How to predict excessive noise in high-speed vehicles

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La percepción acústica es considerada uno de los factores de mayor importancia en la valoración del confort en vehículos de alta velocidad.

El estudio que presentamos se enmarca en un proyecto de investigación desarrollado por ALSTOM Transport y el Instituto de Biomecánica (IBV) con el objetivo de generar un modelo de predicción del disconfort acústico del sonido interior de coches de pasajeros en vehículos de alta velocidad.

Development of a prediction model of acoustic discomfort in high-speed train passenger cars

Acoustic perception is considered as one of the most important factors in the comfort assessment in high-speed vehicles.

The present study is focused in a research project developed by ALSTOM Transport and the Instituto de Biomecánica (IBV) with the objective of generating a prediction model of interior noise acoustic discomfort in high-speed train passenger cars.

Introduction

Acoustic perception by passengers has been studied by numerous authors in the field of sound quality, since it is considered to be one of the most important factors in how passengers assess comfort in a high-speed train. In the railway industry, operators are currently studying the acoustic comfort of passengers using the conventional parameter referred to as A-weighted sound pressure level. However, recent studies have shown that this approach is not enough, and could be improved on through the use of psychoacoustics (the study of human perception of sound).

For this reason, it has become necessary to develop a research project aimed at generating a model to predict acoustic discomfort in high-speed rail vehicles using psychoacoustic parameters. The model includes sound parameters obtained from sounds recorded in various passenger areas of the train (thus acoustically characterising the entire vehicle) and subjectively assessing the acoustic comfort through tests conducted with users (jury tests).

Development

Work plan

The study consisted of performing the tasks shown in **figure 1**. First of all, an in-depth review was conducted of the latest developments in the interpretation of psychoacoustic parameters. Next, in order to obtain the acoustic characteristics of the sound inside the train, sound recordings were taken in various high-speed trains. Subsequently, after

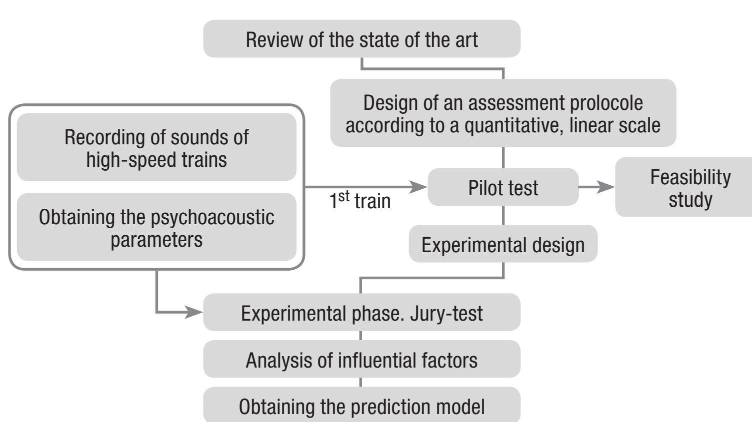

Figure 1. Stages of the study.

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validating the procedure for subjective assessment of the sounds by means of a pilot study, the jury test was conducted using all the sounds obtained. Finally, by statistical treatment, the relationship between the objective parameters obtained and the subjective assessment from the jury test was studied. This yielded a predictive model which calculated passenger comfort according to psychoacoustic parameters.

Field measurements

The sounds were recorded in six high-speed train models, from different rolling-stock manufacturers, while travelling along high-speed lines at commercial speeds. In order to characterise all the sounds inside the vehicle, the measurements were taken at various points in each car and in specific cars within each train.

With a view to realistically reproducing in the laboratory the sound inside a railway vehicle, the field measurements were taken using a HEAD Acoustics device made up of an artificial head using recording software (**Figure 2**). This artificial head is specifically designed for acoustic quality research, enabling binaural sound recording and subsequent playback of the recorded sounds in a laboratory. This meant that the participants in the jury test did not need to be in the vehicles physically in order to receive an acoustic impression of the sound generated by the trains.

