MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Links between representation of outdoor soundscape, noise annoyance at home and outdoor acoustic measurement

Aumond, Pierre [a,b,1], Lavandier, Catherine[b,2]

[a] Ifsttar, Cerema, UMRAE
[b] ETIS UMR 8051,
Université Paris Seine, Université de Cergy-Pontoise, ENSEA, CNRS,
F-95000, Cergy, France

ABSTRACT

As part of the ANR CENSE project, which has started in 2016, a questionnaire was sent to 2293 households in a 1 km² study area in the city of Lorient in France. The main objective of this questionnaire was to collect information on the perception by residents of sound environments in their neighborhood (representation of the soundscape), on their street (representation of the soundscape), and in their home (noise annoyance). In the same study area, 112 sensors were positioned in order to cross the perceptual variables collected through the questionnaire with acoustic measurements. The analyses of the relationships between the perceptual variables themselves will be presented. For example, the dimensions underlying the outdoor soundscape representation will be compared to those of literature. The influence of personal data (such as noise sensitivity, societal category, etc.) will be studied for both the perceived soundscape and the noise annoyance. Finally, the relationships between perceptual data and acoustic measurements will be presented, focusing on the need of identifying the sound sources.

Keywords: Soundscape, Noise annoyance
I-INCE Classification of Subject Number: 61

1. INTRODUCTION

Noise impact on human health has been revealed by numerous studies, due to traffic in urban context, but also due to railway and aircraft industries. The annoyance is considered by the WHO as one of the health impact of this noise [1]. But pure silence has also a negative impact on urban life. So starting in the sixties with Murray Schafer, and developing in the nineties, a soundscape approach has been preferred to address the issue of the urban sound environment, in a more positive way, taking into account that some natural sounds such as bird singing or water streaming, can enhance the pleasantness of a urban situation [2].

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1 pierre.aumond@ifsttar.fr

2 catherine.lavandier@u-cergy.fr

In the annoyance approach, researchers tried to find a relationship between sound exposure, and long term annoyance. Noise annoyance is then considered as a one dimensional variable. At an individual level, it has been shown that the explained variance of the annoyance due to sound exposure is limited to about 30%. At a community level, dose response curves based on L_{DEN} or L_{DN} make it possible to predict the percentage of annoyed or highly annoyed people. These indicators characterizing the sound exposure levels derive from the long temporal weighted equivalent sound levels calculated over 24h. The short temporal variations of the sound level are not taken into account in these indicators.

In the soundscape approach, people are not anymore questioned on only one negative dimension about the impact of the sound environment, but on the different emotional dimensions which support their feelings, with all positive and negative aspects. Some of these dimensions, and especially the pleasantness/unpleasantness dimension, have been correlated not only with acoustic indicators but also with perceptual variables dedicated to sound sources such as their time of presence, their sound level, or their dominance. In this approach, the semantic dimension of sources is then very important.

In both approaches, researches tried to cross the sound measurements with the impacts on people, but this is quite difficult for different reasons. In the first approach, the importance of personal behaviors and social attitudes on long term annoyance is so important that the statistics need more than thousand individual data to be significant. Participants are contacted through mailings or telephonic campaigns. It is then impossible to measure the sound exposure in front of each house for a long duration. So calculations are used. In the second one, people are generally questioned in the streets. It is then easier to measure the acoustic indicators with simple monophonic microphones or with more sophisticated binaural or ambisonic ones, even with mobile microphones. Short temporal variations of the sound level can be captured, but as people are questioned one by one, it is difficult to collect a large amount of data in the same experiment.

In this paper, we present a first analysis of a large campaign of questionnaires distributed in the city of Lorient in the frame of the CENSE project, whose aim is to combine these two approaches. In the same city center, a network of sensors which store the third octave bands each second during about a year will make it possible to compare perceptual data and acoustic ones.

This paper presents the questionnaire that was sent to the inhabitants as well as a first preliminary analysis of the results (answers are currently still being received).

2. METHODOLOGY

2.1 Survey – General information

A questionnaire was sent to about 2293 households in a 1 km² study area in the city of Lorient in France during the second week of January 2019. Until 15 March 2019, it is possible for residents to return a paper version of the questionnaire or to fill it via a web platform. The survey lasts about 20-25 minutes and is composed of 5 parts detailed in the following section.

