Analysis of socio-cultural differences and psychoacoustic parameters in sound perception in a public park and its surroundings

Margret Sibylle ENGEL1; Camella PFAFFENBACH2; Janina FELS1
1 RWTH Aachen University, Institute of Technical Acoustics, Medical Acoustics Group, Germany
2 RWTH Aachen University, Geography Department, Germany

ABSTRACT

The city of Aachen is a university city, surrounded by some green areas, including a recreational area close to the center called: the Westpark. While it is close to the university campus, some of the students’ population lives near to the park and they use it during leisure time. According to the city of Aachen, 36% of the inhabitants living in this area are aged between 20 and 29 years and 16% are non-German. In this study, soundwalks are carried out with users of the park and interviews on sound perception are conducted with local residents. During the soundwalks and interviews, synchronized sound measurements are also performed. Psychoacoustic parameters are calculated based on binaural and omnidirectional recordings, providing the objective data of this study. The subjective data collected from both, the park user and resident interviews, are analyzed using a two-step cluster analysis model. Results of the subjective and objective data are compared to indicate how sound is perceived by the users of a public park and residents who live in its neighborhood.

Keywords: Soundscape, Sound quality, Sociological effects

1. INTRODUCTION

Recently, several studies related to the soundscape quality of urban parks were conducted to confirm whether the sonic environment of this type of area is promoting and preserving the health of the citizens [1, 2, 3].

According to the International Organization for Standardization, soundscape is defined as an “acoustic environment as perceived and, or understood by a person or people, in context” [4]. Some authors define soundscape as physical acoustic environment, e.g. “collection of sounds in a place” [5] or “variations of sound in space and time” [6]. The context includes all non-acoustical components of a place, related to persons, between the interaction of person and place as well as the motivation for undertaking an activity in this place [7]. It is also formed by visual stimuli, knowledge about the place and cultural meanings [8].

As mentioned above, persons and their preferences play a significant role in the soundscape evaluation. Thus, it is important to know the profiles of users’ who are evaluating the soundscape, understand the interaction between person and place, as well the influence of the sonic environment on their everyday lives. A good way to perform user profiling is through a two-step cluster analysis [9] which is capable of handling continuous and categorical variables or attributes [10].

This study is the continuation of the previous work on users’ profiles obtained through cluster analysis [9] and aims to investigate the influence of users’ profiles in sound perception responses on soundscape studies. Therefore, this study considers two scenarios: analysis with and without users’ profiles data. Sound recordings and perception responses compose also the analyzed data set. A Multinomial Logistic Regression is applied in this study.

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1 margret.engel@akustik.rwth-aachen.de , janina.fels@akustik.rwth-aachen.de
2 pfaffenbach@geo.rwth-aachen.de
2. METHODOLOGY

2.1 Study Area

This study was conducted in Westpark in Aachen, Germany (Figure 1).

The park is close to the university campus. Therefore the majority of the population is students and they use it during leisure time.

In this study, soundwalks were conducted in Westpark with 30 participants. They were asked to judge the environment in various aspects, including acoustic, thermal-comfort, air quality, landscape and suitability for their lifestyle. The evaluated locations are represented as green dots and the trekked routes in light orange (Figure 1). Each participant was asked to judge at three locations during the soundwalk. Additionally, interviews were conducted with the residents of the surrounding areas of Westpark (yellow dots). The sample of interviews is composed by 30 residents of the area.

2.2 Sound Collection and Data Treatment

Soundwalks are used to empirically evaluate a soundscape and its components in several locations [11]. It is important to record the sound binaurally during soundwalks to ensure the sound characteristics of the perceived signal of humans [12].

In this study, a Sennheiser KE-4 omnidirectional microphone, a pair of KE-3 microphones (for the binaural recording) and a Zoom-H6 multitrack recording device is used during the soundwalks.

