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Vibrations' influence on Dieselness perception

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ABSTRACT

Up to now, different studies dealing with vibrations' influence on acoustics have been, in most cases, realized on global annoyance. In our case, the present study examines the vibrations' influence on the auditory perception of Diesel character (called Dieselness in this article) of a vehicle. In addition, cultural experience is evaluated by testing two groups of Diesel owners from two European countries (respectively France and Germany). During the experiment, each population was exposed to sound only, and sound and vibrations simultaneously. This perceptual test was realized on a vibration bench (driver seat and steering wheel) with headphones. Three kinds of vehicules and six different driving situations have been tested. Results reveal no differences between French and German. Nevertheless, the adding of vibrations influences the Dieselness evaluation. The participants give slightly higher scores (more Diesel) or equal (as Diesel) with vibrations than without. However, this vibration effect is slightly dependent on the type of vehicles and on the driving situations and it appears less important for German people. In addition, for each group of participants, the other factors vehicle and driving situation have an effect on Dieselness assessment. The effect of vehicle allows to show that 3 cylinders car is significantly different from 4 cylinders and 6 cylinders cars. Finally, the interaction between driving situation and vehicle shows the strongest effect on Dieselness evaluation, among all interactions tested. The vehicle effect is dependent on the driving situation. All results and conclusions have to be taken with care in order not to generalize for all similar classification cars.

1. Introduction

Even without taking into account sound, vibration perception is a very complex topic. Indeed, different random parameters, like postures and participants' sensitivity contribute, among others, to this perception. In addition, the main reason of this topic's complexity lies in the difficulty to reproduce in details previous studies. There is a great disparity between various experimental contexts [1–3]: level and dynamic of vibrations, artificial or real sources, frequency range of stimuli or test methodologies, differ.

The common basis of studies about vibrations is the use of a bench made up of a platform with a seat and sometimes even, a steering wheel [4–6]. Nevertheless, the different authors do not take into account same degrees of freedom: a majority limits their vibration reproduction in the vertical plane along the *z*-axis for the seat [7–9].

By taking into account the whole modalities, the possibilities of experiments are numerous: vibration effect on noise assessment, effect of sound stimulus on vibration appraisal or also, effect of both on the overall evaluation of a parameter (such as comfort for instance [10]). Most studies about this interaction focused on their influence on the perception's threshold (of sound or of vibrations) [11,12]. Indeed, studies of Weber et al. [12] and Bellmann [13] conclude about no significant influence of sound on the perception's threshold of vertical vibrations. With a study about vibrations influence on the loudness assessment, Parizet et al. [9] show the lack of vertical vibrations influence on this loudness evaluation. Conversely, they indicate that a sound stimulus impacts significantly the vibrations level's assessment. Besides, Amari [14] evokes a "*synergistic effect*": the higher the noise level is, the higher the vibration level is considered. In a different register with sound influence on vibrations level's assessment, Miwa and Yonekawa [15] showed that there is no significant effect on it. However, they join Parizet's conclusion on the fact that with a high noise level, vibration level is overestimated.

Other kinds of studies focused on discomfort (or annoyance) assessment [1,16–18], especially for idle driving situation

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[2,4,5,7,17,19]. It has been observed that both modalities can contribute equally to comfort until one becomes highly dominant [17]. The overall sensation seems to be dominated by the more annoying or stronger modality. Besides, Bellmann [13] concludes that there is a state of "balance" to be observed between vibration intensity and sound intensity, expected by drivers. Also, Leatherwood [10] showed that contribution of each modality depends on their respective levels. But their interaction is clear: for vertical vibration levels which affect (in a negative way) the comfort, the add of a sound has little influence. However, with a weak vibration level, the increasing of the noise level raises noticeably the discomfort assessment.

Moreover, comfort issue is a scientific topic often treated in the transport domain (automotive and rail industries). Parizet et al. [17] and Howarth and Griffin [1] have two examples of this kind of studies. Indeed, the first one has realized an experiment in three stages: the discomfort's assessment of a sound stimulus alone, the discomfort's assessment of a sound presented to the participants with a vibro-acoustic stimulus and finally, global discomfort's evaluation of the vibro-acoustic stimulus. Results prove that vibrations have a small but significant influence on sound assessment. For some participants, the overall annoyance is only related to vibrations while for others, it seems to be linked to both modalities. In their study, Howarth and Griffin [1] focused on the discomfort's evaluation caused by sounds and vibrations generated when a train passes close to a domicile. They conclude that vibrations do not affect the annoyance rating. Conversely, noise influences discomfort appraisal due to vibrations according to the relative magnitude of them. Therefore, discomfort caused by low vibrations decreases for higher noise levels and global discomfort is linked to relative levels of noise and vibration stimuli.