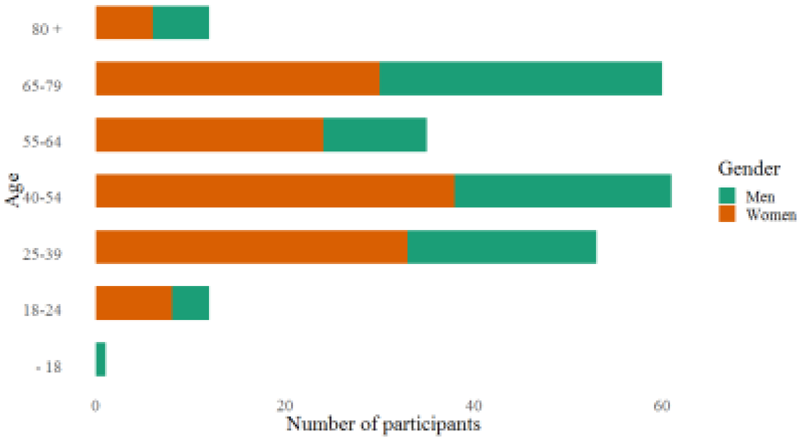


Figure 1. Age and gender of the participants

About 100 people completed the paper form of the questionnaire and about 150 did the answers through Internet. Figure 1 presents some demographic information about the participants. In order to encourage participation, a draw will be held for 5 gift certificates of 50€. Figure 2 shows the study area and a heat map of the responses. The French version of the questionnaire can be consulted at http://www.cense.ifsttar.fr.


Figure 2. Heat map of the number of filled questionnaires in the selected area

2.2 Survey in detail

In the first part, the respondent must assess the quality of the sound environment in his/her neighborhood and then in his/her street (when walking or cycling home). This section is composed of 5 bipolar semantic scales (7 levels) inspired on the Swedish protocol [3]. Table 1 presents the French semantic differential as well as a proposal for translation into English.

Then the respondents must inform a table on the time of presence ratio and on the volume of 13 sound sources that they can hear when they come in or out of their homes, on foot or by bike, on their streets, and during the year. The nomenclature had been previously established using information from sources on sites, and bibliographic work [4]. Table 2 presents the sources to be assessed. A free comment window closes this first section.

Table 1 – Anchors of the bipolar scales. The last column correspond to their codification.

Désagréable	Unpleasant	*Agréable*	Pleasant	Pl
Inerte, Amorphe	Inert	*Animé, mouvementé*	Eventful	Ev
Bruyant	Noisy	*Silencieux*	Silent	Si
Ennuyeux, Inintéressant	Boring	*Stimulant, Intéressant*	Exciting	Ex
Agité, Chaotique	Chaotic	*Calme, Tranquille*	Calm	Ca
En inadéquation avec vos attentes	In inadequacy with your expectations	*En adéquation avec vos attentes*	In adequacy with your expectations	Ad

The second part focuses on the annoyance. Questions on the annoyance following the Guidelines from the noise Team of ICBEN are asked to residents [5]. This part of the questionnaire can be summerized with this sentence:

"Thinking about the last 12 months, when you are here

- at home with your windows closed,
- at home with your windows open or on your balcony or in your garden,
- in the street, when you arrive at home by bike or on foot,

how much does

- global noise
- noise from (noises sources from Table 2)

bother, disturb, or annoy you: Extremely, Very, Moderately, Slightly or Not at all?"

Table 2 List of sources that must be assessed in the questionnaire.

Road Traffic (Tra)	Sirens, alarms (Sir)	Children's voices (schools, playgrounds) (ChV)	Gulls* (Gul)
2-wheel motor vehicles (2Wh)	Urban maintenance (cleaning, garbage...) (UMa)	Music from bars, restaurants, shops... (Mus)	Sources from neighboring dwellings (voices, steps, animals, crafts, music...) (Not used in this analysis)
Rail traffic (Rail)	Expressive voices, festive voices, laughter, shouts (ExV)	Wind in the vegetation (Wnd)	Other ...
Air traffic (Air)	Calm voices, conversations… (CaV)	Small birds (Brd)	Other ...

** Lorient is a harbor city with several complaints in the local press about the noise of gulls.*

In part 3, four windows make a free expression possible for residents about the remarkable environments (pleasant, unpleasant, conducive to walking and conducive to rest) of their neighborhood.

In part 4, personal information is collected: noise sensitivity of the inhabitants based on the 6-item Weinstein's noise sensitivity scale (WNSS) [6], gender, age, socio-professional category, membership (or not) to an association fighting against noise.

Finally, in the 5th part, residents must provide information on where they live: the exact location, so that the questionnaires can be linked with the acoustic measurements made in the area and a set of questions on housing (Table 3).

