TECNIACUSTICA GANDIA • 2006

HOW ACOUSTIC EXPERTS TALK TO "NORMAL PEOPLE"[1]

PACS 43.50.Jh, 43.55.Ka

Michael Vorländer
Institute of Technical Acoustics
RWTH Aachen University
52056 Aachen (Aquisgrán). Alemania
Tel: +49 241 8097 985
Fax: +49 241 8092 214
E-Mail: mvo@akustik.rwth-aachen.de

ABSTRACT

What people usually like to ask about acoustics is the question if the acoustics are "good". Engineering aspects of acoustics are completely unknown to the public. Therefore, the discussion of problems in acoustics is usually simplified by using single numbers, for instance the level expressed in "dB(A)". Special factors of acoustic quality or noise impact on the society, however, cannot be quantified comparably easy since the actual situation of the acoustic problem, the activities of humans acting or being affected and the whole context of the situation must be considered. In this contribution recent developments of simulation and auralization are introduced and demonstrated in examples of characterization and rating of sound insulation and transportation noise.

1. INTRODUCTION

In this paper, "normal people" are defined as being non acousticians, without higher education in acoustics. They are the majority. They have to face acoustical problems, though, and some of them have to decide about investment in actions of noise control.

In noise control engineering, powerful tools of measurement and numerical prediction are available for obtaining information about the specific acoustic situation and possible improvement of acoustic comfort and protection against noise. On the one hand, the acoustic engineer is trained to discuss numerous technical and physical (temporal and spectral) details which may lead to an improved acoustic situation for the client. On the other hand, the discussion must be simplified regarding the description of the problem by using single-number quantities like dB(A), R_w or NC, RC, etc.. Single-number quantities are also important as a common basis for noise control measures, for political discussions and for harmonization of noise regulations and noise limits. Noise-induced hearing loss, for instance, can well be described by single numbers like A-weighted sound levels indeed. But a significant part of acoustic engineering is not related to protection against noise-induced hearing loss, but to acoustic comfort. A general description of acoustic comfort, however, cannot be given since the actual situation of the noise problem, the activities of humans affected and the context of the situation must be taken into account. Therefore the area of noise effects, annoyance research and related fields can be considered to get growing importance in future.

[1] This contribution is an extended version of a presentation at Internoise 2005 in Rio de Janeiro [1].

It is necessary to permanently discuss the relation between acoustic engineering and annoyance definition, its measurement and evaluation. In short: acousticians should communicate with psychologists and sociologists and jointly communicate to the public.

The link between these disciplines and the basis for discussion is in best case a single- number quantity, to be obtained from objective measurements or prediction models. In many situations, however, existing quantities do not reflect all dimensions of the problem. Basic research is required to create new specific single-number quantities which describe the relevant factors of comfort and annoyance with a more specific meaning. This point is in the focus of this paper.

For a combination of acoustic modeling and subjective impressions particularly the modern technique of auralization is beneficial. In this contribution recent developments of auralization in noise control are demonstrated in examples of basic research on acoustic comfort and annoyance. These examples will illustrate the relation between

a) airborne sound insulation and work performance,
b) airborne sound insulation and speech privacy,
c) annoyance from noise in railbound vehicles and

2. SINGLE-NUMBER RATING

The need for handy rules in noise control is obvious. For this reason numerous single-number quantities have been introduced in acoustics. Otherwise transparent and applicable noise regulations would hardly be possible. Imagine we have to explain complex spectra, impulse responses and intensity vector mapping to clients, local authorities or politicians. From the viewpoint of the non-acoustically educated person as well as from the viewpoint of the expert, the communication is only possible on the basis of clear vocabulary. This vocabulary consists of single numbers. In a small example this can be illustrated:

Client:	I want to improve the protection against noise from my neighbor.
Acoustician:	ok, let's measure the weighted sound reduction index and see what we can do.
C:	What is the weighted sound reduction index?
A:	It is a single number derived from a sound insulation curve in frequency bands, representing different sounds from bass to treble frequencies.
C:	I know little bit about sound levels. If my neighbor on his side plays his drums with 95 dB(A), can I calculate level in my room by subtracting the weighted sound reduction index?
A:	Well, no.
C:	I am learning Portuguese language. When I want to concentrate on the vocabulary lesson, I am particularly disturbed by the bass drum. Does this index give information about the loss of memorizing words and grammar?
A:	No, sorry.
C:	And if I want to estimate if my neighbor understands my loud complaints about his drum playing, can I use the index?
A:	No, just talk not too loud.
C:	So, what does the weighted sound reduction index mean?
A:	It gives an average sound reduction, compared with a reference curve representing an average massive wall construction.
C:	?
A:	If you like I can demonstrate the effect of the sound insulation of your wall and several wall linings as improvement. By chance, I have recordings of drums, so we can even have a realistic source signal for your problem, and we have loud speech examples, too.
C:	Go ahead.
	…….. (we stop here)

