# SOUND QUALITY EVALUATION OF INTERIOR VEHICLE NOISE USING AN EFFICIENT PSYCHOACOUSTIC METHOD

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## INTRODUCTION

Psychoacoustics is a scientific field with a long tradition, and during the past decades a variety of different psychoacoustic methods has been presented. These methods have mainly been applied to basic research, e.g., to identify and quantify abilities of the human auditory system. But, for the application in the industrial environment (called *applied psychoacoustics* here) basic requirements concerning the methods are weighted with a different emphasis. Here it is necessary to have methods available which do not only offer a high reliability, but also show a high efficiency with regard to the time required to render results which can directly be used in the tough product development cycle. A corresponding new method will be presented based on a comparison of standard methods. The performance of the method will be depicted for a typical application example.

## APPLICATION EXAMPLE: GEAR RATTLE IN THE INTERIOR VEHICLE NOISE

A typical application for psychoacoustics in industry is the evaluation of the sound quality of a specific sound component embedded in a complex sound. In the case presented here the component is the sound produced by the gear box, called gear rattle, and the complex sound is the interior vehicle noise. The gear rattle occurs in specific driving conditions, and once it is detected by a driver, it can easily be associated with a technical defect - although the gear box is properly functioning.

To approach the problem a sound database with sounds of 20 passenger cars in different driving conditions was established for a laboratory evaluation, and 3 cars with different gear rattle characteristics were selected for an additional field test. The evaluation of the gear rattle is specificly difficult because all cars were equipped with a diesel engine and the diesel

knocking sound is similar to the gear rattle. The psychoacoustic method to be selected thus has to be sensitive enough to resolve the difference between these phenomena, and should on the other hand consider the requirements for the application in the industrial environment.

Due to the similarity of the diesel knocking sound and the gear rattle it became clear early that a direct estimation of the sound quality is not suitable here. Especially untrained subjects tend to confuse the two sound components, so that it is not clear which component they considered for their judgement. In this case such a psychoacoustic method puts a too strong load on the subjects, so that they are overcharged. On the other hand, a pair comparison, which would mean a much easier task for a subject, is not suitable due to the number of stimuli to be evaluated: 400 sound pairs would have to be evaluated in a single test.

## COMPARISON OF PSYCHOACOUSTIC METHODS

The application presented above shows that standard psychoacoustic methods might not be directly applicable in the industrial environment. In order to take a closer look to this the methods will be discussed in the following.

In most cases products and phenomena have to be evaluated which can not be completely simulated, and thus the sound feature to be evaluated usually can not directly be controlled. Adaptive methods which require the possibility to continuously change the feature to be evaluated are thus often not applicable and are not considered here (see e.g., Levitt (1971)).

Different standard methods are compared in Tab. 1 with regard to criteria which are relevant for the industrial application. It is not the intention of this article to give a complete survey of existing methods, so only the most common methods are listed (see, e.g., Green and Swets, 1974). Besides them also a new method is listed, the individual test which will be presented in the next chapter.

## INDIVIDUAL TEST

The application example above shows that the requirements concerning the time to be spent and the demands on the subjects are not both met by standard methods. Required is a method which combines the advantages of pair comparisons (direct comparision of the feature to be evaluated) and direct estimation (absolut judgement of the feature) but which avoids their disadvantages (time consumption and difficulty for similar stimuli). Corresponding features are offered by the individual test: stimuli can be compared (if the subjects whishes), but besides a ranking they are also absolutely rated.

A prerequisite for the test is that stimuli can be directly accessed and played back on request. The stimuli are presented as symbols on a working area, and each time a symbol is selected the corresponding sound is played back. The subject himself now specifies how often and in which order he listens to the stimuli. His task is to arrange the symbols on the working area in such a manner that the feature to be evaluated is judged on a scale, e.g., from bad (buttom) to good (top). A common approach of subjects is that they first produce a rough classification of stimuli, then iteratively refine their judgements by means of selecting specific stimuli pairs, and finally control the resulting ranking and absolute evaluation. The method thus resembles a pair comparison, but not all possible stimuli combinations are tested - the subject can

| Method | Category | Time required* | Accuracy | Demand on subjects | Type of results | Applicability of result | Comment |
|---|---|---|---|---|---|---|---|
| direct estimation, categorial test, ... | absolute | $J = R \cdot N$ | - | difficult (dep. on similarity of stimuli, feature to be evaluated) | ratio scale | absolut evaluation, direct applicable | not suitable for small stimuli differences |
| Pair comparison | relativ | $J = R \cdot N^2$ ** | + | easy | ranking | difficult for the determination of thresholds, suitable to test if thresholds are kept | especially suitable for small stimuli differences |
| Triad test | | | ++ | | | | |
| sem. differential, MDS | absolute or relativ | $J = R \cdot N$<br>$J = R \cdot N^2$ | | for several features complex | up to ratio scale | to resolve relevant dimensions (features) | expensive, for basic investigations |
| Individual test | absolute and relativ | free | + | easy | ratio scale | absolute evaluation also for weak stimuli differences | unifies advantages of absolut and relativ evaluation, avoids disadvantages |

*: J: number of judgements; N: number of stimuli; R: Repetitions; (for one feature to be evaluated)
**: for complete pair comparison

**Tab. 1: Comparison of psychoacoustic methods for the industrial application**

can concentrate himself on testing only those stimuli pairs which are rather similar. At the end the position of the symbol on the working area directly represents the absolute judgement on the selected scale.

