13.2 Guyot F., Fabre B., Castellengo M. and Piron C. : An Experimental Method for the Analysis of the Sound Quality of Ecological Sounds.

Une méthode expérimentale pour l'analyse de la qualité acoustique de sons écologiques. Dans le contexte des études sur la perception des sons naturels, nous avons procédé à une expérience sur des stimuli très courants : des sons d'aspirateurs domestiques. Pour obtenir des résultats significatifs du point de vue cognitif, les sujets sont placés dans une situation d'écoute particulièrement écologique et doivent classer les stimuli selon un critère de 'sensation de confort'. Le concept psychologique qui justifie notre procédure (processus expérimental et méthodes d'analyse) est celui de la catégorisation, développé par Rosch en 1975 et appliqué à d'autres domaines d'étude de la perception. Dans l'étape suivante, nous évaluons la relation entre les paramètres physiques du son et les catégories perceptives obtenues.

An Experimental method for the analysis of the sound quality of ecological sounds

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ABSTRACT

In the context of studies on the perception of natural sounds, we run an experiment using a very common type of stimuli : vacuum cleaner sounds. In order to obtain significant results from the cognitive point of view, the subjects are placed in the most ecological listening situation and are given a precise task of classifying stimuli according to a « comfort sensation » criteria. The psychological background justifying our process (experimental set-up and analysis methods) is the categorisation concept, developed by Rosch in 1975 and applied in other fields of perception studies. In a further step, we evaluate the relationship between physical parameters of sound and the perceptive categories obtained.

1. INTRODUCTION

To perceive is a permanent and individual activity. It allows us to live in good harmony with our environment. The perception is leading our behaviour: in order to pick up an object, we locate ourselves in the surrounding space, to communicate by talking we need to hear and interpret sounds.... Furthermore, perceiving is an immediate action. A behaviour adapted to our environment like surviving, event recognising or communicating supposes formerly perceived events to be memorised. The information deduced from those former perceptions need to be optimally organised in memory.

Working on objects like furniture or vegetables, Rosch (1975) showed that our knowledge is organised according to prototypical categorisation (cf § 2). This concept relies on two basic principles that we will present in the next section. Difficulty arises in perception studies because of the gap between physical reality and the human way to perceive it. There are two reasons for this gap : first of all the limits (vision angle limitations for example) of our human receptors and second, our need to concentrate on a particular perception (eye focus for example) for a specific task. According to the context, we only pay attention to a selected part of all the sensorial information that reaches our brain. Therefore, the same event can be perceived, recognised or categorised in different ways depending on the « perceptive intention » of the subject.

We are interested in studying natural sounds which are, from the point of view of the physical structure of the signal, complex sounds. We already underlined that perception is dependant on the context. Therefore, a sound quality judgement can only be interpreted in a given situation, for a given task and inside an homogenous set of subjects (similar culture or experience etc..). As an example, a violin sound will be interpreted differently by the player, a west European listener or a listener with a different cultural background.

In the experiment we present here, we chose to estimate the comfort sensation evoked by vacuum cleaner sounds. Reasons for this choice are first the fact that manufacturers are now conscious of the importance of the sound that domestic appliances make on the global quality judgement. There is now a great demand for acoustical quality evaluation in the field of domestic appliances. The second reason is that the study of the stationnary part of vacuum cleaner signals is sufficient to relate physical parameters to sound quality judgements.

3.3.b. Results and discussion

The first step in analysing the results is to evaluate the homogeneity of the set of subjects and, if necessary, to put aside marginal subjects. To do this, we constructed a valuated « subjects tree » (fig 1) according to Barthelemy and Guenoche algorithm (1988).

A big category appears under node K. This node is later connected to node G which gathers 8 subjects. This can be interpreted as the judgement of these 8 subjects being different from the judgement of the others. In order to work on an homogenous set of subjects, the results of these 8 subjects were not taken into account for the next steps. Using the 38 sets of answers left, we calculated a valuated « vacuum cleaners tree » (figure 2).

