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WHAT IS THE INFLUENCE OF VIBRATIONS ON THE DIESEL CHARACTER RATING OF A VEHICLE?

A. Frère; R. Weber; C. Péteul-Brouillet; G. Guyader; N. Misdariis; P. Susini

Affiliation: {Renault; CvO Universität Oldenburg; Renault; Renault; STMS Paris; STMS Paris}
e-mail: {aurelie.frere@renault.com; reinhard.weber@uni-oldenburg.de ; claire.peteul-brouillet@renault.com,; gael.guyader@renault.com; Nicolas.Misdariis@ircam.fr, Patrick.Susini@ircam.fr }

Abstract
Up to now, the different studies dealing with the interaction between acoustics and vibrations were, in most cases, realized on global annoyance. In this paper, we want to focus on the influence of vibrations on the dieselness rating. Indeed, this article presents the results obtained with a vibro-acoustics test during which, the participants are exposed to sound only and sound and vibrations simultaneously. This perceptual test was realized on a vibration bench with headphones. During this experiment, participants are asked to evaluate the diesel character (called dieselness in this article) of six different driving situations on a continuous scale from 0 (no dieselness) to 1 (dieselness). The results from this study allow to identify the influence of vibrations (from the driver seat and from the steering wheel) on the evaluation of the dieselness. The results show that the participants give scores higher (more diesel) or equal (as diesel) with vibrations than without. However, the statistical analysis allows to conclude that the difference between the vibro-acoustic score and the acoustics score is in general not significant.

Keywords: perceptual vibro-acoustics test, vibratory bench, dieselness, driving situations.

1 Introduction

Most of studies which focus on the interaction between acoustics and vibrations, deal with the comfort (or annoyance) [1], [2] and [9]. [2] concludes that both modalities can contribute equally to comfort until one becomes highly dominant. Moreover, it evokes that the overall sensation seems to be dominated by the more annoying or stronger of the two modalities. Also, most of the experiments which focus on the vibro-acoustics interaction are realized on the idle situation [2], [3], [4], [5], [6] and [7]. It seems to be difficult to compare the different experiments led on this topic due to the great disparity between the different experimental

contexts [7], [8] and [9] (e.g. artificial or real sources, frequency range, duration of stimuli, sound level or vibration magnitude, sitting postures or psychophysical methods).
In this article, we want to focus on the influence of the vibrations on the acoustics concerning the question of dieselness. Indeed, this article presents the results of a perceptual vibro-acoustics test about the dieselness rating of six different driving situations of three various diesel cars.

2 Test device

2.1 Vibratory bench

A simulation bench equipped with a car seat and a car steering-wheel was used during the experiment. It reproduced the vibrations of three directions (x, y and z ones) for the seat and the vibrations of two directions for the steering-wheel (y and z directions). For this, 12 shakers reproduce the vibrations of the platform (4 shakers for each direction) in a frequency range varying from 20 to 150 Hz. Concerning the steering-wheel, 2 shakers reproduce the vibrations of this one in a frequency range varying from 20 to 300 Hz.
We use two three-axes accelerometers (PCB – ICP) for the calibration of each participant. These accelerometers are placed in the same location where they were positioned in the real car during the recordings (Figure 1).

2.2 Acoustics device

The sound stimuli were presented via a HPS IV amplifier system of Head Acoustics and a Sennheiser half-opened electrostatic headphone.
The whole system was driven by a computer equipped with a multi-channel sound card.

3 Stimuli

Six different driving situations (all from three various diesel cars) are presented to the participants: hot idle, 90-kph, start up the motor, stop the motor, acceleration and deceleration. The three different diesel vehicles are a 3-cylinders car, a 4-cylinders one and a 6-cylinders one. For each driving situation, the two modalities acoustics (A) alone and vibro-acoustic (VA), are exposed to the participants.

3.1 Recordings of data

The data were recorded with synchronization between acoustics and vibro-acoustic data. The equipment used is a LMS SCADAS device and a Head Acoustics HMS III dummy head (in the co-driver seat).
Two three-axis accelerometers were used (x, y and z directions): one located on the steering-wheel and the other one, on the back left side of the driver seat. Figure 1 shows the location of the accelerometers.

