Investigation of the relationship between acoustic perception and thermal comfort of an urban park in Aachen

Margret Sibylle Engel[1], Bastian Paas[2], Christoph Schneider[3], Carmella Pfaffenbach[4] and Janina Fels[1]

[1] *Institute for Technical Acoustics, Medical Acoustics Group, RWTH Aachen University, 52074 Aachen, E-Mail: margret.engel@akustik.rwth-aachen.de , janina.fels@akustik.rwth-aachen.de*

[2] *Physical Geography and Climatology, RWTH Aachen University, 52062 Aachen, E-Mail: bastian.paas@geo.rwth-aachen.de*

[3] *Geography Department, Humbolt-Universität zu Berlin , 10099 Berlin, E-Mail: c.schneider@geo.hu-berlin.de*

[4] *Geography Department, RWTH Aachen University, 52062 Aachen, E-Mail: pfaffenbach@geo.rwth-aachen.de*

Introduction

The interest in microclimate and thermal comfort in urban environments increased during the last decade, due to climate changes and heat stress [1]. Recently some studies started to investigate, in urban areas, the relationship between acoustics and thermal comfort conditions. The investigations started using as acoustical parameter the Sound Pressure Level – SPL, and the adopted thermal index was the Universal Thermal Climate Index – UTCI [2]. Some authors stated that human responses to microclimate may be unconscious [3].

Considering the actual investigations about thermal comfort in conjunction with acoustical data, this study aims to progress with the research on the interaction between sound and thermo-comfort considering objective and subjective data collected on site. To reach this aim, we will test also psychoacoustic parameters and other thermal comfort indices in different seasons.

Study Area and Participants

This study was conducted during spring and autumn 2015 in Aachen, Germany, at the Westpark, an urban park near to the downtown area.

Figure 1: Study area at Westpark in Aachen, Germany

The data collection occurred through soundwalks with 30 participants in each season. Each participant evaluated three evaluation sites (green dots) during the soundwalks (cf. Figure 1).

To minimize bias from subjective parameters, it was selected the subjective responses from participants who evaluated the study area in both seasons. From the sample of 30 participants just seven, 5 female and 2 male, participated in both soundwalks. The age range was between 26 and 36 years old, mainly students and research assistants, with six foreigners and one German, who were living in Aachen less than six years in Aachen and due to educational reasons.

Objective and Subjective Parameters

Objective and subjective parameters were collected on site during the soundwalks.

The sound data was recorded with a Zoom-H6 multitrack recording device with a sampling rate of 44.1 kHz, connected to a set of Sennheiser KE-4 capsules (omnidirectional microphones) and KE-3 capsules (binaural microphones). The microphones calibration was performed with a B&K 4231 calibrator. The recording device was calibrated with a voltage calibrator (0.01V). The collected sound was analyzed with ArtemiS Classic and it was calculated the following parameters: Sound Pressure Level unweighted and A-weighted [4], Loudness [5], Sharpness [6], Roughness and Hearing Model Roughness [7, 8, 9], Fluctuation Strength [7, 8, 9] and Tonality [10].

Meteorological data was collected with a humidity and temperature sensor Testo 625 and an Anemometer Windmaster 2 Pro. Global radiation data was collected through a fixed local meteorological station [11]. From the meteorological, personal (height, weight, gender and age) and type of clothing data, it was calculated with the help of the RayMan model [12] the following thermal indices: *Predicted Mean Vote* (PMV) which provides a (dis-)comfort thermal index at various states of activity and clothing insulation [13]; *Physiologically Equivalent Temperature* (PET), provides a temperature felt at a given place [14]; *Standard Effective Temperature* (SET), which is based on the human energy balance and two-node model [15].

The subjective data was obtained through questions related to background sound (sound comfort) and weather (weather overall, temperature comfort, sun heat, humidity, wind speed and wind speed comfort) in 6-point scale format. From the answers of those questions it was possible to develop two parameters called background sound comfort and weather comfort.

Canonical Correlation Analysis

Statistical analysis was realized with the help of IBM SPSS Statistics 22. In this study the adopted statistical analysis was

Canonical Correlation. This method allows a study of interrelationships between sets of multiple dependent and independent variables [16,17]. The representation of the canonical sets analyzed in this study is shown at Figure 2.

It was analyzed four scenarios to check the importance of each thermal index, in both seasons (spring and autumn), for each Canonical Function generated by the Canonical Correlation Analysis of this study. Scenario 1 considered all thermal indices, acoustic and psychoacoustic parameters. The other scenarios considered the same acoustic and psychoacoustic parameters but evaluated just one thermal index at each time: 2 – PMV, 3 – PET and 4 – SET.