Table 3 Questions about the housing of participants

Tenant / Owner	Courtyard or garden area? (yes/no)	Has quiet room? (yes /no)
House/Apartment	Living space overlooking the street? (yes/no)	Double glazing? (yes /no)
Time of occupancy? (<1 year, 1-3 year, >3 year)	Living space with a view on natural elements? (no, a little, a lot)	Insulation of the facade <10 years ago? (yes/no)

Finally, the respondents must give their level of satisfaction (5 levels) on 4 dimensions:

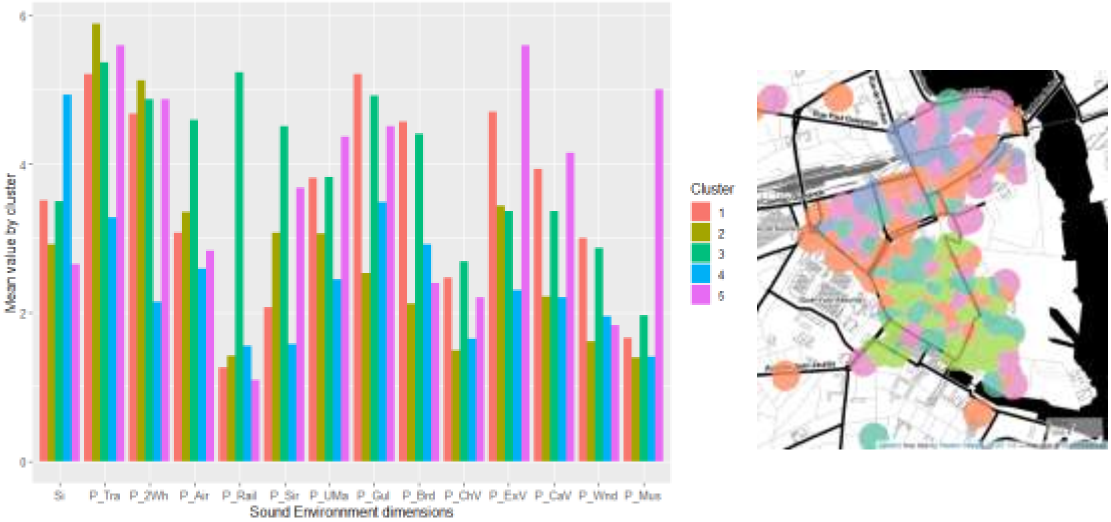
- Acoustic insulation of their housing,
- To what extent they are globally satisfied with their (home/street/neighborhood) as a place to live.

3. ANALYSES

3.1 Categorization of sound environments

Five categories of sound environments can be found on this study area. The perceived time of presence for each 13 sound source (see Table 2) is used in addition to the perceived overall loudness (Si) to perform the categorization. A k-means algorithm is used to cluster the observations into classes in which each observation belongs to the cluster with the nearest mean. Figure 3(a) presents the mean values of the perceived time of presence for each sound source, and for each cluster. Figure 3(b) shows the spatial distribution of these clusters using a spatial interpolation (a value at a point equals to the value of the nearest neighbor within a maximum radius of 80 meters).

- Cluster 1 is located throughout the area, It corresponds to very diverse areas where the perceived time of presence is important for different sources such as birds, wind, traffic or voices.
- Cluster 2 is mainly situated along the main boulevards, and the perceived presence of time for road traffic and two-wheelers is particularly important.
- Cluster 3 corresponds to the evaluations where the time of presence for railway is high. They are consequently located along the railway line.
- Cluster 4 is located throughout the area. It corresponds to low noise areas where birds are often heard.
- Cluster 5 is particularly situated in the hyper-center. It is the area where music from bars, many voices, etc. can be heard frequently.



(a) (b)

Figure 3. (a) Mean values for each sound environment dimensions (Time of presence of sound sources and perceived overall loudness) for each cluster. (b) localization of the clusters (nearest neighbor algorithm)

3.2 Principal components analysis of soundscape dimensions

The six attributes of perceived affective quality of the inhabitant's streets presented in Table 2 were evaluated through correlations. The corresponding matrix was subjected to a PCA. Components 1 and 2 explained 51% and 25% of the variance in the data set, respectively. Component 3 explained 7 %. Thus, the results can be represented mainly in a two-dimensional plane. Figure 4 presents the component loadings of the six attribute scales along the circumplex. All the attributes are organized in the same and expected order along the circumplex: Calm, Pleasant close to the first component, Interesting/Exciting and Eventful close to the second component [7]. The vector "adequation with the expectation" is correlated to the pleasantness of the street but slightly oriented to the vector Interesting/Exciting.

