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Perceptive relevance of soundscape descriptors: a morpho-typological approach

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For assessing the validity of a morpho-typological classification of urban sounds with respect to sound assessment, factor analysis was applied to a database compiled in the city of Lyon and lead to a four-classes classification based on the number of lanes and whether a street is one-way or not. Free categorisation was then carried out on sound excerpts recorded in different sites corresponding to different classes. The main results are: a corpus of 42h of 5-channel recordings of a choice of sites from the classification at different times of the day; the validation of the relevance of the morpho-typological classification for perception; and a confirmation of the semantic oppositions between sources and background noise, as well as holistic and event sequences. Further, annoyance is controlled by the absence or the presence of human or nature sound sources, pleading for research toward automatic identification of sources. Lastly, categorisation confirms earlier investigations based on variance analysis: in narrow and large streets, traffic increase differently governs the increase of both noise level and annoyance.

1 Introduction:

The diagnostic and the management of urban soundscapes require transversal actors and competencies: environment, economy, transportation, and health. Beside objective noise quantification, it must also address the subjective description of sound annoyance.

Today's acoustical indices have been designed for large spatial and temporal scale description of sound exposure only. No index exists for local description of sound nuisance in time and space that can be correlated to noise perception by the inhabitants. The aim of the research presented here is, therefore, to pave the way for indices relevant to noise perception by residents during the sensitive periods of the day, when they fall asleep (evening) or wake up (morning).

2 Urban noise problematic

Today's indices for noise exposure are constructed according to different logics:

- the European Directive: equivalent level, Lday, Levening et Lnight, Lden
- statistical indicators: traffic noise index, level of noise pollution
- event indicators: sound exposure level, number of noise events, masking index, noise and number index, perceived noise decibel, psophic index, etc.

However, they do not take into account differences in time and space that constitutes the acoustical diversity of soundscapes. Therefore, the present research has followed the diagram of Fig.1.

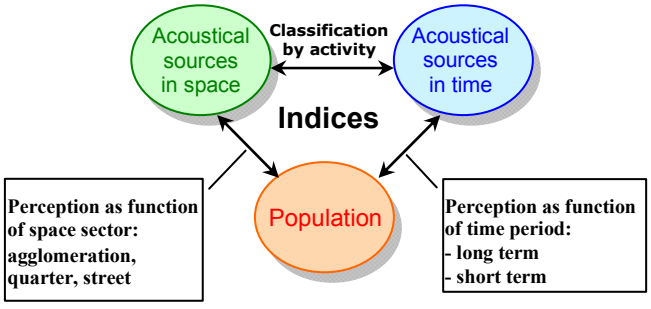

Fig.1 The problematic of urban noise indices.

A quick survey of the literature proves that only the spatial diversity of soundscapes has been evaluated. For example, the Italian partners of the present project [14] have analysed the different variables that influence sound exposure and selected out the factors displayed in Table 1.

Factors	Levels	
Running conditions	double way	one way
Number of lanes	≤ 2 lanes	> 2 lanes
Road width	8 meters	> 8 meters
Traffic divisor	yes	no
Buildings (side 1)	yes	no
Buildings (side 2)	yes	no
Pavement typology	asphalt	other
Number of cars	< 44 veh./ 5 min.	> 44 veh./ 5 min.
Speed of cars	60 km/h	> 60 km/h
Temperature	30 ˚C	> 30 ˚C
Relative humidity	50 %	> 50 %
Wind	absent	present

Table 1 Selection of factors influencing sound exposure.

Taking into account all the combinations is an impossible task. Using multivariate statistical techniques help reducing the number of sites. Nevertheless, the number of factors must be drastically reduced in order to make the test manageable. This is done partly by analyzing redundancy between factors, partly by ruling out the combinations that do not exist in reality. In the present research, a different approach was therefore selected.

3 Classification with noise measurements

Instead of starting from the factors that theoretically influence urban soundscapes, the present research focuses on a survey of existing sites, using powerful factorial analysis to select the relevant combinations of factors (Multiple Correspondence Analysis). The analysis was extended by cluster analysis in order to extract a classification of urban sites.

