Perceptual response analysis based on psychoacoustical changes on acoustic scenes of urban soundscapes.

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Introduction

The topic of sound design in urban soundscapes started to be investigated in 2006 when Kang proposed a framework for designing/engineering the soundscape of urban open public spaces. This framework highlighted several ways to handle soundscape design, e.g., through sound sources (sound pressure level, spectrum, temporal conditions, location, source movement, psychological/social characteristics), effects of the space (reverberation, reflection pattern and/or echogram, general background sound, sound around the space), users (social/demographic factors, activities and behaviours, context) and other environments (temperature, humidity, lighting, visual, landscape and architectural characteristics) [1]. Afterwards, in 2010, urban sound planning approaches were taught, and a framework to address soundscape studies was presented [2].

Initially, it is essential to understand and exchange opinions about the definition, evaluation, description, and modelling of soundscapes. Then, a phase of data collection and documentation through sounds, questionnaires, and case studies is necessary. Harmonisation and standardisation are important to establish indicators, protocols, and standards. Creating and designing are further steps where the development of tools and guidance is expected. All these steps will lead to the outreaching step, where policymakers and the general public will indicate what the overall urban soundscape should be [2].

This study aims to verify the soundscape design by processing the overall sounds of urban soundscapes, helping 1) to establish the role of psychoacoustic parameters, such as loudness, sharpness, roughness, fluctuation strength, and tonality in soundscape perception and 2) verifying suitable semantics for soundscape perception.

Methods

Study Area

The investigations took place in Aachen, Germany, at two public parks and on a busy commercial street. The parks are Stadtgarten-Farwickpark (CA) and Westpark (WP), with areas of 24.6 ha and 6.65 ha, respectively. The busy commercial area was Theaterstrass (TE), with an area of 3.38 ha (Fig. 1). The sound sources near the evaluation spots from Stadtgarten-Farwickpark are dominated by human sounds (playground), natural sounds (birds and ducks) and technological sounds (traffic); in Westpark by human sounds (playground and sports courts), natural sounds (birds and ducks); in Theaterstrasse by humans sounds (pedestrians) and technological sounds (traffic).

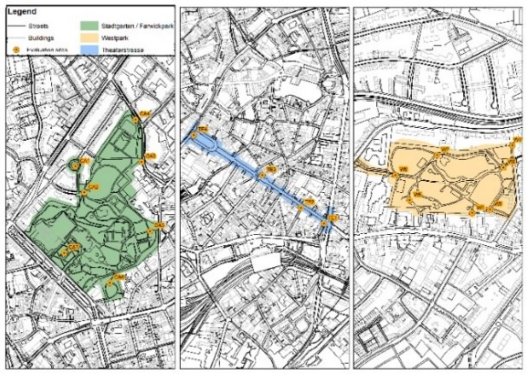

Figure 1: Study areas (Shapefiles were obtained at [3]).

Study Workflow

As observed in Figure 2, the study workflow counted six steps, comprised of **1)** ‘data collection’ which was realised through soundwalks in each study area by collecting sound files and perceptual responses. These will not be analysed in this work; **2)** ‘sample duration edition’, where the sound samples were edited for 30 seconds, containing most of the relevant sound sources observed in the soundwalks. The edition was possible through the Audacity® software; **3)** ‘sound design’, which involves the processing of sound samples for three conditions. The first condition was to keep the audio file in its original sound qualities (normal), the second was to process the psychoacoustic indicators in lower magnitudes (less), and the third was to process the psychoacoustic indicators in greater magnitudes (more). Each psychoacoustic indicator was processed individually in the sound files to verify only their influence on the perceptual responses at the listening experiments, although by changing one indicator, all others are automatically changed; **4)** to estimate the changes in the indicators, a ‘psychoacoustic analysis’ was realised with the help of Artemis Suite ®. The average single values from each processed and non-processed file were calculated for the following indicators: loudness [4], sharpness [5], roughness [6], fluctuation strength [6] and tonality [7]; **5)** ‘listening experiment’ which could have 30 to 50 minutes depending on the participant. The listening experiments counted 39 participants, mostly students and academic staff, who participated voluntarily and signed a consent form for their participation. All participants tested their hearing abilities through audiogram tests. It was developed a Matlab GUI for audio reproduction and perceptual data collection. This GUI presented three phases of data collection. In the first phase, demographic data and knowledge of the study areas were asked through participation in previous soundwalks. In the second phase, six sound samples were reproduced, and overall sonic qualities and perceived sound sources were asked. This study uses only the perceived sound source responses collected in this phase. The third phase consisted of the reproduction of 19 sound samples with processed and non-processed sounds. All sound samples from the second and third phases were reproduced randomly. The following semantic attributes were tested: intensity (noisy to quiet) [8,9], comfort (uncomfortable to comfortable) [9], nuisance (annoying to not annoying) [9], restoration (exhausting to relaxing) [9], pitch (deep to shrill) [8], variety (varied to monotonous) [8], naturalness (artificial to natural) [8] and harmony (chaotic to harmonious) [8]. All of them were rated through a slider, which provided continuous scale responses, and the slider was positioned in the neutral position, equivalent to 0.5. Positive responses tended to 1.00 and negative responses to 0.00; 6) 'statistical analysis' where the perceptual responses data set was analysed with the help of IBM SPSS 23® through a Kruskal Wallis test. It compared the rank averages of the less–normal–more processed conditions of each psychoacoustic indicator. To demonstrate the results graphically, Sankey diagrams were realised with the help of the free web-based tool SankeyMATIC [10]. The Sankey diagram helps to show how the participants express their opinions through the perceptual responses, where the thickness of the 'arrows' shows the magnitudes of the attributes. However, the graph does not show the significance of the results presented.

