Perceptual assessment of operation noises of equipment on construction sites

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Abstract
This study aims to assess objective and subjective aspects of equipment and operational noises on construction sites based on a laboratory experiment. Sixteen audio-visual recordings of machines on construction sites were used as stimuli. In total, 53 participants took part in the laboratory experiments. The participants assessed noises of construction machines using 12 pairs of bipolar semantic differential adjectives to describe acoustic perceptions of the construction machine noises. Principal component analysis (PCA) was conducted using the subjective responses on the 12 semantic differential scales. The PCA revealed four principal components of perceptions construction noises, namely, *Incisiveness*, *Strength*, *Intermittency*, and *Periodicity*. Cluster analysis was then conducted on the PCA results for the sixteen construction noises. The results showed that the equipment noises on construction sites could be grouped into three clusters in terms of perceptual characteristics.

Keywords: Construction sites, Equipment noise, Perception, Soundscape, Semantic differential.

1 Introduction

The number of complaints caused by construction noises has been gradually increasing due to increased construction activities in highly dense urban environments. Unlike other types of environmental noise sources such as transportation and industrial facilities, the acoustical characteristics of construction noises are largely varying because construction tasks are changing throughout the construction stages. Also, construction noises are characterized by high variability in noise levels and spectra-temporal characteristics because various types of equipment are operating on construction sites during the construction periods [1,2].

Despite various acoustic characteristics of construction noises, noise regulations for construction activities primarily consider the maximum permissible noise levels [3,4]. This implies that the current construction noise regulation might underestimate spectra-temporal variations of equipment noises. Therefore, it is necessary to explore various perceptual factors of operating construction machines affecting the annoyance of construction noises. Therefore, this study aims to evaluate perceptual aspects of construction machine noises. Specifically, two research questions are addressed: (1) What are the perceptual components of construction noises? (2) Can we cluster construction noises based on the perceptual components?

To answer the research questions, a laboratory experiment was conducted using various types of construction equipment noises recorded on construction fields. During the experiment, participants assessed the perceptions of recorded construction noises based on a semantic differential method.

2 Method

2.1 Stimuli

As shown in Figure 1, sixteen construction machines were selected as construction noise sources for the laboratory experiment. 3-min binaural recordings of the operating construction machines were carried out on construction fields in Korea using a binaural microphone (Type 4101, Brüel & Kjær (Sound and Vibration Measurement A/S), Denmark) and a digital recorder (DA-21, Rion, Japan). The measurements were conducted at a distance of 10 m from the construction machines, whereby the microphone was placed 1.5 m above the ground and 3-min videos of each operating construction machine was simultaneously recorded using a digital HD video camera (HDV V-1, Sony, Japan). For the laboratory experiment, 30-s audio and video excerpts of each construction machine were excerpted from the 3-min recordings. Table 2 shows 30-s A-weighted equivalent sound pressure levels (SPLs) of the 16 acoustic stimuli. A-weighted equivalent SPLs of the ($L_{\text{Aeq, 30s}}$) ranged from 65.1 dB (Concrete mixer) to 92.0 dB (Concrete plant).

