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In search for soundscape indicators : Physical descriptions of semantic categories

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ABSTRACT

We present converging evidence that people categorize urban soundscapes into semantic categories related to social activities. Examples of such categories are spontaneously described are « markets», « sidewalk cafés » or « parks ». The intensity cannot be considered as a relevant criterion for categorization per se, but rather relative to the kind of human activity underlying categorization. Furthermore, other cognitive properties have to be correlated to account for the categorical structure. The physical measurements of sounds as dimensions of soundscapes categories cannot directly account for noise annoyance. Inasmuch as subjective evaluation rely on the identification and appraisal of the sound sources, acoustic indicators become perceptually relevant only in relation to the range specific to a given meaningful category of sounds. We illustrate our rationale with various examples from field surveys and free sorting tasks of soundscape recordings. Results converge to show that a given acoustic stimulation can be processed in many different ways, depending on subjective factors such as previous (expert or common sense) knowledge, social practices, motivations and attitudes towards noise. Since acoustic stimulations are cognitively processed as semiotic cues pointing to meaningful events, these events need to be identified before measuring physical properties relevant for each category of event and a specific community of subjects.

1 INTRODUCTION

Empirical research in psychoacoustics has mainly developed along the psychophysical paradigm. It has established the "subjective evaluation" of stimuli as described analytically within a multidimensional space described by physics. Stimuli are conceived as dimensions and described as parameters **established by natural sciences**. Answers are collected using « closed » data collection instruments within **a priori categories** also given by the natural sciences, allowing quantitative data analysis of qualitative judgments. The analysis of mental representations of acoustic phenomena within such a psychophysical paradigm is thus conceived as the "subjective" (i.e. psychological) evaluation of "objective" (i.e. physical) measurements. The psychophysical investigation relies on **physical descriptions first** defined to secondly address psychological issues. Subjects are thus conceived as "imperfect" measurement instruments, because of their subjectivity, and in comparison to physical instruments. This line of research is therefore mainly concerned with low level processing (perceptual, discrimination annoyance or even pain thresholds for examples), accounted along dimensions that can be physically measured, and giving a central role to intensity or frequency. In this view, psychological processing is quantified in term of deviation from physical measurements.

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However in the case of complex auditory scenes, it is now accepted that higher-level processes are involved to account for elaborated cognitive representations. Actually, the subjective effects of complex sounds generally encountered in cities (as summarized by the concept of soundscape) rely on the **semantic values** attributed to acoustic phenomena through **cognitive processes**. Specifically, *soundscape research* requires therefore a global approach to urban environments. However, most attempts to define "global" indicators of noise annoyance by combining various different acoustic parameters and specially the ISO norms (even the recent 1996 ones), left aside the semantic value attributed to sounds that cannot be directly captured by physical measurements. The question to be addressed is then how can we account of soundscapes as meaningful acoustical events by means of physical parameters descriptions?

Recently soundscape research has brought attention to common experience where noise is simultaneously perceived from a wide variety of sources, and it has been established that people sort out complex sonic environments into discrete categories in everyday-life situations and that sound quality evaluations need to take into consideration semantic features such as **source identity** and semantic values (as suggested by numerous authors in Dubois & Schulte-Fortkamp, special issue of Acta Acustica united with Acustica on *Soundscapes*, to appear and more specifically in [6][~~2~~]). Furthermore, the importance of sound **source recognition** has also been demonstrated: "Obscuring" the recognition of the sound sources had a strong impact on perceived loudness and sound quality judgments [2][20][12].

