# EVALUATION OF SOUND QUALITY OF VEHICLE PASS-BY NOISES

# BY PSYCHO-PHYSIOLOGICAL METHODS

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## ABSTRACT

The SVEN project funded by the European Commission studies appropriate descriptors for the perception of sound quality of exterior car noises. In the laboratory experiment reported here, subjects were exposed to sets of vehicle pass-by noises of equal sound intensity ($L_{eq}$ about 83 dBA). The sounds of three different motorcars were recorded in three driving conditions with differences in speed and acceleration. During exposure, physiological responses and subjective evaluations were registered. The results show different patterns of physiological and subjective responses which will be related to acoustical properties of the sounds.

## INTRODUCTION

The “sound quality” concept has become indispensable in the context of car interior noise for many years [1]. The SVEN project (**S**ound quality of **V**ehicle **E**xterior **N**oise) funded by the European Commission deals with the applicability of this approach to traffic noise and exterior noise of single vehicles [2]. In a first step, descriptors have to be identified which allow to describe the sound quality experienced by men in typical traffic noise situations as well as with single pass-by noises of cars. Besides the subjective evaluation of sounds by means of questionnaires, psycho-physiological parameters have to be considered as they have proved to be meaningful in similar questions, e.g. in comparing the effects of noises recorded and displayed binaurally vs. monaurally [3, 4, 5]. Results of a laboratory study on human responses to traffic noise have been published elsewhere [6, 7]. In this paper, the second of a set of laboratory experiments is presented which studied human responses to pass-by noises of three different cars under different driving conditions.

## METHODS

Sound stimuli. Single car pass-by noises of three different cars under three driving conditions have been recorded by our project partners on a test driving area. The recordings were modified to a more complex sound situation of 2 min. duration consisting of repeated pass-by sounds from the left and the right side, and the sound intensity of all noises was adjusted to the same level of about 83 $L_{Aeq}$. The following cars have been used:
- **type D:** ***diesel*** car (middle class with 1,9 l volume and 72 kW)
- **type M:** ***middle***-class car with less powerful engine (1,4 l volume and 70 kW)
- **type L:** ***limousine*** (upper middle class, 2,4 l volume and 121 kW).

The driving conditions were: passing by first with *50 km/h speed* (acceleration in 2$^{nd}$ gear), second with *70 km/h* (constant speed), and third a *brake-idle-acceleration* situation. The 3 noises of one driving condition were always presented to the subjects in one block of presentation; the sequence of noises in one block and of the 3 blocks of noises was balanced among the subjects.

Measures of effect. Three different *physiological variables* have been measured:
- fingerpulse amplitude (FPA) as a measure of the peripheral blood circulation
- skin conductance level (SCL) as a measure of the electric skin activity
- electro-myogram of the forearm (EMG) as a measure of the electric muscle activity.

All these parameters reflect changes of the physiological state of the body in a dimension of activation of the vegetative system elicited by external stimuli as well as by physical tension or emotional arousal. They have proven to be reliable measures of noise effects, but respond also unspecifically to other stressors.

The physiological measurements have been taken continuously during the experiment. For the statistical analysis, means for specific time intervals (2, 5 or 10 s) for each subject were calculated and transformed into percentual changes in relation to the baseline value (mean of the measurements taken during last 30 s before start of the noise = 100 %).

In addition to the physiological measurements, the *subjective evaluation* of the noise stimuli by the subjects was assessed in a second stage of presentation of the noises. Several questionnaires had to be filled in after each sound stimulus or each block of noises. Only a few results on this subjective evaluation are reported here.

Study realization. The sample consisted of 24 subjects recruited at the Heinrich-Heine University of Duesseldorf (male students with unimpaired hearing, age from 24 to 29 years), who received a financial gratification for their participation. Before the beginning of the experiment the hearing was checked by means of pure tone threshold audiometry in an introductory meeting for enlistment. The experiments took place in the anechoic chamber of the institute from May to November 2001. For each subject there was one experimental session, and there was only one subject performing the tests at a time.

Due to the limited space, here we concentrate mainly on the physiological responses to the 70 km/h and brake-idle-acceleration (b-i-a) condition in presenting the physiological reactions of the fingerpulse amplitude (FPA) and the skin conductance level (SCL).