For data processing the software ArtemiS ® (by HEAD acoustics) was used. The following acoustic and psychoacoustic parameters were calculated: Sound Pressure Level, Sound Pressure Level A-Weighted, Loudness (DIN 45631/A1 [13]), Loudness N5 (DIN 45631/A1 [13]), Sharpness (DIN 45692 [14]), Roughness (Sottek [15, 16, 17]), Hearing Model Roughness 1/1 Bark (Sottek [15, 16, 17]), Fluctuation Strength (Sottek [15, 16, 17]) and Tonality (DIN 45681 [18]).

2.3 Subjective Data Collection and Processing

Through the subjective sample collected during soundwalks, the study provides an overview of the sound perception of the users of the park. With the interviews conducted with the residents of the area, the subjective data is collected by the people who are familiar with the acoustic environments of the evaluated park area.

For this study, similar questions were asked on soundwalks and questionnaire surveys, containing the questions as displayed in Table 1.
Table 1 - Questions used for the soundwalks and interviews

<table>
<thead>
<tr>
<th>Socio-cultural parameters</th>
<th>Sound and landscape parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nationality</td>
<td>What do you think of the current location?</td>
</tr>
<tr>
<td>Profession</td>
<td>The general background noise at this place is acceptable?</td>
</tr>
<tr>
<td>Gender</td>
<td>Please evaluate the background noise according its: intensity, comfort, nuisance and restoration.</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>How long you lived in Aachen?</td>
<td></td>
</tr>
<tr>
<td>Why do you live in Aachen?</td>
<td></td>
</tr>
</tbody>
</table>

Scaling examples used on the questions above are described in Engel et al. [9]. Data tabulation and treatment was carried out with the help of the statistical software IBM SPSS 22.

2.4 Cluster Analysis: Users Profiles

As shown in the previous study by Engel et al. [9], a two-step cluster analysis on soundwalks and interviews samples was conducted separately.

In the two-step cluster analysis, the parameters denote a set of predictors and evaluation fields. All socio-cultural parameters in this study were considered as evaluation field predictors and led to users’ profiles from each formed cluster (c.f. Table 1).

The soundwalk sample formed three clusters with a clear subdivision of positive, negative and neutral responses related to sound and landscape perception. In the interview sample there were two clusters: positive-neutral responses and negative-neutral responses.

The socio-cultural profiles and the main relative frequencies are shown on Table 2.

Table 2 – Socio-cultural profiling from two-step cluster analysis

<table>
<thead>
<tr>
<th>Samples</th>
<th>Clusters</th>
<th>Age</th>
<th>Gender</th>
<th>Profession</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soundwalks</td>
<td>Cluster 1: negative responses (21.9%)</td>
<td>22 – 30</td>
<td>Female</td>
<td>Students (36.8%)</td>
</tr>
<tr>
<td></td>
<td>Cluster 2: positive responses (36.7%)</td>
<td>22 – 30</td>
<td>Female</td>
<td>Research A. (31.5%)</td>
</tr>
<tr>
<td></td>
<td>Cluster 3: neutral responses (42.2%)</td>
<td>22 – 30</td>
<td>Male</td>
<td>Students (63.2%)</td>
</tr>
<tr>
<td>Interviews</td>
<td>Cluster 1: neutral to negative responses (32.3%)</td>
<td>22 – 30</td>
<td>Male</td>
<td>Students (20%)</td>
</tr>
<tr>
<td></td>
<td>Cluster 2: neutral to positive responses (67.7%)</td>
<td>22 – 30</td>
<td>Female</td>
<td>Teacher (20%)</td>
</tr>
</tbody>
</table>

2.5 Multinomial Logistic Regression

As a part of the data set includes qualitative or categorical variables including dependent variables, for a further analysis the Multinomial Logistic Regression is used. This model is used when the response variable or dependent variable provide more than two outcomes. In this model, the response variable is the question whether the general background noise at this place is acceptable.

As in the cluster analysis, the Multinomial Logistic Regression was calculated for two samples: soundwalks and interviews (9). Each sample was tested for two scenarios: Scenario 1 considered the users profiles (clusters) obtained with the two-step cluster analysis; and Scenario 2 is not considered users’ profiles. The clusters are considered as categorical or factor predictors. This model works also with covariates and they must be continuous predictors such as the single values from psychoacoustic parameters.