Auralization solved the communication problem in this case. But the discussion should have come to a good end without auralization, too. Rating systems and single numbers of too condensed meaning do not adequately match the question in the specific case. Furthermore, as discussed by Rasmussen [2], among others, in European countries a formally "harmonized" noise rating system was introduced, but in fact in Europe 24 different specific single number quantities are in use to describe the same thing: protection against noise from neighbors. The same can be observed in regulations of noise limits, maximum levels indicators by using time weighting S, F or I, etc., just to give these examples. Ten Wolde [3] stresses the fact that simple noise descriptors are essential, but he also states that noise indicators describing different sources can hardly be combined into one indicator, because knowledge about the noise impact of single events is not yet available sufficiently. Which is, then, the general single number quantity describing the overall effect? A review over all up-to-date noise measures was published by Maquis-Favre et al. [4]

What is desirable is a more psycho-acoustically motivated research on noise effects and the combination in various situations in the living and work environment and, in consequence, modern tools like sophisticated instrumentation. Further, a few general rating systems based on sound levels as "first approach", some others added with more specific meaning, expert systems for reduction of the complex information into a single number of "annoyance" [4, 5], "acoustic comfort", "speech privacy" [6], "health protection". This goal can only be reached by expanding intensive studies of noise effects and by expanding the question of each test towards comfort and health effects caused by mid and low sound levels.

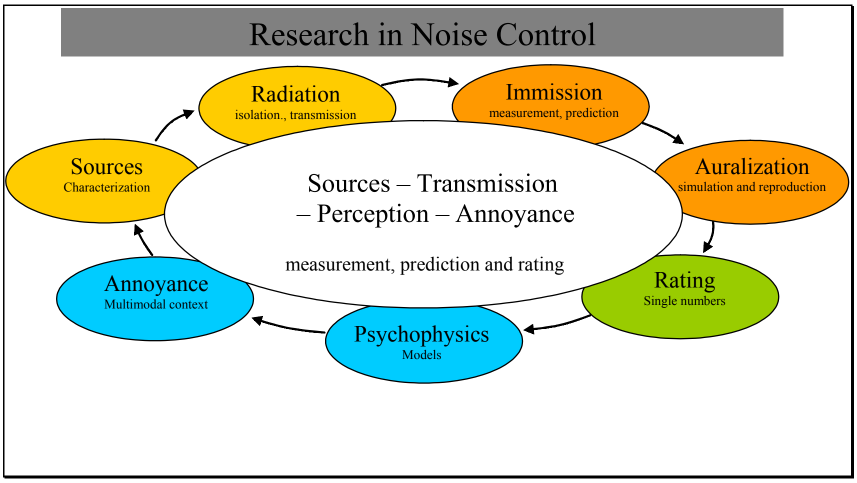


Figure 1: Scientific disciplines dealing with noise control and their interaction

The field of noise control engineering illustrated in Fig. 1 contains methods of classical engineering and methods of psychology. In the upper right part of the figure, the techniques of immission measurement, prediction, simulation and auralization can be considered as a bridge between acoustic engineering and rating processes and annoyance evaluation. Measurement data and recordings in-situ indeed serve as database for annoyance research. Much more flexibility, however, is given when the tool of auralization is used for creation of sound stimuli. This approach can also be extended, where appropriate, by using the multimodal approach of virtual reality systems.

3. VIRTUAL ACOUSTICS: SIMULATION AND AURALIZATION

Auralization is a well-known technique in room acoustics. It was developed during the last decade as an exciting feature of computer simulation in room acoustics. Auralization, however, is an interesting and powerful tool in other disciplines of acoustics, too. Auralization means that a sound source, a sound transmission path, a room or any other system creating or transmitting sound is made audible. An interesting application of auralization was described above: In sound demonstrations we can listen to the acoustic solution directly. And this possibility opens manifold fields of applications, convincing clients to invest in noise control, advertise acoustic products in the Internet, and also applications in basic research.

In noise control research we can apply powerful analysis tools of signal theory and psychoacoustics. And we can apply numerous measurement methods. Why do we then need auralization? The answer to this question is that we can create hundreds and thousands of noise situations. These noise situations can be studied further in listening tests in the laboratory and in the field, in psychophysical tests, in physiological tests including sleep laboratory. Extensive field studies dealing with noise impact can partly be avoided. At least some of the perceptual aspects can, thus, be solved and first hints for noise indicators can be obtained. For a complete figure, auralization and subjective tests, however, are not the final solution. The real listening experience “at home” or “at work” as such can only be measured and interpreted in the real (or virtual) environment, including the physical and mental activity, multimodal stimuli, sensor fusion and the physiological and psychological reaction.

One might also ask why the problem cannot simply be treated by using a mono signal and an equalizer. The necessity of binaural representation is given by the fact that human hearing extracts information about the sound event and the sound environment (acoustic ecology) by segregation of acoustic objects due to common cues of spectral, temporal and spatial attributes. This, for instance allows us to identify one speaker out of a cloud of diffuse speech (cocktail party effect). In situations of noise immission the similar spectral, temporal and spatial cues are extracted to judge the event as pleasant, annoying, informative or neutral.

