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QUANTITATIVE DESCRIPTIVE ANALYSIS METHODOLOGY APPLIED TO THE DESCRIPTION OF VEHICLE SOUND QUALITY

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ABSTRACT
The specification of the quality of vehicle sound is an important topic for the automotive industry. The problem for the acoustic engineers is to determine the acoustic parameters responsible for this sound quality to adjust them. In this paper, we propose to apply a classical approach used to develop food product (the classical sensory profiling analysis) to specify sensory attributes of the perception of vehicle sounds. In the first part, we justify the sensory analysis strategy with regard to the classical psychoacoustic method and psychological knowledge. In the second part we present the classical sensory profiling analysis. Finally, we develop an application of this method for vehicle sounds and comment on results of panels with specific statistic tools (performance, repeatability and discrimination).

1 - INTRODUCTION: THE WAY OF A SENSORY ANALYSIS STRATEGY

Perception has been studied according to different point of view, such as the analysis of audition mechanisms and different models of psychology.
At first, we have to take into account the physical and physiological aspects of perception which has been widely described by [1]. Stemmed from works in psycho-physic 50 years ago, the psycho-acoustic studies allowed to improve our knowledge in audition using simple sounds without any meanings (pure noise, white noise, typical harmonic noise...). The fundamental results of these works are the usual psychoacoustic parameters like loudness, sharpness, Roughness ... All these models are of course part of a monaural representation of perception. Works on the physical aspects of the binaural perception are now well known, especially to explain the localization of acoustic sources. But the perception of a complex auditive scene has to be studied.
All these models are very appealing to work, but have not been developed to describe the perception of complex sounds like internal vehicle noises.
Actually, perception is the result of complex operations which are described by different fundamental theories and continue to be discussed. One can remind himself of the different schools who propose psychological models of perception. First of all, The "behaviorist" theory of perception is based on a simple "stimulus-response" relation. This vision has been widely used by the classical psychoacousic approach and is well adapted to audition studies. The "Gesthalt" theory brought a new point of view considering that the subject structures and organizes his environment. On the contrary of the first theory, this vision has been introduced to explain the perception of real objects thus real sounds. More recently, the "ecological" theory introduced by Gibson, near the "behaviorist" conception, considers that all the elements of perception are contained in the environment. The specificity of his theory is the global conception of perception which refutes the idea of subject contribution to perception. This global vision introduced the ecological validity concept which is very useful in the experimental work.
Nobody today assumes all these excessive points of view. Actually, modern schools consider that the perception is the result of a complex relation between the subject and the sound (cognitive theory). The subject is a complex system with a model of organization of the world. Submitted to a specific acoustic

stimulation, his answer will depend on different internal factors, his knowledge of the environment, his motivations, his attention and his anticipation.
One of the most interesting concepts of the modern psychology is the categorization paradigm. Research on this model, renewed by Rosh, supposed that perception is organized according to different levels of categories and each category is organized around a prototype [2]. Moreover these categories are not especially an objective data produced by reality but the reflected image of each subject's world. Probably, main categories depend on common social dimensions but also on the knowledge of the subject.
Dubois [3], psycholinguist, has conducted studies on different sensorial domain to validate the concept of this perceptive organization. Her main hypothesis is that our verbalization is the reflected image of our perception.
The perception of sounds is thus not especially based on physical and physiological dimensions of perception. At first, the process of recognition and identification allows to classify the noises. The description is thus relative to the process of categorization. The subject will differentiate sounds in terms of acoustic sources or in terms of acoustic attributes according to his knowledge.
To study the perception of vehicle sounds and to create pertinent acoustic specifications, we have to take into account all the factors of perception. Our work has to be led on a homogeneous database of sounds in which vehicle noises are different according to acoustic attributes.
Among these vehicles, some are preferred because they evoke comfort cars, sportive cars... These judgements depend on customers, but to explain the reasons of the preference, we have to determine the objective sensorial attributes which will help to build acoustic parameters.
The sensory analysis [4] is a specific tool used to find out the sensorial attributes of perception. This work has to be led in two step, the first one to find out the preference level of the sounds studied with customers, the second to get the sensorial description of the perception, with specific customers trained to describe their sensation.

