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Exploratory analysis of the factors involved in the perception of the quality of urban soundscapes

García-Checa, Francisco[1]; Pérez, Germán[1]; Torija, Antonio J.[2] & Ruiz, Diego P.[1]

[1] Dpto. Física Aplicada, Facultad de Ciencias, Campus Fuentenueva s/n, Universidad de Granada, 18071 Granada, Spain. Tel: +34 958 244 161Fax: +34 958 243 214 E-mail: druiz@ugr.es.
[2] ISVR, University of Southampton, Highfield Campus, SO17 1BJ Southampton, UK, E-mail: ajtorija@ugr.es

Summary
The identity of urban environments are largely determined by their history and current use, which should be closely related. Moreover, the particular sound of a specific urban site should be a distinct component of its image and identity, thanks to which, the latter should be compatible and coherent with its use. At present, the range of city operations often has a negative impact on sound, which results in the degradation of the soundscape o sound environment; thus, usually soundscapes might not be a differentiating factor. This research approaches the study of the urban sound environment from a holistic point of view, based on the perspective of the concept of soundscape.
This paper presents the findings of a research study aimed at evaluating the sound quality of urban environments, whereby we try to identify and assess the significance of the factors influencing their appreciation concerning either their type, context and use, or associated measurable acoustic parameters. To this end, we selected eleven sites representative of Central District Granada, which were evaluated *in situ* by university students using the *soundwalk* technique. In addition, during the walks, binaural recordings were made and photographs of each environment were taken. These were then displayed to subjects of similar characteristics in the laboratory for evaluation. In each listening trial, the subjects were asked to fill in a questionnaire with open-ended and bipolar scale questions, with and without the image corresponding to the evaluated soundscape. We were thus able to analyze the influence of the visual environment on the perception of sound in public places.
In order to analyze the relationships between the latter and the judgments made by the subjects themselves, we took into account the calculation of physical and psychoacoustic parameters corresponding to the recordings

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1. Introduction

The sound environment plays an important role in a subject's relations with his surroundings, either enhancing them or, on the contrary, creating situations of dissatisfaction and/or isolation by having a significant effect on the place's acceptance or rejection. [1-2]. Until now, most of the actions undertaken in this regard by environmental technicians or officers have been based on conventional approaches to combating noise, considered merely as a pollutant, with the focus on the study of the degree of inconvenience for the population and, where possible, on methods of control. Indeed, ISO/TS15666:2003 specifies a method for evaluation of sound-induced annoyance using social and socio-acoustic surveys. This type of approach can sometimes be obsolete and insufficient, as it does not respond to the wide variety of situations that fall outside annoyance in the urban context. Over the past 20 years, many researchers have analyzed the influence of the sound context in the perception of the urban landscape, either by means of controlled studies in

the laboratory [3-4], or in field studies by surveying of the opinions of the users of these spaces [5-6]. An example of this new approach began in 2008 with the setting up of ISO/TC 43/SC study group 54, to undertake the study of a standardized method for evaluation of the quality of the soundscape in outdoor environments.

The present study forms part of a methodological approach which, from the viewpoint of the soundscape [7-12] aims to evaluate the quality of environmental sound in the central district of the city of Granada (Spain).

The general goal of this research was to study the relationships between the opinions given by individuals regarding certain urban soundscapes according to different types of listening (*in situ* and in the laboratory).

2. Methodology

2.1. Subjective evaluation

Eleven places were selected as representative of the Central District of Granada (Table I), which were evaluated using the *soundwalk* technique by students of the University of Granada. The binaural response for each space was recorded suing a SQuadriga I (HEAD Acoustics) player/recorder with sampling at 48 kHz. The study was completed using two modes of laboratory listening test. Two listening conditions were evaluated : (i) a fragment of the soundscape of each of the chosen locations was played back with no reference of any sort, and (ii) the same soundscapes fragments were played back along with an image of the correspondig location.

As tools for meaurement of perception in any of its forms, we designed questionnaires to be answered individually after each listening experience. The items were the same for all the different evaluation procedures.

The questionnaire contained a bipolar scale consisting of 13 adjectives referring to the soundscape, as used previously by other researchers. These adjectives were *pleasant*, *quiet*, *annoying*, *varied*, *nearby*, *natural*, *chaotic*, *exciting*, *stable*, *familiar*, *sharp*, and *safe*. Questions were to be answered on a five-point scale: « Strongly agree », « Agree », « Neither agree nor disagree », « Disagree » and « Strongly disagree ». For easier understanding of the questions, the scale was presented horizontally with the same space between answers and the respondent was informed that the other end of the scale represented the antonym of the adjective in question. In all cases, replies to the questionnaires were individual.