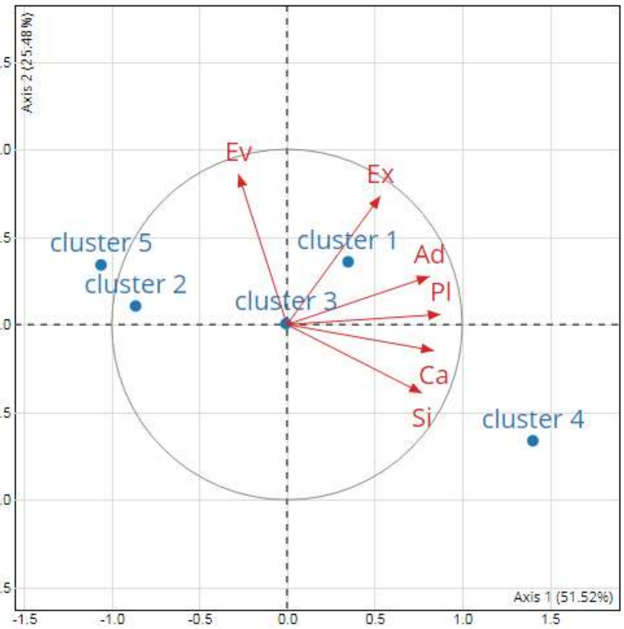


Figure 4 Principal Component Analysis of the soundscape dimensions and projected clusters

The 5 previous clusters of sound environments are also projected on the PCA representation. As expected, cluster 4 is located in a pleasant area in the direction of the calm and silent vectors. Clusters 2 and 5 are located in an area perceived as unpleasant by residents. Cluster 1 is located in an area considered "interesting" and rather pleasant. In a subsequent more advanced analysis, this projection encourages us to propose different models of soundscape indicators (Pleasantness, Eventfulness) for each of the sound environment we came across in this town. For example, for cluster 3, the role of the sound source (rail traffic) will be much more important for the soundscape assessment than for the other clusters.

3.3 Models for annoyance and for affective dimension (all clusters included)

For this preliminary analysis, we will focus on modeling the following variables: pleasantness (in the street), noise annoyance (closed windows), noise annoyance (open windows, garden or balcony) and noise annoyance (in the street).

As independent variables, the dimensions that describe the external sound environment are first used as for the sound environment categorization (section 3.1). To select the models presented Table 4, the leaps v3.0 package in R is used. It allows selecting a subset of multiple linear regression (exhaustive search).

Table 4 Selection of regression models for soundscape dimensions based on sound environment dimensions. Standarized coefficient, Adjusted R-squared and p-value (*** <.001, ** <.01, *.05, $^{+}$.1)

	Pl	Annoyance (CW)	Annoyance (OW)	Annoyance (Street)
Si	.45***	-.38***	-.39***	-.28***
Tra	-.13*			
2Wh			.14*	.30***
Air	-.14**	.14**		
Rail				.14*
ExV	-.11*	.16*	.23***	
CaV			-.11^{+}	
Mus		.17**		
Brd	.27***	-.16**	-.13*	-.21***
R_{adj}^2	44%	34%	35%	29%

Table 4 shows that 44% of the variance on pleasantness can be explained by a model based on the dimensions of the sound environment present in the street. In accordance with the literature, for all annoyance models, the variance explained by the external noise environment is around 30%. For the first three models, overall loudness is the variable that obtains the highest standardized coefficients. This variable is followed by the time of presence of two-wheelers (2Wh) or road traffic (Tra). However, all theses variables are significantly correlated and one of them could easily be replaced by another while maintaining a similar value for the adjusted R^2 (e. g. r=.74, p<.05) between the two-wheelers and traffic and r=.37 (p<.05) between two-wheelers and the overall loudness (Si).

Expressive voices or music has a negative impact on the pleasantness or increase annoyance at home (open or closed windows). As before, the music (Mus) and Expressive Voice (ExV) variables are quite correlated (r=.56, p<.05) and one could be subtracted to the benefit of the other. This reflects the proximity of the leisure districts with the presence of many inhabitants of the hyper-central area in our corpus.

The presence of birds (Brd) appears in all models and reduces discomfort or increases pleasure. This positive effect can be directly related to the noise environment but also in the context of a reduction in the annoyance of the closed window, such as a proxy for the presence of vegetation near the dwelling.

3.4 Adding personal information

In this section, the age range variables (Age) (transformed into a continuous variable), Gender and noise sensitivity (NS) are added to the previous annoyance models.