The first point is to clearly establish the specificity of the two objects under considerations, a physical event occurring in the world, and (a) corresponding psychological object(s) that can be considered as mental representations or interpretations of the incoming stimulation [8]. As Bruner [3] among others pointed out, the specificity of psychological investigations is to figure out how the physical world **affects** people and how people elaborate a **representation** of the world on the basis of their **sensory experiences**. Soundscape research now claims for a pluridisciplinary approach [20][31]. In this view, human sciences aim is to objectively describing subjective phenomena that cannot be reduced to either physical descriptions, or simple "errors" derived from physical measurements of yet another object: the physical world. The empirical question remains to elaborate an adequate theory that explicitly related the specific properties of each object. Our proposal is to more precisely identify the relevant cognitive categories of soundscapes within contemporary theories of natural categorization [29][24][10] in order to first elucidate the relevant properties that could be further physically described.

2 A REPRESENTATIVE SET OF RESULTS

We will present here some representative results in order to illustrate the rationale that could yield new insights into collaborative research between acoustics and human sciences. Guastavino [13] conducted a free sorting task of 16 recordings of urban ambient noise recordings using a 6.1 Ambisonic reproduction system. 26 participants were asked to freely organize the recordings according to perceived similarity. The 2-dimensional representation of the dissimilarity matrix derived from the free sorting task is shown in Figure 1 (stress = 0.049, 97.5% of variance explained). The dissimilarity between two recordings is represented by the euclidean distance between the two corresponding points in space. Participants categorized the urban soundscapes along semantic categories related to social activities, namely « markets» (67-73 dBA), « sidewalk cafés » (64-66 dBA) « traffic » (65-69 dBA) and « parks » (65-68 dBA).

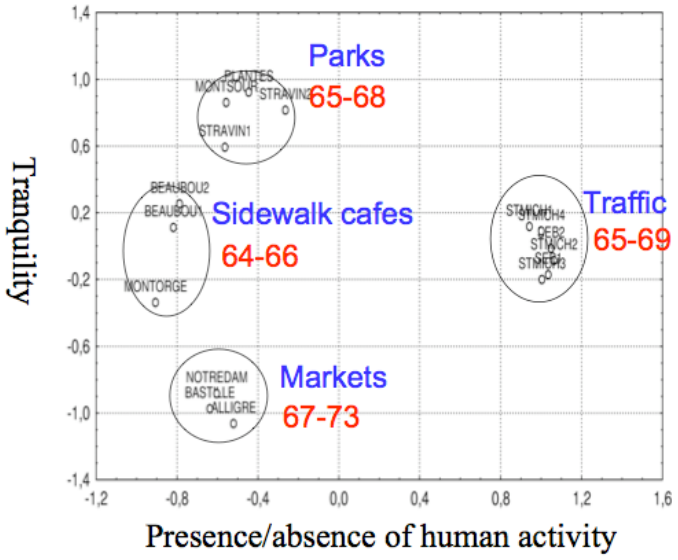

Figure 1: 2-dimensional representation with the dBA range and verbal descriptor for each category.

Intensity was measured as the Leq dBA over the duration of the sound samples, i.e. 13s. A one-way ANOVA revealed a lack of significant difference in intensity across the 4 main categories ($F(3,11)=2.63$, $p>0.1$). Several psychoacoustic parameters were computed and used for statistical analysis to predict category membership from physical parameters of the sound samples. Both logistic regression and discriminant analysis were carried out. The acoustic parameters investigated were the spectral centroid, the sound pressure level in dB Lin and dB(A)i in third octave bands, the loudness and the L5, L10 , L50 and L95. No significant interaction between psychoacoustic parameters and category membership was observed. Together with the observed lack of spontaneous descriptions of physical properties, these results suggest that people categorized the recordings on the basis of semantic features rather than perceptual ones. Acoustic indicators cannot be considered as a relevant criterion as such in categorization. We have therefore to elucidate the intermediate relevant variable that will enable us to connect internal structure of properties of the cognitive representations to relevant physical parameters.

In the present case, the intensity values as physical indicators get their relevance along with the **range** of intensities **within each categories** in relation to the kind of human activities typically performed in this situation. For example, 67 dBA is just **normal** for a soundscape in the park category (because it is quiet enough to take a walk), but it is **quite high** for soundscape in the sidewalk café district (where you want to be able to chat without having to yell), and **quite low** for a market (typically noisy environments with many street vendors).

