# Perceptual Test on Annoyance Threshold Linked to Vibrations and Sounds of a Modified Car Engine

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## ABSTRACT

New drivetrains are currently worked on with a goal of constant improvement of engine performance and reducing vehicle gas consumption. Vibro-acoustic environment in the car cabin is in certain case considerately modified and could be annoying for drivers or passengers. We focus here on a specific modified 3-cylinders engine whose properties are changed from those of a usual engine. With such a configuration, new engine harmonics are present in addition of already existing 3-cylinders engine ones. Those harmonics are perceived as well as sound than as vibrations through the seat leading to particularly annoying low frequencies.

A previous perceptual experiment conduced on a naïve panel showed that softer horizontal suspensions should lead to a lowering of the annoyance due to longitudinal high magnitude vibrations at low engine speed around 1500 rpm. In the experiment presented here, we investigated the notion of acceptability threshold between usual vibrations and those due to this particular engine. Moreover, several sonifications are added to the original engine sound in each vibrating configuration. The aim of this test is to evaluate the impact of sound quality on vibration perception and overall annoyance in the car.

Keywords: Car comfort, Vibrations, Sound I-INCE Classification of Subjects Number(s): 13.2.1

## 1. INTRODUCTION

Effects of softer horizontal suspensions on perceived vibrations were studied in a previous experiment (1). It has been shown that comfort in the car was dependent on modal parameters of the horizontal wheel suspension. More precisely, during a run-up, comfort increased when magnitude and central frequency of the first mode decreased. The next study was devoted to the influence of other engine vibrations filtering devices (e.g. dual mass flywheel) on driver's comfort. Moreover, two sonification strategies were used in order to determine if they could improve vibro-acoustic comfort.

## 2. Perceptual test

To answer these questions, a perceptual test was conducted on a static simulator reproducing sound and vibrations (in both horizontal and vertical directions).

### 2.1 Stimuli

Vibro-acoustic measurements were done for two engine configurations (with the usual and a modified combustion strategy), during a run-up (full throttle, third gear). A triaxial accelerometer was fixed on the driver slide seat and an acoustic manikin was located on the passenger seat.

For each of the two configurations, engine orders temporal amplitudes were computed. These amplitudes were higher when the modified combustion strategy was applied. An interpolation between both conditions allowed creating a set of 9 intermediate conditions.

Moreover, as it was hypothesized that sonification could improve comfort; two strategies were applied to the original sound of the modified engine condition. Each of them was applied at four different levels, which gave a number of nine configurations.

The combination of all these possibilities leads to a set of 99 stimuli.

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### 2.2 Test bench

The experiment was conducted on a vibro-acoustic simulator shown in figure 1. It is composed of a car seat mounted on a rigid platform. This structure is excited by two electrodynamics shakers, one for each direction (vertical and horizontal). Sound reproduction is provided by headphones and a subwoofer is located in front of the seat to improve the realism (2).

Figure 1 – Test bench with vibro-acoustic simulation

### 2.3 Protocol

30 subjects participated to the experiment. They were asked to sit comfortably on the seat and to imagine themselves driving on a straight line on a smooth road. The experiment was divided in two steps:

- The first part was a 2-AFC procedure (3) done on each sound. The subject had to say whether he felt comfortable or not. If he did, the vibration level was increased for the next stimulus, while this level was decreased if the subject felt uncomfortable. The procedure was stopped after five inversions and the threshold was computed as the mean of the levels at these inversions. This procedure was repeated twice (starting either at the lowest or the highest vibration level) and the final threshold was the mean of the two values;
- In a second part, the 99 stimuli were presented according to a random presentation order defined by Latin square. The task of the participant was to evaluate overall discomfort, using a scale ordered from 0 (meaning "*absolutely not uncomfortable"*) to 10 (*"very uncomfortable"*).

## 3. Results

### 3.1.1 Annoyance threshold evaluation

- **Preliminary results**

A classification of the subjects (using their mean annoyance thresholds) showed that there was no huge consensus between subjects. The panel could be separated into 3 different groups with similar sizes. Figure 2 shows the dendrogram of the participants.

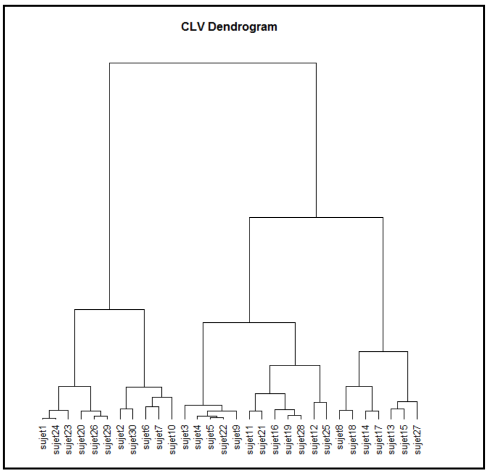


Figure 2 – Dendrogram of the participants

- **Analysis of variance of mean annoyance threshold**

For each group, an analysis of variance was conducted on subjects' thresholds, factors being sonification strategy (2 levels), gain and their interaction.

