HOW FAR IS THE SOUND QUALITY OF A DIESEL POWERED CAR AWAY FROM THAT OF A GASOLINE POWERED ONE?

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ABSTRACT

The following question was assessed: can the sound quality of the outdoor idling noise of a diesel powered car be improved by means of absorbing measures in such way that subjects would prefer it to that of a gasoline powered car.
In addition to the simulation of a broadband absorbing measure (from 1 to 5 kHz) the whole spectrum was also attenuated uniformly by up to 15 dB. In psychoacoustic experiments the subjects' preference was measured with the methods "Paired Comparison" and "Random Access".
In the same way, the signals of hard vs. standard adjustments of the motor of one diesel powered car were modified and assessed.

INTRODUCTION

In former investigations [1] it was shown that by (simulated) broadband absorbing measures the loudness of the outdoor idling noise of a diesel powered car could be reduced up to 40 % (with an attenuation between 1 and 5 kHz by 15 dB). In the same way the perceived "dieselness" of the sounds dropped for 25 %. The sound quality standing in a strong relation with the perceived loudness and dieselness was enhanced accordingly.
In the present study the question was assessed whether by means of such absorbing measures on the one hand a diesel powered car with a hard motor adjustment (which evokes a strong dieselness) can be "reeducated" to a diesel powered car with a standard motor adjustment, and on the other hand a diesel powered car with standard motor adjustment to a gasoline powered car.

EXPERIMENTS

<u>Signals</u>
All experiments are based on three recordings by a dummy head system of HEAD Acoustics (recording position: 1m lateral to the front wheel at a height of 1.70m): the outdoor idling noise

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of a gasoline powered car ('gp') and the outdoor idling noises of a diesel powered car at hard motor adjustment ('dp ah') and with a standard motor adjustment ('dp as').
The signals 'dp ah' and 'dp as' should to be modified in such a way that the sound quality of the hard motor adjustment ('dp ah') approaches that of the standard one ('dp as'), and that of the standard motor adjustment 'dp as') that of the gasoline powered car ('gp'). Therefore, the signals 'dp ah' and 'dp as' were filtered.
In figure 1 the approach of modifying the stimuli is sketched in a block diagram. As input signals the outdoor idling noise of two different motor adjustments of one diesel powered car was used. The realized filters should simulate possible and most efficient absorbing measures.

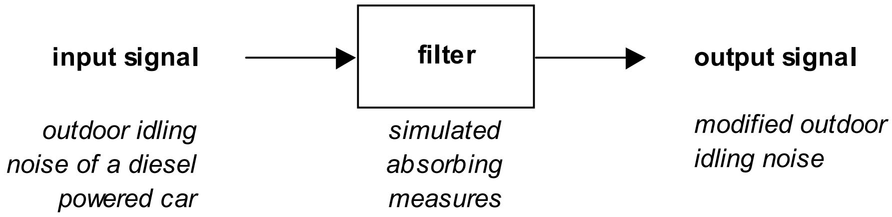

Fig. 1.- Block diagram of the approach of modifying the stimuli 'dp ah' and 'dp as'.

In table 1 the realized filters and the thus resulting output signals are plotted. Additionally to the attenuation of the whole spectrum in 3 dB steps up to 15 dB, also a broad band attenuation of the 1/3 octave bands from 1 to 5 kHz was realized for the two input signals 'dp ah' (the diesel powered car with the hard motor adjustment) and 'dp as' (the diesel powered car with the standard motor adjustment).

list of output signals			**input signals**	
			'dp ah': diesel powered car with hard motor adjustment	**'dp as':** diesel powered car with standard motor adjustment
filter	**f1:** attenuation of the 1/3 oct. bands from 1 to 5 kHz	**3 dB**	dp ah f1 3dB	dp as f1 3dB
		6 dB	dp ah f1 6dB	dp as f1 6dB
		9 dB	dp ah f1 9dB	dp as f1 9dB
		12 dB	dp ah f1 12dB	dp as f1 12dB
		15 dB	dp ah f1 15dB	dp as f1 15dB
	f2: attenuation of the whole spectrum uniformly	**3 dB**	dp ah f2 3dB	dp as f2 3dB
		6 dB	dp ah f2 6dB	dp as f2 6dB
		9 dB	dp ah f2 9dB	dp as f2 9dB
		12 dB	dp ah f2 12dB	dp as f2 12dB
		15 dB	dp ah f2 15dB	dp as f2 15dB

Tab. 1.- List of the output signals realized by filtering the two input signals 'dp ah' and 'dp as' with the two filters 'f1' and 'f2' by different amounts.