The principle of auralization in noise control was illustrated in [7]. The aim is to generate sound signals from starting with data sets representing the actual situation, the source and the transmitting object. As shown in Fig. 2, the basic elements of sound generation, transmission, radiation and reproduction must be treated by modeling and sound reproduction. The identification of interfaces between source signals and transmission filters is an important part of the procedure. In airborne noise auralization, the interfaces are unambiguous. In case of structure-borne sources, the mounting mobility and source impedances play an important role. The complexity of the simulation and auralization model can be quite high or the problem can be described rather simple. In the end, the resulting signal must be plausible enough to represent a sufficient basis for listening tests and psychoacoustic evaluation.

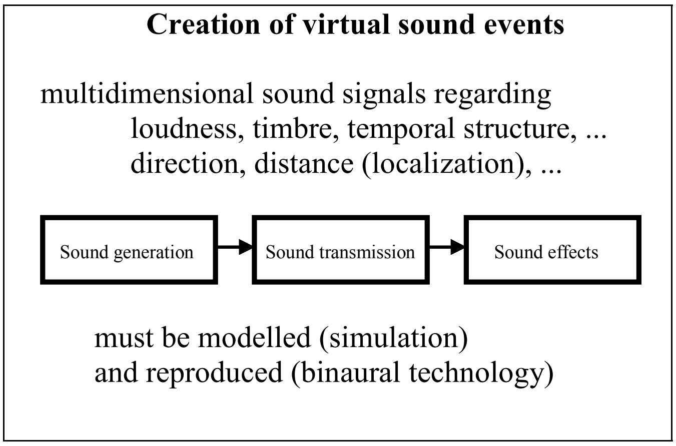


Figure 2: Principle of Auralization.

In the following, three examples for auralization models and applications in acoustic comfort and annoyance research are presented. It is demonstrated that the combination of acoustic engineering and concepts of noise control with methods of annoyance measurement lead to specific solutions, whereas the evaluation by using single-number quantities, even up-to-date psychoacoustic quantities like loudness, roughness, sharpness, is too rough an approach.

4. SUBJECTIVE EFFECTS OF AIRBORNE SOUND INSULATION

On the basis of an auralization module for application in problems of sound insulation in buildings [8], the speech privacy in buildings and the diminishment of the short-term memory was studied. This should represent the effects of privacy and of disturbing sound on the work performance in office situations, for instance. The sound affecting people may be transmitted through a wall or over a screen. Both cases can be described by a sound level difference and some kind of level reduction and low-pass effect. The acoustic performance of an insulating construction is usually by the standardized sound level difference or the screen insertion loss, in dB, measured or calculated in one-third octave bands and standardized with regard to the reverberation in the receiving room. Starting with these input data, auralization filters can be created and applied on convolution with input stimuli (see [8]).

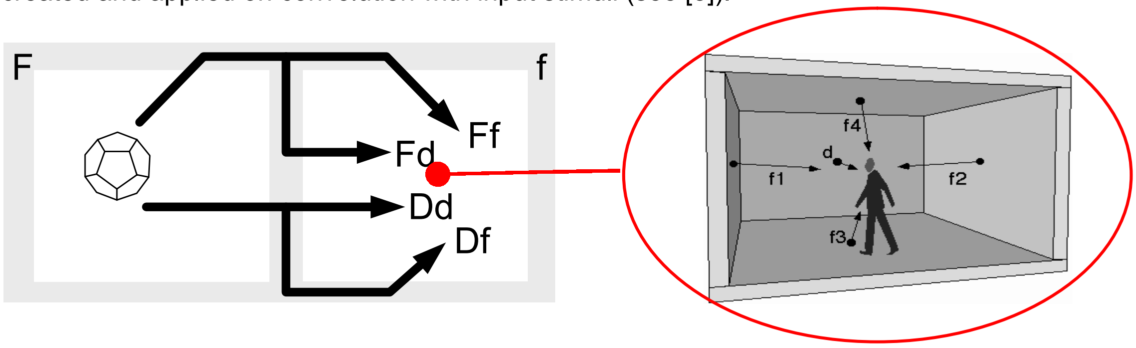


Figure 3: Auralization or airborne sound transmission.

4.1 Noise Impact On Work Performance

Auralized “receiving room” signals were presented to test subjects in a test on the so-called “Irrelevant Speech Effect”, in cooperation of the Institute of Work, Environmental and Health Psychology at the Catholic University of Eichstätt-Ingolstadt together with the Institute of Technical Acoustics at RWTH Aachen University. A randomized series of numbers from 1 to 9 was presented to every subject in 9 seconds. Each number was visible for 0.75 seconds and after a pause of 0.25 seconds the next number was presented. After the presentation of the numbers, the subject had to remember the series of numbers in the order as displayed. The total error rate and the errors per position in the series are then evaluated. This test was performed in silence and with noise stimuli. Klatte and Hellbrück [10] found that this effect is invariant against level variations between 40 and 76 dB. Significant differences, however, occurred when the modulation of the signal was speech-like. It was also argued that the intelligibility of the speech will have an influence and not just the level of the speech. There should be differences when listening to native or unknown language due to quite different attention the signal is paid to. But the speech content had at first no influence on the error rate.

