Free verbalizations analysis of the perception of noise and vibration in cars at idle

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This study dealt with comfort in diesel cars running at idle. A reproduction bench was used to reproduce vertical vibrations of the seat, vibrations of the steering wheel and noise at the ears of the driver. A paired comparison test was conducted, involving stimuli recorded in seven cars, among which four were equipped with a 3 cylinders engine. 30 people participated to that experiment. The task of a subject was to evaluate the similarity between the two simulated situations of the pair, indicate which one was the most comfortable and, freely express the similar and different features of the stimuli and explain the reasons of their choice. Those free verbalizations were recorded and carefully analysed, which gave useful information about the way sound and vibrations were perceived and participated to the evaluation of overall comfort. Also, the similarity evaluations were analysed through a multi-dimensional scaling technique to establish the perceptive space. These two analysis gave the following results:

- words used by subjects to describe vibrations were much less than those used to describe noises, which indicates a smaller description capacity of the subjects;
- verbalisations were very helpful for the understanding of the perceptive space: the three first axes of that space could be related to the irregularity of stimuli (especially important for 3 cylinders cars), the amplitude of steering wheel vibrations and the pleasantness of noise, as described by subjects.

1 Introduction

In order to reduce fuel consumption in cars, some manufacturers are developing three-cylinders engines. That solution can be convenient for small cars, with capacities around 1200 cm³. Due to the combination of internal efforts (created by fuel combustion and inertia of moving parts), the efforts exerted by such engines on the chassis are very different from those exerted by four-cylinders engines: dominant frequencies are lower and the torque component (in the direction orthogonal to the plane of the cylinders) is important. For the supplier of engine mounts, the challenge consists in proposing parts, which can reduce the efforts transmitted to the chassis and maintain a good level of comfort for passengers.

The goal of this study was to compare noise and vibration in three and four cylinders cars running at idle and to evaluate the characteristics of the signals influencing that comfort.

2 Experimental method

2.1 Sound and vibration events

The simulation bench previously developed by the Laboratoire Vibrations-Acoustique and Hutchinson Paulstra was used. That bench is described in detail in [1]; it allows reproducing seat and steering wheel vibrations (in the vertical direction for the seat and along the steering column) as well as noise recorded with a dummy-head. Therefore, a subject can be placed in a situation representing a car running at idle in a realistic way.

For the present study, recordings have been conducted in seven Diesel engine cars, among which four were equipped with 3-cylinders engines and three with 4-cylinders engines. The cubic capacities were from 700 cm³ to 1900 cm³; all engines were from the common rail type. From these recordings, 15 seconds samples were prepared; they consisted in four synchronous tracks (seat vibrations, steering-wheel vibrations, noise at the two ears of the dummy-head). After a convenient
filtering for compensating the mechanical transfer function of the bench and the realizing the audio compensation of binaural recordings, they were available for the subjective experiment.

2.2 Subjective experiment

The method of free verbalizations was used. Its principle [2] is that, provided that a correct procedure is used, the verbal expressions of a subject whose task is to compare two stimuli are closely related to his perception and can be used to understand that perception. A careful analysis of these verbalizations can lead to the identification of events features that were used by listeners during the experiment. The importance of each feature for perception can also be evaluated through this analysis.

In that study, subjects were asked to compare comfort of various cars; they were not focused on noise or vibrations, so that each of these stimuli could contribute to their evaluation of comfort in a natural way. All possible pairs of different cars (21 pairs), plus two learning ones were presented to subjects, in a randomised order. For each pair, subjects had, first of all, to evaluate the similarity between cars (by giving a number between 0 and 10), then to indicate the most comfortable car and, finally, to freely explain their answers. Their verbalizations were recorded as an Mpeg file.

30 subjects participated to the experiment; they were mainly students from the Institute, or members of the laboratory.

3 Results

3.1 Perceptual space

The individual similarity evaluations were analysed using the Indscal algorithm [3]; it appeared that a 3-dimensional space was convenient to represent the perceptual space. This 3-dimensional space is represented in figure 1; the first axis clearly distinguishes between three and four cylinders engines (labelled 4c1 to 4c3, while the first ones are labelled 3c1 to 3c4). It could be thought that the second axis was related to vibrations of the steering wheel: cars 4c1, 4c2 and 3c4 had very low levels of such vibrations (in car 3C4, the engine is located at the back of the car, so that the steering-wheel has no connections with it). But the third axis could not be understood.