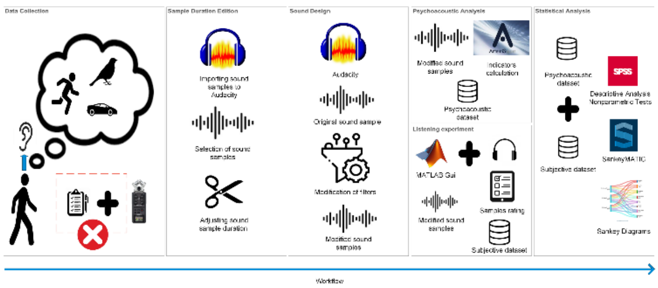

Figure 2: Study workflow

Results

Demographics

Of the 39 participants, 11 were female (28.2%), and 28 were male (71.8%). The major age category was 21 to 30 years old (26; 66.7%), but the sample had participants aged from 17 to 60. Most of them were students (24; 61.5%), followed by research assistants (6; 15.4%). They report that they have participated in the soundwalks before (25; 64.1%).

Predominant sound sources

As observed in Figure 3, the predominant sound sources reported in Stadtgarten-Farwickpark (CA) were technological sound sources (128; 29.6%), followed by 'No answer—N/A' (111; 25.7%), human sounds (101; 23.4%), and natural sounds (92; 21.3%). In Theaterstrasse (TE) the reports were from technological sounds (82; 42.7%), 'No answer—N/A' (64; 33.3%), human sounds (40; 20.8%) and natural sounds (6; 3.2%). In Westpark, they reported technological sounds (109; 34.9%), 'No answer—N/A' (77; 24.7%), human sounds (72; 23.1%) and natural sounds (54; 17.3%).

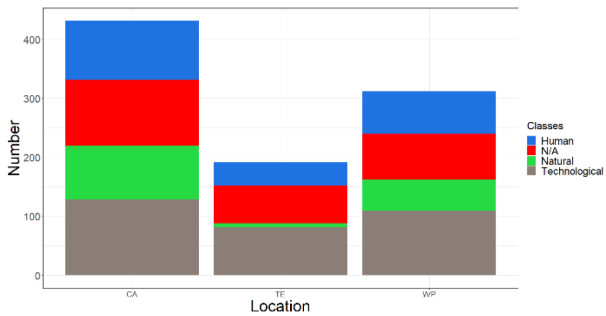

Figure 3: Predominant sound sources

Psychoacoustic indicators averages

Table 1 shows the results for processed (less and more) and non-processed (normal) audio files for the corresponding psychoacoustic indicators. As observed in the loudness results, the greatest values are at TE, and the smallest values are at WP. For sharpness, the greatest values are in WP, and the smallest values are in CA. Regarding roughness, the greatest values are observed in TE, and the smallest are observed in WP. For fluctuation strength, the greatest values are in CA, and the smallest are in WP. For tonality, the greatest values observed are in WP, and the smallest are in CA.