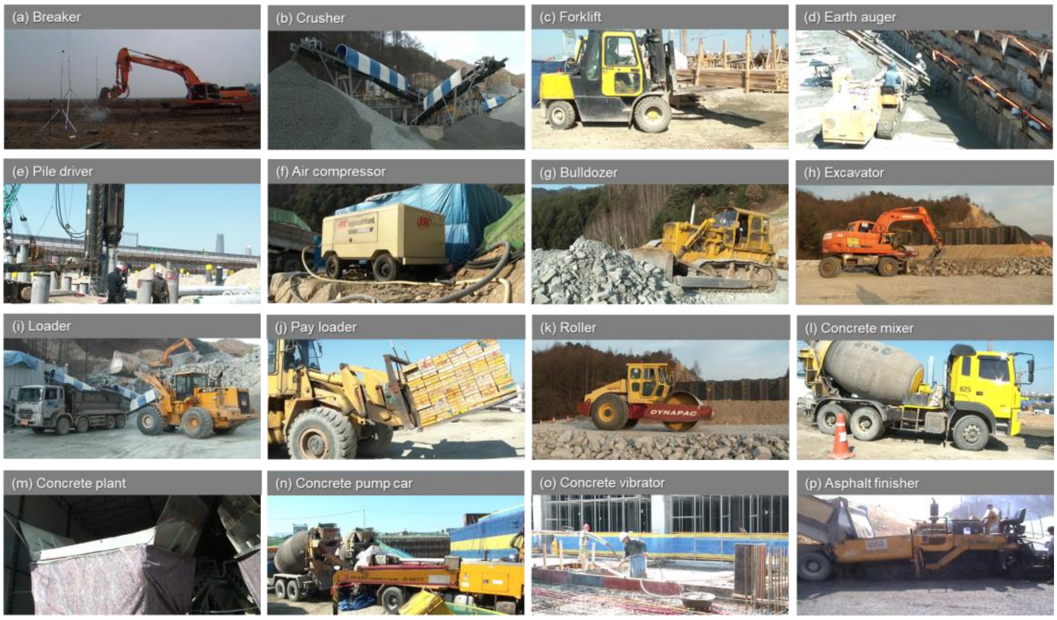

Figure 1 – Photos of sixteen construction machines.

Table 1 – 30-s A-weighted equivalent sound pressure levels ($L_{\text{Aeq, 30-s}}$) of the 16 acoustic stimuli.

Machine	$L_{\text{Aeq, 30-s}}$ [dB]	Machine	$L_{\text{Aeq, 30-s}}$ [dB]
(a) Breaker	86.4	(i) Loader	83.5
(b) Crusher	76.2	(j) Pay loader	83.3
(c) Forklift	71.3	(k) Roller	76.7
(d) Earth auger	78.8	(l) Concrete mixer	65.1
(e) Pile driver	91.7	(m) Concrete plant	92.0
(f) Air compressor	74.8	(n) Concrete pumpcar	81.0
(g) Bulldozer	83.5	(o) Concrete vibrator	86.7
(h) Excavator	67.8	(p) Asphalt finisher	83.6

2.2 Subjective evaluation

A semantic differential test was employed to evaluate various perceptions of the construction machine noises. Based on previous studies on perceptions of sounds [5–7], as presented in Table 2, 12 pairs of bipolar adjectives were selected to include various aspects of perceptions of sounds including pitch sensation, strength, variety, and fluctuation. Participants were asked to evaluate the perceptions of each construction noise based on a 7-point bipolar scale of -3 to +3.

Table 2– Twelve pairs of bipolar semantic differential (SD) adjectives

No	Perceptions	SD attributes	
1	Pitch	Dull	Sharp
2		Dark	Bright
3		Low-pitched	High-pitched
4	Strength	Quiet	Loud
5		Gentle	Harsh
6		Un-energetic	Energetic
7	Variety	Boring	Lively
8		Smooth	Rough
9		Uneventful	Eventful
10	Fluctuation	Non-stationary	Stationary
11		Continuous	Intermittent
12		Non-periodic	Periodic

2.3 Procedure

In total, 53 participants (25 males and 28 females) took part in the experiment. Mean age of the participants was 23.4 (SD= 2.4). The study protocol used in this experiment was approved by the institutional review board (IRB) of the Nanyang Technological University, Singapore (IRB-2017-07-025).

The acoustic stimuli were played to the participants through headphones (Beyerdynamic Custom One Pro, Germany), while the video recordings were presented on a 23-inch display monitor (HP z23n, Hewlett-Packard, US). The laboratory test was conducted in a recording studio with $L_{\mathrm{Aeq,3\text{-}min}}$ of ~28 dB.

