took part in the experiment. The ages of the participants ranged from 19 to 60 years, with a mean age of 27.9 years and a standard deviation of 10.9 years. The study protocol was approved by the Institutional Review Board (IRB) of Nanyang Technological University in Singapore (IRB-2017-07-025). The listening test was conducted in a soundproof room with an A-weighted background noise level of approximately 28 dB. Acoustic stimuli were randomly presented to the participants through headphones (Custom One Pro, Beyerdynamic, Germany).

3. RESULTS

3.1 Principal perceptual components of birdsongs

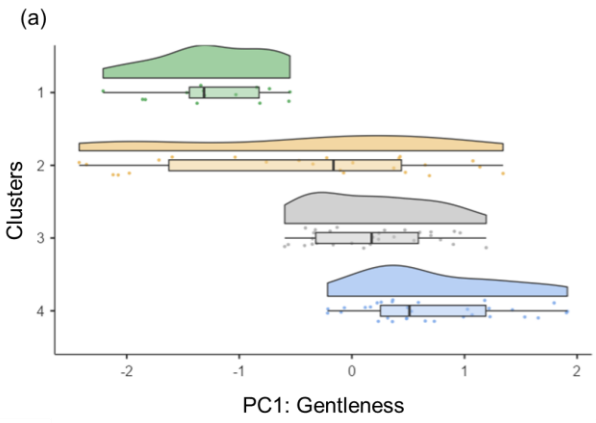
To represent the perceptual qualities of each of the 100 birdsongs, the arithmetic mean was calculated for all 13 semantic differential attributes. These mean values were then used in a principal component analysis (PCA) to identify the key dimensions underlying birdsong perception. The analysis revealed four principal components with eigenvalues greater than 1. The first three components together accounted for 83.2% of the total variance, with PC1, PC2, and PC3 explaining 43.2%, 22.1%, and 17.9% of the variance, respectively.

PC1 was characterized by strong positive loadings on descriptors such as "Gentle," "Pleasant," "Like," "Melodious," and "Calm," and a negative loading on "Loud," suggesting it reflects the soothing and favorable aspects of birdsongs—hence, it was labeled *Gentleness*. PC2 was most strongly associated with "Sharp" and "High-pitched," leading to its interpretation as *High-pitch*. PC3 loaded heavily on "Eventful," "Lively," "Continuous," and "Rough," indicating it could be interpreted as *Liveliness*.

3.2 Hierarchical cluster analysis of birdsongs

Hierarchical cluster analysis (HCA) was performed to identify distinct clusters of birdsongs that share similar perceptual characteristics, based on the PC scores obtained from the PCA. The HCA revealed four distinct clusters of birdsongs: Cluster 1 (n=14), Cluster 2 (n=24), Cluster 3 (n=30), and Cluster 4 (n=32).

Figure 1 shows the PC scores of 100 birdsongs across the four clusters. Cluster 1 includes sharp and lively birdsongs with low gentleness. Cluster 2 features less sharp and less lively songs but still retains a harsh quality. Cluster 3 represents moderately gentle but calm and subdued birdsongs. Cluster 4 consists of both gentle and lively birdsongs, offering a dynamic yet soothing sound profile distinct from the other clusters.



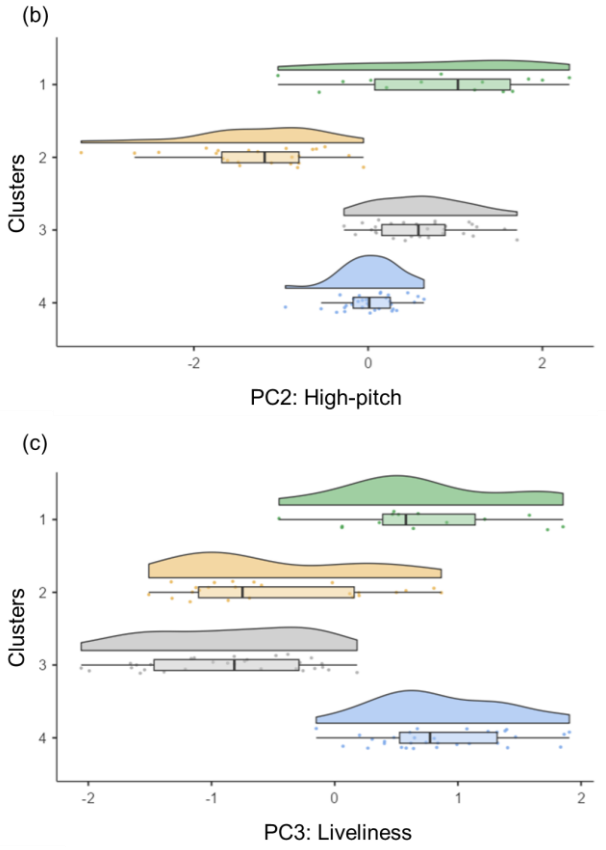


Figure 1. The distribution of four clusters of birdsongs based on principal components: (a) PC1: Gentleness, (b) PC2: High-pitch, and (c) PC3: Liveliness

4. CONCLUSION

This study examined the perceptual and psychoacoustic features of birdsongs to assess their suitability for soundscape design. Principal component analysis revealed three core perceptual dimensions, and subsequent cluster analysis categorized the birdsongs into four distinct groups. Clusters 1 (sharp and loud) and 2 (less sharp and non-dynamic) were associated with harsher acoustic characteristics, making them less favorable for restorative environments. In contrast, Clusters 3 (gentle and subdued) and 4 (lively and soothing) exhibited more pleasant and dynamic qualities, positioning them as ideal candidates for soundscape enhancement. These findings support a perception-based framework for the strategic integration of birdsongs into urban soundscapes, enabling more informed selection based on their psychoacoustic profiles.

5. ACKNOWLEGEMENTS

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