Table 1: Psychoacoustic indicators averages

Indicator/Location	Less	Normal	More
Loudness (soneGF) CA	2.2	4.5	8.6
Loudness (soneGF) WP	2.1	3.6	4.7
Loudness (soneGF) TE	12.5	15.1	19.1
Sharpness (acum) CA	0.7	1.6	3.2
Sharpness (acum) WP	0.8	1.6	3.4
Sharpness (acum) TE	0.8	1.5	2.2
Roughness (asper) CA	0.011	0.082	0.15
Roughness (asper) WP	0.005	0.102	0.147
Roughness (asper) TE	0.096	0.21	0.21
Fluctuation Strength (vacil) CA	0.007	0.012	0.036
Fluctuation Strength (vacil) WP	0.007	0.01	0.011
Fluctuation Strength (vacil) TE	0.004	0.011	0.019
Tonality (tuHM) CA	0.0607	0.0626	0.0904
Tonality (tuHM) WP	0.673	0.686	0.791
Tonality (tuHM) TE	0.0959	0.111	0.113

Kruskal Wallis Test

The Kurskall Wallis Test shows results with two degrees of freedom for all attributes (Table 2). The psychoacoustic parameter that presented the most significant results was sharpness, except for 'variety' at TE and 'harmony' at WP and TE. The second indicator that presented the most significant results was roughness (19 significant results), followed by fluctuation strength (13 significant results), tonality (7 significant results), and loudness (1 significant result).

Table 2: Kruskal Wallis Test (H) results (* p-value <.05, ** p-value<.001)

Semantics	N	S	R	FS	T
Intensity CA	5.364	8.297*	14.298*	3.550	10.975*
Intensity WP	1.661	26.045*	36.504**	21.701*	0.427
Intensity TE	0.464	12.518*	12.025*	19.900**	16.129**
Comfort CA	5.302	14.179*	16.540**	0.333	3.656
Comfort WP	0.824	13.177*	15.916**	9.562*	2.188
Comfort TE	0.985	19.076**	16.511**	14.676*	8.508*
Nuisance CA	8.642*	10.471*	11.842*	0.288	4.308
Nuisance WP	0.365	13.537*	19.481**	12.468*	2.684
Nuisance TE	0.990	10.304*	10.724*	21.610**	11.392*
Restoration CA	3.497	14.927*	15.407**	0.462	0.654
Restoration WP	4.284	12.316*	13.857*	13.870*	1.547
Restoration TE	0.234	17.599**	9.955*	15.682**	8.974*
Pitch CA	0.404	20.246**	24.848**	0.625	7.053*
Pitch WP	0.006	35.448**	30.465**	18.312**	3.706
Pitch TE	0.138	13.693*	14.863*	16.260**	14.481*
Variety CA	1.722	7.931*	6.922*	5.342	4.145
Variety WP	1.053	15.746**	5.403	3.897	1.553
Variety TE	2.999	5.710	0.110	6.814*	0.695
Naturalness CA	2.351	21.265**	12.492*	2.149	2.672
Naturalness WP	2.355	10.427*	6.641*	2.940	1.570
Naturalness TE	3.496	18.649**	4.640	16.116**	2.444
Harmony CA	4.107	7.248*	0.230	3.802	2.696
Harmony WP	2.032	0.225	6.185*	5.193	0.328
Harmony TE	1.616	4.796	2.694	19.119**	3.888

Sankey diagram

The Sankey diagram shows the distribution of preferences from the participants regarding the processed and non-processed audio files. Figure 4 shows the graphical representation through the Sankey diagram of the responses for the sharpness indicator. The perceptual attributes 'pitch' with a sum of ranks of 1.44 and 'naturalness' with a sum of ranks of 1.90 can be highlighted. These attributes are the best example of how participants changed their preferences according to the increase or decrease of the sharpness indicator.

Conclusions

The sound design using processed audio files showed excellent results for sharpness and roughness and significant results for 'intensity', 'comfort', 'nuisance', 'restoration', and 'pitch' for all study areas. Additionally, sharpness also showed significant results for 'naturalness' in all areas. Other attributes also presented significant results, but they were mostly connected to specific sound sources.

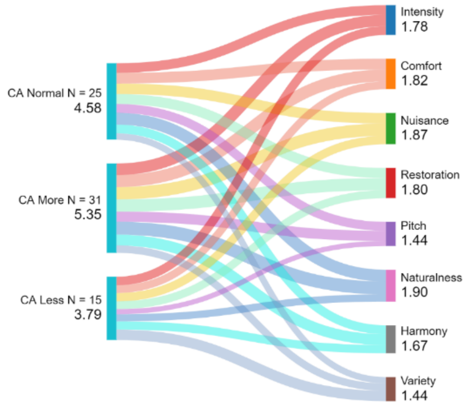

Figure 4: Sankey diagram for processed and non-processed audio files at Stadtgarten-Farwickpark (CA) regarding sharpness

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