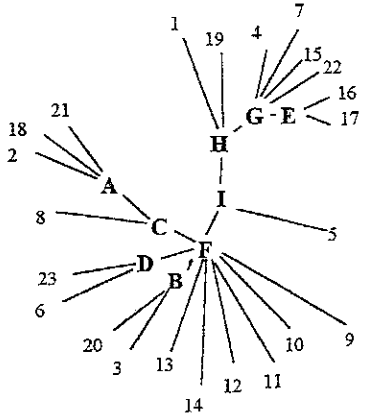

Figure 2 : Vacuum cleaners valuated tree

The tree was completed within 4 iterations of the algorithm. This very low number of iterations indicates a high coherence of the data gathered. This coherence is also responsible for the fact that the last step of the tree construction is the vertices between 2 nodes, F and H, each representing a big category. The category under node F is, according to the verbal attributes given by the subjects filled with vacuum cleaners ranging from « best », » to « normal » or « classical ». On the other side, the category under node H includes the vacuum cleaners ranging from « inferior » to « appalling ».

The next step in our analysis is to find out physical parameters which could discriminate those categories. We will then have to give a closer look to each of these two categories and evaluate relations between acoustical parameters and node A, B, C ...

4. PHYSICAL ANALYSIS

4.1. Sound intensity

The sound pressure levels calculated for all stimuli are plotted fig 3. Comparison with the tree plotted figure 2 shows that the 8 stimuli gathered under node H are among the 9 strongest sounds. On the other hand, the 14 stimuli gathered under node F correspond to the 14 weakest sounds. Furthermore, the 3 stimuli under node A which are considered as the most comfortable have the weakest sound pressure level. Only stimuli #5 disturbs this nice dichotomy.

Unfortunately, this simple relation is only valid at the level of categories F and H. A closer look under node A indicate that stimuli #8, corresponding to a better « comfort » sensation than stimuli #9and 14, is

not the weakest. At this point, sound level is not anymore a relevant physical parameter, which is not surprising considering the very small sound level differences between stimuli #8 and the other two (0.7 dB and 1.4 dB).

In a similar way, categories under nodes E, G, H can not be interpreted using only sound pressure level. There is obviously a need for a more detailed analysis of the physical structure of the signals : spectral analysis will be our next step.

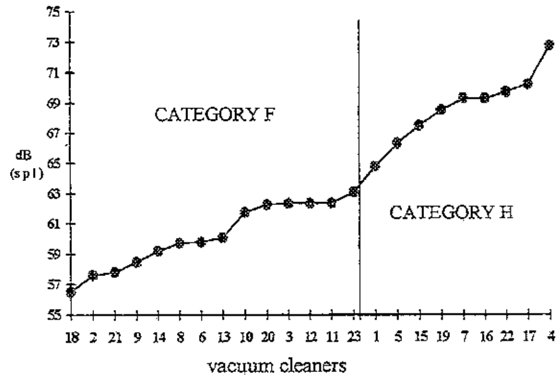

fig 3 : sound pressure level

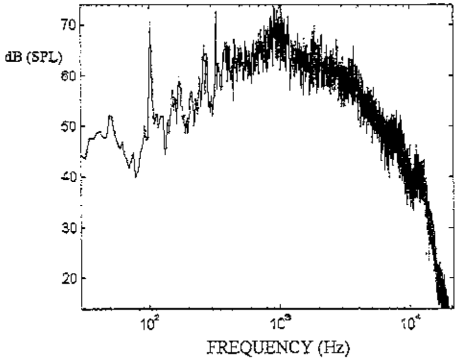

fig 4 : example of vacuum cleaner spectrum

4.2. Spectral analysis

For each stimuli, 17 DFT (0.4s) calculations have been averaged over 4 seconds of quasi stationary sound, with an overlap factor of 2, using a Hamming window. (fig 4)

All the 23 spectrum share a common shape : two frequency lines at 50 Hz and 100 Hz, probably induced by the rotation of the motor ; a quasi linear growth of the wideband noise spectrum up to a maximum between 500 Hz and 1000 Hz except for the spectrum of the sound # 7 growing up to about 2500 Hz. The average slope is +20dB/decade indicating that radiation could be responsible for that growth of spectrum with frequency.

Above the frequency of maximum, we observe a decreasing spectrum with different slopes for the different sounds. Apart from the sounds #3, 2, 20, 9 spectrums show a few frequency lines between 10 kHz and 13 kHz. All spectrum share a hump between 10 kHz and 13 kHz probably induced by the airflow in the vacuum cleaner pipe.

4.3. Interpretation

We tried to relate the calculated spectrum with the categories of fig 2. In relation with the ear sensitivity, we considered, inside each of the categories F and H the frequency and the importance of the spectral lines between 300 Hz and 3 kHz.