The Multinomial Logistic Regression model fitting must check some model outcomes, such as: likelihood ratio tests; the efficiency of the model’s fit is measured by means of Chi-Square significance tests and the Deviation; and Pseudo-R’s. The Pseudo-R’s are calculated through the Cox & Snell coefficient, which never reaches the maximum value of 1 (100%). The Nagelkerke coefficient normalizes the Cox & Snell coefficient, so that the maximum value can reach 1 (100%). The McFadden coefficient is the most reliable one, since it indicates the adjustment of the model. Values between 0.2 (20%) and 0.4 (40%) are suitable for the adjustment [19].

The statistical model flow chart adopted in this study is shown in Figure 2.
3. RESULTS AND DISCUSSION

The results will be shown in two parts:
- Part 1 – Results of the Multinomial Logistic Regression from the soundwalks sample
- Part 2 – Results of the Multinomial Logistic Regression from the interviews sample.

As mentioned before, each part consists of two scenarios: models with and without factor predictor (cluster data).

3.1 Results of the Multinomial Logistic Regression from Soundwalks

3.1.1 Models with and without cluster data

Based on a Chi-Square test, it was found that $X^2(36) = 100.632$ with $p = 0.000$ for the model with cluster data and $X^2(36) = 100.174$ with $p = 0.000$ for the model without cluster data. The $p$-values showed that both models are significant. It can be concluded that there is at least one independent variable that significantly influences the dependent variable (acceptance of the background noise).

The efficiency of the model’s fitting is measured by means of Chi-Square significance tests and the Deviation. Table 3 shows that loudness, roughness, tonality, hearing model roughness 1/1 Bark, fluctuation strength and loudness N5 fits well in this model without cluster data. For the model with cluster data it is possible to see that loudness, roughness, tonality, hearing model roughness 1/1 Bark fits well to this model as covariates, as well as the clusters as factor predictor.

In the model without clusters data, the results of the Pseudo-$R^2$ logistic regression were as follows: Cox & Snell $R^2 = 0.684$, Nagelkerke $R^2 = 0.705$ and McFadden $R^2 = 0.327$. Thus, the model indicated that 68.4% (the Cox & Snell $R^2$) of the interdependencies between the independent variables and the dependent variable can be explained in the model without cluster data. Also, the variables were well adjusted to this type of model, since the result of McFadden’s $R^2$ was between 0.2 and 0.4.

For the model with cluster data the pseudo $R^2$ logistic regression were as follows: Cox & Snell $R^2 = 0.720$, Nagelkerke $R^2 = 0.742$ and McFadden $R^2 = 0.362$. The model indicates that 72% (the Cox & Snell $R^2$) of the interdependencies between the independent variables and the dependent variable can be explained. The result also indicates that the variables were well adjusted to this type of model, since the result of McFadden’s $R^2$ was between 0.2 and 0.4. The model fitting increased around 4% with the addition of the clusters information.
### 3.1.2 Comparison of the parameters estimation from model with and without clusters data

The addition of the clusters data permitted an explanation of the model with more psychoacoustic parameters and more answer categories. The categorical answers with the respective influence of the significant independent variables are shown above.

- **Yes, at evening time:**
  
  In the model without cluster data tonality had a greater weighting \( \beta_{\text{tonality}} = 245.956, p = 0.011 \) compared with the model with cluster data \( \beta_{\text{tonality}} = 134.994, p = 0.025 \). The parameter hearing model roughness 1/1 Bark had lower weighting in the model with cluster data \( \beta_{\text{hmroughness}} = -5.463, p = 0.001 \) compared with the model without cluster data \( \beta_{\text{hmroughness}} = -4.229, p = 0.032 \). Roughness \( \beta_{\text{roughness}} = 877.430, p = 0.041 \) and loudness \( \beta_{\text{bloudness}} = -1.710, p = 0.005 \) are extra parameters that helped on the explanation of the answer “Yes, at evening time” in the model with cluster data.