For the purposes of this study, the sound quality of any urban space was understood as being directly related to the pleasantness and acceptability that the soundscape provided to its observers. For this reason, a new variable ($Total_{LIKERT}$) was introduced in the data processing, consisting of the sum of the variables with best correlation between their values with pleasant variable (>0.4). We considered this variable to be directly related to the sound quality and, therefore, another element in its measurement.

Table I. Description of locations

Name	Short description and main sound sources identified
Jardines del Triunfo	Broad sloping esplanade with gardens centred on the Monument to the Immaculate Conception and its fountain. Sources : People, distant traffic, birds. etc.
Avenida de la Constitución	Wide boulevard-like avenue with central walk slightly raised above street level. Sources : Taffic, passers-by, etc.
Plaza de la Universidad	Small square with car access via narrow, one-way cobbled street. Sources: Traffic, birds, etc.
C/ Puentezuelas	Pedestrian precinct with traffic restricted to residents. Sources : Pedestrians, music, children, etc.
Plaza de la Trinidad	Square with central stone fountain and many large trees. Sources : People talking and walking, braking cars, etc.
Calle Mesones	Very busy, exclusively pedestrian street. Sources : Music, footsteps, conversations, etc.

Plaza de las Pasiegas	Square on two levels connected by steps in front of cathedral façade. Sources : Street sellers, footsteps, talking, etc.
Plaza de Bibrambla	Andalusian or Castilian-type square, but without colonnade or public buildings. Sources : Machinery, fountain, voices, etc.
Puerta Real	One of the busiest places in the city at the intersection of its main streets. Sources : Traffic, horns, footsteps, etc.
Calle Navas	Pedestrian street very close to the City Hall, with heavy pedestrian traffic due to its numerous restaurants. Sources : Horns, laughter, people talking, etc.
Reyes Católicos	A very busy street at the centre of the main administrative and commercial area. Sources : Traffic, people walking and talking.

2.2. Physical evaluation of the soundscapes

We analyzed the temporal and spectral characteristics of the sound pressure level. [12] [13]. Psychoacoustics covers an important field in the different dimensions involved in the evaluation process of ambient sound, so we also calculated several psycho-acoustic parameters related to hearing and sound quality [14] (Table II).

TABLE II. Descriptive statistics of some acoustic variables, calculated for all 11 soundscape excerpts (Summary).

Acoustic variable	N	Min	Max	Mean	SD
$L_{Aeq\ (60\ s)}$ (dBA)	11	53.0	69.2	62.5	4.56
L_{A10}-$L_{A90\ (60\ s)}$	11	3.2	15.3	7.8	4.7
L_{Ceq} - $L_{Aeq\ (60\ s)}$	11	2.7	13.7	7.5	2.78
$TSLV_{(60\ s)}$ (Time sound level variance)	11	0.4	27.7	8.3	10.01
$CF_{(60\ s)}$ (Crest factor)	11	0.1	0.5	0.35	0.13
$G_{(60\ s)}$ (Spectral centre of gravity)	11	89	604	299	160
$N_{average\ (sone)\ (60\ s)}$	11	8.7	23.8	16.1	5.27
$R_{average\ (asper)\ (60\ s)}$	11	1.5	2.5	2	0.33
$S_{average\ (acum)\ (60\ s)}$	11	1.5	2.6	2.1	2.94
$Fs_{average\ (vacil)\ (60\ s)}$	11	0.006	0.053	0.018	0.344
$T_{average\ (tu)\ (60\ s)}$	11	0.045	0.168	0.074	0.033
$SIL_{average\ (dB)\ (60\ s)}$	11	14.3	69.9	37.8	18.39

3. Results and discussion

3.1. Reliability analysis

The analysis of correlations between variables used for the Likert scale allows to obtain the direction of the correlation for their recoding and use in such scale. The recoded variables were: Pleasant, Quiet, Natural, Organized, Safe, Soft and Comfortable. The sum of all of them allowed for the creation of a new variable. The reliability factor (Cronbach alpha) rose to over 0.85.

3.2. Descriptive study

A descriptive study of the Likert scores by location and type of evaluation procedure (soundwalk and laboratory listenings with and without photos)

showed that the lowest mean values were obtained in Puerta Real, Reyes Católicos and Avenida de la Constitución. The highest values were found in Triunfo, Puentezuelas and Plaza de la Trinidad. As expected, the worst scores were found in locations affected by road traffic.