The subjective judgments were made according to the loudness rather than to speech intelligibility and semantic content. The next figures illustrates the results from a questionnaire covering the subjective impression of disturbance (without knowing the results from the short-term memory effect). After each test sequence, the test subject should respond to the following questions:

- How difficult was the performance of this test?
- How demanding was the test?
- How disturbing were the background sounds?
- How annoying were the background sounds?
- How good could you concentrate on the task?

The responses were scaled from 0 to 4 with the verbal descriptors (see figure 3):
extraordinary = 4, fairly = 3, moderate = 2, hardly=1, not at all = 0.

From these preliminary results, secure conclusions cannot yet been drawn. It seems that speech content is crucial for annoyance effect and that not only the speech spectrum but intelligibility plays a role for the differences between the auralized sounds at 35 dB(A) since these differences vary if German and Japanese speech is presented to German listeners. Detailed investigations on the modulation spectrum of the sounds and more sound insulation situations have to be carried out [11].

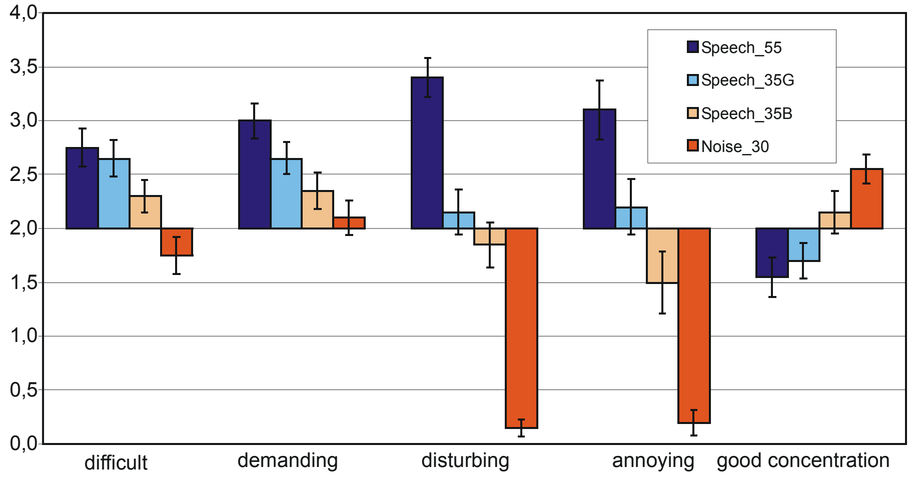


Figure 4: Total error rates for the ISE test with German speech at 55 dB(A), auralized speech at 35 dB(A) with different speech intelligibilities and pink noise at 30 dB. Mean value and standard deviation.

4.2 Speech Privacy In Buildings

For listening tests concerning the speech intelligibility effect of sound insulation, in total six situations were modeled, consisting of three pairs of identical single-number ratings and sound insulation classes, SIC, ("Schallschutzstufen" SSt) according to the German VDI directive 4100 [12]. It is interesting that in this directive the sound insulation classes are defined in relation to speech transmission: SIC 1: Speech can be understood , SIC 2: Speech can fairly be understood and SIC 3: Speech can be noticed but cannot be understood. SIC 3 means that speech yields half the subjective loudness than SIC 2.

Sound examples were taken from a so-called sentence test, which is a list of sentences covering the statistical distribution of linguistic phonems of German language. This test was developed for experiments in audiology and hearing aids research.

Of course, speech intelligibility depends not just on the absolute level, but on the signal-to-noise ratio, too. Therefore the consideration must include the background noise level and its spectrum, the absolute signal level and the sound insulation. In this study, the background noise was not varied but fixed by choosing steady state pink noise with absolute level of 20 dB(A). The auralised speech signals corresponding to the six cases (Fig. 5 to 7 were presented to the test subjects who were instructed to repeat the words understood in the break between two sentences. The test operator marked the correctly recognized words in a list for further statistical evaluation.

The results are shown in Fig. 8. They illustrate that different quantitative speech intelligibility results may be obtained although the same single-number rating is present. Furthermore, it is easily possible to achieve higher speech privacy already with SIC 2 (compared with SIC 3), even if the single-number rating is 3.6 dB less. The reason is, of course, the specific sound insulation spectrum in case SIC 2A with an extreme low pass characteristic which allows no formants and consonants to be transmitted into the receiving room.

