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PRIVACY VERSUS SOUND QUALITY IN HIGH SPEED TRAINS

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ABSTRACT
The disturbance of privacy in high speed trains has become more evident in recent years. In psychoacoustic investigations, the contradictory requirements of unwanted speech intelligibility disturbing privacy on the one hand, and the desired sound quality on the other hand, were assessed. Speech intelligibility was measured with different typical indoor noises of high speed trains as background noise. In separate listening tests, the sound quality of those background noises was investigated. The results are compared. Furthermore, two different shielding barriers attenuating speech were simulated. The thereby obtained deterioration in speech intelligibility, i.e. improvement in privacy at same sound quality is compared to the results without shielding measures.

1 - INTRODUCTION
As a result of successfully performed noise reduction measures in recent years, the noise level in high speed trains has reached such low values that in large cabins privacy of conversations across the tiers is no more guaranteed. Furthermore, passengers are disturbed by the conversations of other passengers in mental activities. Therefore reducing speech intelligibility can be seen as an aim of saving privacy. As there occur inside high speed trains in different situations – e.g. due to the motor, corrugated rails or ballastless track – different indoor noises, it will be assessed how speech intelligibility is influenced by those typical indoor noises of high speed trains as background noise. However, it can be assumed that not only speech intelligibility will change but also the perceived sound quality.
In the first part, for different background noises the results of speech intelligibility tests are opposed to the data of sound quality tests for those background noises. In the second part it was investigated, how speech intelligibility could be lowered by shielding measures for a specific indoor sound quality. The necessary measures to ensure privacy without reducing sound quality are discussed.

2 - EXPERIMENTS – PART I

2.1 - Subjects
Fourteen normalhearing subjects (12 male, 2 female) with an age between 18 and 54 years (median 26 years) participated in the experiments. Before the experiments, the threshold in quiet of all subjects was measured. Nine of the subjects belonged to the departement's staff and were trained in psychoacoustic experiments. Five of the subjects had no practise in psychoacoustic experiments.

2.2 - Methods
Speech Intelligibility. To measure the speech intelligibility Sotscheck's rhyme test for German language [1], [2], [3] was used. A monosyllable word of the form consonant-vowel-consonant was presented to the

subjects. At the same moment a list of six rhyming monosyllable words, which differed only in one phoneme (initial sound, vowel or final sound), were visualized on a monitor. As answer the subjects had to mark the presumably heard word with a mouseclick on the monitor. Each word was introduced with the phrase "Please mark the word". As there is the possibility of randomly guessing the answer, all given values of speech intelligibility were corrected in this regard. Compared to other word tests (for example Marburger or Freiburger test), this test has the advantages of a "closed" wordstock. Furthermore the test can be widely automated.

Sound Quality. To measure the perceived sound quality of the different background noises, the method "Comparison of Stimulus Pairs" was used. One sequence consisted of a stimulus pair A/B with A being always the basic noise. The subjects were instructed to imagine they were sitting in a train and they liked to read a book. With this background information, they had to classify the soundpairs due to their differences in sound quality by symbols. They had the choice between: "the sound qualitiy of B is compared to that of A much better (+++), better (++), slightly better (+), the same (O), slightly worse (-), worse (–), much worse (—)".

2.3 - Stimuli

All sounds were presented idiotically in a soundproof booth via an electrodynamic headphone Beyer DT 48 with freefield equalizer [4].

Speech Intelligibility. To measure speech intelligibility Sotschecks' rhyme test was carried out with four different typical indoor noises of high speed trains as background noise at different signal to noise ratios (SNRs). The presentation level of speech was varied between 89 dB (lin) and 52 dB (lin) of the calibration signal [5], [6], [7], [8]. This meant with a presentation level of 89 dB (lin) for all background noises a variation of the SNR between 0 dB and -37 dB.