In the categories of the « uncomfortable » appliances, we could not find any simple relation between the spectrum calculated and the categories H, G, I. For example, stimuli #7 has wideband noise maximum between 2 kHz and 3 kHz together with a spectral line at 2100 Hz, while stimuli #4 also classified under node G, shows a spectral line at 380 Hz, 30 dB above the wideband noise. Also under node G, stimuli #22 shows 3 spectral lines at 320 Hz, 1 kHz, and 2 kHz. The spectrum calculated can sometimes give way to contradictory interpretation : spectrum of sound #17 seems more similar to those of sounds #7, 4 than to the spectrum of sound #16 which is classified in the same under-category E.

In the category for « comfortable » vacuum cleaners (node F) we did have more success in relating spectrums and under categories : for instance, sound # 18 shows a spectral line at 500Hz and a fast decay

Our aim is to settle, for real signals, a method for studying the sound quality. Based on the concept of prototypical categorisation we run an experiment on free categorisation in a set of 23 vacuum cleaner sounds. The task given to the subject was to classify the stimuli according to the comfort degree they evoked. This method allows us to separate several categories which we characterise from both points of view : the perceptive side and the physical side.

2. BASIC PRINCIPLES : ROSCH'S HYPOTHESIS OF PROTOTYPICAL CATEGORISATION

Each category is defined as a set of objects structured along within category similarities and between category dissimilarities. The origin of Rosch's concept is build on the observation of our natural environment structure and of humans behaviour in this environment. The concept is justified by two fundamental principles which are « cognitive economy » and « perceived world structure » In fact, categorising, permit event encoding and access to a maximum of data with a minimum of cognitive work, because the association of an object into a category allows us to infer, with a high probability, many properties of this object. This process is called the « Inductive Inference » (Smith, 1990). The second principle of categorisation relies on the fact that events in the world don't have the same probability of occurring. We are more used to observing a bird with feathers than with fur.

The structure of categories results from the second principle of categorisation, the « structure of the perceived world », leading to prototypes and fuzzy boundaries. The prototype is defined as the more representative object of a category, that means, the object that shares the more salient features of the other members of its category. Each member of a category is weighted by a degree of typicality. The degree of similarity is relative to perceptual similarities between a member of a category and the prototype of the considered category, for example it could be stated that the sparrow is a more prototypical bird while the ostrich is a less prototypical bird.

Such a conception of categorisation which is grounded in the notions of « basic level », « prototype » and « similarity » was explored using natural and manufactured objects. The categorisation of such visual objects results from a common process of learning for all people of a same culture. Moreover we wonder if it is the same for other perceptual events from other modalities such as images, sounds, smells and so on. More recent work, and particularly Dubois' work (1993) have shown the relevance of Rosch's concept (1975), for different stimuli such as road photographs . These results encouraged us to study noise categorisation within this framework.

3. EXPERIMENT

3.1. Sound recording

The recording procedure was defined with the goal of placing subjects in the best ecological listening conditions. Recording took place in an office. The floor was covered by a fitted carpet. Vacuum cleaners were manipulated in a traditional way except for the pipe not being moved around.

Two AKG D24 electrodynamic microphones were used for coincident recording at 1.8 m above the floor, 50 cm aside from the engine. The position of the microphone set was adjusted to give the most reliable sound compared to direct hearing. Recording was done on a Sony TCD-D3 R-DAT through a EAA PSP2 microphone amplifier. Calibration sequences on the tape allow absolute reference.

We recorded a set of 23 vacuum cleaners from different trademarks. The measured level, with a sound level meter, at the position of the head of the operator (1.65 m high, 30 cm aside from the vacuum cleaner) was 88 dBA for vacuum cleaner #2.

3.2. Listening test

A free categorisation method was used. Each subject was asked to classify the stimuli into a many categories as he wanted. The subject was asked to imagine himself operating the vacuum cleaners and to classify the sounds according to the comfort sensation they evoked. By the end of that task, each subject was asked to name or to give verbal attributes to the categories he had formed. The test run on a PC 486 equipped with a Sound Blaster 16 Scsi-2 extension board. Binaural listening trough Beyerdynamic DT 48 200 Ohms headphones was used. The sound level was adjusted in order to measure, at the listener's hear position, 88dBA while playing track #2.

The sounds duration was 5s, including the onset of the vacuum cleaners.

