HAL
open science

Contribution of noise and vertical vibration to comfort in a driving car

Etienne Parizet, M. Amari, Vincent Roussarie

To cite this version:

Etienne Parizet, M. Amari, Vincent Roussarie. Contribution of noise and vertical vibration to comfort in a driving car. EuroRegio 2010, 2010, Ljubljana, Slovenia. pp.1. hal-00993903

HAL Id: hal-00993903

https://hal.science/hal-00993903v1

Submitted on 20 May 2014

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1st EAA – EuroRegio 2010
Congress on Sound and Vibration
15 - 18 September 2010, Ljubljana, Slovenia
With Summer School for Young Researchers from 13 - 15 September 2010
Slovenian Acoustical Society

Contribution of noise and vertical vibration to comfort in a driving car

Etienne PARIZET[a], Mael AMARI[b] and Vincent ROUSSARIE[b]

[a] Laboratoire Vibrations Acoustique, INSA-Lyon, 25 bis av. Jean Capelle, 69621 Villeurbanne, FRANCE, email : etienne.parizet@insa-lyon.fr
[b] PSA Peugeot Citroën, route de Gisy, 78943 Vélizy-Villacoublay, FRANCE

ABSTRACT

In a driving car, passengers are submitted to complex sound and vibration stimuli. These stimuli are integrated in a complex way and contribute to the comfort for passengers.
This talk will summarize some work related to that field, during which a noise and vibration simulator was used to evaluate the relative contributions of noise and vibration to comfort in a driving car. A first step showed that this evaluation was only slightly modified by vision (of a video showing the road on which the car was driven on). Then a complete experimental plan was used : sound and vibration levels were independently varied and the subjects were asked to evaluate the comfort of the overall situation. The results were in concordance with the existing literature, i.e. the interaction between both stimuli is very small. But the relative contributions of sound and vibration to comfort were different from the existing models; this was certainly due to the range of levels used in that experiment, which represented usual levels measured in cars.

.

1. INTRODUCTION

A car passenger is submitted to many stimuli, including acoustic and vibratory ones. These noise and vibration signals can be due to the engine, but also to the road. Road induced noise and vibrations increase with the roughness of the road. On very bad road surfaces, even at low speeds (around 30 km/h), inside noise levels can be of 85 *dB* SPL (60 *dB(A)*). Vertical vibrations, when measured at the seat track, can reach a level of 1 m/s^2, which represents about 0.3 m/s^2 at the seat cushion.

Many studies investigated the contribution of noise and vibration to comfort; but most of them focused on planes [1,2], trains passing along a house [3, 4], or passing trams [5]. Studies about cars were devoted to an idle situation [6] or papers relating such studies did not include enough details [7]. One goal of this study was thus to compare these two contributions in the case of a driven car.

Another goal was to specifically look for an interaction between visual stimuli and vibro-acoustic ones. Indeed, in a car, passengers (at least front ones) can see the road. They are able to anticipate some holes or bumps in the roadway before the car will pass on them. In some other cases, it has been shown that an interaction between visual and auditory stimuli exists [8, 9]. Is that true in this driving situation ?

2. EXPERIMENTAL DEVICE

The vibration test bench is presented in details in [6]. It is made of a platform lying on four springs and vertically moved by a shaker (LDS V555). The subject can sit on a car seat fixed on the platform. The transfer function between the shaker and the seat track is easily corrected so that it is possible to accurately reproduce the vertical vibration measured at the seat track in the car. It should be noted that, if the seat does not correspond to the actual one in the car, the vibration which the subject is submitted to are not reproduced, as the seat attenuation is not taken into account.

One advantage of exciting the platform with an electrodynamic shaker is that the noise from this actuator is rather low – especially if the amplifier and the cooling turbine are located in another room. Therefore, it is possible to also present sounds to the subject. These sounds are recorded with a dummy-head (Head Acoustics *HMS III*) and can be reproduced through electrostatic headphones or a transaural four speakers device (Genesis *GeneTrans*). In both cases, a subwoofer is in use in order to reproduce very low frequencies at a correct level, as it had been shown that this can be important [10].