Table 5 Selection of regression models for soundscape dimensions based on sound environment dimensions. Standarized coefficient, Adjusted R-squared and p-value (*** <.001, ** <.01, *.05, $^{+}$.1)

	Annoyance (CW)	Annoyance (OW)	Annoyance (Street)
Si	-.36***	-.36***	-.24***
2Wh		.16*	.31***
Air	.14*		
Rail			.15**
ExV	$.12^{+}$	.20**	
CaV		-.16**	
Mus	.17**		
Brd	-.16**		-.16**
NS	.13*	.24***	.26***
Age	-.17**	$-.10^{+}$	
R_{adj}^2	37%	40%	36%

Table 5 shows that these variables allow a slight increase in the explained variance. According to the literature, noise sensitivity plays a significant role in linear regression. Age is also sometimes involved in the model but less significantly. However according to the literature, age does not behave always linearly with noise sensitivity and annoyance.

3.5 Adding housing information

In this section, all housing variables (part 4 of the questionnaire) are added to the noise annoyance models. Only models concerning annoyance inside home are therefore concerned.

Table 6 Selection of regression models for soundscape dimensions based on sound environment dimensions. Standarized coefficient for numeric variables, Adjusted R-squared and p-value (*** <.001, ** <.01, *.05, $^{+}$.1)

	Annoyance (CW)	Annoyance (OW)
(Intercept)	-.20**	-.15*
Si	-.34***	-.32***
2Wh		.13*
ExV	.15*	.16*
CaV		-.15**
NS	.13*	.21***
Age	-.17**	-.11*
Quiet_Room - Yes - No	.62***	.47***
R_{adj}^2	40 %	44%

Table 6 shows that adding the housing variable allows an increase in the explained. One variable seems to have much more influence than the others. It is the possession or not of a quiet room in his dwelling.

4. CONCLUSIONS

All the results are not yet known (end of March 15) and only these preliminary results could be presented. However, the following conclusions can already be drawn:

- The Swedish protocol once again shows its robustness and interest in describing the soundscape,
- The study area contains a wide variety of sound environments that will allow for a rich analysis of the results,
- The use of the perceived presence of time for different sound sources combined with the perception of global sound level seems to confirm that it is a robust and interesting way for predicting soundscape indicators.
- In accordance with the literature, the addition of personal information (age, noise sensitivity) as well as housing information (quiet room) often explains a significant portion of the expressed annoyance.

A next step will be to cross all these variables with the acoustic variables measured by the sensors set in the area. As part of the CENSE project, it is also planned to work on the automatic recognition of sound sources from acoustical measurement. Models of the soundscape could then be proposed on the basis of physical measurements of the sound environment.

5. ACKNOWLEDGEMENTS

The authors want to thank the city of Lorient and in particular J.C. Baron and P. Crépeaux from *"le pôle cadre de vie et development durable"* (the life and sustainable development center). This work was financed under the ANR project CENSE No. ANR-16-CE22-0012.

6. REFERENCES

[1] A. L. Brown et I. van Kamp, « WHO Environmental Noise Guidelines for the European Region: A Systematic Review of Transport Noise Interventions and Their Impacts on Health », *Int J Environ Res Public Health*, vol. 14, nº 8, 03 2017.

[2] R. M. Schafer, *The Tuning of the World: Toward a Theory of Soundscape Design*. University of Pennsylvania Press, 1977.

[3] Ã. Axelsson, M. E. Nilsson, et B. Berglund, « The Swedish soundscape-quality protocol », *The Journal of the Acoustical Society of America*, vol. 131, nº 4, p. 3476-3476, avr. 2012.

[4] P. Aumond, A. Can, B. De Coensel, D. Botteldooren, C. Ribeiro, et C. Lavandier, « Modeling Soundscape Pleasantness Using perceptual Assessments and Acoustic Measurements Along Paths in Urban Context », *Acta Acustica united with Acustica*, vol. 103, nº 3, p. 430-443, mai 2017.

[5] J. M. Fields *et al.*, « Standardized General-Purpose Noise Reaction Questions For Community Noise Surveys: Research And A Recommendation », *Journal of Sound and Vibration*, vol. 242, nº 4, p. 641-679, mai 2001.

[6] H. Kishikawa, T. Matsui, I. Uchiyama, M. Miyakawa, K. Hiramatsu, et S. A. Stansfeld, « The development of Weinstein's noise sensitivity scale », *Noise and Health*, vol. 8, nº 33, p. 154, janv. 2006.

[7] Ö. Axelsson, M. E. Nilsson, et B. Berglund, « A principal components model of soundscape perception », *The Journal of the Acoustical Society of America*, vol. 128, nº 5, p. 2836-2836, nov. 2010.