A complete testlist of Sotscheck contains 100 words; 34 words belong to the initial sound part (the alternates differ only in the initial sound), 33 to the vowel part (the alternates differ only in the vowel) and 33 to the final sound part (the alternates differ only in the final sound). To eliminate learning effects, nine different testlists with the same phoneme distribution for the target are available. The mean deviation between the phoneme distribution of German language and that of the target phonemes of one testlist amounts +0,7 % [2].

The background noises (Fig. 1) were synthesized out of 1/3-octave band filtered pink noise. The 'basic spectrum' (noise A) is the simulation of a typical indoor noise of high speed trains, noise B is simulating the indoor noise on a ballastless track (broadband deviation starting at 315 Hz, having a maximum of +15 dB at 1 kHz and ending at 8 kHz), noise C is the simulation of the motor (enhancement of 15 dB in the 1/3-octave band at 630 Hz) and noise D that of corrugated rails (enhancement of 15 dB in the 1/3-octave band at 1250 Hz).

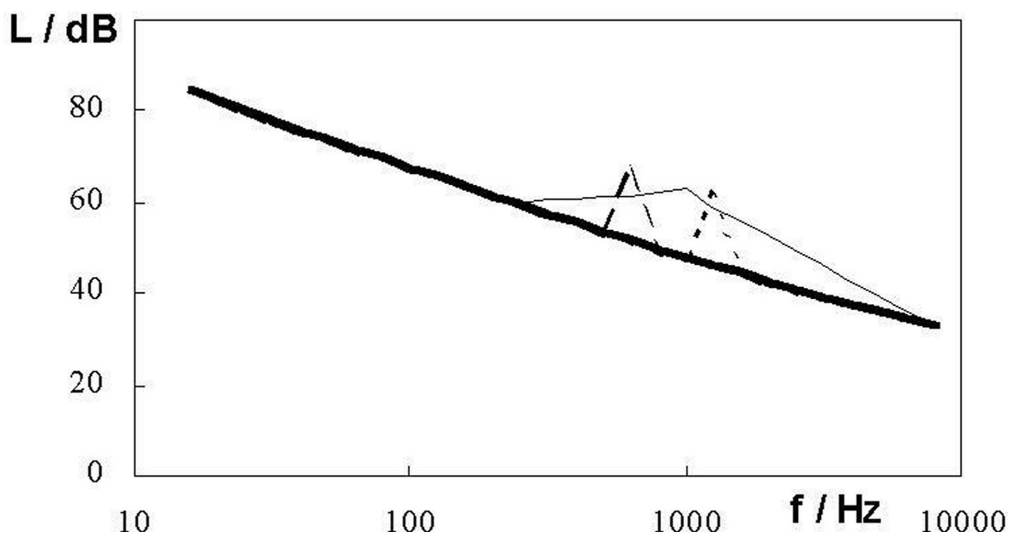

Figure 1: Spectra of the different simulated background noises: noise A (thick solid), noise B (thin solid), noise C (broken) and noise D (dotted).

Sound Quality. The stimuli had a duration of 2 seconds. In addition to the spectra enhanced by +15 dB (noise B, C, D), also sounds with enhancements of +6 dB were used as test stimuli.

3 - RESULTS – PART I

Speech Intelligibility. To verify the following results, first test measurements were carried out, in which speech intelligibility with a background noise according to CCITT [9] was measured. The results were in conformity with those published in the literature [3], [8].
In figure 2 the results are displayed for background noises indicated in the bottom right corner. The data obtained with noise A as background noise (fig. 2, left panel) confirm the well-known excellent intelligibility. With a signal to noise ratio of -20 dB, nearly 100 % intelligibility is reached. If the level of speech is reduced by 10 dB (SNR = -30 dB), still 75 % is intelligible. To arrive at 50 % intelligibility as criterion, a SNR of -37 dB is needed.
Though speech intelligibility is with background noise B at a SNR of -20 dB still nearly 90 %, it is now deteriorating to about 52 % if the speech level is reduced by 10 dB (-30 dB SNR). The 50 % -criterion for noise B is at a SNR of -31 dB instead of the -37 dB for noise A.
The results for the background noises C and D are quite similar and don't show significant differences to the results of the basic spectrum. For a signal to noise ratio of -20 dB and -30 dB, speech intelligibility is matching with that of background noise A. However, for background noise C, the deterioration for the signal to noise ratio of -35 dB is worse. The 50 % intelligibility value is reached already at -35 dB SNR instead of the -37 dB with background noise A.