Finally, a vertical screen (2 *m* x 3 *m*) is placed 3 meters in front of the subject. It is used to play a video recorded in the car, in the meantime of vibration and noise signals. For that purpose, a high-definition camera is fixed on the wind shield. It records the road as seen by the front passenger (the dashboard cannot be seen to prevent the subject from identifying the car).

All signals are carefully synchronised during the measurements and this synchronisation is maintained during playback.

3. IMPORTANCE OF VISUAL STIMULI

The goal of this first step was to evaluate how visual stimuli can modify the evaluation of comfort in the laboratory. Indeed, recording and playing back synchronized videos enhance the complexity of the set-up. If they were not necessary, the experiments would be much easier.
In order to answer this question, two experiments were conducted.

First experiment
Recordings were made in 8 middle size cars, driven at 30 *km/h* (in second gear ratio), on two roads :
- the pavement of the first one (road A) was rough, with a stationary visual aspect;
- on the second one (road B), the surface suddenly changed from very smooth to very irregular. This change could be seen on the video and had a clear consequence on vibration and sound signals.

For each road, 3 test sessions were conducted :
- in the first one (denoted as VIS), all stimuli (vibration, image, sound) were played back (using the transaural technology for sounds). The 8 signals (their duration being 6 *s*) were presented in a random order to the subject. The task of the subject consisted in evaluating how comfortable each combination was. He gave his answer by moving a cursor along a continuous scale (5 levels were indicated with various labels from "*not at all comfortable*" to "*very confortable*"). Each combination could be played again if the subject asked for.
- in the second one (VS), vibration and sound stimuli were used, without any visual signal. The procedure was the same as in the previous session;
- in the third one (V), only vibration stimuli were used, using the same procedure.

64 subjects (47 men and 17 women) participated to the study. Each of them had thus to realise 6 sessions. The order of these sessions was varied between subjects.

Individual evaluations were recorded as number (from 0 : *not at all comfortable* to 100 *: very comfortable*) and averaged, as the inter-individual variation could be neglected.
Results showed that noise was an important feature for one car (V1), as evaluations were quite different in conditions V and VS for that car (figure 1). That can be due to the frequency content of that sound, which was a very low-frequency one.

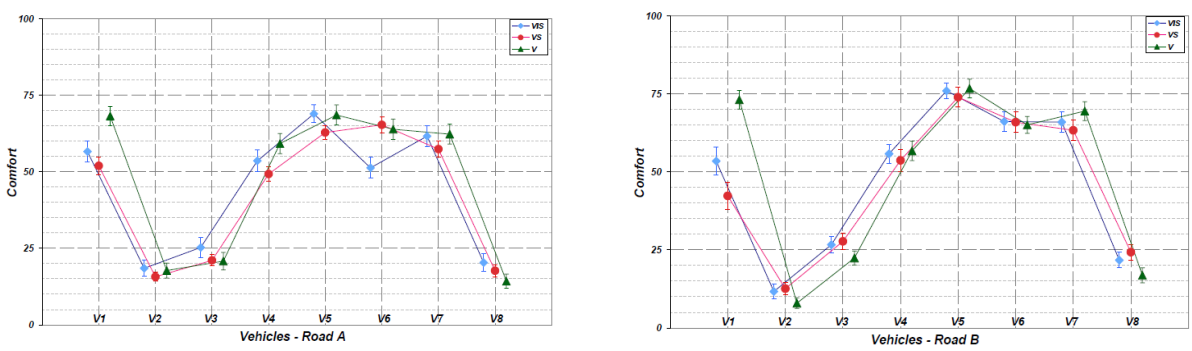

Figure 1. Comfort evaluations for the two roads, in the three test sessions.

Generally speaking, using video stimuli slightly increased the evaluations from subjects. But the difference was significant for 4 couples of data only (3 cars for road A, 1 for road B). In one of these cases (road A, car 6), the effect is the opposite one (comfort is lower in the VIS condition than in the VS one), which could not be explained. It can be seen on figure 1 that differences between VIS and VS curves were very limited : the influence of visual stimuli was small.

