Evaluation of comfort for vibroacoustic transient excitation

Vincent Roussarie, Mickaël Sauvage
PSA Peugeot Citroën, Division of Research and Automotive Innovation, “Perception and Human factors” Department, Route de Gizy, F-78943 Vélizy-Villacoublay Cedex, France, {roussarie, sauvage}@mpsa.com

Elise Gressant
GRADIENT, Université Technologique de Compiègne, France, elise.gressant@mpsa.com

Emmanuelle Diaz
SGCP, 4 rue Chaptal 75009 Paris, France, emmanuelle.diaz@mpsa.com

Automotive comfort for transient stimulation knowledge mainly emerge from one perception domain studies (as for examples: acoustics comfort studies, vibration comfort studies etc). However, subject perception of comfort is not a response to a mere sum of single sensations but mostly to simultaneous sensory stimulations. Following one of our recent study which showed high subject sensitivity for transient vibration level, we designed a new experiment in order to model vibroacoustics comfort against transient vibration and sound levels. A study has been simultaneously designed in order to identify the JND’s for transient signals in acoustics and vibration. Signals from two vehicles which sound and vibration levels are modified according to experimental design method are used to build two groups of stimuli. These two groups are then used for a test comfort. The results for the two models are highly significant, but not coherent when compared to each other. Thus, it is not possible to obtain a general model for both vehicles. Furthermore, only main effects appear in these two models, no interactions has been identified. On the one hand, we obtain a first order model, on the other hand we obtain a first order model with a quadratic effect. Thus, levels effects on comfort appeared on the results, but we cannot conclude about a mere level effect on comfort, showing therefore that other sensory variables influence comfort judgment.

1 Introduction

Investigating automotive comfort, especially for transitory events, requires taking into account the two sensorial modalities vibration and sound as both of them provide simultaneously major information to the driver. Though, many studies already published have investigated comfort by studying each modality apart (acoustics or vibratory) and only a very few of them deal with vibroacoustics stimulations and cross modal interactions.

As a matter of fact, literature deals with three types of interactions: physiological interactions, cross-modal interactions and cross-modal interactions related to affective states. In the physiological case, authors have studied the influence of impulsive vibrations on the perception of impulsive sounds [5,8], or the contribution of each modality on the adverse effect on human body [6]. Both modalities appear to be influential on human body’s health. Others authors found out that when a vibration stimulus is added to a sound stimulus, it steps up the strain on the cochlea which can lead to serious physiological damages and induce a loss of auditive sensitivity [5,8]. While in study [6], they found out that loudness reduction as well as vibration reduction contributes to the prevention of adverse effects on human body when using vibrating tools.

Cross-modal interactions have also been studied in several experiments in a perceptive context. These show appreciable differences between experimenters. Some authors admit that there must be an influence of vibratory level on the perception of noise level [7,8 11], while others tends to think there is no apparent influence of one modality on another [1, 2, 3], or that it may be an artefact [2]. In the third case, when the emotional assessment of vibroacoustic stimuli is concerned, many publications attempt to show the presence of cross-modal interactions [1,8,10,12]. Some authors found out that comfort depended on the additive interaction of the relative magnitude of sound and vibration, according to a linear model [4,8,10]. Others tried to explain the comfort thanks to a 2 dimensions space (arousal and valence). They found out first that the assessment of comfort for vibroacoustic stimuli couldn’t be carried out with one dimension scale as comfort is a combination of valence and arousal. They also proved that there is a difference between multimodal perception (vibroacoustic) and unimodal perception (acoustic) and, hence, that studying unimodal perception induces a lack of information.

However, the experimental conditions of these studies are various and explain this results dispersion. They differ on the following points:
The vibratory stimuli can be real stimuli produced by a train or a hammermill [1, 8], or an artificial stimuli built by synthesis with sinusoidal signals [10].

The acoustics and vibratory levels selected vary from a publication to another: 85 dB(A) in a case [3] and up to 95 dB(A) in the other [2], for acoustics level.

Whether they are placed inside a simulator [10] or on a vibroacoustic bench [7], subjects are not submitted to the same conditions.