3 Results

3.1 Principal component analysis

To find the critical perceptions of construction machine noises, principal component analysis (PCA) was conducted using the subjective responses of 12 adjective attributes. As shown in Table 3, four principal components were found. Component 1 was highly associated with the attributes (*Dull-Sharp, Dark-Bright, Low-pitched-High-pitched*, and *Uneventful-Eventful*), which could be interpreted as *Incisiveness*. Component 2 has high correlations with the attributes (*Quiet-Loud*, *Gentle-Harsh*, *and Unenergetic-Energetic*) representing the *Strength* of construction machine noises. Component 3 had high component loadings of the attributes (*Non-stationary-Stationary* and *Continuous-Intermittent*), which could be characterized as *Intermittency* of sounds. Component 4 only was correlated with the attribute (*Non-periodic-Periodic*) representing *Periodicity* of construction noises.

Table 3. Rotated component matrices of the PCA using subjective responses for the 12 adjective attributes

SD attributes	Component (Explained variance, %)			
	Incisiveness (43.6)	Strength (11.5)	Intermittency (9.3)	Periodicity (8.8)
Bright	0.81	-0.04	0.03	0.06
Lively	0.75	0.29	0.18	0.10
High-pitched	0.69	0.34	0.10	-0.20
Sharp	0.67	0.51	0.14	-0.07
Eventful	0.65	0.21	0.27	0.17
Energetic	0.60	0.53	0.13	0.22
Harsh	0.24	0.90	0.05	0.00
Loud	0.20	0.87	0.02	0.06
Rough	0.16	0.80	0.22	0.03
Stationary	-0.16	-0.08	-0.85	0.16
Intermittent	0.17	0.13	0.78	0.25
Periodic	0.07	0.06	0.04	0.95

3.2 Hierarchical cluster analysis

Hierarchical cluster analysis (HCA) for 16 construction machine noises was carried out using the principal component scores calculated from the PCA. As shown in Figure 2, 16 construction machine noises were grouped into three clusters. Cluster 1 had eight equipment noises (air compressor, concrete mixer, concrete pump car, crusher, earth auger, excavator, forklift, and roller), while six equipment noises (concrete plant, asphalt finisher, loader, concrete vibrator, bulldozer, and payloader) were classified into Cluster 2. Two machine noises (breaker and pile driver) were grouped into Cluster 3.

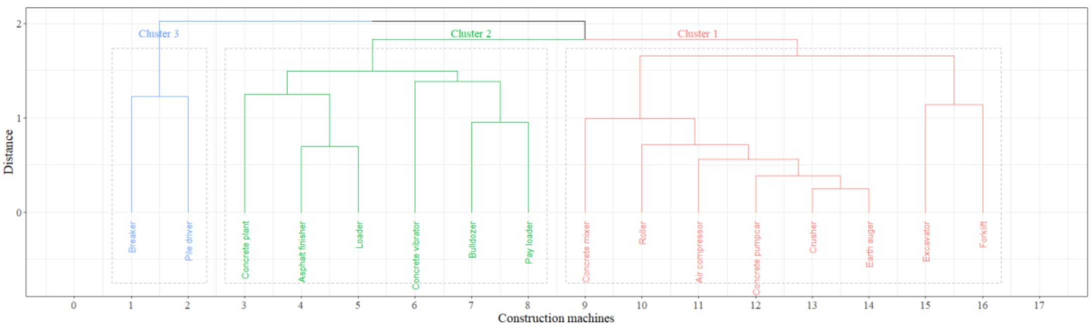

Figure 2 – Dendrogram of hierarchical clustering of 16 construction

Figure 3 shows mean principal component scores of the three clusters. Cluster 1 showed negative component scores for *Incisiveness* and *Strength*. This indicates that machine noises in Cluster 1 had lower sound power with low frequencies. Clusters 2 and 3 exhibited positive *Incisiveness* and *Strength* scores, However, Cluster 2 obtained negative *Periodicity* and neutral *intermittency* scores, whereas Cluster 3 had highly positive component scores for *Intermittency* and *periodicity*. This indicates that Cluster 2 includes machines with high noise levels and low temporal variation, while Cluster 3 contains either discrete impulse noise (e.g., pile driver) or quasi-steady impulse noise (e.g., breaker).