Second experiment

A following experiment confirmed this result. Recordings from the 8 cars on road A were used in three sessions. In each session, subjects were submitted to vibrations, videos and sounds. In the first one, videos were those recorded on road A, while in the second and first sessions videos recorded on two other roads were presented : a very smooth pavement (road C) and a very rough one (road D). Therefore, the vibroacoustical and visual stimuli did no longer fit together. The same procedures were used, with the exception that sounds were emitted through headphones (plus subwoofer) instead of a transaural set-up. 60 people (40 men and 20 women) participated to that experiment. Among them, 20 had already been involved in the first experiment.

Results are presented on figure 2. Once again, the road video had a real but small effect : the differences between the three values attributed to each car were rarely significant.

These results are in accordance with the one from the first experiment : visual stimuli only slightly modified the evaluation of comfort. As a practical conclusion, these stimuli can be omitted, which eases the experiment (during recordings in the cars and playback in the laboratory).

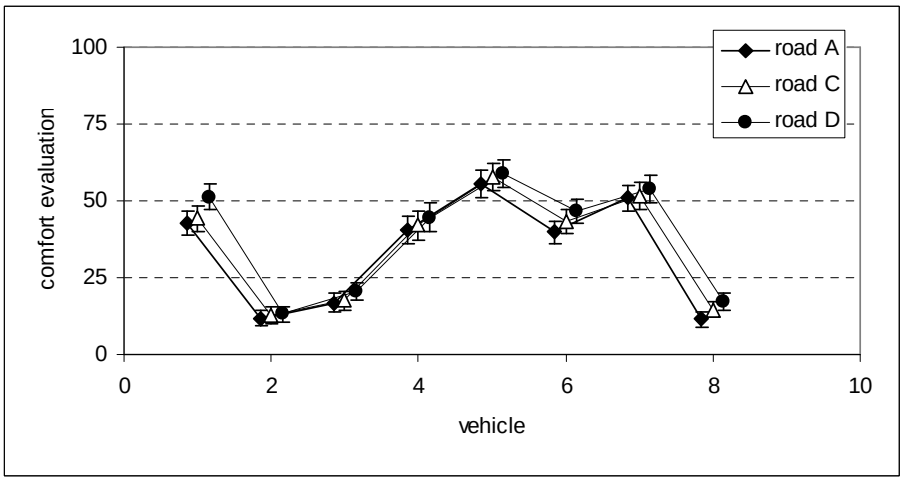

Figure 2. Comfort evaluations for the two roads, in the three conditions.

4. CONTRIBUTION OF NOISE AND VIBRATION

The goal of the next step of the study was to evaluate the relative contributions of noise and vibration to comfort in a driving car. Signals previously recorded in cars V1, V2, V3 and V6 were used. Their levels were adjusted according to a complete experimental plan. The factors of this plan were cars (4), vibration amplitude (5 levels) and noise amplitude (5 levels). For

noise, the arithmetic mean of sound pressure levels, measured at the two ears of the dummy head, was considered. The levels for vibration and noise amplitudes can be seen in table 1. 25 sets of stimuli were prepared for each vehicle. The duration of stimuli was still 6 *s* and the transaural sound device was used.

Table 1. Noise levels L_n (dB SPL) and vibration levels L_v (dB ref. 10^{-6} $m.s^{-2}$)

	L1	*L2*	*L3*	*L4*	*L5*
L_n (dB)	90	87	84	81	78
L_v (dB)	115	112	109	106	103
L_v ($m.s^{-2}$)	0.56	0.4	0.28	0.2	0.14

68 subjects participated to this experiment. All stimuli were randomly presented and the subject had to achieve the same task as before.

First of all, a classification of individual results and a principal component analysis showed that the inter-subject agreement was correct. Therefore, no clustering of subjects was necessary and the whole panel was considered.