When affective states are concerned, vibroacoustic assessment can be done using Semantic Differential [10] or bipolar scales [12]. These experimental differences don’t allow us to extract a general cross-modal interaction phenomenon that could exist in our specific case: automotive comfort for transient excitation. Hence, we built upon this context the following study in order to: complete knowledge on transitory events and vibroacoustics interactions, get a better evaluation of the respective contribution of these two modalities on comfort and propose recommendations. We carried out a test in two steps:

- Difference Threshold: The difference threshold is measured in order to know both human vibration and acoustic sensitivity for transient events in a multimodal case (vibroacoustic) and unimodal case (acoustic or vibration).

- Analytic Approach of Comfort: According to an experimental design, we built 9 signals upon a real vibroacoustic signal in order to obtain a comfort model for transitory events. The real vibroacoustic signal that has been measured on a vehicle is then amplified to obtain the final 9 signals. This experiment is repeated twice using two different vehicles as original signal.

2 Material and subjects

2.1 Stimuli

Whether difference threshold or analytic approach is concerned, each stimulus used was built upon real vibroacoustic stimuli, measured in a vehicle recorded in a synchronous way:

- The vibratory signal is measured by a B&K accelerometer stuck on the seat’s slide,

- Binaural signal is measured by an acoustic head (Head Acoustics) placed on the momentary seat. It is synchronized with vibration measure.

The signals are measured on a calibrated obstacle and car speed is 30 km/h.

2.2 Subjects

66 male and female volunteers from the company participated in the experiment. They were aged between 18 and 40 [mean 32] years with an average weight of 79.2 kg. None of them worked in the acoustic and vibratory field.

2.3 Apparatus

2.3.1 Vibratory restitution

Restitution is carried out on a bench provided by the INSA’s vibroacoustic laboratory. Excitation is produced by a vibrator powered by a PA-1000 amplifier. It allows a linear vibratory restitution in the frequency range of [4, 100] Hz. The system allows to be used up to a charge of 200 kg. The exciter (in white) excites the vibrating part of the bench (in blue) which is posed on 4 springs with a cut-off frequency of 3.5 Hz. The springs are posed on a fixed frame (in black). Subjects sit on a real car seat and put there feet on a footrest. Both were fixed on the bench.

Figure 1: Vibroacoustic bench

Vibration was generated and measured using Labview software and a digital computer. In order to ensure an accurate restitution of the signals, each original signal is filtered by the inverse response of the whole system. This response is independent of the magnitude as the vibration exciter behaves in a linear way.
2.3.2 Acoustics restitution

Headphones reproduction has been selected to produce a sound as real as possible thanks to the Head Acoustics binaural recording. Head Acoustics HMS3 was used for the recording, and a digital playback system was used for the restitution. This digital playback is made up of 3 elements: a PVA4 amplifier, a PEQ4 pre-amplifier and electrostatics headphones.

3 Part 1: difference thresholds

3.1 Experimental method

3.1.1 Protocol

The protocol was built upon the 3-down-1-up method also called “adaptive method”. The principle is to present the stimulus with gradually increasing (or decreasing) levels, as long as the subject produces always the same response (“not perceived”, for example). As soon as the answer changes (“not perceived” to "perceived"), the variation direction for the stimuli presentation is reversed (for instance: from increasing, levels become decreasing).

In a vibroacoustic context, it is necessary to proceed to four types of difference thresholds evaluation. We wish to obtain the difference thresholds in 4 cases: with vibratory stimuli, with acoustic stimuli, with acoustic stimuli in presence of vibratory (coupled situations) and finally with vibratory stimuli in presence of acoustics. The evaluations always start with the test in the coupled situation. Thus, it prevents us from checking the hypothetical influence of one stimulus on the other.

3.1.2 Signal

These threshold values have been calculated from an original signal which magnitude is located in the average of our vehicles vibroacoustic mapping. We made the assumption that Weber’s law is true in the values domain studied after.

3.2 Results

Difference thresholds are characterized by higher and lower values of the average gain. These values are defined as the change in a stimulus required for a human being to recognize a “just Noticeable Difference” in the stimulus.