3.1 Factorial analysis

Based on the database provided by Acouphen, a selection of 42 extensively documented site was used for the factorial analysis. Since the analysis requires more sites than variables, the later were reduced to the most relevant ones and the best documented. Thus, only a handful of variables are available: traffic related variables; street related variables relatives such as street type, traffic direction, lane width, etc.; and the degree of openness of the street, that is, the ratio height/width. Only one acoustical variable was available for *all* sites: LAeq (6h – 22h). Since it did not discriminated the sites in a preliminary study, acoustical variables were not kept as independent variables but only as illustrative variables in order to help the interpretation of the factorial axes.

Fig.2 presents the first factorial plan thus obtained. Axis 1 opposes narrow, one-way, U-shaped streets with weak traffic (circled in orange), to wide, double-way open streets with heavy traffic (circled in green). In a similar way, axis 2 opposes wide, double-way streets with heavy traffic to less wide and circulated one-way streets: on axis 2, configuration and degree of openness do not play a role.

Fig.2 First factorial plan from site analysis.
Axis 1: degree of openness; axis 2: traffic level.

3.2 Cluster analysis

Ascending hierarchical classification makes it possible to define between 3 and 7 classes, according to the degree of granularity adopted. However, some classes are underrepresented, so that it make sense to complete the cluster analysis with the analysis of the factorial space. This critical analysis leads to retain the typology of 4 classes presented in Fig.3. As this typology is based on morphological variables only, and does not contain any acoustical variables, it constitutes a morpho-typology of urban spaces.

However, analysis of the acoustical variables showed some correlation with the classes. Classes A and B, which correspond to *boulevards*, are linked high acoustical indices as expected. Similarly, classes C and D, corresponding respectively to *double*-way and *one*-way streets, are linked to low acoustical indices, especially in the morning period (6h-7h). This is a first hint toward the relevance of sorting out the sensitive periods of the day.

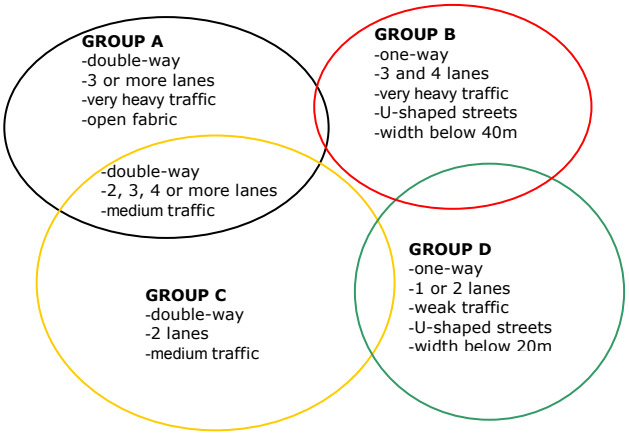

Fig.3 Morpho-typology of urban sites in 4 classes.

4 Perceptual categorization of urban areas

In order to test the perceptual relevance of the morpho-typology of Fig.3, sound recordings were carried out on 6 urban sites chosen among the 4 classes of the typology.

4.1 Recording soundscapes

The recording technique used is the same as in previous studies [7, 8, 9], where it proved its perceptual relevance for urban soundscapes. It is based on the Ambisonics technique, carried out with a Soundfield microphone, to which an omnidirectional microphone is added ensure accurate recording of the low-frequency content of the soundscapes.

The microphone system was placed outdoors, on a balcony or in front of the window of apartments, the locations of which were selected to correspond to the 4 classes of the typology. These sites were selected according to the description of the classes in Fig.3, that is:

- double-way, heavy traffic, several lanes
- one-way, heavy traffic, several lanes
- double-way, weak traffic, 2 lanes
- one-way, weak traffic, 1 lane

Since the study concentrated on sensitive periods of the day, 3 time periods were selected for the recordings at each site:

- morning, between 6h and 9h,
- evening, between 20h and 24h
- and a test period, between 10h and 11h, when traffic has reached its peak.

4.2 Listening set-up

The listening tests took place in the listening room at LAM, which basically is constituted of a very damped, fully insulated room equipped with a rig of 12 loudspeakers and a subwoofer. Only 6 loudspeakers, located on a horizontal hexagon centred on the listener's head, were used for the

listening tests, using standard Ambisonics decoding. The subwoofer, located in one corner of the room, completes the set-up. A full description of the rig is given in [8, 9].

For practical reasons, it is impossible to fully use of the 7 hours of recording at each site during the listening tests. Therefore, 4 sequences were extracted per site, 2 in the morning and 2 in the evening, corresponding respectively to the beginning and the end of each period. For the same reason, the duration of the sequences was kept to values between 20 and 40 seconds. Weather conditions made some of the recording unusable, so that a total of only 22 sound sequences were played back in the listening room.