An example for a working area of the individual test is outlined in Fig. 1. Here the symbols for six stimuli are the corresponding numbers. The left graph shows the starting outlook of the working area, and the right graph the final result. Ranking and abolute judgements can be seen.

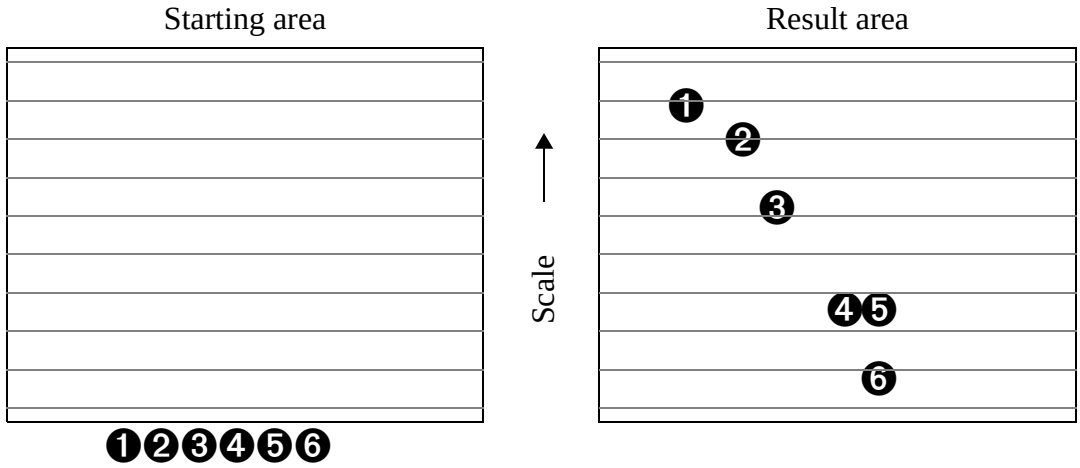


**Fig. 1** Working area at the beginning (left) and the end of the test (right).

In the individual test the subject thus specifies how often he listens to stimuli, and therefore how much time he needs to finish the test. For control purposes the number of presentation of each stimuli should be documented.

In contrast to the other methods mentioned above the individual test represents a kind of “free“ method, which means that although the subject gets clear instructions he can control the run of the experiment by himself. He thus is actively involved in the experiment, which usually results in a higher motivation. Furthermore the subject has no longer the impression to be controlled by the test, so that his self-reliance increases and his stress is reduced.

Since the prerequisite of the individual test is that the stimuli can be directly accessed, and the working area has to be updated after each presentation, the most elegant way to implement it is in form of a complete computer controlled test. In this case the symbols can easily be selected and positioned with the mouse.

## COMPARISON OF RESULTS

In order to compare the results rendered by the different methods five stimuli were evaluated in a laboratory condition by 14 subjects. The methods used were absolut estimation, pair comparison, and the individual test. Furthermore, to test the relevance of the results of the laboratory condition, a field test with 20 subject, but only three selected cars was also conducted. The cars investigated there showed strong, medium, and weak gear rattle, while the two sup-

plementary cars for the laboratory test had very strong and medium gear rattle. For the absolute judgement a 10-point-scale was used. The tests were implemented on a PC-based psychoacoustic system[1] and conducted at Ford.

Fig. 2 shows the results determined with the different methods in the laboratory condition. In order to compare them they are depicted in form of percent ranking values.