Therefore, intensity is not a relevant parameter per se, but get a relevant significance in relation to membership within a semantic category. In other words, the physical measurements of sounds as dimensions of soundscapes categories cannot directly account for noise annoyance. Inasmuch people subjective evaluation rely on the identification of the meaning of the sources, structured in categories, the physical measures of intensity get relevance from its range within a meaningful category of sounds. Dimensionality, even for intensity, is relevant **within a range related to one specific categorical membership**.

3 POLYSEMY OF GRADING ON SEMANTIC SCALES

If intensity is already problematic as a strict dimensional parameter, further results show that is even more difficult to connect physical parameters with other cognitive properties identified as being relevant in the structure of the categories of soundscapes such as frequency, temporal structure, or continuity. Raimbault [28] in her analysis of verbal comments on scoring differential semantic scales showed that, when asked to explicitly comment their scoring, respondents give a large diversity of meanings to the poles of each scale, and also to the intermediate values of the scale. For example, the spatial scales middle grade covers a diverse range of answers for the *near - far scale* (the middle category of which gave 22% of responses for the overall locations) and *unclear – distinct* one (12%). Examination of verbal reports revealed the difficulties to state a unique semantic answer on a scale for these spatial features. A so-called dimensional scale could therefore account for different meanings to be closer examined (see below 4.), even for the only middle values that could appear to be either "*both of them*" or "*one or the other* (*it depends*)".

As previously explored on linguistic grounds (here above and [5]), the polysemy of verbal labels is neither a default nor an exception but just a normal state for our common sense linguistic performance for soundscapes, as for every sensory modality (see [9] for olfaction and [7]): we do not commonly communicate about acoustic phenomena and therefore we did not elaborate a consensual labelling, as we did for colors for example. The only consensual meaning is the one required by scientific discourse of physics where words as **terms** (nouns and adjectives) nicely and univocally fit to well-defined concepts. Given the polysemy of psychological answers, the research question then becomes: how can one correlate such a diversity with a unique simple acoustic parameter?

4 DIMENSIONS OR ATTRIBUTES?

Another question concerns the "dimensionality" of such scales, generally state as an a priori grounded in the conceptualization of physics but not quite addressed as a genuine empirical (psychological) question. The problem being in some way solved before having been addressed, through the help of quantification on a priori "scaled" properties that entail further statistical processing (such as MDS) also relying of similar a priori. However, research on categorization has revealed that the categorical internal structure is mainly structured along on **correlates of heterogeneous properties, features** or **attributes** (physical, functional, semantic etc…) that can be discrete, binary, more frequently than being purely dimensional or even multidimensional. For example, can we consider that, as far as biological categories are concerned, the number of legs is a proper **dimension** allowing for quantification along a continuum, rather than discrete criteria (2 legs, 4 legs, 6 or 8 legs, others… for membership definition).

An example borrowed from soundscape studies can be found in the analysis of verbal justifications to the semantic differential grid scales, the *monotonous- varied* scale already being presented as a significant example [28][26]. Psycholinguistic analysis of the verbal answers to the *monotonous-varied* scale has enabled us to distinguish two cognitive representations of urban soundscapes that worth discussing. It can be show that, for a same situation, people disagree on their evaluations of soundscapes. The verbal reports associated to the ***varied*** answers to the scale

referred to the description of a diversity of specific sound sources (66% of the expressions, mostly nouns) relating "*human presence*" (40%) and "*traffic*" (26%) and depending on the adverbial prepositions for locations (*close to, next to, in front of*) and time (*at night, during the day*). Psycholinguistic analysis thus suggests that subjects process a **"descriptive listening"** mode which aimed at the identification of acoustic sources or events, referring to discernable "objects" of the world.