For the experiments, the sound were presented in a sound proof booth via a freefield equalized [4] STAX headphone calibrated to produce the original sound level.

Methods
Two different methods - Paired Comparisons and Random Access [1, 2, 3] - were used to measure the sound quality improvement of the output signals reached by the realized filters.
In the Paired Comparisons experiments, pairs of stimuli were presented to the subjects and they had to determine which of the stimuli had the better sound quality or whether it was the same. In a series DP AH VERSUS DP AS the subjects had to decide between the sound 'dp as' and the sound 'dp ah', the modifications of 'dp ah' or 'dp as' itself, in a series DP AS VERSUS GP they had to decide between 'gp' and 'dp as', the modifications of 'dp as' or 'gp' itself.
In the Random Access experiments, all stimuli of one series (series DP AH VERSUS DP AS: 'dp ah', the modifications of 'dp ah' and 'dp as'; series DP AS VERSUS GP: 'dp as', the modifications of 'dp as' and 'gp') were represented on the monitor by symbols. The subjects

could listen to them as often and in any order they like. The task was to arrange the symbols by drag and drop according to their sound quality.

Subjects

All experiments were carried out with 15 normalhearing subjects trained in psychoacoustic experiments (age between 23 and 28, median: 24 years). It was assured that the subjects could distinguish in every day life between diesel and gasoline powered cars.

RESULTS

Series DP AH VERSUS DP AS

In figure 2 the results of the Paired Comparison experiments are plotted for the series DP AH VERSUS DP AS. The abscissa shows the stimuli which have been compared to the stimulus 'dp as', split in the results for filter 1 (attenuation of the 1/3 octave bands from 1 to 5 kHz) on the left hand side, and the results for filter 2 (attenuation of the whole spectrum) on the right hand side. The gray partition of the bars represents the percentage of the subjects' decisions for "the sound quality is the same", the red partition for "the sound quality of the stimulus plotted on the abscissa is better" and the blue partition for "the sound quality of 'dp as' is better".

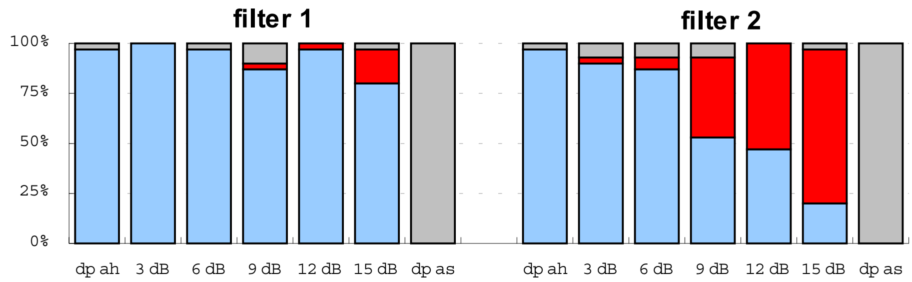

Fig. 2.- Percentage of the subjects' answers for the series DP AH VERSUS DP AS. Filter 1: attenuation of the 1/3 oct. bands from 1 to 5 kHz, filter 2: attenuation of the whole spectrum. Gray partition: sound quality is the same, red partition: sound quality of the stimulus plotted on the abscissa is better, blue partition: sound quality of 'dp as' is better.

At first it should be mentioned that in comparing 'dp as' with 'dp as' all subjects recognized the stimulus and decided the sound quality to be the same (full gray bars on the right hand side of each panel). If the spectrum of the input signal 'dp ah' is filtered merely between 1 to 5 kHz (filter 1), even with the maximum attenuation of 15 dB subjects prefer the sound quality of the modified outdoor idling noise in only 17 % and in 3 % they judge it the same. However, an attenuation of the whole spectrum (filter 2) by 12 dB causes more than 50 % to judge the filtered signal to be better in sound quality.

The results of the Random Access experiments are displayed in Figure 3. The medians and interquartile ranges of the given ranks of all subjects are plotted for all the twelve stimuli on the abscissa. Rank 1 means best and rank 12 worst sound quality.