2 - EXPERIMENTAL STUDY OF VEHICLE SOUNDS

Acoustic noise in a vehicle is a complex combination of the different acoustic sources (aerodynamic noise, rolling noise, engine noise). The complex acoustic field is various according to the different driving situations, that is why acoustic studies are often provided for each driving situation separately. Recordings are realized with an artificial head and reproduced in the laboratory. This method allows to verify the principle of "ecological" validity, subjects listen to sounds of the environment.
The aim of the sensory evaluation methodology is to get an objective representation of sensory properties of sound. The strategy used is based on classical sensory profiling analysis [NF XPV09501] developed for food products. We have to use a panel consisting of 12 to 20 trained people, called sensors, to get the sensory profile of a set of sounds.
Trained people are current customers of vehicle with no specific knowledge in acoustics but with specific training to evaluate their analytical sensory perception. At the beginning of their work, they have sensorial acuity, logical and verbalization capacities, and motivation. The aim of our work is to develop an analytical point of view which is more objective than the global impression expressed, in reference to affective and cognitive aspects of perception. The classical customers will speak of the vehicle noise with personal representation of the noise, It is a sportive car... A trained subject will speak of the vehicle noise with an objective description.
The objective description is based on the choice of specific descriptors during initial sessions and used in a consensual way. The different steps of the elaborated list are:

- individual production of words or expressions
- qualitative sorting work: selection of pertinent words excluding hedonic and no mono-dimensional terms
- statistical sorting work to choose a limited and exhaustive list.

3 - SENSORY EVALUATION METHODOLOGY

This first step, which provides a limited list of pertinent words, is fundamental to address the problem of the sound description. The use of a verbalization approach is not new in acoustic and has been practiced by different authors: [5], [6], [7], [8], [9]. Most of the time, there is no justification for the list of terms which are already defined and the list is very often mixed up hedonic and qualitative descriptors. The evaluations are made by naïve subjects (thus, can we consider for example that the "soft noise" expression has the same representation for all people?) or acoustic experts (Thus, can we consider that

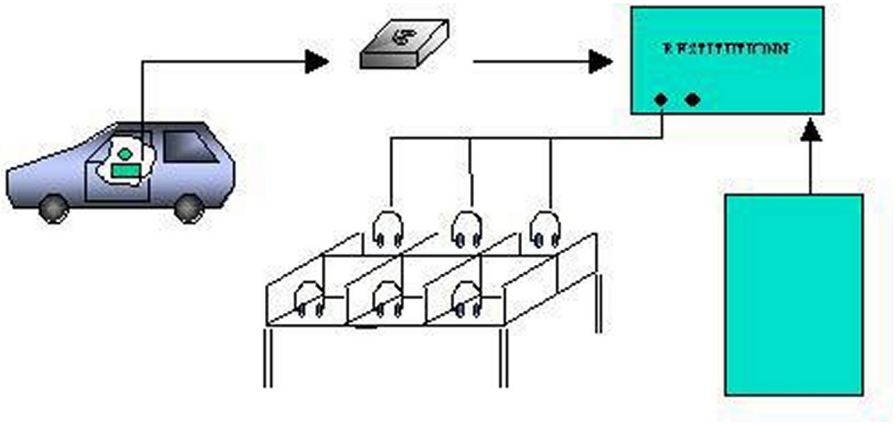

Figure 1: Scheme of laboratory.

the technical representation of the product is similar to an analytical sensorial point of view of a usual customer).
A clear strategy is necessary to elaborate descriptors, the building of the list and the training to its use have to be made in a consensual way.
The second step is thus to give a definition of each term and to verify with a classification evaluation if the perception is common.
The third step is the practice of testing performed with a metric scale then specific training is achieved with simple and complex sounds. Reference sounds are used for each descriptors. This strategy allows to find a relative evaluation according to a common reference.
Finally, the performance of the panel is judged on repeatability and discrimination criterions (ANOVA). The global sensory description is obtained with a profile representation and proximity evaluation can be illustrated with Principal Component Analysis methodology.

4 - VEHICLE NOISE APPLICATION

To illustrate this method, we choose to work with a set of homogeneous sounds according to a specific driving situation. The set of 20 sounds was composed of different cars. The aim of the study was to specify the different sensorial attributes responsible for the global differences.
The list of descriptors is:

- " grondant " (" rumble ")
- " Bourdonnant " (" booming ")
- " Bourdonnant grave/aigu (" pitch of booming ")
- " Rugueux " (" roughness ")
- " Chuintant " (" hissing noise ")

We ask to each subject to give an estimation of the intensity rate between the sound and the reference. For each descriptor, the evaluation is made with a specific scale composed of two non structural scales relative to each sound.
The reference is chosen among the set of noises for each descriptor, its intensity is average. If the sound is more intensive than the reference, the subject judge the rate perceived in using full scale for the most intensive sound.

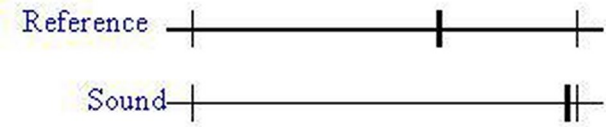

Figure 2.