On the other hand, studies of verbal reports associated to the ***monotonous*** answers refer to abstract sound descriptions, such as "*background noise",* mainly mentioning duration features, like "*continuous*" (55% of the expressions), and "*traffic*" noises (25%). From these analyses, we further infer that the monotonous judgment would rather refer to a "**holistic hearing**" mode which processes the soundscape to as a whole, without specific semantic processing of any sources. In short, the "same" semantic scale can be differently processed by different subjects (see section 8 for further discussion on this topic), and the two poles of the *monotonous-varied* scale refer to two different properties resulting in different processing that cannot be considered as adequately represented by a dimensional scale.

5 CATEGORICAL STRUCTURE AS CORRELATED ATTRIBUTES

If, from a cognitive point of view, there is no "objective" measurement of "intrinsic" intensity of the noise per se, but that it rather **depends on the type of source** which can be considered as "noisy" or not, how to account for the diversity of sources that characterize soundscapes? Can we consider that the overall result is the sum of the parts, the parts being to the single sounds object or limited spatial units, such as cars, trains, airplanes and workplaces which can be experimentally studied in laboratories? Sound sources can be considered "noisy" or not depending on the meaning attributed to the activity producing noise (see also UK project RUROS). This question also highlights the differences between soundscapes evaluation methods and psychoacoustics approaches which are limited. Human sounds are usually judged as less unpleasant that mechanical sounds. But finer grain categorization distinguished sub-categories according to semantic features. In the case of traffic noise, **public transportation** noise (train, tram) appears to be better accepted than private vehicles [14][30]. More generally, traffic noise evaluations are influenced by the value given sound source (with generally negative judgements for **road** traffic noise and less negative ones for **railway** noise), that is to the **social value** (individual vs. collective) of **noise** as a **semantic cue** and **not** as an intrinsic property of the **acoustic signal** (see [22] for other variables such as noise control). These observations indicate once more that the well-established dimension of intensity only become cognitively relevant in connection with a specific meaningful sound category, or to a set of correlated properties defining such a category.

Guski [18] already noticed that listeners often take loudness as indicating the distance of a sound source. Guastavino [16][17] conducted a more precise linguistic and cognitive analysis of the **spatial properties of "background noise**" in actual outdoors environments showing the complexity and the requirement of not eliminating spatial attributes in order to ensure ecological validity in laboratory conditions. This highlights the difficulty to use dimensional and a priori labeled scales, considered as **independent** dimensions (in the world), on which subjects can make independent judgments about their representations (in mind) in laboratory setting, inasmuch they only have experienced them in correlation.

Furthermore, accounting for the specificity of cognitive representations imposes to also consider as relevant the properties associated in **memory including other sense modalities**

properties (visual, kinesthetic, olfactory etc ..). The evaluation of urban soundscapes, even in laboratory settings is not strictly dependent on the present experience, but on past (memorized) experiences of the environment which contributed to developing attitudes and expectations regarding the incoming stimulation.

6 THE SAME STIMULUS DIFFERENTLY PROCESSED : SOME MORE EXAMPLES

Linguistics analysis of verbal data about urban soundscapes from common city users has shown that a unique acoustical phenomenon could give rise to various cognitive objects opposing the classical objectivist (object-centered) point of view to a subject-centered one considering soundscapes as effects from the environmental situation. However, our linguistic investigation indicated that, even within the object-centered conceptualization of soundscapes, a finer distinction could be identified, represented by the contrasted two labels of "***bruits*** *– noises*" and "***sons***- *sounds*" [5]. The most frequently reported linguistic devices used to describe the category of "noises" are names of the object-sources attributed to the sound sources (such as "*le bruit de mobylette*" i.e. *"the noise of motorbike"* or "*alarme de voiture"* i.e. "*alarm of car*") and nominal forms constructed on verbs *("grincement de frein"* i.e. *"squeaking of brakes*"), whereas "sounds" are lexicalized as acoustic patterns and described with adjectives. These findings highlight the fact that soundscape descriptions are processed as semantic features, through the shared meaning given to the object-source emitting noise, rather than to perceptual features, described as physical properties of "sound", even in object-centered descriptions.