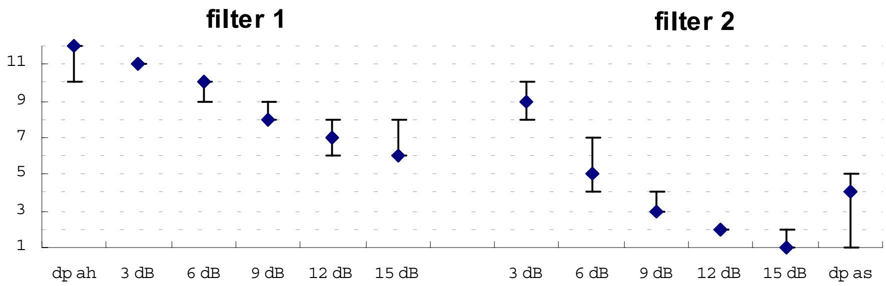

Fig. 3.- Median and interquartile ranges of the rankings for the series DP AH VERSUS DP AS. Filter 1: attenuation of the 1/3 oct. bands from 1 to 5 kHz, filter 2: attenuation of the whole spectrum.

In the mean, the subjects rank the non modified signal 'dp ah' worst in sound quality. However, the target sound 'dp as' is not ranked best, it has been caught by the modifications of 'dp ah' with filter 2 by 9, 12 and 15 dB. Furthermore, it should be remarked that the sound quality of the signals attenuated in the 1/3 octave bands from 1 to 5 kHz by 9, 12 and 15 dB are preferred to that of the signal attenuated over the whole spectrum by 3 dB.

Series DP AS VERSUS GP
The results of the Paired Comparison experiments for the series DP AS VERSUS GP are shown in figure 4.

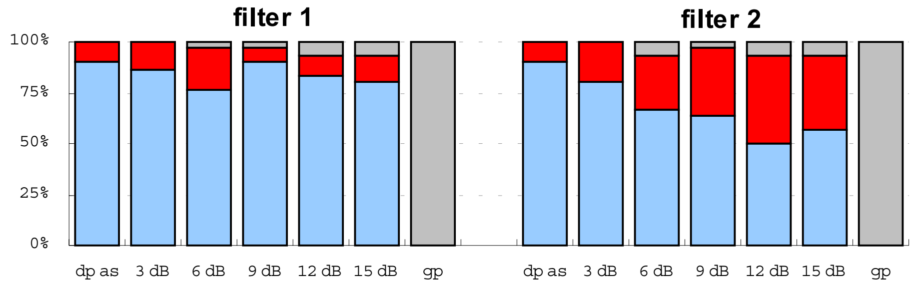

Fig. 4.- Percentage of the subjects' answers for the series DP AS VERSUS GP. Filter 1: attenuation of the 1/3 oct. bands from 1 to 5 kHz, filter 2: attenuation of the whole spectrum. Gray partition: sound quality is the same, red partition: sound quality of the stimulus plotted on the abscissa is better, blue partition: sound quality of gp is better.

A more detailed illustration of the results is displayed in the three panels below.