4.3 Listening test

The test comprised three tasks. In the first task, the subjects had lo listen to the sequences and answer 3 questions for each sequence. Since the wording of a question influences the responses, the French originals are systematically given with their tentative translations:

- "Avez-vous l'impression de vous retrouver dans une situation de tous les jours ?" (Do you have the feeling of experiencing an everyday situation?)
- "Pouvez-vous indiquer le type de lieu dans lequel vous imaginez être et où vous situez-vous dans ce lieu ? " (Can you indicate the type of place where you imagine to be and where do you locate yourself in the place?)
- "Pouvez-vous préciser à quelle période de la journée ces séquences sonores peuvent se produire ? " (Can you specify the period of the day when this sound sequence can happen?)

The second task consisted in the free categorisation of the 22 sequences. Listeners were given the instruction to "regrouper ensemble les séquences sonores qui selon vous se ressemblent" (group together the sequences that sound similar to you). When the groups were constituted they were asked to select a prototype, that is, "la séquence sonore qui représente le mieux chaque groupe" (the sound sequence that best represents each group), and then to give the main characteristics of each group and justify them.

The third task was linked to annoyance ("gêne"): subjects had to choose the most and less annoying sequences ("la plus et la moins gênante").

4.4 Results

The results presented here are partial since they concern 12 subjects only, all male but one, aged between 25 and 55 years. It is planned to resume the tests as soon as possible to reach a minimum of 24 subjects, with similar proportion of males and females. These preliminary results for the first task shows that listeners are able to successfully associate a sound sequence to a type of site, as proved by the low number of "don't know" responses (9.5%). However, they only recognize the type of site once out of three times (35,6%), with a similar error rate (38,6%). On the other hand, they are not able to recognize the period of the day: only one out of six responses is correct (16,3%), and half of the responses are wrong (45,8%); subjects don't know in 35,3% cases.

The second task, categorisation, was analysed with the aggregation method of Barthélémy and Guénoche [1], an algorithm based on Sattath and Tversky [15] that builds up an additive tree to represent a distance matrix. In the present case, ultrametric distances are used, that is, the distance between two sequences is set to 0 when they belong to the same group and 1 otherwise; the final distance matrix is obtained by adding the distance matrices obtained for each subject. Thus, sequences always grouped together cannot be differentiated, as is the case for sequences 2 and 13 in Fig.4 which presents the result of the tree analysis of the data from task 2. Segments in Fig.4 are called branches, and link nodes where several branches are connected; terminal nodes are called leaves as expected from the tree analogy. The lengths of the branches correspond to mean distances. Numbers next to branches indicates the reliability of the discrimination, with 1 indicating unanimous agreement.

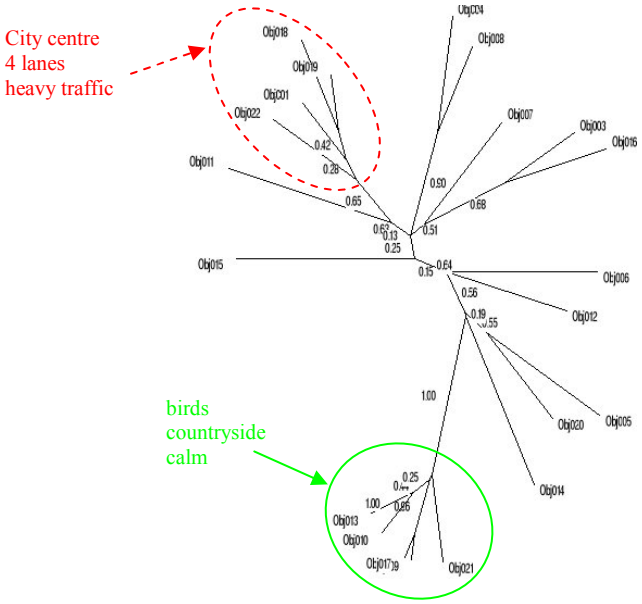

Fig.4 Tree-analysis of the categorization task. Sequences 2 and 13 are superposed.

Fig.4 singles out one class, circled in green, discriminated by *all* subjects. No other grouping stands out, stressing a remarkable feature of free-categorisation tasks: beside *dissimilarities*, like more traditional multidimensional scaling, they take into account *similarities*. All the other sequences are organized around a single node, revealing that the sequences are adequately discriminated by the subjects. Most of all, it stresses the perceptive relevance of the initial morpho-typological classes.