Figure 2. Artificial head placed in the passenger car.

Acoustic characterisation

In order objectively to represent the recorded sounds, the parameter known as A-weighted sound pressure level was obtained, as well as the following psychoacoustic parameters: loudness, sharpness, roughness, fluctuation strength and tonality. The parameters were calculated using the ArtemiS analysis software from HEAD Acoustics (**Figure 3**).

Jury test

The playback equipment consisted of a system of headphones connected to a Head Acoustics PEQ V equaliser. This equipment was used to accurately play back binaural recordings, providing the listeners with a realistic acoustic impression

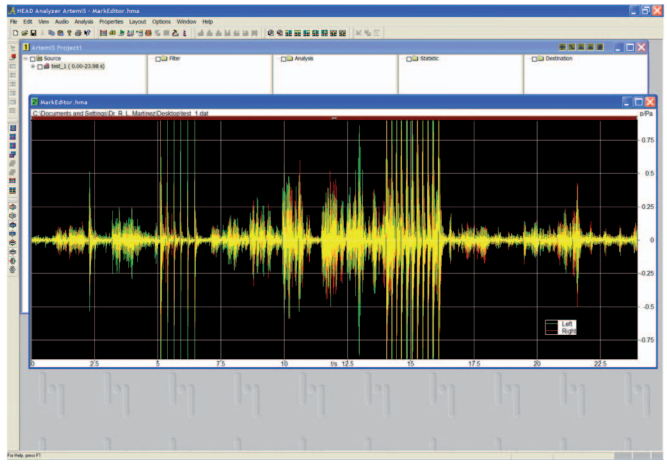

Figure 3. Calculation of the main psychoacoustic parameters.

similar to what they would receive if they were inside the train.

The procedure, previously defined during a pilot test, was based on having frequent users of railway vehicles assess the sounds. The nuisance assessment consisted of appraising the sounds according to a sliding scale from "0 = no nuisance" to "10 = major nuisance", using reference sounds at the ends of the scale as assistance (sounds with extreme loudness parameters).

Using a magnetic board and identification magnets (markers) for each sound to be assessed, the subjects classified them according to a nuisance scale (**Figure 4**).

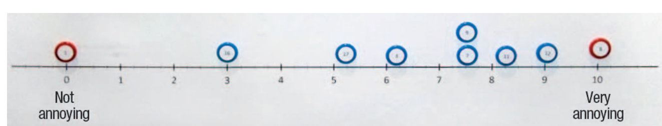

Figure 4. Assessment of sounds on a magnetic board.

The tests were conducted with the study participants sitting in a quiet room where they would not be bothered by any external noise. They sat in a high-speed train seat in order to simulate the perception of travelling by train, recreating an atmosphere similar to that where the recordings were made (**Figure 5**).

For the jury test, a total of 50 sounds were recorded and eight appraisals were given for each sound. The jury test thus provided 400 subjective assessments of train sounds.

Results

The purpose of the model was to predict the assessment of nuisance for each sound, using psychoacoustic parameters as predictors. These potential predictors were the 5th, 50th and 95th percentiles and the ranges (95th percentile – 5th percentile) of the A-weighted sound pressure level, loudness, sharpness and roughness (the parameters of fluctuation strength and tonality were excluded due to the lack of relevant values). The resulting variable was the mean value of

Figure 5. Participants during a session.

the acoustic assessment obtained from the jury tests. After examining the data, the multiple regression technique was selected as being best suited for calculating the model.

The model obtained uses the A-weighted pressure level parameter (95th percentile) and the sharpness parameter (5th percentile) as predictive variables. The model obtained using the psychoacoustic parameters is highly accurate (0.90 R2 accurate), increasing the prediction of nuisance level by 25% compared to only using conventional acoustic parameters (0.65 R2 accurate). This improvement can be seen in figure 6, which shows the model obtained when psychoacoustic parameters were included (left) and the model predicted according to conventional acoustic models (right).