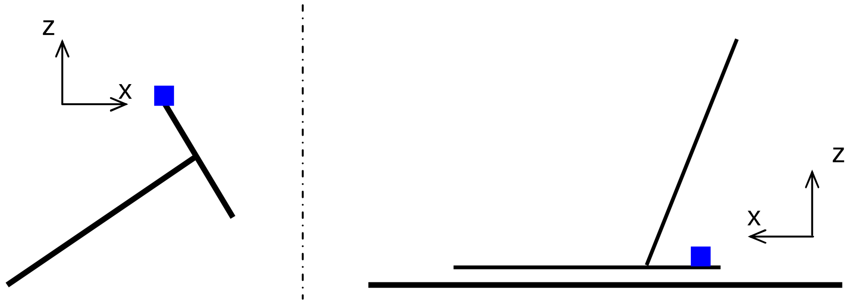

Figure 1 – The location of the three-axis accelerometers (blue) on the steering-wheel (left side) and on the left-back side seat (right side).

The two digital outputs of the dummy head and the three channels (directions x, y and z) of each accelerometer were linked to the eight inputs of the LMS SCADAS. All records were realized on a test ring.

3.2 Preparation of the data

As already mentioned before, acoustics and vibrations signals were recorded with LMS SCADAS device and a Head Acoustics dummy head in synchronization. Different processes were applied to signals in order to prepare them for the perceptual test:
- all recordings were exported in a wave format with a 44.1 kHz sampling frequency and 16 bits quantification;
- vibration signals of the seat (x, y and z directions) were filtered from 20 Hz to 150 Hz;
- vibration signals of the steering-wheel (y and z directions) were filtered from 20 Hz to 300 Hz.

No treatment was realized for the acoustics signals.

Remark: For the three vehicles, the lengths of the stimuli are different. They vary from 2s for start up the motor and stop the motor to 30s for the acceleration for instance.

4 Perceptual test

4.1 Participants

35 participants who do not work in automobile or acoustics domains, performed the vibro-acoustic test. All of them are regular diesel drivers and healthy (aged between 19 and 70 years old with a mean age of 29 years old). Table 1 summarizes the averaged anthropometric data of the subjects like body-size or weight.

Table 1 – Anthropometric data of the subjects.

Parameters	Mean
Age [y]	29
Body-size [cm]	178
Weight [kg]	80

26 men and 9 females participated to this test. The mean time made by the participants for the whole test is 39 min.

4.2 Test

This test allows to know how the people rate the dieselness of different situations. We use, in this article, the dieselness term in a neutral manner. Indeed, using the dieselness term, we want to refer to the diesel character: what, in the stimuli (sound alone or sound and vibrations together), remind to the participants their experience with a diesel car. We use this term in the same way as Fastl and al [10], [11] and [12].

The test is made up of two parts. The first one is an orientation phase during which, the participants listened to a sample of the stimuli that they will have to evaluate afterwards. The second part allows the participants to assess the diesel character (called dieselness) of each stimulus. Each subject evaluates 72 stimuli (6 driving situations * 3 vehicles * 2 modalities * 2 for the repetition). The stimuli are presented in a random order.

The question asked is: 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?
They evaluate each one with a score on a continuous scale from 0 to 1 such as:
- 0 means that they think the stimulus does not evoke a diesel engine at all,
- 1 means that they think the stimulus evokes a diesel engine perfectly.

We ask them to evaluate the overall dieselness of each stimulus.

During the test, the same instruction is given to the participants. They had to put their hands in the same place on the steering wheel (with a marker on it) and they have to lay their feet down flat on the platform. Before starting the experiment, a calibration of the bench (steering-wheel + seat) is realized for each participant.

At the end of the test, a small interview was realized with each subject in order to have the anthropometric data and to know their impression about the test.

5 Results and discussion

5.1 Results: Acoustics modality VS Vibro-Acoustic modality

The first step of analysis is to focus on the participants who appear like reliable on their evaluation. Indeed, during the second part of the test (the rate of dieselness), each stimulus was presented twice in a random order. A statistical analysis allows to see that 34 participants (over 35) are reliable in their evaluation. Therefore, the results presented in the following parts, take those 34 participants into account.

In this part, we present the scores and standard deviations of the six different driving situations for the two modalities A and VA (3-cylinders car in Figure 2A; 4-cylinders car in 2B and 6-cylinders car in 2C).
Each graph is divided in two parts with the two stationary driving situations at the left side (hot idle and 90-kph) and the four unstationary situations (from start up the motor to deceleration) at the right side.