Fig.4 also opposes the class circled in green at one extremity of the tree to the sub-group circled in red at the other extremity. This opposition is confirmed by multidimensional scaling analysis (MDS), where it builds axis 1 which can be interpreted as sound intensity when using the descriptions of the groups given by the subjects.

An informal linguistic analysis of the descriptions of the groups by the subjects reveals a large variability of class denominations. However, subjects predominantly make use of denominations belonging to linguistic categories:

- places (roads, parks, etc.)
- sources (birds, etc.)

- activities (traffic)

Besides, very few pronouns or verbs are used in the descriptions, the latter being mostly verbs of movement. This informal linguistic analysis, therefore, confirms the work of V. Maffiolo [11, 12, 13] and C. Guastavino [7, 8], who showed that French subjects predominantly describes soundscapes with sources, and less frequently with physical descriptions. And the use of "places" to describe the groups also confirms that the association of a site to a sound sequence is "natural", but not the periods of the day which are never used in the descriptions. However, the period of the day is discriminating for the grouping, but only because it changes the rhythm and the intensity of the traffic.

As regards the third task, most of the subjects chose one of the sequences of the red sub-group as the most disturbing, and 5 chose sequence 17 in the green class as the less disturbing. Analysis of the reasons given by the subjects for their choice shows that disturbance opposes the physical register of traffic (dense, continuous, repeated intervals, high level, too high, permanence) to varied or far-away sources like *birds* or *animals*.

A formal linguistic analysis will be carried out when the full test results are available.

5 Toward event-related indices

The present research was aimed toward the differences in time and space that constitutes the acoustical diversity of soundscapes, as is illustrated in Fig.1. However, the perceptual tasks have only confirmed the relevance of space diversity, not of time diversity, at least at the scale of the periods of the day. On the other hand, at the scale of the event, time diversity becomes relevant in the opposition between permanent noise, which is disturbing, and noise *variety in time and nature*, which is *relaxing*.

When considering the different acoustical indices available, and sorting them according to their ability to describe differences in time and space (Table 2), its strikes out that no index so far reflects this variety in time and nature. Thus, there is a need to develop event-related indices, and the automatic identification of sound sources, as proposed by Defréville et al. [4], is a step in the right direction, but in the case of traffic, the distribution of passing-bys must also be taken into account.

Time → / Sites ↓	*Short term (seconds, minutes)*	*Mean term (hours)*	*Long term (days, weeks…)*
Agglomeration	L_{max}	L_D, L_N, L_E	L_{DEN}, L_N
Quarter	ΔLAeq (1s), Lx, L_{max}TEL	Leq (1h), Lx… L_D, L_N, L_E	L_{DEN}, L_N
Street	L_{max}, ΔLAeq (1s), TEL, NNE	Leq(1h), Lx, L_D, L_N, L_{max}, NNE	L_{DEN}, L_N, NNE

Crossing activities

Table 2 Classification of present acoustical indices.

The importance of sources linked to *nature* for the quality of the environment has been confirmed by other researches [6, 10], which further proved that the temporal structure is a crucial parameter for soundscapes [2, 3].

6 Conclusion

The present research has made use of complementary methodologies to validate the perceptual relevance of a typological classification of urban soundscapes based on morphological parameters only, that is, on the characterisation of urban sites and traffic. A two-step approach was used, first to classify urban areas and select typical urban sites, then to perceptually characterize these sites by use of soundscape recordings at different periods of the day.

Beside a database of 42h of sound recordings in extended Ambisonics format (5 channels) at 6 typical sites, the present research brings some precision about the features of soundscapes that are responsible for annoyance or the lack of it. Thus, sound sources linked to nature induce a relaxing character to soundscapes, provided that streets and cars are far away. Thus, automatic source recognition must belong to the panoply of quality indicators for soundscapes. Further, the repetition or superposition of traffic events at short intervals deteriorate this quality, pleading for the inclusion of rhythm indicators at different scales in the panoply. These are the two main directions for developing new indicators better inked to perception of soundscapes by the inhabitants [5, 16].

An unexpected finding from the present research has also been the difficulty to use databases from consultant firms. This finding pleads toward a standardized procedure for acoustical environmental measurements, together with some sort legal "depot" for preserving the accessibility and availability of these measurements for research purposes.

Acknowledgments

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