## RESULTS ON PASS-BY NOISES AT 7O KM/H CONSTANT SPEED

Fingerpulse amplitude. As can be seen in figure 1 the graphs of the fingerpulse amplitude show a rapid decline reaching the minimum 8 s after noise onset and a gradual recovery towards the baseline. Such a response is expected during any exposure to noise of sufficient intensity.

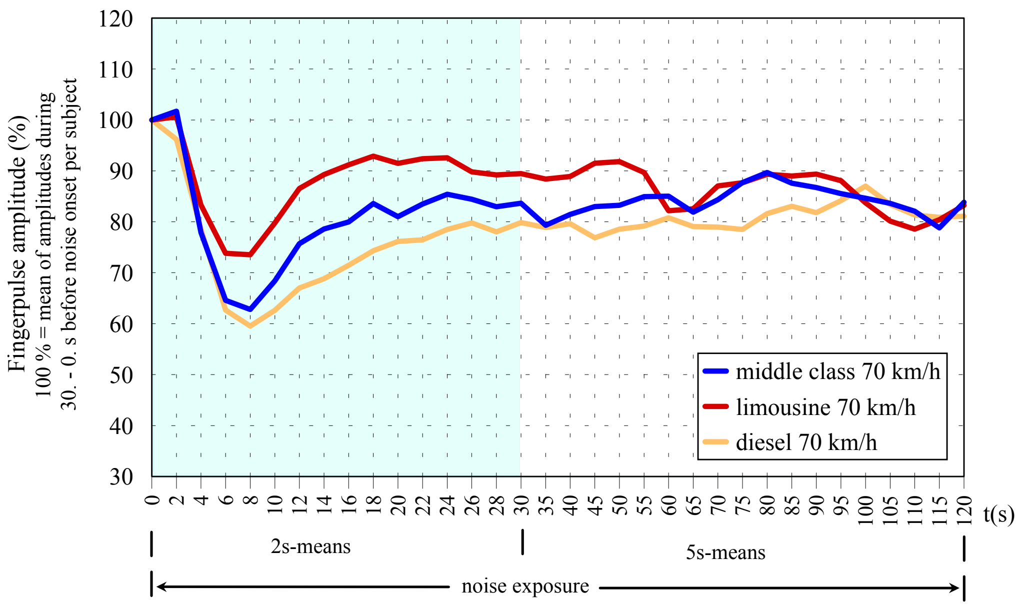


Fig. 1.- Reaction of fingerpulse amplitude to pass-by noises of 3 different cars at 70 km/h constant speed.

For the noise of the ***limousine*** car, the FPA decreases less than for the other cars, and already after 20 s it returns to about 90% whereas the measures for ***middle-class*** and especially for the ***diesel*** car remain at a lower level. For the time intervals from 8th to 16th s differences in the FPA prove themselves to be significant by ANOVA (p = 0.03; two-tailed significance). After 60 seconds all three graphs draw nearer to each other at a level of about 80% and stay at that level till the end of the exposure as there is still a physiological response to the stimuli going on.

<u>Skin conductance.</u> The skin conductance level also shows a significant change in its reaction to the different pass-by noises. As can be seen in figure 2 there is a strong increase in SCL during the onset of exposure to the noise of the ***diesel*** car up to over 130%, whereas the values for the ***limousine*** and the ***middle-class*** cars rise to 110 respectively 116 % only. For these two cars, the graphs start declining to baseline level very soon, but the values for the ***diesel*** car still remain at a high level with even a second increase after 75 seconds of exposure time. These differences show themselves to be highly significant in statistical terms if the non-parametric Friedman test is used.