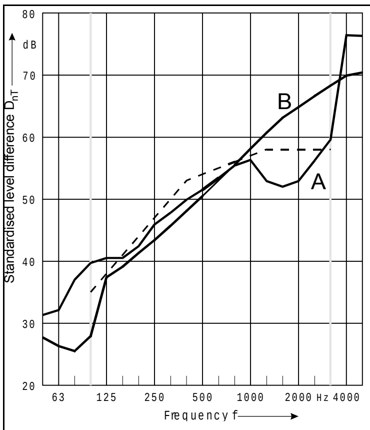


Figure 5: DnT for SIC1

A: R'_w = 53.0, R'_w + C = 51.0
B: R'_w = 52.9, R'_w + C = 50.9

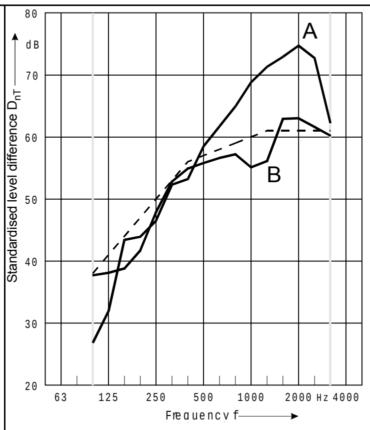


Figure 6: DnT for SIC2

A: R'_w = 55.9, R'_w + C = 52.9
B: R'_w = 56.0, R'_w + C = 51.0

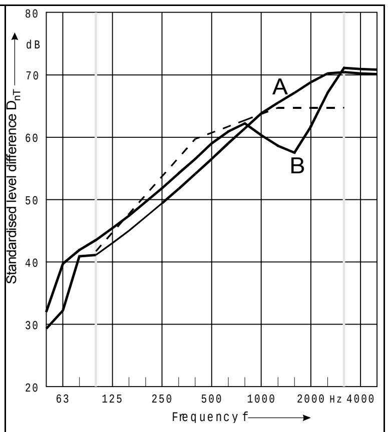
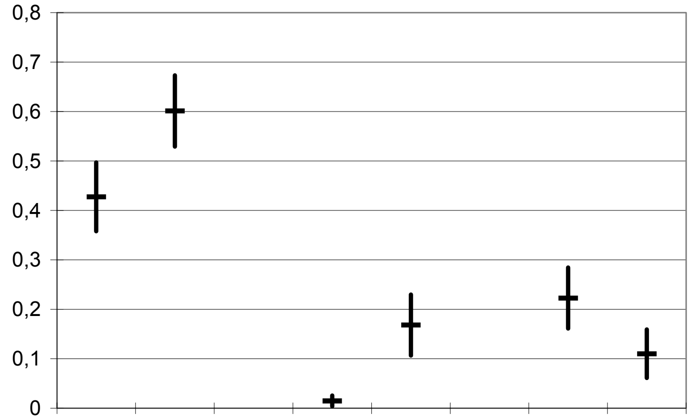


Figure 7: DnT for SIC3

A: R'_w = 59.6, R'_w + C = 57.6
B: R'_w = 59.6, R'_w + C = 57.6

Figs. 5 - 7 show the standardized sound level differences of the three pairs and the numerical data.



	SIC 1 A	SIC 1 B	SIC 2 A	SIC 2 B	SIC 3 A	SIC 3 B
Rw	53.0	52.9	55.9	56.0	59.6	59.6
Rw+C	51.0	50.9	52.9	51.0	57.6	57.6

Figure 8: Results of the listening tests. Shown is the mean value of the percentage of speech intelligibility and the 90% confidence intervals

It is interesting that the novel rating R'_w+C seems to be useful for separation of the cases SIC2, where the insulation in case A is rated 2 dB higher than in case B. But in cases SIC 1 and 3, the spectrum adaptation term C is identical in A and B, respectively, and could not predict the differences in speech intelligibility.

Many other details can be investigated. The coloration of the speech and the quite low level are related to the sound insulation spectrum and to the spectrum of the background noise. Hence these first results can only be interpreted in these special cases. They cannot be generalized. Partly it was extremely difficult to concentrate on the speech signal, since the level was very low. It is therefore desirable to replace the subjective tests by an objective method for determination of a suitable speech intelligibility index. Perhaps the most elementary parameter, the "Speech Transmission Index" STI, which depends on the signal to noise ratio in different frequency bands is sufficiently robust. This must be studied in future, based on the work by Thaden [9] and by Bradley [6].

It is hoped that these investigations will lead to new single-number quantities, as indicators for evaluation and improvement of working conditions in offices, e.g., by focusing on reducing intelligibility instead of reducing the level. Auralization proved as a helpful tool for these kinds of investigation. Neither classical speech intelligibility measures like STI nor loudness or other psychoacoustic methods were able to predict these results. AI and STI approaches in modified versions, however, are candidates for a single-number quantity representing speech privacy in buildings and open-plan offices. For this, a sensitivity function must be developed representing the relation between the objective STI and the subjective speech intelligibility. A close look into methods of modeling speech intelligibility of hearing-impaired persons and into perception of modulated signals seems to be very promising.

5. ACOUSTIC COMFORT IN TRAINS

Traffic noise, particularly vehicle noise, tyre noise and its relation to noise emission from roads was investigated in numerous projects. The same holds for noise emission from trains, due to knowledge about aerodynamic and structural-acoustic sources of wheel-rail contact. Detailed knowledge, too, is available for description and optimization of sound in cars, including tyre noise, pass-by noise, sound quality and sound design strategies. Much less knowledge, however, is available concerning the indoor sound in trains and the acoustic comfort for the passengers. Typical situations in local trains or subways, for instance, are characterized by the frequent stop and go from station to station. This noise scenario is very specific, even characterizing the city's local train system acoustically. This observation leads to the question of sound quality in trains and to traveling comfort in subways which affects thousands and thousands of people going from home to work day by day. It is, therefore, obvious that aspects of sound quality are in the same amount relevant as for car industry.