Since a same physical phenomenon may give interpretation to at least two distinct cognitive representations, it becomes problematic to define new unique indicators based on community noise measurements. Moreover, a cross analysis between survey data and acoustic parameters (see [27]) indicates the limitation of matching a unique acoustic descriptor for all locations: if the sound level is appropriate to the description of main thoroughfares and holistic noises, it is not relevant for describing similar sound level locations including activities, such as square, market, or playground. If assessments of urban soundscapes are varying between subjects' processing and also across types of situations (i.e. combination of activity, time and environment), physical and qualitative measurements are not univoqual but remain relevant **within the categorical structure of soundscapes** identified from a **subject-centered analysis**.

7 BUT WHAT ARE THE RELEVANT CATEGORIES ?

Soundscapes are thus represented as events reflecting interactions between individuals and an environment through shared knowledge and activities, either from a psycho-social description (a perceived and individual evaluation) or a physical measure (but not only acoustical).Guastavino's analysis of the ideal urban soundscape clearly underlines relevant sound quality criteria and reveals the salience of human produced sounds: soundscapes mostly composed of traffic noise were described as unpleasant, whereas soundscapes in which human sounds were dominant were appreciated and subcategorised according to the significance of the type of socialized activities performed [13][14]. Soundscapes are essential for well-being, not only as music but as an integral part of living situations (i.e. meaningful). If ideal urban soundscapes should reflect life through sounds communicating human presence and activities, noise annoyance is interpreted by the fact that "traffic" is the obvious salient factor describing the environment of cities [25]. Sound sources symbolizing "traffic" are used to describe the urban

soundscapes in terms of the occurrence but also the lack of sound objects (truck, car, or motorcycle etc.). These findings point to the fact that urban planners should share psycho-social experiences and expert physical requirements in order to compose new urban soundscapes. If semantic features attributed to sound sources allow assessing the diversity of urban soundscapes, highly depending on the outside/inside or public/private or street/home socio-cultural way of life and activities, it appears pertinent to evaluate urban soundscapes through the analysis of semantic features attributed to sound sources and not directly through noise level measures only.

Schafer's classification [30] can be used to describe sound-producing urban activities, such as: road traffic (car-truck-motorcycle), other transportation (railway, aircraft), working machines (street cleaning, working site), music, people presence (speech, walking), nature (wind, animals). Considering previous research findings for urban situations [23][25], these classifications could be synthesized in two main categories, namely: *'transportation or works'* (from road traffic, railway, building site…) versus '*people presence'* (from department store, coffee shop terraces, traveling shoppers…). Both categories could be subcategorised in two more. Category of 'transportation or works' in either in-between soundscapes associated with people presence or amorphous soundscapes without any other presence. Likewise, defined category of 'people presence' was divided in lively soundscapes (with animation such as music, activities) and relaxing ones when linked to patterns of nature (such as birds in trees, fountain…). More research however has to be pursued to more precisely identifiy relevant categories of soundscapes to further related to acoustic parameters.

8 CATEGORIES OF SOUNSCAPES AND/OR CATEGORIES OF SUBJECTS?

If categories differ according to subjects' experience and values, comparisons between categories of subjects can be another way of getting at the identification of the relevant properties of soundscapes. We will now report here some results from Raimbault [25][26] revealing contrasts between city users and urban planner's points of view. An open questionnaire was constructed that included general questions about main ideas in urban planning management, technical criteria, integration of city-user expectations, as well as more specific questions about the soundscape concerns. People from various administrative institutions as well as engineers, architects, town planners and landscape designers participated in the study. The collected verbal data were analyzed according to previous psycholinguistic grid relevant for the study of non-experts' comments in order to compare planners' descriptions with non-experts' descriptions. The analysis of free-format answers underlined a lack of consensual description and set off that planners mainly feel wordless when asked to describe their expectations or even to take stock of sound urban situation. The categorical linguistic analysis showed that planners used much more technical vocabulary and generic expressions when describing soundscapes than city-users did. Moreover, descriptions of sound ambient environments were often linked to other multimodal criteria, such as visual, aesthetic or functional parameters.