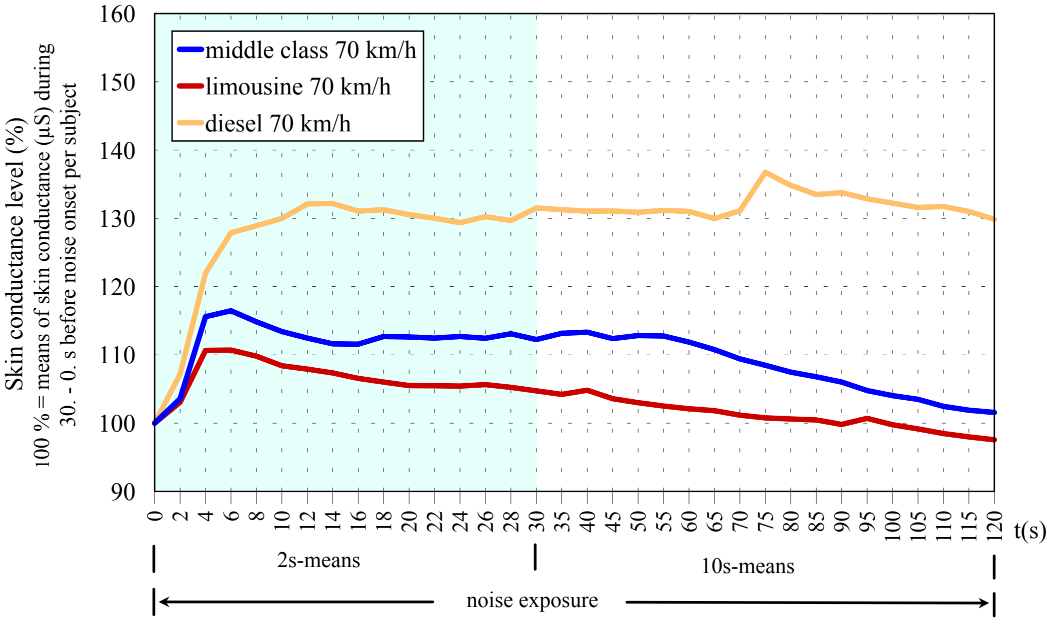


Fig. 2.- Reaction of skin conductance level to pass-by noises of 3 different cars at 70 km/h constant speed.

<u>Direct comparison of the noises by questionnaire.</u> One of the tools for assessing the subjective evaluation of the noises was a questionnaire which was filled in after listening to each block of noises during the second presentation.

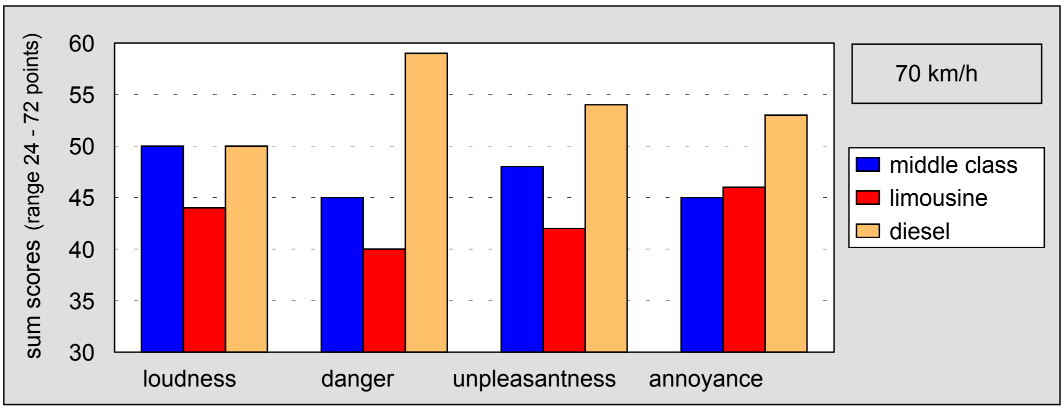


Fig. 3.- Rating scores (sum of 24 Ss) for pass-by noises of 3 different cars at 70 km/h constant speed with regard to loudness, danger, unpleasantness and annoyance.

The subjects were asked to rank the 3 sounds in terms of loudness, danger, unpleasantness, and annoyance. For statistical analysis, the votes were transformed to a sum score counting each 1st rank of a sound (loudest, most dangerous, most annoying etc.) with 3 points, each 2nd rank with 2 points, each 3rd rank with 1 point. With 24 Ss, the range of the sum score was from 24 to 72 points for each item in each noise condition.

Fig. 3 shows the results of this direct comparison of the 3 car noises. It becomes obvious that the ***diesel*** sound is unambiguously judged as the most dangerous and also as more unpleasant and annoying as the other two cars. The ***limousine*** sound is judged most favourable in 3 of the 4 items.

Conclusions. As shown in figures 1 and 2, the pass-by noise of the ***diesel*** car evoked the strongest physiological responses in this driving condition, whereas the ***limousine*** sound resulted in relatively moderate responses. The same tendencies are reflected in most items of the direct comparison between the sounds presented in fig. 3, and it has to be added that these results are supported by the other questionnaires applied. For the driving condition of constant speed at 70 km/h, the different physiological and subjective measures correspond to a large extent in ascertaining a ranking of the three noises in terms of activation and emotional arousal which might reflect the sound quality of the cars.