In order to study the problem of cabin noise in railbound vehicles, the principles of source mechanisms and sound transmission were coupled to questions of annoyance (Klemenz [13-17]). The starting phase of the train is especially interesting since wheel-rail contact and aerodynamic sources are not significant at low speed, but instead, the "singing" tunes of the electric machine and the gearbox are quite significant. These elements are not concentrated in one locomotive but distributed in the bogie of each train car, as in the newest German high-speed train ICE and in almost all modern local trains and trams, for instance.

Sound-quality optimization is surely not a new topic of research, but it can often be observed in the related literature that it just focuses on the evaluation of different product sounds in order to find out an optimum. Another important task, i.e. the finding of the technical parameters that result in these varied sounds, is often carried out by the manufacturer alone, i.e. without direct advice from psychoacoustics. The gap between the two disciplines can again be closed by using the technique of simulation and auralization. Fig. 9 shows a typical FFT/time diagram of a regional train in the starting phase. As can be seen, the sound consists mainly of tones of mostly constant or increasing pitch. Rolling-noise components play only a minor role.

A detailed explanation of the technical effects which produce these sounds can be found in (Klemenz [13, 14, 17]). To summarize, tones produced by the motor are mainly the double switching frequency (and its harmonics) in the first phase called "asynchronous switching" and 6 times the electric basic frequency (and its harmonics) in the second phase called "synchronous switching". The transition between the two phases is visible in Fig. 9 at 8.5 s. The tone caused by the gear coupling is the motor frequency times the teeth number of the small primary wheel (and its harmonics). The whole signal flow is sketched in Fig. 10.

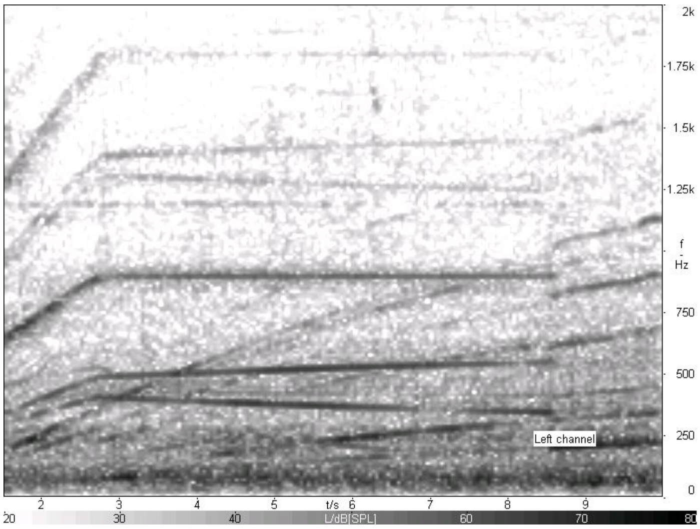


Figure 9: FFT/time diagram of sound pressure measured inside an accelerating regional train

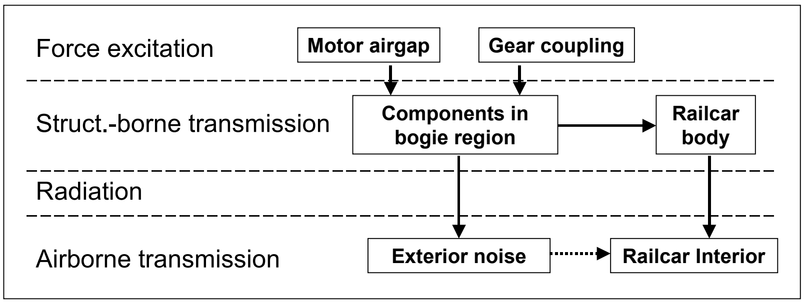


Figure 10: Signal-flow diagram of noise due to traction components inside trains

Now, the job of an acoustic engineer could be to improve an existing machine/train system. The question is which technical details can be changed at all without affecting the efficiency of the traction. Apart from conventional measures that reduce the sound level, also some rather unknown parameter can be varied indeed, like current feed and switching sequences of the electric engine or the teeth number of the gears. A variation of these parameters on a real vehicle is often too difficult or expensive, so that an attempt was made to predict the effect of sound-quality optimization measures with the help of an auralization tool. It is based on sound synthesis, and the corresponding user interface is shown in Fig. 11.

With this model, listening tests and roughness calculations have been carried out, and they are able to prove that the pleasantness of the sounds is indeed dependent on the gear teeth number [17]. It should be emphasized that without the know-how of both sound generation and psychoacoustic evaluation, this parameter would not have been detected. This means that without a dialogue between these two disciplines, it might happen that a psycho-acoustician is not aware of the existence of this effect, and the manufacturer is not aware of its importance. Another example focuses on the motor noise, i.e. the switching frequency in the phase of asynchronous switching. Fig. 11 shows examples for possible signal spectra, and the engineer can principally choose between them [16].