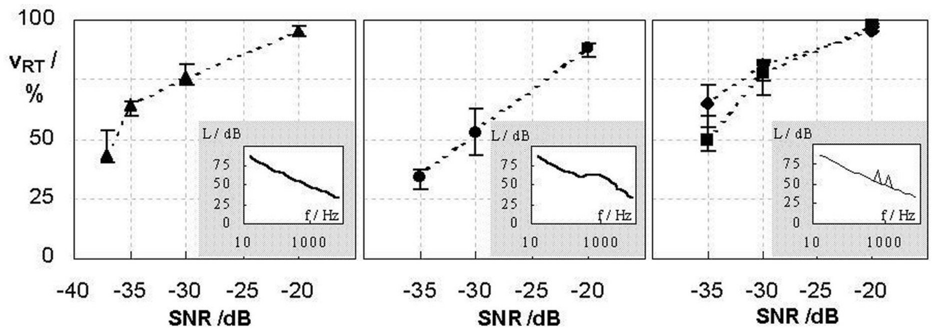

Figure 2: Median and interquartile ranges of speech intelligibility for the background noises illustrated by the insets: noise A (▲) [left], noise B (●) [middle] as well as noise C (♦) and noise D (■) [right].

Sound Quality. The results are shown in figure 3. For the test stimuli with 0 dB enhancement – which means comparing the basic stimulus (background noise A) with itself – all subjects recognized "no difference" (O) in sound quality. For each kind of modification, enhancements of 6 dB lead to a deterioration in sound quality of one category ("slightly worse" (-)). For enhancements of 15 dB – which means comparing background noise B, C or D with background noise A – sound quality is deteriorating in all cases by two categories ("worse" (- -)).

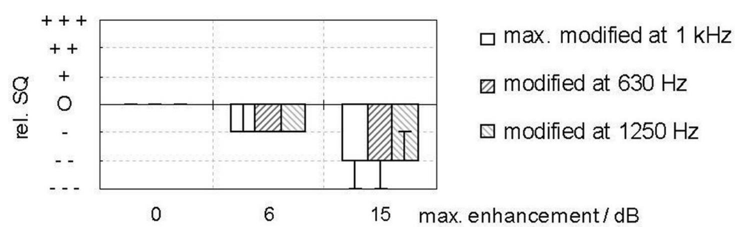

Figure 3: Median and interquartile ranges of the evaluated change in sound quality in dependence of the maximum enhancement in the modified (resp. max. modified) 1/3-octave band.

4 - DISCUSSION – PART I

To discuss the above results, we will focus on three different kinds of conversation: a quiet conversation, a normal, and an intensive conversation. The values for L_{Aeq} for the respective kind of conversation (Tab. 1, 2nd col.) are clues used in practice, the maximal value measured with the time constant *fast* $L_{AF\ max}$can be supposed about 7 dB higher (Tab. 1, 3rd col.). With these assumptions, for a typical indoor level of 92 dB (lin) the displayed values in the 4th column for the signal to noise ratios would be obtained. The last four columns of Table 1 show the results of the experiments for each SNR and each kind of noise. If an indicated SNR was not measured, the maximum or minimum v_{RT} obtained is given.