- **Yes, at night time:**
  
  In the model without cluster data tonality had a greater weighting \( \beta_{\text{tonality}} = 301.708, p = 0.006 \) compared with the model with cluster data \( \beta_{\text{tonality}} = 173.216, p = 0.012 \). The parameter loudness had lower weighting in the model without cluster data \( \beta_{\text{bloudness}} = -3.270, p = 0.048 \) compared with the model with cluster data \( \beta_{\text{bloudness}} = -2.378, p = 0.003 \). Roughness \( \beta_{\text{roughness}} = 1296.757, p = 0.009 \) and hearing model roughness 1/1 Bark \( \beta_{\text{hmroughness}} = -3.858, p = 0.009 \) are extra parameters that helped on the explanation of the answer “Yes, at night time” in the model with cluster data.

- **Yes, during any time:**
  
  The respondents accepted better loudness when they gave the answer “Yes, during any time” to the acceptance of the background noise by comparing the loudness weighting \( \beta_{\text{bloudness}} = -1.134, p = 0.040 \) with the other categories of answers.

Answers with “Yes, during day and evening” are observed on the cluster with tendency of positive answers related to sound and landscape perception. Persons that tended to give negative answers left more frequently questions without answer.

### 3.2 Results of the Multinomial Logistic Regression from Interviews

#### 3.2.1 Models with and without cluster data

Based on a Chi-Square test, it was found that \( X^2(15) = 42.430 \) with \( p = 0.002 \) for the model with cluster data and \( X^2(15) = 28.979 \) with \( p = 0.016 \) for the model without cluster data. The p-values

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Table 3 – Likelihood Ratio Test from soundwalks sample with and without clusters as factor predictor

<table>
<thead>
<tr>
<th>Effect</th>
<th>-2 Log Likelihood of Reduced Model</th>
<th>Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>172.371</td>
<td>28.623</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Intercept (^a)</td>
<td>170.203</td>
<td>0.000</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Loudness</td>
<td>170.138</td>
<td>26.391</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Loudness</td>
<td>203.633</td>
<td>33.431</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Roughness</td>
<td>175.219</td>
<td>31.471</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Roughness (^a)</td>
<td>187.446</td>
<td>17.244</td>
<td>6</td>
<td>.008</td>
</tr>
<tr>
<td>Tonality</td>
<td>190.837</td>
<td>47.089</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Tonality (^a)</td>
<td>206.507</td>
<td>36.304</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Hearing Model Roughness 1/1 Bark</td>
<td>185.397</td>
<td>41.650</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Hearing Model Roughness 1/1 Bark (^a)</td>
<td>198.361</td>
<td>28.158</td>
<td>6</td>
<td>.000</td>
</tr>
<tr>
<td>Fluctuation Strength</td>
<td>162.640</td>
<td>18.892</td>
<td>6</td>
<td>.004</td>
</tr>
<tr>
<td>Loudness N5</td>
<td>158.342</td>
<td>14.595</td>
<td>6</td>
<td>.024</td>
</tr>
<tr>
<td>Clusters</td>
<td>207.999</td>
<td>37.796</td>
<td>12</td>
<td>.000</td>
</tr>
</tbody>
</table>

Legend: gray color: model without clusters data as factor predictor; white color: model with cluster data as factor predictor; \(^a\) This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.
showed that both models are significant. The Chi-Square showed in the interviews sample a clear difference between both models and a greater fitting with the addition of cluster data. It can be also concluded that there is at least one independent variable that significantly influences the dependent variable (acceptance of the background noise). The efficiency of the model’s fitting is measured by means of Chi-Square significance tests and the Deviation. Table 4 shows that loudness N5, fluctuation strength and loudness fit well in this model as covariates in the model without cluster data. In the model with cluster data roughness, loudness N5, sharpness fit well in the model as covariates, as well as the clusters as factor predictor.