Which one is of best sound quality, is subject to psychoacoustic analysis and listening tests. A result from a listening test is shown in drawn in Fig. 12.

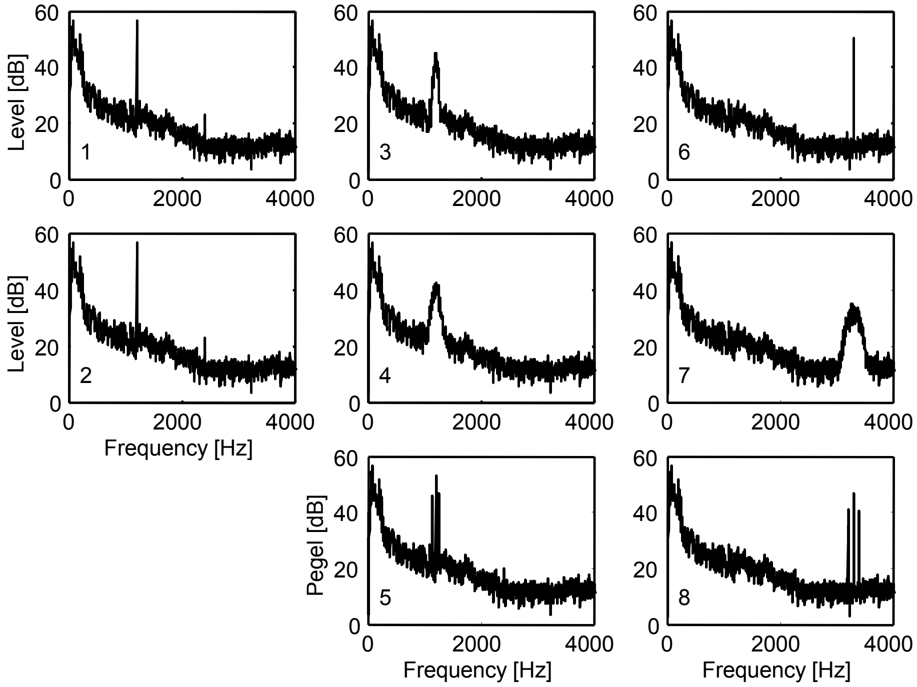


Figure 11: Spectra of possible sound produced by the induction machine
in the phase of asynchronous switching

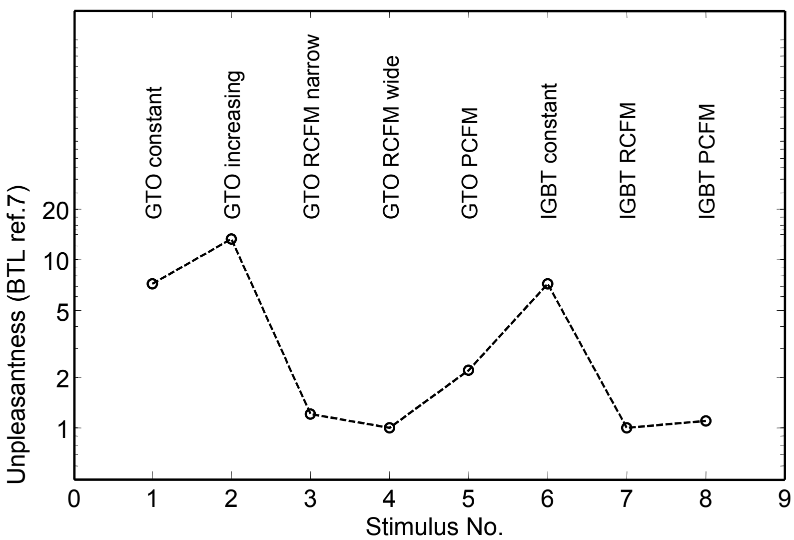


Figure 12: Average unpleasantness judgments for different sounds produced by the
induction machine in the phase of asynchronous switching
(GTO = Gate-Turn-Off-Thyristor , IGBT = Insulated-Gate-Bipolar-Transistor)

It is interesting, however, that the "PCFM" sounds, judged quite pleasant, were expected to have a low pleasantness with respect to psychoacoustic quantities. This indicates that instrumental parameters do not always reflect the whole subjective impression, since the context of the signal has a significant influence on the judgment. More exact descriptors, their inter-relation and their product dependence are still not known for this specific noise scenario, so that more investigations should be done in future.

In addition, this example is demonstrating that psychoacoustic analysis and the mismatch between noise indicators and subjective results may lead to totally new strategies of acoustic engineering. The problem of tonality and harmonic ratios between the motor and the gearbox cannot be identified by using standard methods, not even involving psychoacoustic standard indicators.

6. CONCLUSIONS

Acoustic engineering, its results, a technical solution with “good” acoustic performance requires not only detailed knowledge of technical acoustics and noise control engineering, but specific strategy to create the appropriate sound. The final goal must be put into relation with other aspects of the product, like its technical process, the environment the product is used, the expectation and the experiences with the product etc. One sound might be very annoying in one case, but rather adequate for another, even differing in the judgment of people from different cultural areas.