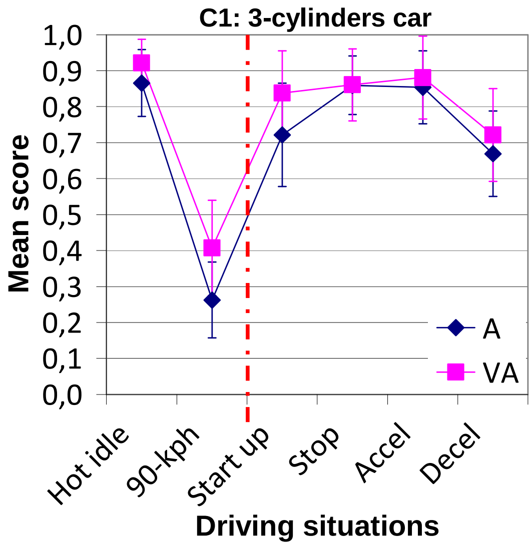

Figure 2A – Dieselness scores and standard deviations of the six driving situations for acoustics (A: blue diamond-shaped) and vibro-acoustic (VA: pink square) modalities for C1.

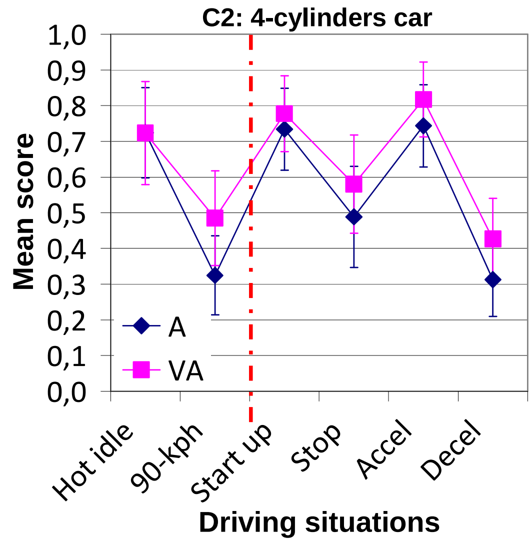

Figure 2B – Dieselness scores and standard deviations of the six driving situations for acoustics (A: blue diamond-shaped) and vibro-acoustic (VA: pink square) modalities for C2.

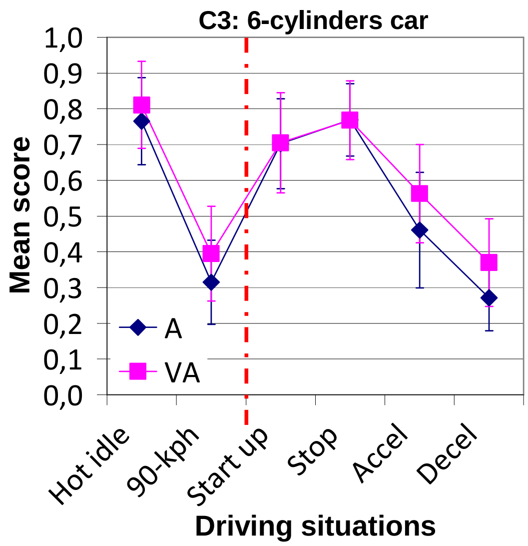

Figure 2C – Dieselness scores and standard deviations of the six driving situations for acoustics (A: blue diamond-shaped) and vibro-acoustic (VA: pink square) modalities for C3.

The higher the score for one driving situation is, the more the dieselness is perceived by the participants. The first remark concerns the fact that for each car and for each driving situation, the participants assess more diesel the VA modality than the A modality or at least, as diesel (with stop for C1, hot idle for C2 and start up and stop for C3 for instance).

An ANOVA analysis was realized about the different results for each car (Figure 2A to Figure 2C).

Figure 2A:

- The statistical analysis shows that the 90-kph situation is significantly different from the other driving situations. This result is valid for A and VA modalities.
- The same ANOVA analysis between the two modalities (A VS VA) allows to conclude that for this 3-cylinders car (C1), there is a significant difference (p=0,015) for the 90-kph situation. For the five others driving situations, the difference between the score given for the A modality and the VA modality is not significant.

Figure 2B:

- For the 4-cylinders car (C2), those 90-kph, stop the motor and deceleration appear significantly different from the three others situations. Those results can be generalized for the two modalities.
- Comparing the two modalities, we can conclude that the difference between the two modalities is really significant for the 90-kph and deceleration.