![Figure 1: perceptual axis of similarity evaluations](image)

3.2 Analysis of verbalizations

Verbalizations produced by subjects were written down and analysed according the scheme detailed in [2]. The first step consisted in separating the meaningful verbal units (e.g. “the first car is the noisiest” or “in the second car, seat vibrations are irregular”). These verbal units entered into a database along with other information (e.g. the subject’s number, the stimuli of the pair during which the verbal unit had been produced, the complex event to which it referred, etc.); that gave a table of more than 5600 lines. The next steps of the analysis refined the description of verbal units; finally, they were labelled as referring to noise, vibrations or to the general situation (e.g. “the first car is more comfortable”). For a verbal unit referring to vibrations, another field indicated whether it was related to seat or steering-wheel vibration (or to vibrations in the general meaning).

The number of verbal units produced by a subject varied from 133 to 414. In the following, when comparing the relative use of the different descriptive
categories, the number of uses of a given category for a given subject was normalized with respect to the total number of verbal units produced by that subject.

The last step of the analysis consisted in grouping together verbal units that were thought to refer to the same characteristics of the events; for example, “the noise is louder” and “the sound level is greater” were grouped into the same “loud” category. 15 categories thus appeared, among which 6 were very rarely used; in the following, only the 9 main categories will be taken into account.

First of all, it should be noted that the number of verbal units explicitly related to noise or vibration were similar: 115.3 for noise and 112.2 for vibrations. On the other hand, verbal units only describing the situation in general (e.g. “both cars are rather comfortable”) were less often produced (18.4), which indicated that subjects distinguished between the events in a natural way.

An important difference between sound and vibration descriptions is that fewer categories were used for vibrations (figure 2). The category “high level” was by far the most commonly used (75% of the total number of verbal units related to vibrations); other categories were “shaking”, “annoying”, “pleasant” and “regular”. For noise descriptions, rates of use were less different: the most important one (“loud” once again) represented only 25% of the total number. Subjects had a greater analysis capability for sounds than for vibrations.

An useful result was that these verbal portraits could be used to understand the perceptual space obtained from the Indscal analysis of similarity ratings. The correlation coefficients between stimuli coordinates on each axis of that perceptual space and the values of the verbal portraits (as some examples are presented in figure 3) were computed. It appeared that:

- the shaking characteristics (in general) was highly correlated with the first axis (R=-0.95); as that axis made a clear difference between three and four cylinders engines, that feature can be seen as distinctive of the number of cylinders;
- the subjective level of steering wheel vibrations explained the second axis (R=0.93);
- noise pleasantness was the underlying factor of the third axis (R=0.93).

Therefore, the analysis of verbalisations allowed the understanding of the perceptual space. As mentioned earlier, it had been noted from the perceptual space that its first axis was related to the number of cylinders of the engine; but the perceptual reason of that relation was only understood from the verbalisations analysis. That was also true for the third axis; as it is related to a complex attribute (sound pleasantness), any direct interpretation of that axis could not have been obtained.

Figure 2: rates of use of the different verbal categories

Figure 3: examples of stimuli verbal portraits
3.3 Preference model

The values of events according to the characteristics "shaking", "high level of steering wheel vibrations" and "noise pleasantness" were used as inputs to a regression model of preference within pairs. It appeared that the level of steering wheel vibrations was not related to preference. A reliable model could be built from the two other characteristics ($R=0.83$, $F(2,18)=19.9$).

4 Conclusions

An analysis of verbalization thus provides useful information about subjects perception in complex (multi-modal) situations. The quantification of features for the various stimuli (verbal portraits) can be related to data obtained from psycho-physical studies (the perceptual space computed from similarity ratings); moreover, these verbal portraits can be used to explain this perceptual space.

The next step of the study will consist in understanding the signal characteristics to which the subjective features, as described by subjects, are related.

References