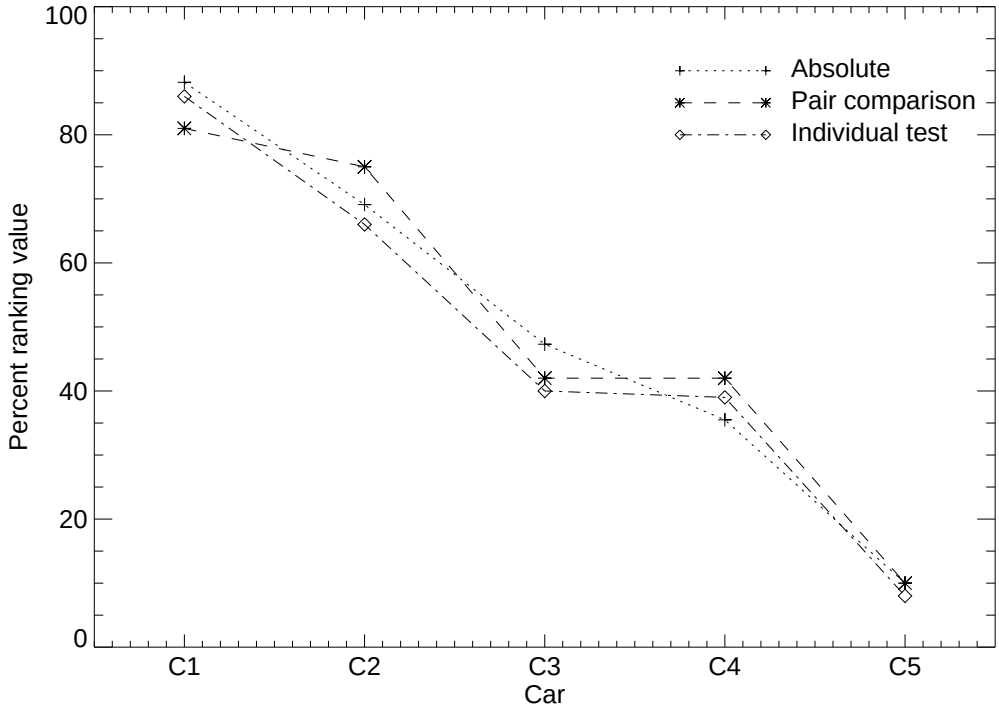


**Fig. 2** Results determined with the different methods in the laboratory test.

The different methods render rather conform results. But, differences can be observed for cars C3 and C4. While they are rated equally in the pair comparison and the individual test, they are rated differently in the absolute test. As mentioned before, those cars had similar gear rattle, but different engine noise since it were different car types. It thus seems that these different sound features influenced the results of the absolute test, while the other methods focus the concentration of the subjects towards the sound feature to be investigated.

Fig. 3 opposes the absolute judgements from the laboratory test to those from the field test. It can be seen that the results from the laboratory correspond to results from the field. The results from the individual test are closer to the results of the field test than the results from the absolute test.

1. PATS from Synotec

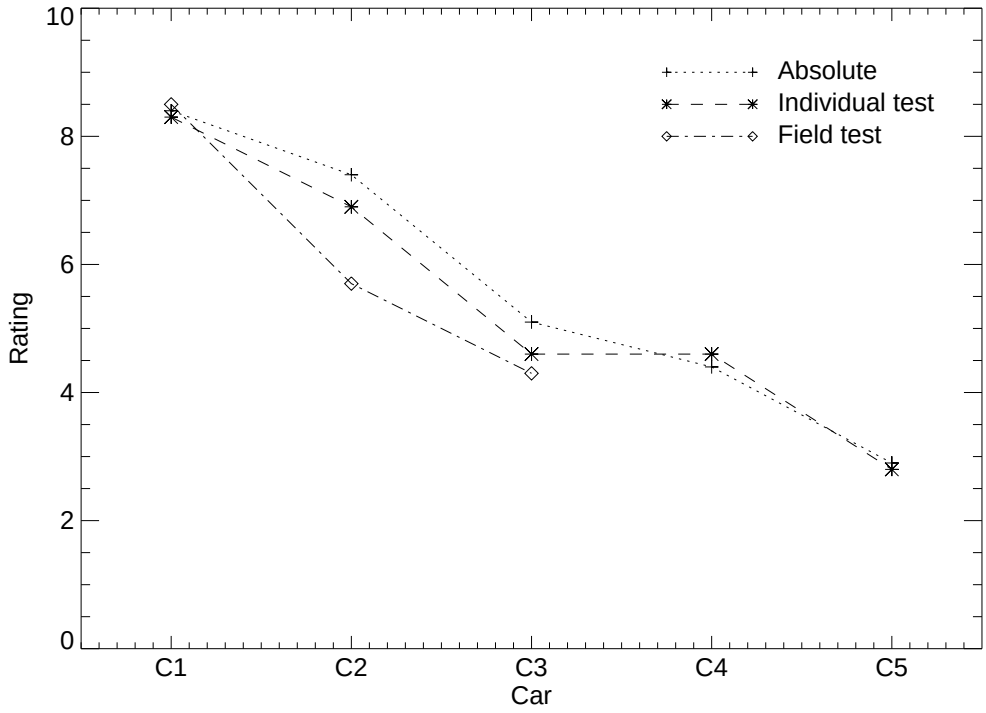


**Fig. 3** Comparison of results from the laboratory test (absolute judgement and individual test) and the field test.

## SUMMARY

Based on the comparison of standard psychoacoustic methods a new method has been presented. This individual test is especially designed to meet the requirements of an application in the industrial environment. Since it combines the advantages of the relativ and absolute methods and avoids their disadvantages, the test renders not only an exact ranking, but also an absolute judgement. By means of involving the subject into the run of the test, the motivation and the self-confidence of the subject increased while his stress is reduced.

## REFERENCES

D.M. Green, J.A. Swets, *Signal Detection Theory any Psychophysics*. (Krieger, N.Y., 1974)

H. Levitt, “Transformed Up-Down Methods in Psychoacoustics“. J. Acoust. Soc. Am. **49**, 467-477 (1971)