3.3. Differences in perception by gender

We tested the differences in Likert scores between men and women for the perception sound environment. We carried out a t comparison for the quantitative variable for both groups. Statistically significant differences were detected (Table III.

3.4. Perceptive differences according to the type of audition (variable $Total_{Likert}$)

A variance analysis with the corresponding *post hoc* tests showed the influence of the type of listening on the subjects' assessment of the soundscape. We found that in general the listening group without photos gave lower values for the overall score than the other two types of listening. However, the locations most subjected to traffic noise were given the lowest values in the direct experience of the soundwalk.

In the case of men (Table IV), significant statistical differences were found at a higher number of locations. All the squares obtained the highest values during the soundwalk, and the same was true of the two pedestrian precincts (Navas and Puentezuelas). No statistically significant differences were found in the assessments of the locations most affected by traffic noise (Puerta Real and Reyes Católicos).

Women gave a noticeably more homogeneous evaluation than men (Table V), with statistically significant differences only at three of the eleven locations (as against eight for the men). These were Triunfo, Avenida de la Constitución and Plaza de la Trinidad, which are the locations with most vegetation and natural elements. With only slight traffic noise, the Triunfo Gardens scored more highly during the soundwalk, whereas the Plaza de la Trinidad had the highest score during laboratory listening with a visual image. With more traffic noise, the Avenida de la Constitución had a lower score in both the soundwalk and in the laboratory listening without a photographic image.

Table III. Perceptive differences by gender

	Mean (Men)	Mean (Women)	T statistic	p-value
Likert score	18.482	19.475	-3.1645	0.0016

Table IV. Perceptive differences by location according to type of audition and gender (Men)

	Soundwalk Mean	Listening Mean	Listening+Photo Mean	F statistic	p-value
Jardines del Triunfo	20.375^{ab}	19.6667^{a}	24.667^{b}	9,057	0.00034
Avda. de la Constitución	$14,625^{a}$	14.9697^{a}	17.7879^{b}	5.609	0.005
Plaza de la Universidad	23.625^{a}	$17,2424^{b}$	18.6970^{b}	6.276	0.00026
Puentezuelas	25.50^{a}	20.9394^{b}	21.5455^{b}	3.914	0.024
Plaza de la Trinidad	26.625^{a}	20.000^{b}	21.3030^{b}	7.97	0.001
Plaza de las Pasiegas	25.6250^{a}	19.5455^{b}	20.0909^{b}	5.83	0.005
Plaza de Bibrambla	21.750^{a}	15.6970^{b}	19.3030^{ab}	7.356	0.001
Mesones	18.750	16.2424	18.5455	3.429	0.038
Puerta Real	14,933	15,137	14,667	0.089	0.915
Calle Navas	21.750^{a}	16.0909^{b}	16.6970^{b}	5.464	0.006
Reyes Católicos	14,533	16,235	15,686	0.265	0.768

Superindices a and b indicate statistically significant differences

Table V. Perceptive differences by location according to type of audition and gender (Women)

	Soundwalk Mean	Listening Mean	Listening+Photo Mean	F statistic	p-value
Jardines del Triunfo	27.000[a]	16.7143[b]	20.833[b]	14.557	0.0000018
Avda. de la Constitución	14.000[a]	15.1111[ab]	19.50[b]	5.532	0.008
Plaza de la Universidad	20.7143	19.222	23.111	2.958	0.063
Puentezuelas	22.5714	22.111	23.000	0.289	0.750
Plaza de la Trinidad	21.1429[ab]	20.111[a]	25.333[b]	5.788	0.006
Plaza de las Pasiegas	22.7143	19.500	22.2778	2.014	0.147
Plaza de Bibrambla	17.1429	17.6667	21.111	2.001	0.148
Mesones	17.2857	18.4444	19.4444	0.528	0.594
Puerta Real	14,7143	15,8333	14,7143	0.831	0.443
Calle Navas	21.000	18.667	18.500	0.900	0.415
Reyes Católicos	14.000	16.611	16.000	0.618	0.544

Superindices a and b indicate statistically significant differences

3.5. Perceptive differences between locations

Variance analysis with the $Total_{Likert}$ variable and the locations differentiated by gender showed that we could refute the hypothesis of equality of means in both (men: F=24,430, p<0.0001; women: F=13,189, p<0.0001). The corresponding Post Hoc tests again showed a more homogeneous assessment by women (Tables VI and VII). These differences become more accentuated on introduction of the type of listening in the study of the cases. The type of audition was less critical in the perception of sound environment for women than for men.