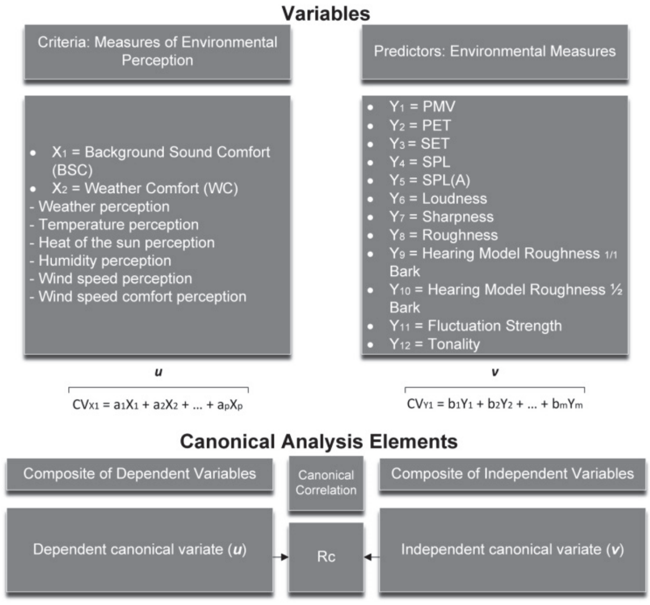

Figure 2: Variables set composite design of the general scenario

Results and Discussion

In Table 1 it is shown that in each scenario it was generated two Canonical Functions. All functions are significant, but due the aim of this study, we are presenting in this section just the results which had correlations between acoustic, psychoacoustic and thermal-comfort data. The functions which present this interaction are indicated in gray color at Table 1.

In all scenarios the combination of the investigated parameters appeared in the Spring data, and on the general scenario this interrelationship happened too. The strongest Canonical Correlation occurred in the general autumn scenario (Rc= 0.996) showed on Figure 4.

In all scenarios the Weather Comfort (WC) parameter had greater influence compared with Background Sound Comfort (BSC) inside the criteria set. Predicted Mean Vote (PMV) presented the greatest thermal comfort coefficient in the single scenario (Figure 5).

Table 1: Canonical correlation analysis model fitting

Scenario	Seasons	Canonical Function	Wilk's	Chi-SQ	DF	Sig.
		1	0.072	188.389	24	0.000
	Spring	2	0.479	52.699	11	0.000
		1	0.002	445.452	24	0.000
General	Autumn	2	0.234	103.790	11	0.000
		1	0.078	185.096	20	0.000
	Spring	2	0.503	49.784	9	0.000
		1	0.011	328.000	20	0.000
PMV	Autumn	2	0.305	86.056	9	0.000
		1	0.092	172.863	20	0.000
	Spring	2	0.488	52.044	9	0.000
		1	0.003	426.015	20	0.000
PET	Autumn	2	0.235	105.065	9	0.000
		1	0.097	168.994	20	0.000
	Spring	2	0.503	49.764	9	0.000
		1	0.009	338.901	20	0.000
SET	Autumn	2	0.275	93.664	9	0.000

Loudness and Sharpness are the most representative psychoacoustic parameters inside the interaction between sound and weather comfort. Sound Pressure Level (SPL) is the acoustic parameter with greater coefficients compared with SPL(A).

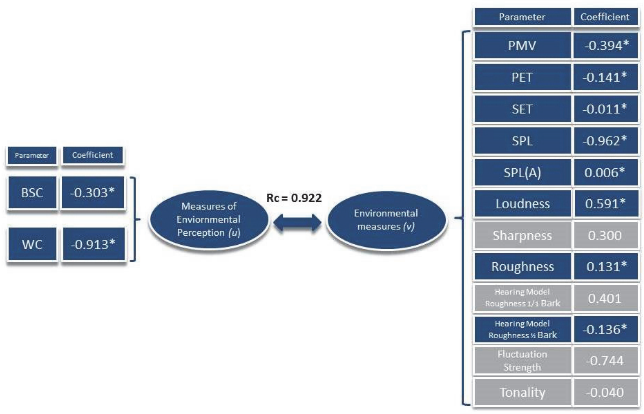

Figure 3: Results from general scenario (Spring) 1st Canonical Function, Legend: (*) = Significant coefficient when Canonical Loading cut-off ≥ 0.32