Noise indicators based on the sound level reduce the noise effect or the sound reduction into a number useful in first approximation, but these numbers do not reflect all important dimensions of noise effects. More categories like speech privacy, disturbance of work or annoyance could lead to a better and more specific description of acoustic phenomena and technical solutions, representing a better impression which can also be easily understood by non-acousticians. Only if acoustic problems and solutions are communicated in daily-life language, the acoustic expert can reach the community and the authorities who decide on investment in noise control.

Single-number quantities are the right way to achieve this goal, if we don’t restrict this idea by using just dB(A), R_w, STI, NC, etc. The psychoacoustic standard parameter, loudness, sharpness, etc., allow a significant step towards an extension of acoustic engineering, but they do not form a compete set of indicators. In every special case, it must be checked how the total acoustic impression is to be built and if, maybe, parameters must be modified or new parameters must be added. In many cases the psychoacoustic approach leads to innovative solutions of acoustic engineering. It is hoped that new methods of simulation and auralization will lead to more cooperation between acoustic engineering and annoyance research on national and international level.

7. ACKNOWLEDGEMENTS

Rainer Thaden finished his PhD at RWTH Aachen University in early 2005. His work yielded a generally applicable auralization tool for sound insulation in buildings, the first elements of which were presented in 1997. The content of chapter 4 was based on parts of his research. Martin Klemenz finished his PhD thesis at RWTH Aachen University at the end of 2004. His work is a milestone in sound quality research for electric railbound vehicles, see chapter 5. Only by all their work the presentation of the three case studies in this contribution was possible. Brigitte Schulte-Fortkamp is acknowledged for her good arguments in discussions on noise effects and annoyance.

8. REFERENCES

[1] Vorländer, M., Acoustic Engineering meets Annoyance Research. Proc. Internoise 2005, Rio de Janeiro. 2005.

[2] Rasmussen, B., Sound insulation between dwellings - Classification schemes and building regulations in Europe, Proc. Inter-Noise '04, Prague, Czech Republic, 2004.

[3] Ten Wolde, T., The EU Noise Policy and the Related Research Needs. Acta Acustica united with Acustica 89 (2003), 735-742.

[4] Maquis-Favre, C., Premat, E., Aubrée, Vallet, M.. Noise and its effects – A review on qualitative aspects of sound. Part 1: Notions and Acousti Ratings. Acta Acustica united with Acustica 91 [2005], 613.

[5] Schultz, T., Synthesis of social surveys on noise annoyance. J. Acoust. Soc. Am. 64 (1978) 377-405.

[6] Schulte-Fortkamp, B., The meaning of annoyance in relation to the quality of acoustic environments. Noise and Health, Cambridge (2002), vol 4 issue 15.

[7] Bradley, J. S., Predictors of speech intelligibility in rooms, J. Acoust. Soc. Am. 80 (1986), no. 3, 837–845.

[8] Vorländer, M., Auralization in Noise Control. Proc. Inter-Noise '03, Jeju, Korea, 2003.

[9] Vorländer, M., Thaden, R., Auralisation of Airborne Sound Insulation in Buildings. ACUSTICA / acta acustica 86 (1) [2000], p. 70-76.

[10] Thaden, R., Auralisation in Building Acoustics, PhD Dissertation, RWTH Aachen University 2005. http://www.bth.rwth-aachen.de/job/disslist.pl

[11] Klatte, M., Hellbrück, J., “Der Irrelevant Speech Effect”: Wirkungen von Hintergrundschall auf das Arbeitsgedächtnis, Zeitschrift für Lärmbekämpfung, 40 (1993), p. 91-98.

[12] Schlittmeier, S. J., Thaden, R. Wirkung irrelevanter Sprache unterschiedlicher Sprachverständlichkeit auf die Arbeitsgedächtnisleistung. In Fortschritte der Akustik - DAGA 2005, München (in print).

[13] VDI 4100, Schallschutz von Wohnungen – Kriterien für Planung und Beurteilung (Noise control in buildings – criteria for planning and assessment). VDI Directive 1994.

[14] M. Klemenz, Die Geräuschqualität bei der Anfahrt elektrischer Schienenfahrzeuge. Ph.D. Dissertation, RWTH Aachen University, 2005. http://www.bth.rwth-aachen.de/job/disslist.pl

[15] M. Klemenz, Sound-generating Parameters of Starting Electric Railbound Vehicles and their Influence on Sound Quality. Proc. CFA/DAGA '04, Strasbourg, S. 749, 2004.

[16] M. Klemenz, Sound Quality of Starting Electric Railbound Vehicles - Dimensions of Hearing and Relevant Psychoacoustic Quantities. Proc. CFA/DAGA '04, Strasbourg, S. 751, 2004.

[17] M. Klemenz, A Sound Synthesis Model for Sound-Quality Optimisation of Starting Electric Railbound Vehicles. Proc. Inter-Noise '04, Prague, Czech Republic, 2004.

[18] M. Klemenz, Sound Synthesis of Starting Electric Railbound Vehicles and the Influence of Consonance on Sound Quality. Acta Acustica united with Acustica 91 (2005), 779.