Figure 2C:

- 90-kph, acceleration and deceleration situations are significantly different from the three others situations for A and VA modalities.
- For the 6-cylinders car (C3), the results show that there is no difference between A and VA for all situations.

Table 2 – ANOVA analysis for a comparison A VS VA
for the three diesel cars
(The significant difference results are in bold)

Driving situations	C1	C2	C3
Hot idle	0,155	0,983	0,445
90-kph	**0,015**	**0,009**	0,191
Start up the motor	0,071	0,420	0,973
Stop the motor	0,976	0,180	0,991
Acceleration	0,603	0,173	0,166
Deceleration	0,389	**0,034**	0,067

5.2 Results: comparison between vehicles

In this part, we compare the mean score of dieselness obtained for all driving situations for all cars (C1: 3-cylinders car, C2: 4-cylinders car, C3: 6-cylinders car). Each chart presents one modality. Figure 3A presents the mean score given by the participants who evaluate the dieselness of the acoustics stimuli and Figure 3B, when they rate the dieselness of the vibro-acoustic stimuli.

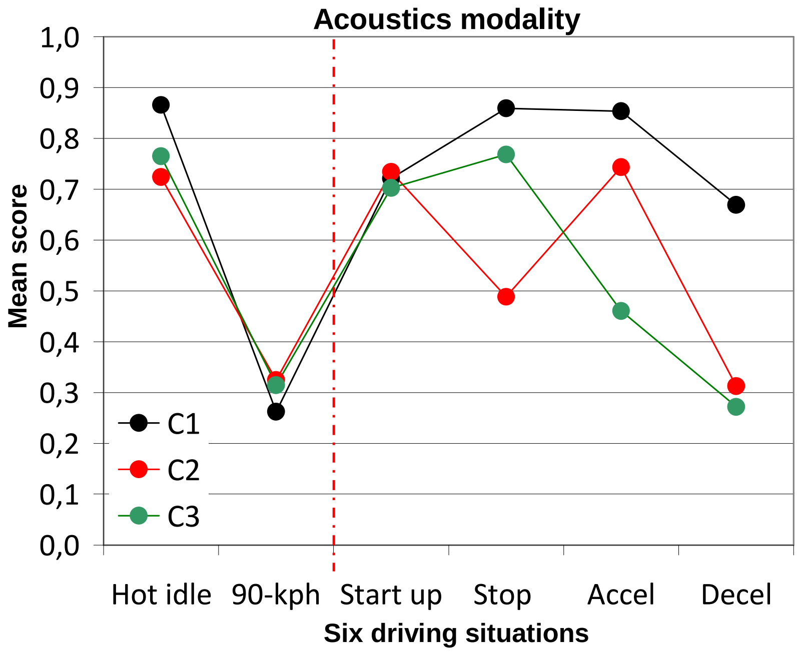

Figure 3A – Dieselness scores of the six driving situations for all cars (C1, C2 and C3) for the A modality.

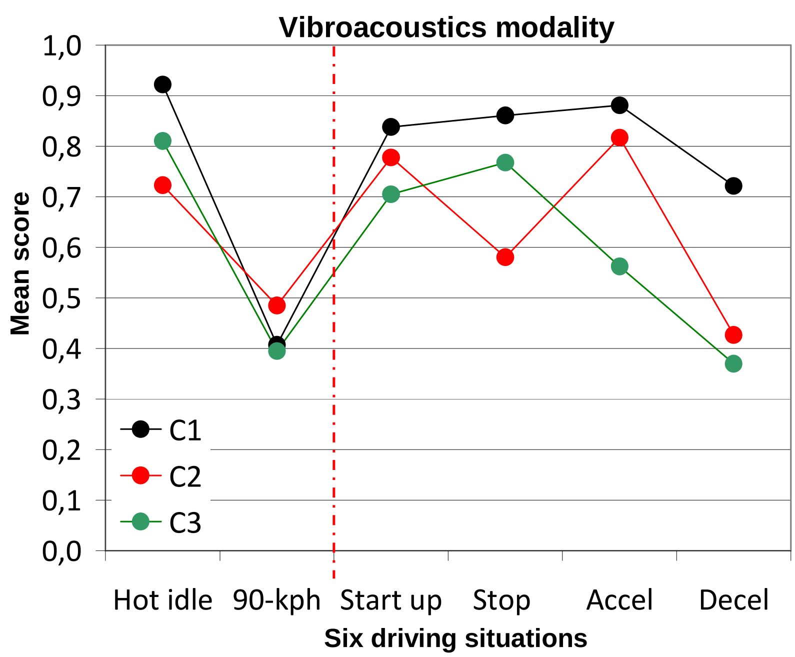

Figure 3B – Dieselness scores of the six driving situations for all cars (C1, C2 and C3) for the VA modality.