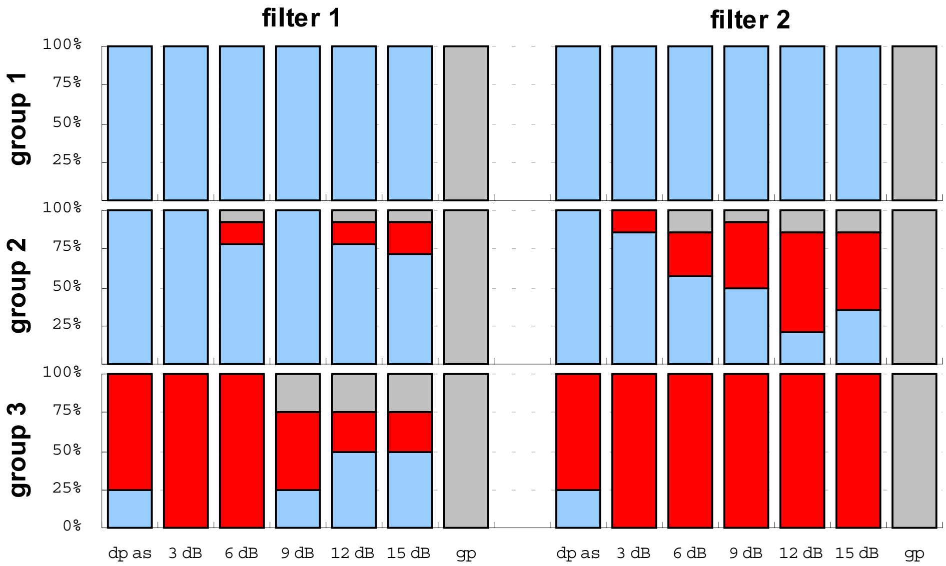

Fig. 5.- Percentage of the subjects' answers split in three groups of subjects for the series DP AS VERSUS GP.

Six subjects never judged the sound quality of the modified signals better than that of the gasoline powered car (figure 5, upper panel). In contrast, two subjects did not prefer the sound of the gasoline powered car in most cases, even if compared with the non-filtered signal of the diesel powered car 'dp as' (figure 5, lower panel). Only the signals attenuated with filter 1 by 12 and 15 dB is preferred in 50 %. However, a group of 7 subjects judges similar to the results of the series DP AH VERSUS DP AS: signals attenuated only in the frequency range between 1 and 5 kHz are mostly rejected, signals attenuated over the whole spectrum by 9, 12 and 15 dB are preferred in about 50 %.
Figure 6 shows the results of the Random Access experiments for the series DP AS VERSUS GP. In the mean the signals attenuated with filter 2 by 12 and 15 dB result in the sounds with the best sound quality, followed by the target sound 'gp'. However, attenuations in the frequency range between 1 and 5 kHz are judged in this series always worse than the attenuations over the whole spectrum.

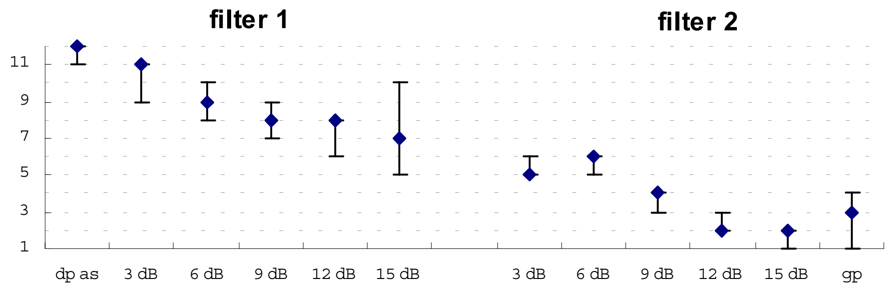

Fig. 6.- Median and interquartile ranges of the rankings for the series DP AS VERSUS GP. Filter 1: attenuation of the 1/3 oct. bands from 1 to 5 kHz, filter 2: attenuation of the whole spectrum.

DISCUSSION

In the following it will be discussed, whether the subjects based their sound quality judgement on loudness differences reached by the filters.

For this purpose, in figure 7 and 8 the loudness-time functions of all signals investigated are sketched. The red lines indicate the loudness of the respective target sound.

If subjects really judge on the basis of the signals' loudness pro and contra the sound quality, for the series DP AH VERSUS DP AS (figure 7)

(1) the signals attenuated with filter 1 by 12 and 15 dB and the signal attenuated with filter 2 by 6 dB should be judged similar to the target sound (similar loudness),

(2) the signals attenuated with filter 2 from 9 dB on should be ranked better than the target sound, and

(3) the signal attenuated with filter 2 by 3 dB should be placed behind the signals attenuated with filter 1 by 9, 12 and 15 dB.

Looking at the results (figure 3), statement (2) and (3) can be confirmed. Only at similar loudness (statement 1) the subjects' judgement is for the benefit of the target sound.