Finally, a last study, particularly interesting for our work, has been realized by Amman et al. [20] on driving situations. The participants have assessed the respective contribution of sound and vibrations (with six degrees of freedom) on assessments of driving situations (unsteady ones or passing on small obstacles) reproduced in a simulator. The experiment, linked to a preference issue, shows that the contribution of each modality is equivalent to the total preference evaluation of a driving situation.

As we have seen, the great diversity of studies conducted with sounds and vibrations makes it difficult to compare them. One can still conclude that a large number of the researchs agree that global discomfort of a studied parameter depends on both modalities.

In the present study, we focus on vibrations' influence concerning Dieselness issue. Indeed, Diesel vehicle is one of many daily-life sound sources that each person may qualify according to its sensitivity. However, each person defines its own Diesel noise with its own feelings which allows him to recognize it and often to disparage it. By using Dieselness term, we want to refer to "Diesel character": what, in the stimuli (sound alone or sound and vibrations together), reminds participants of their experience with a Diesel car. Fastl et al. [21–23] define the Dieselness term as "*the typical sound character of Diesel engine*". On the contrary, we did not use this exact definition to explain the Dieselness term to participants. The instruction of experiment gave details only as following: *Up to what point does this stimulus corresponds to a typical driving situation of a Diesel car? In other words, up to what point does it call up a Diesel stimulus? Up to what point does it allow to be aware of a Diesel car?*. We have let people to keep their own definition of Diesel character.[1]

[1] In the following, we will use "Dieselness" or "Diesel character" terms to express the same idea.

This article presents results of the perceptual vibro-acoustics test about Dieselness rating of six different driving situations of three various Diesel cars. It is made up of three parts. In the first part (Section 2), data recordings and processings (of sound and vibrations) are presented. Secondly, the experiment is detailed by precising the experimental setup and the protocol (Section 3). Finally, results are presented and discussed taking into account the two populations (French and German). Do perceptual differences exist between those two European populations, known as being two countries which possess the most Diesel vehicles in their respective markets [24,25]? If yes, what are the perceptual differences between those countries? Previous studies on intercultural differences have already been realized more particularly between Europe, America and Asia which have shown some differences between those different continents [26,27]. But what happens between two countries on the same continent? Moreover, previous marketing studies between those two countries have been performed at Renault [24,25]. Results highlight the differences between the two markets by distinguishing the driving style and the bought vehicle type. Also, this study precises that French and German agree with their expectations about the vehicle and its engine. Our hypothesis about cultural difference seems to be not to find big differences between those two populations because they both belong to the Europe and they represent the most Diesel market of Europe.

2. Sound and vibrations database

2.1. Recording

Acoustics and vibro-acoustic data are recorded simultaneously. The equipment used is respectively a Head Acoustics system (HMS III dummy head) in the co-driver seat and a LMS device (Scadas SCM-05). To record vibrations, two three-axis accelerometers are used (x, y and z directions): one located on the steering wheel's hoop and the other one, on the left back side of the driver seat. Fig. 1 shows the accelerometers' position. Two outputs of the dummy head and three channels of each accelerometer are linked to the eight inputs of LMS Scadas device. According to measurement's system used, sound and vibrations' recordings have been made respectively with a 102.400 kHz and a 4.096 kHz sampling frequency. All records are realized in a same section of a test ring.

2.2. Apparatus

A simulation bench equipped with a car seat and a car steering-wheel is used during experiments. It reproduces vibrations of three directions (x, y and z) for seat and two directions for steering-wheel. Nevertheless, benches used for experiments in France and in Germany, do not reproduce the same directions for steering wheel; in France, x and z directions are reproduced whereas in

Fig. 1. Locations of the three-axis accelerometers (blue) on the steering-wheel (left side of the figure) and on seat (right side of the figure) during the vibrations' recordings. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)