The same sound is evaluated three times by each subject on the same descriptors. The repetitions are produced each week. The presentation is balanced to avoid the effects of order.
To evaluate the quality of the results, we have to estimate capacities of repeatability and discrimination of each subject.
To evaluate the quality of the repetition, we used the variation coefficient for the repetitions:

$$Variation\ coef. = \frac{Standart\ deviation}{Average} * 100$$

This factor is applied for each sound, each subject and each descriptor. Theoretically, we will consider that a subject is repeatable if for 80% of sounds the variation coefficient is less than 25%. For our study only 50% of sounds are in this criterion.
In the same way, to evaluate the capacity of discrimination, we use a model of variance with one factor (sound effect for each subject), with 1% threshold. The Duncan test allows to group sounds which are not significantly different.

Results and analysis

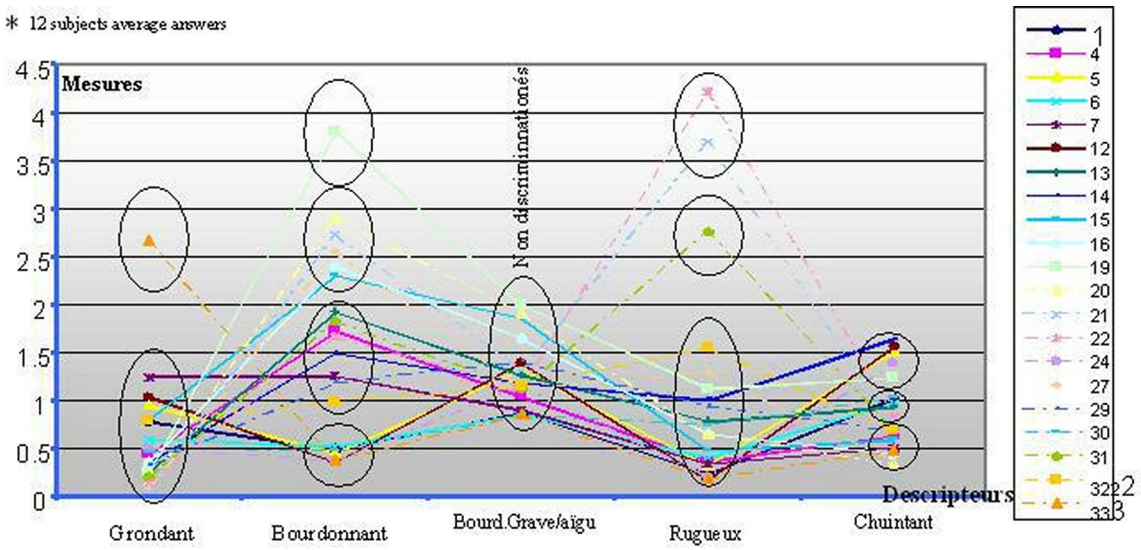

Figure 3: Sensory profile of the 20 recorded sounds.

This figure gives the sensory profile of each sound. The groups of sound for each descriptor are the result of the Duncan test (5%) [4]

5 - TOWARDS A SOUND DESIGN STRATEGY

This sensorial representation is interesting because of the limited number of dimensions in comparison with acoustic parameters (for example frequencial representation). It is now interesting to evaluate the links of classical parameters with these sensorial stable attributes. Results of correlation are not good. The classical psychoacoustic parameters are not sufficient to illustrate the space of sensorial attributes. Specifications can be made with the sensorial attributes. PCA of sensory profiles lead to a simple 3D-vizualisation of the result in geometric space allowing to explain clearly proximity (figures 4a and 4b).
These sensory profiles of sounds give an objective description which allow to explain preferences of customers. Of course these stable profiles are an interesting tool to define target sound for a vehicle project.

6 - CONCLUSION

In this paper we proposed a strategy, widely applied for evaluation of food products, which allows to get stable and objective specifications of sounds. In comparison to the multidimensional scaling based on a global difference evaluation [9], [10], [11], it mainly brings a sensorial interpretation of the perceived differences. Moreover, it clearly demonstrates that the using of "universal" psychoacoustic parameters is not sufficient to reflect sensorial attributes of the perception.

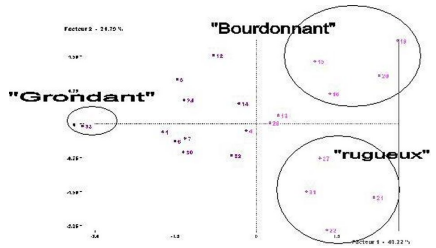

Figure 4(a): [1 2] principal component analysis plan.

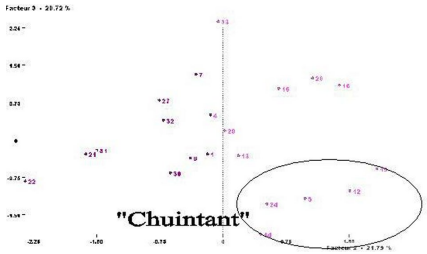

Figure 4(b): [2 3] principal component analysis plan.

Works has to be conducted to improve the subjects performances, but the first tools developed are today useful to interpret preference.

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