## RESULTS ON PASS-BY NOISES IN THE BRAKE-IDLE-ACCELERATION SITUATION

Figure 4 displays the graph of the fingerpulse amplitude during exposure to the noise recordings at the brake-idle-acceleration condition for the three different cars used.

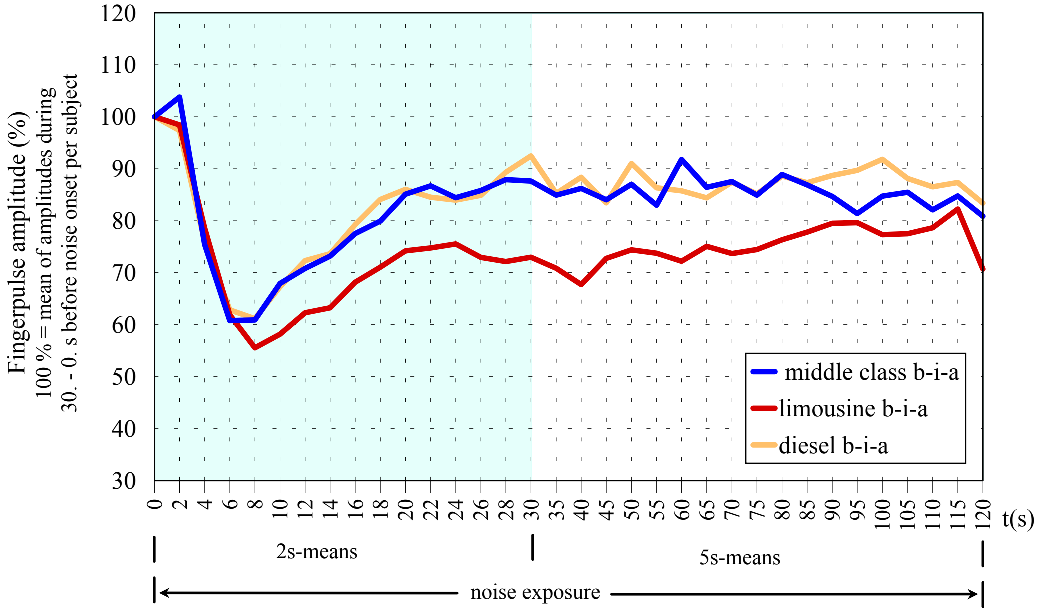


Fig. 4.- Reaction of fingerpulse amplitude to pass-by noises of 3 different cars at the brake-idle-acceleration situation.

The initial decrease of the FPA down to 60-55 % is even lower than the decrease in the previous experimental condition. This time the pass-by noise of the ***limousine*** leads to the strongest decrease in FPA down to 55%. All three graphs start to return to baseline slowly with the values for the ***limousine*** staying under 80% of the baseline value till the end of exposure. After 35 seconds of noise exposure, for example, the FPAs for the ***middle***-class- and ***diesel*** cars reach almost 90% of the baseline value whereas the FPA for the ***limousine*** remains near 70% (one-way ANOVA, p= 0.03; two-tailed significance).

Skin conductance. As shown in figure 5, the skin conductance level shows a clear increase in the initial phase for all three recordings, but strongest for the exposure to the ***limousine*** car, followed by the ***middle***-class car. For both the increase is clearly higher as compared with the

70 km/h condition. All three graphs adjust slowly to the baseline level, but especially the values for the ***limousine*** stay between 120 and 130% for most of the noise exposure and keep a higher level than the graph of the ***middle***-class car most of the time. The SCL for the exposure to the ***diesel*** car noise on the other hand shows the fastest decline to baseline level.