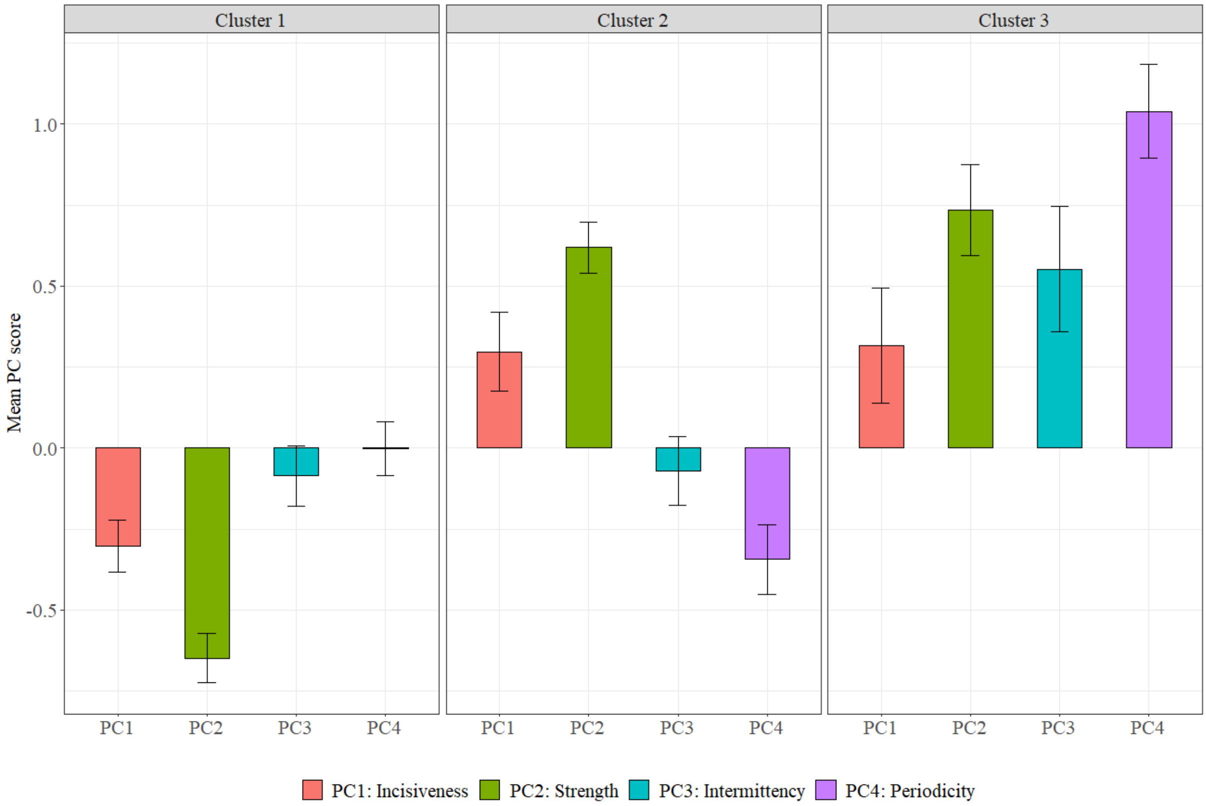

Figure 3 –Mean principal component (PC) scores in terms of clusters.

4 Conclusions

This study aims to investigate perceptual components of operating construction machines and based on a laboratory experiment. Sixteen audio-visual recordings of machines on construction sites were used as stimuli. Multidimensional perceptions of 16 construction equipment noises were evaluated based on the semantic differential method using 12 pairs of adjectives, which describe various acoustic perceptions of construction noises. The PCA results revealed that there are four principal components (i.e., *Incisiveness*, *Strength*, *Intermittency*, and *Periodicity*). Based on the PCA resutls, sixteen construction noises were clustered into three groups. The mean *Strength* score of noise in Cluster 1 was relatively lower than those of Clusters 2 and 3. Both Cluster 2 and 3 had higher *Incisiveness* and *Strength* scores, but *Periodicity* and *Intermittency* scores of Cluster 3 were higher than those of Clusters 2. These findings demonstrate that loudness and temporal variability of noises are important components to distinguish the three clusters of the construction noises.

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