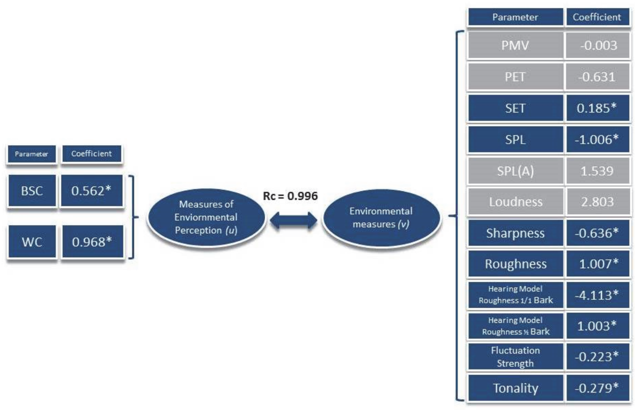

Figure 4: Results from general scenario (Autumn) 1st Canonical Function, Legend: (*) = Significant coefficient when Canonical Loading cut-off ≥ $\mathbf{0.32}$

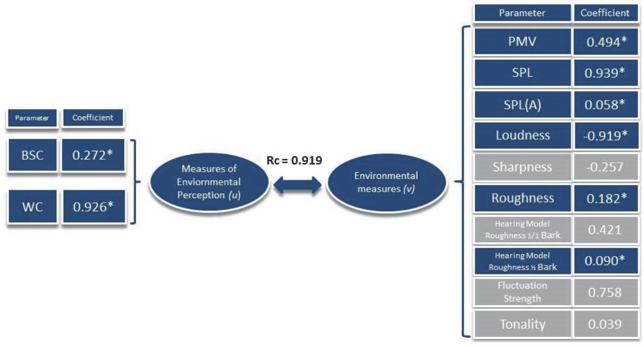

Figure 5: Results from *Predicted Mean Vote* scenario (Spring) 1st Canonical Function, Legend: (*) = Significant coefficient when Canonical Loading cut-off $\geq \mathbf{0.32}$

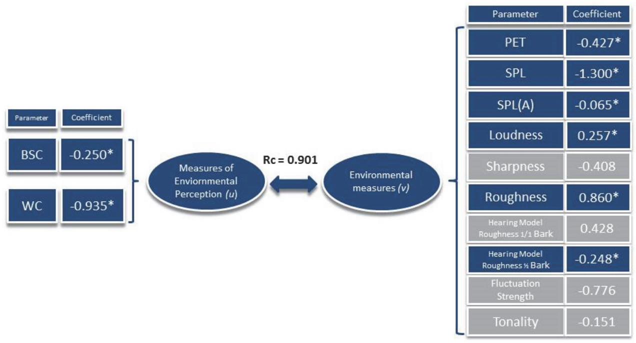

Figure 6: Results from *Physiologically Equivalent Temperature* scenario (Spring) 1st Canonical Function, Legend: (*) = Significant coefficient when Canonical Loading cut-off $\geq \mathbf{0.32}$

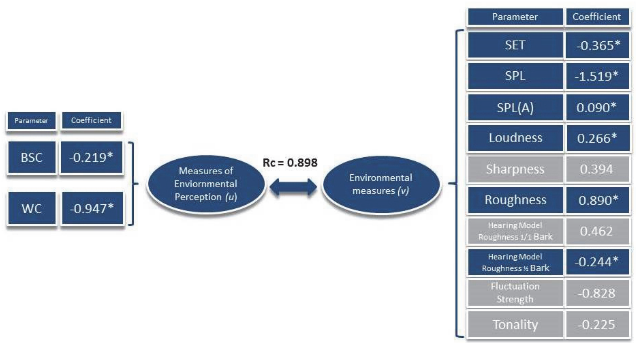

Figure 7: Results from *Standard Effective Temperature* scenario (Spring) 1st Canonical Function, Legend: (*) = Significant coefficient when Canonical Loading cut-off $\geq \mathbf{0.32}$

Conclusion

The aim of this study was to check the interaction between sound and thermo-comfort considering objective and subjective parameters.

1. It was concluded that the interaction between sound, thermal comfort and physical data worked well in the **Spring scenario** because of the **quantity of reported sound sources** in this season;
2. The strongest Canonical Correlation occurred in the **General scenario – Autumn;**
3. **Weather Comfort** had greater coefficients in the criteria set**;**
4. In the individual scenarios, **PMV** presented the greatest coefficient from the thermal indices;
5. **Loudness and Roughness** are the psychoacoustic parameters with greater coefficients ;
6. **SPL** was the acoustic parameter with greater coefficient;
7. It is recommended to do further analysis with **all indicated thermal indices** together because they helped to check interactions with **positive and negative** responses.

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