An analysis of variance was then realized (repeated measures). It appeared that all factors were significant : noise level L_n ($F(4, 268) = 156.8$), vibration level L_v ($F(4, 268) = 452.4$) and cars ($F(3, 201) = 18.7$). The significance of the last factor indicates that the frequency spectrum of signal measured in a car cannot be neglected, though the F value is less than those related to the overall level of stimuli. A closer examination of results showed that this was mainly due to the first car, in which noise spectrum is quite particular, as previously noted. In the following, the evaluations obtained by the four cars for a given combination of noise and vibration level were averaged. Many interactions between factors were significant, as, for example, the one between noise and vibration levels ($F(16, 1072) = 24.8$).

Figure 3 represents the evaluation for a given combination of sound and vibration levels (averaged over the four cars).

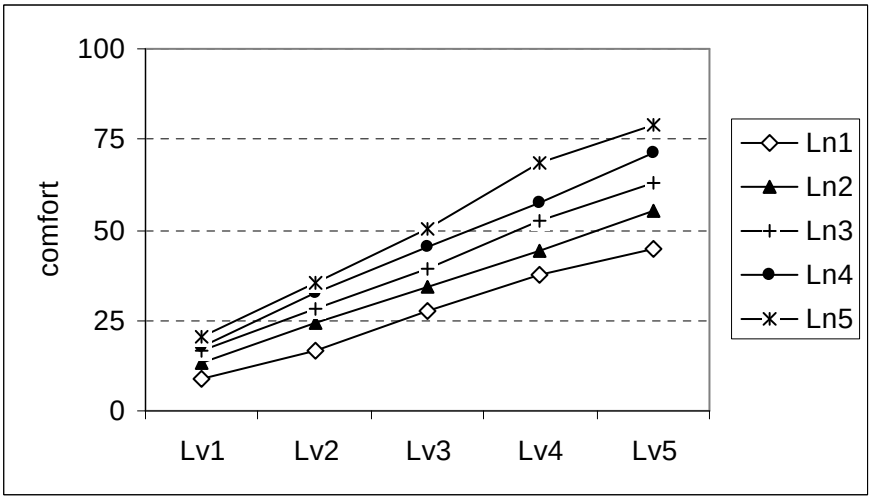

Figure 3. Averaged comfort evaluations.

The slopes of the curves and the differences between them indicate that the contribution of vibration level is higher than the one of sound level, as confirmed by the F values of these two factors. Also, the interaction between these factors can be detected on figure 3.
When averaging data over the 4 cars, an accurate model for comfort could be proposed, using Eq. (1) :

$$E = -2L_n - 4L_v + \alpha \tag{1}$$

In this model, L_n and L_v are noise and vibration level, expressed in dB as in table 1, α is a constant. This model proved to be very accurate (R^2 = 0.975), even if it could be improved taking count of the slight interaction between the two factors. But the increase of accuracy was limited (the coefficient of determination grew up to R^2 = 0.997).

As sound from V1 had a particular frequency balance, noise levels were expressed in dB(A). That way, a second model could be proposed as in Eq. (2), using the whole set of values :

$$E = -1.7L_{nA} - 4L_v + \beta \tag{2}$$

The accuracy of the model was also quite good (F (2, 97) = 944, R^2 = 0.9, see figure 4).

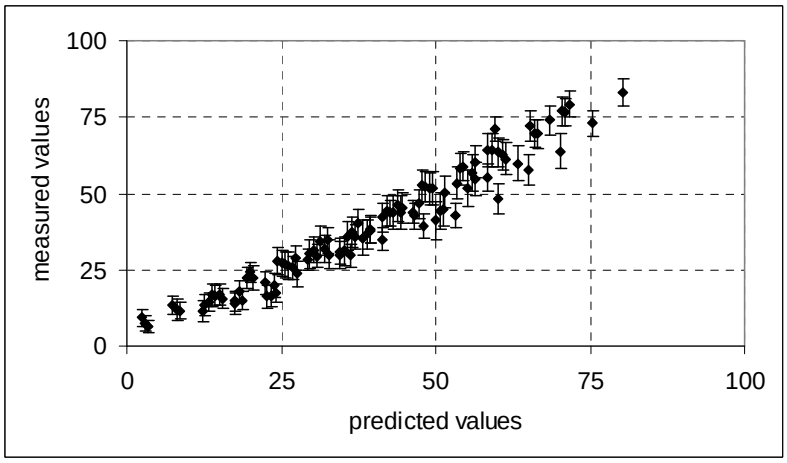

Figure 4. model of comfort for the four cars.