In this context, the average difference thresholds observed are 3dB for acoustics and 0.045 m/s² for vibratory. These values are very close to those observed for basic signals (sine). Furthermore, the presence of one modality during the evaluation of another has no significant influence on results. The detected thresholds are slightly higher in the presence of the two methods but it is no significant.
4 Experiment 2: Modelization of vibroacoustic comfort

4.1 Experimental design

4.1.1 Theory and plan

Experimental design theory is a statistical method for organizing and conducting scientific experiments, which enables experimenters to reduce the number of trials run, while retaining all the parameters that may influence the results. Nevertheless, there is a direct link between experimental design quality and the conclusions validity drawn from experimental results. Hence, as the choice of ideal experiments is based on mathematical concepts, in this case, Central Composite Design has been chosen in order to estimate curvature.

Models equation:

\[ y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_12 X_1X_2 + \beta_22 X_2^2 + \beta_12^2 X_1^2 + \epsilon \]  

Equation (1)

\( X_1 \) and \( X_2 \) are the vibratory and acoustic level variables respectively. The composite centred plan enables us to model main effects, quadratic effects as well as interactions of each factor (vibratory level and acoustic one). Each coordinate of the plan is mathematically calculated from the vibration and acoustic levels of the centre point (0,0). The magnitudes of the signal corresponding to this point are those measured on real situation.

4.1.2 Signal

Two experimental designs were used in order to obtain comfort information with two distinct vehicles. Hence, the experimental design once selected is applied to two different region of the vibroacoustic magnitude mapping. This choice is done by the necessity to explore the classical automotive area. Maximum amplitude variation is 6 dB for the acoustic signal and 0.16 m/s² for the vibration signal.

<table>
<thead>
<tr>
<th>Lower limit</th>
<th>Higher limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veh.1</td>
<td>Veh.2</td>
</tr>
<tr>
<td>X1 (dB)</td>
<td>-3</td>
</tr>
<tr>
<td>X2 (m/s²)</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

Table 1: lower and higher limit of the vibroacoustic gain

4.2 Results

The selected experimental design makes it possible to evaluate main effects contributions, cross-modal interactions and possibly quadratic effects for each case. During our test, no effect of interactions was noted for the signals built on vehicle 1 or 2. Only principal effects as well as the vehicle2 acoustic quadratic term are significant for model construction.

<table>
<thead>
<tr>
<th>Original signal</th>
<th>Models obtained between the predictive comfort (Y) and both vibration (X1) and acoustic (X2) parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veh. 1</td>
<td>[ Y = 3.94 - 0.90 X_1 - 0.53 X_2 ]</td>
</tr>
<tr>
<td>Veh. 2</td>
<td>[ Y = 2.82 - 0.63 X_1 - 0.58 X_2 + 0.19 X_2^2 ]</td>
</tr>
</tbody>
</table>

Table 2: comfort models obtained

In the case of vehicle 1, both modalities impact the comfort with almost twice more weight for vibrations. In the case of vehicle 2, the impact of the two modalities is more balanced with a weight slightly higher for the vibratory variable. The vibroacoustic level ratio (rms vibration level divided by rms acoustic level) is higher for the vehicle 1. This can explain why the first model gives more weight to the vibration.

![Figure 2: modelling with vehicle 1 as basic signal](image)
The second model quadratic term expresses a non-linear role of the acoustic for the highest values. This can be explained by the high acoustic level in the original signal. As we observe on the Figure 3, the comfort is strongly decreased when the acoustic level is high. This model confirms that the linearity of the models is probably not true when level is increased.

The differences observed between the coefficients of these two models reveal the lack of sensory information contained in the selected variables X1 and X2. Actually, the original signals which were used for the signals construction result from two different vehicles submitted to the same measurement conditions. If the vibroacoustics magnitudes were sufficient to describe all sensory information, we would obtain the same coefficients. Thus, vibratory and sound magnitudes are not the only variables that explain comfort variation. Other parameters like damping and attack will be tested to improve these models.

5 Summary

The difference thresholds were treated in the first experiment, and no differences were found between vibroacoustic and non-vibroacoustic thresholds. Values are very close to usual vibration threshold for acoustics, but vibratory thresholds are higher than those found in a previous study which dealt with stationary signals. In the second part, the comfort for vibroacoustic transient signals was investigated. Both models have significant main effects, but only one of them has significant quadratic effects. The results also showed there were no significant cross-modal interactions between acoustics and vibratory stimuli levels when people were asked to judge vibroacoustics comfort. As these experiments were done in the same experimental conditions, the model parameters are good but not sufficient to explain the whole vibroacoustics comfort.

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References