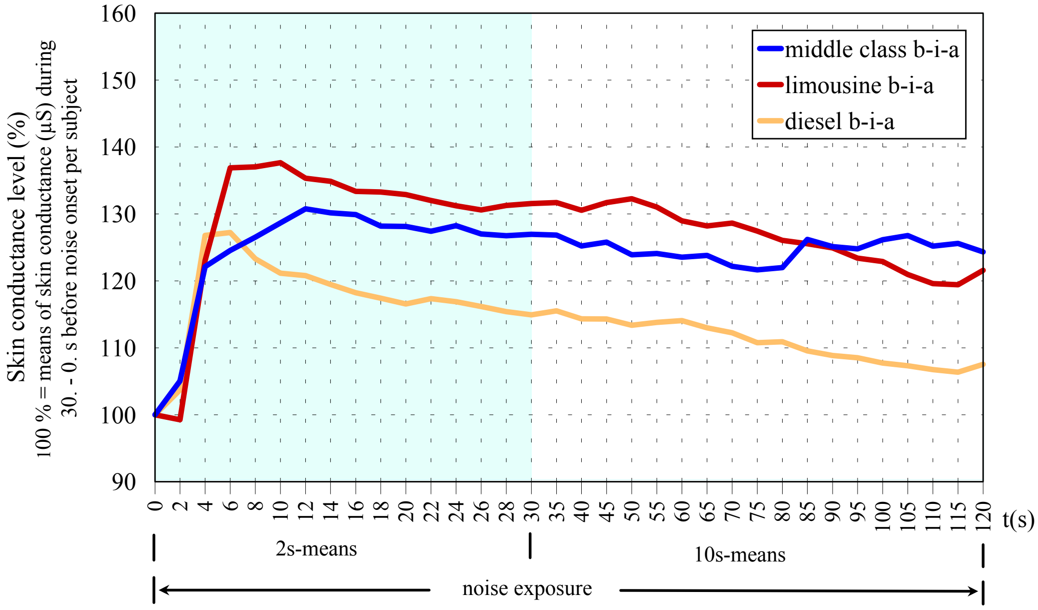


Fig. 5.- Skin conductance level for the pass-by noises of the three different cars at the b-i-a situation.

<u>Direct comparison of the noises by questionnaire.</u> The sounds of the brake-idle-acceleration condition were directly compared by questionnaire as described in the previous chapter. The ***middle*** class car has got the highest scores referring to "danger" and "annoyance", whereas the ***diesel*** is considered to be the loudest and most unpleasant and also quite annoying (- but anyway the differences in scores between these two cars are very small -). The ***limousine*** gets the distinctly lowest scores for "loudness", "unpleasantness" and "annoyance".


Fig. 6.- Rating scores (sum of 24 Ss) for pass-by noises of 3 different cars at the brake-idle-acceleration condition with regard to loudness, danger, unpleasantness and annoyance.

<u>Conclusions.</u> For this driving condition, the synopsis of results from different measures leads to other conclusions. Again there is a great correspondence between the physiological measures, describing the responses to the ***limousine*** noise as the strongest and to the ***diesel*** noise as relatively weak. But the subjective evaluation as illustrated in fig. 6 and as measured with other tools with similar tendencies show quite favourable judgements for the ***limousine*** sound and

more negative results for the other two cars. Here we have to state a contradiction between physiological and subjective measures which has to be discussed.

## DISCUSSION

The physiological measures presented here confirm each other in assessing a distinct ranking of the stimuli in terms of *intensity of physiological activation*. This is quite noteworthy, as all the sounds were of a similar type and even adjusted in sound intensity.
In the first driving condition (70 km/h constant speed) there was a good correspondence of the physiological and subjective results, whereas in the condition "brake-idle-acceleration" there was a clear contradiction of results. Some possible explanations shall be discussed:
In a factor analysis based on an adjective list of 19 items describing the subjective perception of the sounds, the ***limousine*** noise in the "brake-idle-acceleration" condition is strongly associated with a factor representing "sportiness" which is not judged as annoying or unpleasant. As the physiological measures just indicate bodily activation or emotional arousal without a negative connotation, this perception of sportiness might have evoked such a strong physiological response to the ***limousine*** car.
Furthermore, the "brake-idle-acceleration" condition includes three very different components which might find expression in physiological and subjective measures in different ways. In general, vehicle exterior noises are so complex that even in acoustics it is not easy to define their "sound quality". With regard to the sound quality perceived by man the difficulties increase because of the variation between subjects with regard to sensitivity, expectations, cognitive attitudes and so on. To find reliable differences between such similar pass-by noises and to resolve the individual factors of influence will require a larger number of subjects than available in our study.
In conclusion, the assessment of perceived sound quality of environmental noises still raises many questions. A methodological approach as applied in this study leads to a sound profile or pattern emerging from a variety of physiological and psychological data which reflects different aspects of human response to a specific sound. This combination of methods might be a useful tool in finding the relevant correlations with acoustical parameters explaining sound quality.

## ACKNOWLEDGEMENTS

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