The signs ">" or "<" should hint that there might be higher or lower values for speech intelligibility if it would be measured at the respective SNR.

kind of conversation	L_{Aeq}/ *dB*	$L_{A\ Fmax}$/ *dB*	*SNR / dB*	v_{RT} / % **(A)**	v_{RT} / % **(B)**	v_{RT} / % **(C)**	v_{RT} / % **(D)**
quiet	~ 50	~ 57	-35	64	**34**	65	49
normal	~ 60	~ 67	-25	85	70	89	88
intensive	~ 70	~ 77	-15	> 96	> 89	> 96	> 98
rel. sound quality				O	- -	- -	- -

Table 1: Values for L_{Aeq}, L_{AFmax} and the signal to noise ratio for an assumed background noise level of 92 dB (lin) for the resp. kind of conversation, the measured speech intelligibilities for the resp. kind of conversation, and the measured relative sound quality for all assessed background noises A to D.

The comparison of the results in Table 1 shows that for normal and intensive conversations speech intelligibility would be with any background noise very good. The only combination which is protecting privacy sufficiently (speech intelligibility of 34 %) is with background B, the simulation of a ballastless track, for quiet conversations. But it is questionable if this improvement in privacy can justify the reduction in sound quality for two categories.
As it seems, a deterioration in sound quality due to an enhancement in the spectrum of the background noise wouldn't be acceptable for the improvement in privacy reached. Therefore, it seems to be the only solution to lower speech intelligibility by shielding measures, whereby sound quality isn't changing. Hence, in the next part two different shielding measures attenuating speech were simulated.

5 - EXPERIMENTS – PART II

For details about subjects and kind of speech intelligibility experiment see part I.
STIMULI.
The speech of Sotscheck's rhyme test was attenuated in the following two kinds, whereby measure A1 is simulating a simple sound barrier between the tiers with absorbing surroundings, and measure A2 an additional lateral sound barrier, which means nearly a semicabin.

f / Hz	**32**	**64**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
A1 / dB	0	1	2	3,5	5	6	6,5	7	8
A2 / dB	2	4	7	11	14	16	18	20	22

Table 2: Attenuations in the resp. frequency range of the two shielding measures A1 and A2.

In this part, speech intelligibility was measured with noise A or noise B as background noise. The presentation level of the background noise was kept constant at 65 dB(A), what meant for noise A 92 dB(lin) and for noise B 84 dB(lin). So for example with noise A as background noise and with the shielding barrier A1 as measure, 0 dB SNR stands for a noise level of 65 dB(A) resp. 92 dB(lin) and a presentation level of speech of 92 dB (lin) of the *unattenuated* calibration signal.
The next figure shows the spectra of the two different background noises A (fig. 4, left panel) and B (fig. 4, right panel) together with the measured spectra of Sotscheck's rhyme test with and without the shielding barriers for 0 dB signal to noise ratio.

6 - RESULTS – PART II

In figure 5, left panel the speech intelligibilities measured with background noise A are shown with unattenuated speech or with speech attenuated as described in Table 2.
Without measures, the 50 % – criterion is reached at -37 dB, with simulation A1 at -17 dB and with simulation A2 at -30 dB. This is a shift in signal to noise ratio of 20 dB or 7 dB, respectively, which is in the same order of magnitude as the attenuations of the shielding barriers at 4 kHz. Correspondingly, the results for background noise B are plotted in the right panel of Figure 5. In this case, 50 % speech intelligibility is reached at a SNR ratios of -31 dB (without measure), -11 dB (barrier A1) and -24 dB (barrier A2). The differences in the signal to noise ratios to reach 50 % intelligibility are in the same order of magnitude as before.