Conclusions

The model obtained can accurately predict acoustic discomfort in high-speed train cars under real-life conditions. The results show the increased accuracy of the model when psychoacoustic parameters are added to a model obtained using exclusively conventional acoustic parameters.

The improved possibilities for application and the realism compared with other studies is basically due to the variety of high-speed trains used, the complete characterisation of the trains with various measurement points inside the train and the realism of the measurement conditions. All the sounds were recorded at standard commercial speeds, with no alteration using sound-editing programs, thus accurately representing the sound to which passengers are exposed in real-life conditions.

This study will enable ALSTOM Transport to apply the main results to the design of future rolling stock, thus guaranteeing optimal acoustic comfort in high-speed trains, which is considered a key factor in passenger satisfaction.

Acknowledgements

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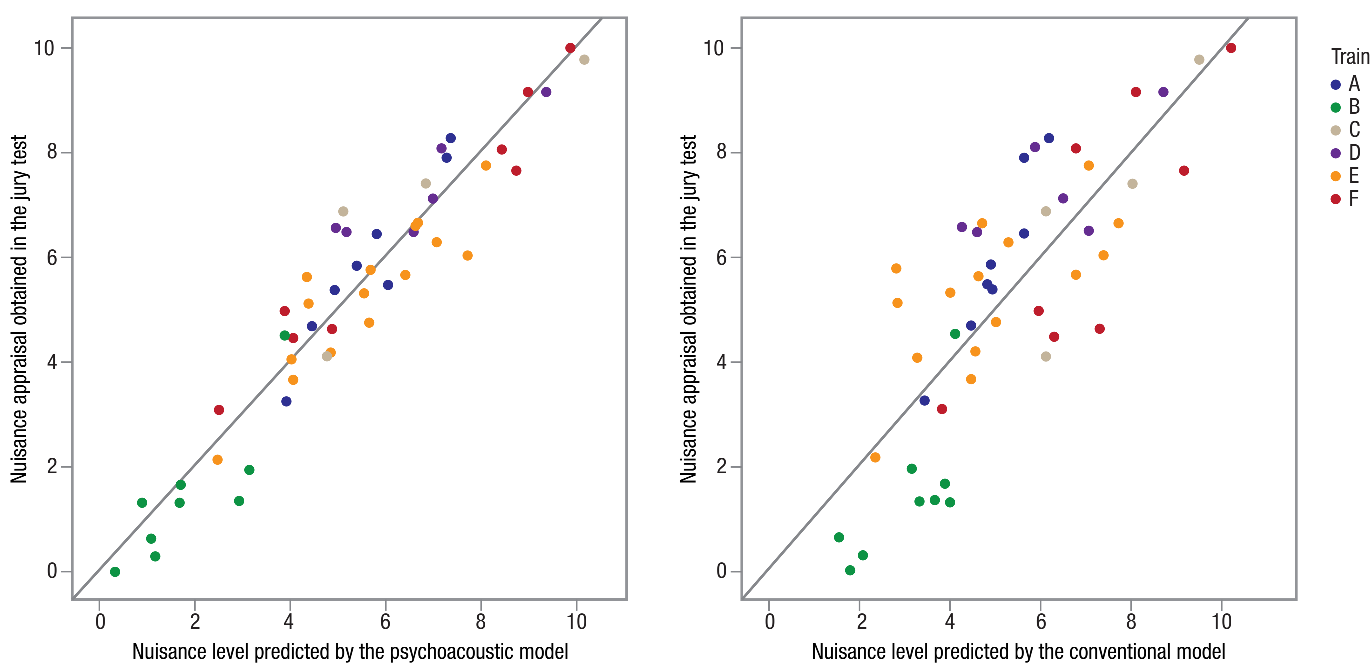

Figure 6. Comparison of the model with psychoacoustic parameters (left) and conventional acoustic parameters (right).