Such findings confirm other research which establishes that subjects differently process the "same" sound according to their previous experiences concerned with acoustic phenomena. It is the case for the evaluation of the timbre of musical instruments [4] and more precisely in the case of piano timbre [1]. In the latter research, the categorization of piano sounds given by experts (pianists) was more closely linked to the structures described by the physical parameters, and especially when it comes to the inharmonicity, while the non-experts used a different categorization strategy associating physical parameters of the model with a semantic interpretation integrating other criteria like the spectral centroid.

This last research allows to introduce a further distinction in sound processing to be worked on, opposing a categorization of meaningful events such as soundscapes as entities (classification on **extensional**, exemplar based criteria), where subjects tend to classify stimuli regarding to the nature of the supposed source which produced them, to timbre variations, where the qualitative properties of stimuli produced by a unique source (piano), are treated in an « **intensional**» way, and mainly as an expert way grounded on knowledge of physical dimensions and parameters of the acoustic signal. In other words, different categorical structures resulting from different processing cannot correspond to the unique description of the stimuli in the physical space. These structures depend on different strategies that supposedly rely on the variations in expertise and experience of the different subjects.

9 CONCLUSION: HOW TO GO BACK TO PHYSICAL INDICATORS

Usual harmonized indicators of noise exposure have definitely not taken into consideration the fact that soundscape evaluations vary from situation to situation, inducing different processing. Is thus the development of global descriptors the proper direction to go in order to specify soundscapes? The aim of this paper was certainly not to model the noise annoyance but to evaluate and advise the quality of soundscapes in developing more accurate and reliable tools for measuring **subjective experience** of sounds **before** measuring physical parameters. It becomes clear that since soundscapes as a concept accounts for the relations between persons, activities and the environment, common sense conceptualisations of our environment are not (necessarily) structured along the same principles of categorisation as scientific concepts and knowledge even when they are superficially named by the same words [7]. The research presented here indicates that people categorize urban soundscapes on the basis of high-level semantic features when specific sound sources can be isolated. These features include the identity of the source producing the sound and judgement of (its) pleasantness. However, it has been shown that in the presence of numerous sound sources hindering the process of source identification, urban soundscapes are processed as a whole rather than as independent sound events, and they are then described as *ambient background* noise along more dimensional parameters. However, even background noises are organised by meaning in relation to human presence and activities. Soundscapes where human sounds are present tend to be perceived as more pleasant than soundscapes consisting of mechanical sounds only. These results suggest that people categorise the sound samples on the basis of semantic features rather then strictly perceptual ones, which means that semantic properties are non directly reducible to causal physical parameters. For humans, acoustic stimulations are **cues** [11] reflecting the presence of something meaningful (or not) they have individually **experienced** in the world, **processed** and **memorised**, and that they have collectively elaborated as shared **knowledge** of the world (as physics among the natural sciences). Soundscapes are therefore necessarily qualitative first: as cognitive objects they are first effects produced by noise on human subjective (psychological) processing. This latter cannot be directly quantitatively measured in terms of physical parameters since the subjective evaluation is determined by the meaning attributed to the activity producing sound rather than by inherent properties of sounds. This judgment is qualitative in nature and highly cultural since it relies on the values given to different activities in a specific environment. Expertise and knowledge can bring subjects to identify physical parameters in the same stimulus, but such a description relies on a highly abstracted conceptualisation (the one acquired by physics) and cannot be considered as a perceptual primitives. In other words, soundscapes should be conceived and investigated as “acts of meaning” [3][5] to **first** identify the relevant semantic

features and **further** correlate them with quantitative parameters. Such results justify the need to further research and computations of new indicators firstly driven by cognitive research grounded in psychological evaluation.

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