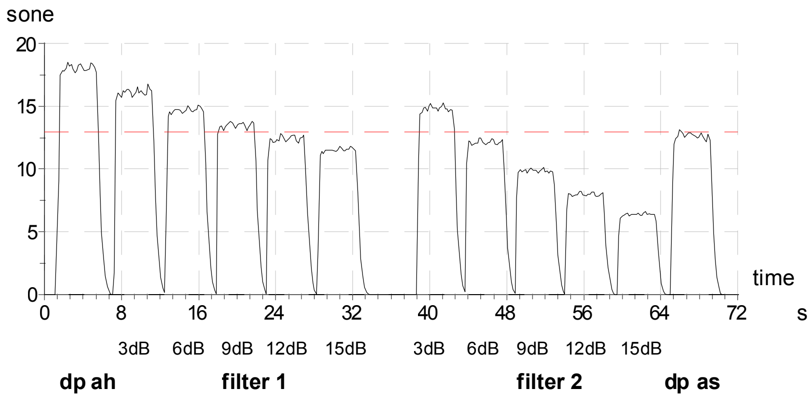

Fig. 7.- Loudness-time functions for the stimuli of series DP AH VERSUS DP AS. The red line indicates the value in loudness of the target sound 'dp as'.

In regarding the loudness-time functions for the series DP AS VERSUS GP (figure 8), the following statements should apply:

(1) similar ratings of the signals attenuated with filter 1 by 12 and 15 dB, the signal attenuated with filter 2 by 6 dB and the target sound,

(2) better rank for the signal of the diesel powered car attenuated with filter 2 from 9 dB on than for the gasoline powered car, and

(3) the signals attenuated with filter 1 by 12 and 15 dB should be rated better than the signal attenuated with filter 2 by 3 dB.

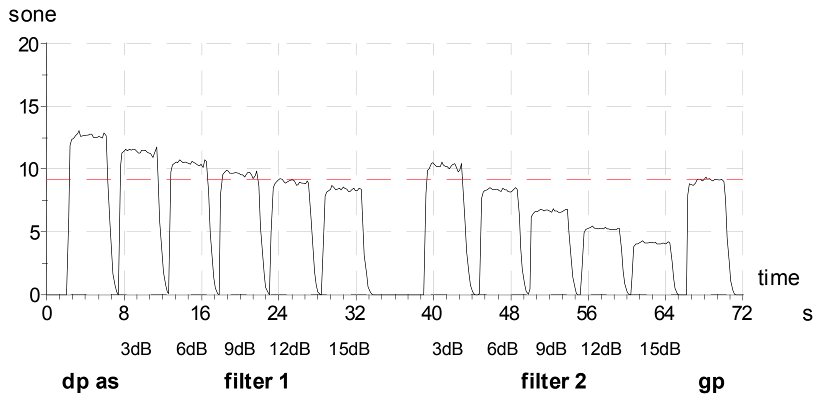

Fig. 8.- Loudness-time functions for the stimuli of series DP AS VERSUS GP. The red line indicates the value in loudness of the target sound 'gp'.

Comparing the above statements with the results (figure 6), a somewhat worse matching arises than for the series DP AH VERSUS DP AS: Again statement 1 does not apply, the judgement is clearly for the benefit of the target sound. Statement 2 fits from an attenuation of 12 dB on, even though the overlapping interquartile ranges of the signal with those of the target sound seem to underline the statement. However, statement 3 does not match at all, the attenuation of the whole spectrum even from 3 dB on is preferred all measures simulated by filter 1.
As the sounds 'dp as' and 'gp' (diesel versus gasoline powered car) differ both regarding their timbre and mainly regarding their time pattern much more than the sounds 'dp ah' and 'dp as' (both diesel powered cars) do, it seems to be particularly in this case not only the loudness which is the clue for the subjects' sound quality judgements.

CONCLUSION

If a diesel powered car with a hard motor adjustment shall be "reeducated" in sound quality by passive absorbing measures to one with a standard adjustment, no broad band measure - as in our case from 1 to 5 kHz - is sufficient. To convince more than 50 % of the subjects of the better sound quality of the filtered signal an attenuation of the whole spectrum by at least 9 dB is necessary. However, a broad band measure from 6 dB on is more efficient than an attenuation of the whole spectrum by 3 dB.
Comparing the modified standard adjusted diesel powered car with the gasoline powered, very specific patterns of judgements occurred. In the mean, an attenuation of the whole spectrum by at least 12 dB is necessary to equate the sound quality of the standard adjusted diesel powered car with the gasoline powered. Attenuations in the frequency range between 1 and 5 kHz are judged consistently worse in sound quality than the minimum (3 dB) attenuation of the whole spectrum.

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