In the case of group 1 (figure 3, left panel), results indicated a principal effect of sonification strategy $F(1,72)=17.83$, $p<0.05$ and an interaction between the sonification strategy and its gain $F(3,72)=3.056$, $p<0.05$. A post-hoc test of Duncan revealed a significant difference between the first sonification strategy (M=3.10) and the other one (M=4.68). When no sonification was applied, the average threshold (M=4.68) was not different from the one obtained in the case of the second strategy.

Opposite results were obtained for group 3: thresholds were higher when the first strategy was applied (figure 3, right panel).

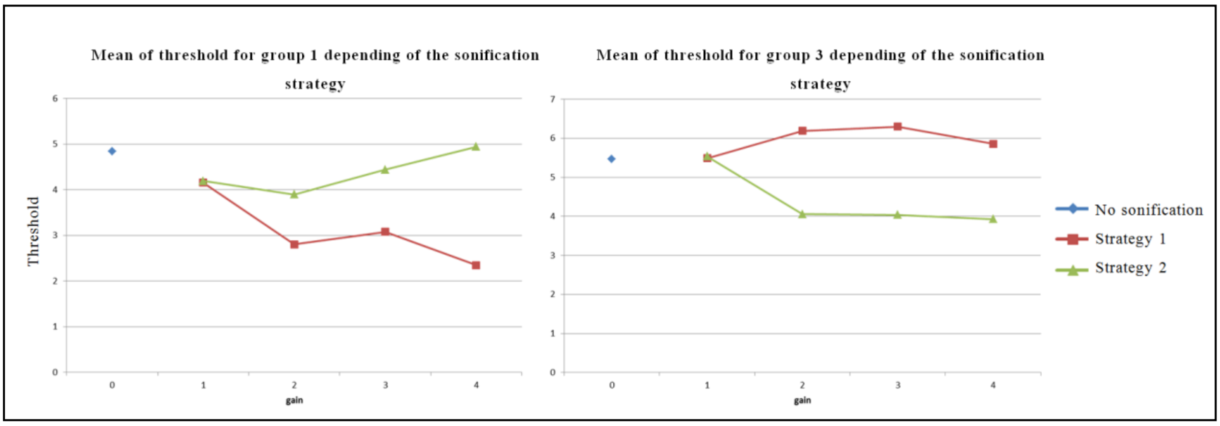


Figure 3 – Mean annoyance thresholds depending on gain and sonification strategy for group 1 on the left and group 3 on the right

Concerning group 2, results indicated a principal effect of the gain only ($F(3,64)=11.25$, $p<0.05$).This was due to the highest value of the gain, which was significantly different to lower ones.

### 3.1.2 Discomfort evaluation

- **Preliminary results**

Consensus among subjects was evaluated by computing a principal component analysis of individual ratings. This time, the panel could be separated into 2 groups. But one group was made of 6 people only, so it was decided not to consider results from these participants.

- **Influence of sounds and vibrations**

An ANOVA showed a main effect of vibration ($F(10,2676)=390.77$, $p<0.05$), sonification strategy ($F(1,2676)=17.04$, $p<0.05$) and gain ($F(3,2676)=40.59$, $p<0.05$), as well as two 2-ways interactions.

Figure 4 shows the variations of discomfort depending on the vibration level: 1 refers to the existing engine vibrations and 11 for the prototype engine ones. Each curve represents one sound (dotted black line: without sonification, blues lines: first strategy 1 and red lines: second strategy). For each colored curve, the darker the curve, the higher the sonification gain.

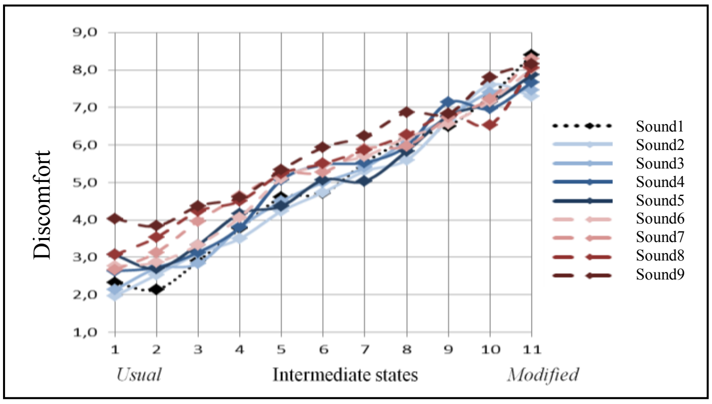


Figure 4 – Discomfort rating depending on intermediate states and sounds

As it can be seen on figure 4, the prototype engine is considered as far more unpleasant than the existing one. The intermediate stimuli are evaluated as it was expected, except for the first two ones which are very similar to the existing stimuli. Finally, applying the two sonification strategies does not reduce discomfort.

## 4. Conclusion

In this experiment, the influence of increasing vibration level on comfort has been evaluated. This can give to the manufacturer some recommendations about what an acceptable level could be. Moreover, two sonification strategies have been considered. Unfortunately, it appeared that they could not reduce discomfort due to high level of vibration. It seems that some kind of dominant source model applies: when their level is too high, vibrations dominate the overall evaluation. This will be checked in the following of the study.

## ACKNOWLEDGEMENTS

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