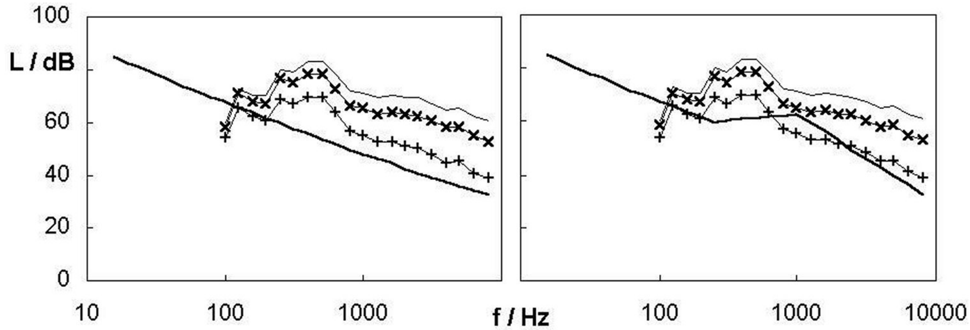

Figure 4: The spectra of noise A (left panel, thick black line) resp. noise B (right panel, thick black line) and of Sotscheck's rhyme test without measure (thin solid line) and with the shielding barriers A1 (**x**) and A2 (+) for 0 dB signal to noise ratio.

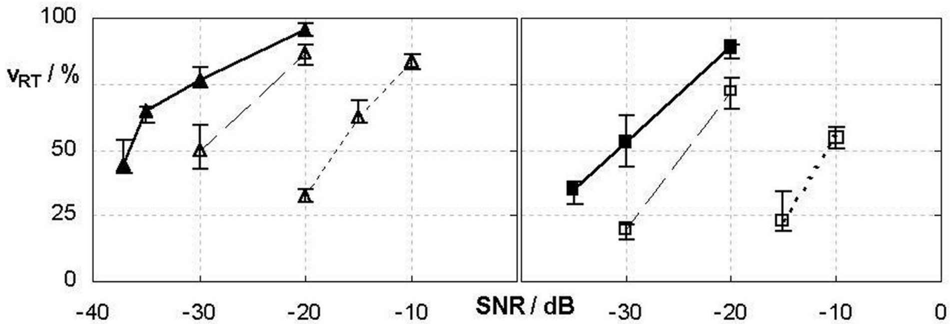

Figure 5: Speech intelligibilities with background noise A (left panel) or background noise B (right panel). Solid line: without measure, broken line: with shielding barrier A1, dotted line: with shielding barrier A2.

7 - DISCUSSION – PART II

If we assume the same values for the three kinds of conversations as presented in the discussion of part I (Table 1) and an indoor noise level of 92 dB (lin), the results of part II can be predicted as follows for background noise A in Table 3 on the left side and for background noise B on the right side.

speech intelligibility / % for	**background noise A**			**background noise B**		
kind of conversation / *Shielding measure*	without	A1	A2	without	A1	A2
quiet (i.e. SNR = **-35 dB**)	65	<**50**	<**33**	**34**	<**20**	<**23**
normal (i.e. SNR = **-25 dB**)	85	70	<**33**	65	**48**	<**23**
intensive (i.e. SNR = **-15 dB**)	>96	>86	62	>89	>72	**23**

Table 3: Speech intelligibility for the different kinds of conversations for the two background noises without measure and with shielding barriers A1 or A2.

As illustrated in the table above – if we assume background noise A – privacy would be ensured for quiet conversations with the shielding barrier 1 or 2. For normal conversation only the semicabin A2 would be sufficient and for intensive speech none of the two simulated shielding barriers would ensure privacy.

If we assume a background noise like ballastless track (noise B) it has to be kept in mind, that the subjects estimated sound quality compared to noise A with "worse". But in this case both simulated shielding barriers would help until normal speech; for intensive conversations only the semicabin (shielding barrier A2) would be sufficient.

8 - CONCLUSION

To ensure privacy in large cabins of high speed trains across the tiers, and at the same time not to reduce sound quality much, intensive measures would be necessary. However such an intensive shielding measure, as for example the simulated semicabin, can not be placed afterwards in an existing train, but has to be considered already in the definition phase of the train. In case of the proposed shielding measure A2, persons sitting in the next tier would understand of a quiet or even normal spoken conversation less than one third, so that privacy across the tiers can be regarded as ensured. Loud conversations, however, would still be disturbing in mental activities for other passengers sitting in the next tier. A possibility to solve this problem would be, to offer the passengers different large cabins for different operations.
Overall it can be stated that by means of basic psychoacoustic tools quantitative results are received by which a reasonable cost-benefit calculation could be established.

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