Table VI. Perceptive differences between locations (Men)

	Location	N	Subset for alpha = 0.05				
			1	2	3	4	5
Scheffé[a]	Puerta Real	74	14.9595				
	Reyes Católicos	74	15.6892	15.6892			
	Avenida de la Constitución	74	16.1892	16.1892			
	Calle Navas	74	16.9730	16.9730			
	Mesones	74	17.5405	17.5405	17.5405		
	Plaza de Bibrambla	74	17.9595	17.5950	17.9595		
	Plaza de la Universidad	74		18.5811	18.5811	18.5811	
	Plaza de la Pasiegas	74			20.4459	20.4459	20.4459
	Plaza de la Trinidad	74				21.2973	21.2973
	Puentezuelas	74				21.7027	21.7027
	Triunfo	74					21.9730

Table VII. Perceptive differences between locations (Women)

	Location	N	Subset for alpha = 0.05		
			1	2	3
Scheffé[a]	Puerta Real	43	14.8140		
	Reyes Católicos	43	15.9302		
	Avenida de la Constitución	43	16.7674	16.7674	
	Mesones	43	18.6744	18.6744	18.6744
	Calle Navas	43	18.9767	18.9767	18.9767
	Plaza de Bibrambla	43	19.0233	19.0233	19.0233
	Plaza de la Universidad	43		21.0930	21.0930
	Plaza de la Pasiegas	43		21.1860	21.1860
	Plaza de la Trinidad	43			22.4651
	Puentezuelas	43			22.5581
	Triunfo	43			22.7442

3.5. Relation between physical and psycho-acoustic parameters measured by evaluation of urban sound quality.

In order to relate the subjective evaluations of the participants in the experiment with quantifiable acoustic parameters, we undertook a discriminant analysis. First, the evaluations were classified into three groups according to the Likert score and gender: Low Level, Medium Level and High Level. This was done using a cluster analysis of K-means with three conglomerates.

The resulting optimal set of discriminant variables consisted of $L_{A10} - L_{A90}$, $L_{Ceq} - L_{Aeq}$ and $R_{average}$. These variables are related to temporal variability, the low-frequency content and the presence of the characteristic modulation of road traffic.

Finally, each location was classified on the basis of the discriminant variables. Once the discriminant functions and centroids of each group had been defined, we calculated the discriminant scores of the two functions for each location, the probability of belonging to each group and the final assignation of the values of the three variables discriminant functions and centroids of each group had been defined, we calculated the discriminant scores of the two functions for each location, the probability of belonging to each group and the final assignation of the values of the three variables (Table VIII).

Table VIII

	Score1	Score2	Prob1	Prob2	Prob3	Group
Triunfo	-1.917	2.122	.0746	.1650	.7604	**High lev.**
Avda de la Constitución	.603	.073	.4635	.34829	.1882	Low lev.
Plaza de la Universidad	-.1230	-1.088	.29365	.44122	.26513	Medium lev.
Puentezuelas	-.9045	-.2798	.18161	.36728	.45111	**High lev.**
Plaza de la Trinidad	-1.406	.04399	.12127	.30977	.56896	**High lev.**
Plaza de las Pasiegas	-.8494	-1.378	.17778	.44170	.38052	Medium lev.
Plaza de Bibrambla	-.0928	-.1179	.31951	.38163	.29886	Medium lev.
Mesones	1.0818	.12122	.56037	.31204	.12759	Low lev.
Puerta Real	1.3752	.07960	.61380	.28876	.09744	Low lev.
Calle Navas	.59804	-.9838	.42967	.40790	.16243	Low lev.
Reyes Católicos	1.6594	1.5741	.70843	.20265	.08892	Low lev.

4. Conclusions

1. The type of listening and the gender of the observer affected the evaluation of the soundscapes.
2. Women perceived environmental sound as louder and more pleasant than men.
3. Women gave a more homogeneous evaluation of soundscapes, with much less influence of the type of listening than men.
4. Women perceived fewer statistically differentiated environmental groups ; as with the type of listening, their evaluation of the soundscape according to location was much more homogeneous than that of the men.
5. The locations with higher sound levels had the lowest scores, even when the source was mainly human (e.g., Mesones and Navas).
6. When the source of the predominant sound was traffic, no perceptive differences were observed according to the type of listening for either gender.
7. Some physical parameters successfully used in previous experiments, such as loudness and the spectral centroid, do not seem to correlate or discriminate well with perceived pleasantness in this experiment.

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