We can see, still here, the two stationary driving situations at the left side and the four unstationary situations at the right side.

Tables 1 and 2 which follow, present the results of ANOVA analysis which focus on the comparison 2*2 between all cars C1, C2 and C3.

Figure 3A: Acoustics modality

Table 3 – ANOVA analysis for a comparison 2*2 of the diesel cars for the acoustics modality (S: Significant difference / NS: No Significant difference)

Driving situations	C1 VS C2	C2 VS C3	C1 VS C3
Hot idle	S	NS	NS
90-kph	NS	NS	NS
Start up the motor	NS	NS	NS
Stop the motor	S	S	S
Acceleration	S	S	S
Deceleration	S	NS	S

Table 3 presents the difference more or less significant between the scores obtained for each car for the A modality. Each column represents:
- **C1 VS C2**: the difference between the 3-cylinders and the 4-cylinders car;
- **C2 VS C3**: the difference between the 4-cylinders and the 6-cylinders car;
- **C1 VS C3**: the difference between the 3-cylinders car and the 6-cylinders car.

The first remark seeing this Table 2 is that the participants rate with score really close the three diesel cars for 90-kph and start up the motor (NS difference between the vehicles 2*2) whereas for stop the motor and acceleration the difference between all comparison of cars, is significant. Apart for the 90-kph and start up the motor, the 3-cylinders car seems to be, each time, more diesel than the other cars.
On the one hand, for hot idle, only 3-cylinders and 4-cylinders cars are significantly different on the acoustic evaluation. On the other hand, the results between 4-cylinders and 6-cylinders cars are not significantly different for deceleration,

Figure 3B: Vibro-acoustic modality
Few differences are obtained with the results of acoustics modality. Indeed, the 3-cylinders car seems to be more diesel than the other cars except for 90-kph situation.
In the same way as Table 3, Table 4 presents the results obtained after an ANOVA analysis for the vibro-acoustic modality. The differences which appear with Table 4 are specified in bold italics.

Table 4 – ANOVA analysis for a comparison 2*2 of the diesel cars for the vibro-acoustic modality (S: Significant difference / NS: No Significant difference)

Driving situations	C1 VS C2	C2 VS C3	C1 VS C3
Hot idle	S	NS	***S***
90-kph	NS	NS	NS
Start up the motor	NS	NS	***S***
Stop the motor	S	S	***NS***
Acceleration	***NS***	S	S
Deceleration	S	NS	S

We can notice in Table 4 that some inversions appear when we compare 3-cylinders car with one of the two others. On the one hand, in the presence of vibrations, the dieselness evaluation of hot idle and start up the motor increases more for the 3-cylinders car than for the 6-cylinders one (for instance, for start up the motor, C1 grows up from 0.72 to 0.84 whereas C3 remains the same). On the other hand, the difference of rating for stop the motor becomes_slightly insignificant between C1 and C3. It is the same, for the acceleration between C1 and C2: in presence of vibrations, the difference becomes insignificant.

6 Conclusion

This article deals with the interaction between acoustics and vibrations but especially about one question: is there an influence of the vibrations on the assessment of diesel character? The diesel character (called dieselness) of six different driving situations and of three various diesel cars was rated by 35 participants during a perceptual vibro-acoustic test.

The results show that we can not generalize concerning the impact of the vibro-acoustic modality on the overall diesel character rating. Indeed, the effect of the vibrations on this evaluation depends on different parameters: the kind of diesel cars (3-cylinders, 4- cylinders or 6-cylinders car) and the driving situation. First, 90-kph is considered like really different (less diesel) from the other driving situations (for the whole cars). More precisely, in the presence of vibrations, the dieselness evaluation of this driving situation increases strongly for the 3-cylinders and the 4-cylinders cars. The things we can underline is that for each car and for each driving situation, the score given for the dieselness is higher or equal with vibro-acoustic modality than with acoustic modality.

As a conclusion, we could see that depending on the kind of cars and on the driving situation, we do not obtain the same results. In most of cases, the participants gave scores higher (more diesel) with vibrations than without. However, we can not predict the importance of the impact of vibrations on the dieselness evaluation.

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