The coefficients appearing in Eq. (1) and Eq. (2) are different from those proposed in the existing literature [4, 5], which may be due to the kind and level range of stimuli used in this experiment (recorded in a car while the cited studies focused in in-house noise and vibration). In this study, it appeared that the contribution of vibration was approximately twice as the one from noise. This could be related to the exponent of Stevens' power law, relating the physical and psychophysical magnitudes of vibration and noise. For sound, a common value of this exponent is 0.6 (sound magnitude being expressed in pressure values). For whole-body vibration, the agreement is not so high. Values proposed by the existing literature vary from 0.5 to 2 [11]. A study conducted in the laboratory gave a value close to 1.4 (for 10 Hz sinusoidal vibrations). This result was determined from two different procedures : magnitude estimation and magnitude production.
Therefore, while adding 10 dB to the sound pressure level will twice loudness, adding the same value to whole-body vibration will multiply the psychophysical magnitude by a factor 5. This 2.5 ratio is roughly the same as the ratio between the two factors in Eq. (2).

5. CONCLUSIONS

This study is an example of in-laboratory investigation about customers' comfort in a car. A simulator has to be used – and defining the complexity of this simulator is a key factor for the realization of such experiments. It seems that showing to subjects a video of the road is not necessary, even if it increases the realism of the situation (as related by some subjects). Using the simulator made it possible to find very simple comfort models, the input of which being sound and vibration levels. Such a model can be used by a car manufacturer to evaluate prototypes or predict comfort level from computational models.

6. REFERENCES

[1] Dempsey T., Leatherwood J. and Clevenson S., " Development of noise and vibration ride comfort criteria". Journal of the Acoustical Society of America, vol 65, 1979, pp. 124-132.

[2] Leatherwood J., Clevenson S. and Stephens D., "The development of interior noise and vibration criteria". NASA Technical Report NAS 1.15:102736; NASA-TM-102736, 1990.

[3] Howarth H. and Griffin M., "Subjective response to combined noise and vibration : summation and interaction effects". Journal of Sound and Vibration, vol 143, 1990, pp. 443-454.

[4] Howarth H. and Griffin M., "The annoyance caused by simultaneous noise and vibration from railways". Journal of the Acoustical Society of America, vol. 89, 1991, pp. 2317-2323.

[5] Paulsen R. and Kastka J., "Effects of combined noise and vibration on annoyance". Journal of Sound and Vibration, vol. 181, 1995, pp. 295-314.

[6] Parizet E. and Brocard J., "Influence of noise and vibration to comfort in diesel engine cars running at idle". Acustica united with Acta Acustica, vol. 90, 2004, pp. 987-993.

[7] Amman S., Mouch T. and Meier R., "Sound and vibration perceptual contributions during vehicle transient and steady-state road inputs". International Journal of Vehicle Noise and Vibration, vol. 3, 2007, pp. 157-171.

[8] Viollon S., Lavandier C., Drake C., "Influence of visual setting on sound rating in an urban environment". Applied Acoustics, vol. 63, 2002, pp. 493-511.

[9] W. Ellermeier, S. Legarth, "Visual biais in subjective assessments of automotive sounds", Proceedings of Euronoise, Tampere, 2006.

[10] E. Parizet, M. Mouret, " Improvement of dummy head recordings realism with an additional subwoofer", Proceedings of Forum Acusticum, Sevilla, 2002.

[11] Griffin M.J., "Handbook of human vibration". Elsevier, London ,1990.

[12] Geiger V., "Vérification de la loi de Stevens pour les vibrations (sujet assis)" (Stevens' law for whole-body vertical vibration (seated person)), Master thesis, INSA-Lyon (2007).