### Table 4 - Likelihood Ratio Test from interviews sample with and without clusters as factor predictor

<table>
<thead>
<tr>
<th>Effect</th>
<th>-2 Log Likelihood Reduced Model</th>
<th>Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>59.751</td>
<td>19.590</td>
<td>5</td>
<td>.001</td>
</tr>
<tr>
<td>Intercept</td>
<td>35.709</td>
<td>0.000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Roughness</td>
<td>54.269</td>
<td>18.560</td>
<td>5</td>
<td>.002</td>
</tr>
<tr>
<td>Loudness N5</td>
<td>58.668</td>
<td>18.507</td>
<td>5</td>
<td>.002</td>
</tr>
<tr>
<td>Loudness N5</td>
<td>59.430</td>
<td>23.721</td>
<td>5</td>
<td>.000</td>
</tr>
<tr>
<td>Fluctuation Strength</td>
<td>58.441</td>
<td>18.280</td>
<td>5</td>
<td>.003</td>
</tr>
<tr>
<td>Loudness</td>
<td>57.643</td>
<td>17.482</td>
<td>5</td>
<td>.004</td>
</tr>
<tr>
<td>Sharpness</td>
<td>50.719</td>
<td>15.011</td>
<td>5</td>
<td>.010</td>
</tr>
<tr>
<td>Cluster</td>
<td>55.215</td>
<td>19.506</td>
<td>5</td>
<td>.002</td>
</tr>
</tbody>
</table>

Legend: gray color: model without clusters data as factor predictor; white color: model with cluster data as factor predictor;

* This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

In the model without clusters data, the results of the Pseudo-$R^2$ logistic regression were as follows: Cox & Snell $R^2 = 0.607$, Nagelkerke $R^2 = 0.644$ and McFadden $R^2 = 0.327$. The variable “acceptance of the background noise” were correlated with 60.7% of the psychoacoustic parameters in this study. Also, the variables were well adjusted to this type of model, since the result of McFadden’s $R^2$ was between 0.2 and 0.4.

For the model with cluster data the Pseudo-$R^2$ logistic regression were as follows: Cox & Snell $R^2 = 0.746$, Nagelkerke $R^2 = 0.791$ and McFadden $R^2 = 0.479$. The model indicates that 74.6% (the Cox & Snell $R^2$) of the interdependencies between the independent variables and the dependent variable can be explained. In other words, 74.6% of the psychoacoustic parameters in this study were correlated with the variable “acceptance of the background noise”. The result also indicates that the variables were well adjusted to this type of model, since the result of McFadden’s $R^2$ was between 0.2 and 0.4. The model fitting increased around 13.9% with the addition of the clusters information.

3.2.2 Comparison of the parameters estimation from model with and without clusters data

Loudness N5 is the parameter that appeared most frequently as independent variable related to perception responses in both models. On the model without cluster data loudness N5 had a greater weighting when the response indicated that the background noise was not acceptable at the study area ($b_{\text{loudness}N5} = -671.661$ $p = 0.000$), by comparing acceptance responses like: “Yes, day and evening time” ($b_{\text{loudness}N5} = -18.739$ $p = 0.000$) and “Yes, evening and night time” ($b_{\text{loudness}N5} = -19.057$ $p = 0.000$) from the model with cluster data.

4. CONCLUSIONS

The aim of this study was to investigate the influence of users’ profiles in sound perception responses on soundscape studies.

This study showed that users profiling can increase the explanation of the Multinomial Logistic Regression Model related to background noise acceptance in an urban park. The increase of the explanation of the model was in the order of 4% with soundwalks samples and 13.9% with interviews samples.

The perception response related to the background noise acceptance is divided in categories of
answers. Each category of answers can be explained by a group of significant psychoacoustic parameters, as well as users’ profiles information. With the use of users’ profiles data the models shown a greater scope of psychoacoustic parameters involved on the perception response of urban parks.

In Engel et al. [9] the cluster analysis showed that the residents are more concerned about nuisance and intensity than comfort and restoration. The acceptance of the background noise for this public had a great influence of the psychoacoustic parameter loudness N5, which explain better characteristics of nuisance and sound intensity than the other psychoacoustic parameters. On the same study, Engel et al. [9] showed that the participants of soundwalks are more concerned about restoration, nuisance, which the sound characteristics involve a greater scope of psychoacoustic parameters. In this study, it was possible to verify that loudness, hearing model roughness 1/1 Bark and tonality are good parameters to describe the background noise acceptance of an urban park during soundwalks.

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