46 subjects, all used to vacuum cleaner sounds, went through the test, some of them being musicians. It took an average 45 minutes for one subject to go trough the test.

3.3. Analysis and results

3.3.a. Method

The arborescent analysis of the results, from Barthelemy's and Guenoche's (1988) algorithm gives a visual representation of the results. The method of valued trees which was developed by Barthelemy and Luong is close to the classical cluster analysis, but it gives more information : the clustering of the subject agreements and the relative distances between objects in a same category and in opposed categories. A valued tree is characterised by nodes, leaves and vertices. From each node starts a vertices at the end of which there is a "leaf" which represents a stimuli. If we follow the contrast model (Tversky, 1978), we can interpret each node as the prototype of the category it creates, and the length of each vertices as depending on the degree of typicality. The algorithm runs through several iterations : the letters we will use on our trees indicate the order of appearance of the nodes. Therefore, node A is the first to appear and indicates the easiest grouping the algorithm finds. For the next iterations, stimuli grouped under node A does not exist individually : they are all represented by the node A.

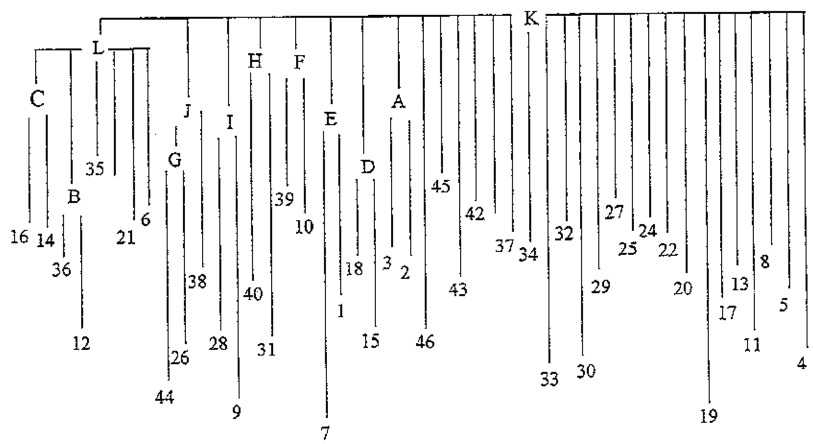

Figure 1 : subjects valuated tree from Barthelemy and Guenoche algorithm (1988)

(-40 dB/decade) wideband noise spectrum between 1 kHz and 10 kHz while sound #2 (also under node A) does not show any spectral line (apart from the common 50Hz and 100 Hz spectral lines) but a slow decay (-20 dB/decade) of wideband noise.

Our simple spectrum analysis appears to be too crude for discriminating the inner structure of categories H and F. However, spectrums clearly show that the worst stimuli (# 7, 22, 16, 15...) accumulate the sounding disturbances : high sound pressure level together with frequency lines and wideband noise maximum in the most sensitive frequency range of the ear (2kHz to 3kHz).

This suggests that the sound analysis should be related to our knowledge on hearing : the use of Bark scales and cochlea models would maybe give rise to a more adapted analysis of sound. Another direction can be found looking at the verbal attributes gathered during the test : they indicate that the subjects used different attitudes to classify the stimuli. It seems that a global sensation of « good » or « bad » working order of the appliance, as well as the sensation of « new » or «old » vacuum cleaner ,or a global efficiency sensation have been used to form the different categories.

These criteria should be taken into account when searching for acoustical parameters. For example, the analysis of irregularity in the structure of the sound signal might be related to the sensation of « good » or «bad » working order of the vacuum cleaner.

5. CONCLUSION

We developed procedures for studying the perception of real sounds, noises or musical sounds : our recording and listening test process has been confirmed to be efficient by the easy analysis of the results (only 4 iterations of the analysis algorithm were necessary, two main categories were easily discriminated). This indicates that the task given to the subjects as well as the test setup were adapted.

The sound level proved to be a reliable parameter for separating sounds evoking « comfortable » and « uncomfortable » vacuum cleaners. For a more detailed analysis of the structures formed inside the two main categories, we did not succeed in defining a physical parameter accounting for them. This is not really surprising considering the variations in those inner structures when the set of subject used for analysis is slightly modified.

The analysis of verbal attributes is a lead in the search for physical parameters related to the categories perceived. Furthermore, in a following experiment, we will consider a more developed semantic approach.

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