Psychoacoustics and its Benefit for the Soundscape Approach

Klaus Genuit, André Fiebig
HEAD acoustics GmbH, Ebertstr. 30a, 52134 Herzogenrath, Germany. [klaus.genuit][andre.fiebig]@head-acoustics.de

Summary
The increase of complaints about environmental noise shows the unchanged necessity of researching this subject. By only relying on sound pressure levels averaged over long time periods and by suppressing all aspects of quality, the specific acoustic properties of environmental noise situations cannot be identified. Because annoyance caused by environmental noise has a broader linkage with various acoustical properties such as frequency spectrum, duration, impulsive, tonal and low-frequency components, etc. than only with SPL [1]. In many cases these acoustical properties affect the quality of life. The human cognitive signal processing pays attention to further factors than only to the averaged intensity of the acoustical stimulus. Therefore, it appears inevitable to use further hearing-related parameters to improve the description and evaluation of environmental noise.

A first step regarding the adequate description of environmental noise would be the extended application of existing measurement tools, as for example level meter with variable integration time and third octave analyzer, which offer valuable clues to disturbing patterns. Moreover, the use of psychoacoustics will allow the improved capturing of soundscape qualities.

PACS no. 43.50.Qp, 43.50.Sr, 43.50.Rq

1. Introduction
The meaning of soundscape is constantly transformed and modified. The inflationary use of this term refers to the large diversity of interpretations with respect to the content of the soundscape idea – making it impossible to present a general acknowledged definition. Often, the institutional and disciplinary backgrounds of the researchers have a sustainable effect on their soundscape concept. Schafer, a “soundscape pioneer”, describes the vital question in this context: "What is the relationship between man and the sounds of his environment [. . . ]? [. . . ] Only a total appreciation of the acoustic environment can give us the resources for improving the orchestration of the world soundscape” [2]. A soundscape is not an objectively existing reality (you cannot overflow the soundscape and take a picture), but it is a culturally-affected environment constituted by human perception [3].

Today, environmental noise is calculated and depicted in noise-maps with the A-weighted sound pressure level (SPL). Those noise maps neglecting the specific character of a soundscape are often the basis for discussions and interpretations regarding noise annoyance. In this context, it is necessary to reflect also the meaning of annoyance. Annoyance will be used here as an overall evaluation of disturbances and unpleasantness of environmental noise, a negative feeling evoked by sound. However, annoyance is sensitive to subjectivity, thus the social and cultural backgrounds have an important influence on the subjective attitudes of people to noise [4] and they must be considered besides physical parameters. Therefore, the complexity of noise annoyance and the description of soundscapes, which means more than only the determination of annoyance, cannot be simply described with a single parameter, because many factors contribute to it. Hence, individual, contextual or physical variables, causing a deviation from the “law of averages” implied by dose-response relationships, must be determined with respect to an improved understanding of annoyance as caused by environmental noise [5].

Psychoacoustics will make a meaningful contribution to it and will allow the detection of specific soundscape features.

2. Psychoacoustics in soundscape research
2.1. Psychoacoustics and soundscapes
Psychoacoustics covers one important field of the different dimensions involved in the environmental noise evaluation process. It describes sound perception mechanisms in terms of several parameters, such as loudness, sharpness, roughness, and fluctuation strength as well as further hearing-related parameters.
Soundscapes consist of a number of spatially distributed sound sources, which give the soundscapes their distinctive features. The emitted noise of each source could be measured and analyzed in terms of several parameters. However, the annoyance due to given individual sound sources cannot be transferred to the overall annoyance of an entire, complex soundscape containing the noise of different sound sources, because of e.g. masking effects [6].

Surveys have documented that spatiality plays an important role for physiological reactions and annoyance. In the context of industrial noises, a study has investigated the influence of the direction of sound incidence (unidirectional, multi-directional) on physiological reactions and loudness evaluation. It could be observed that the reaction to the multi-directional situation was higher than the reaction to the uni-directional situation, although both noise situations produced the same SPL at the position of the listener [7]. Therefore, the spatial distribution of sound sources as well as the direction and speed of any movement of these sources can be relevant for the perception and evaluation of environmental noise.

In fact, the determination of noise annoyance caused by complex sound situations arising from the superposition of the emitted sounds by a number of sources is very complicated and the (binaural) signal processing involved in human hearing has to be considered. The use of aurally-accurate measurements provides the opportunity to consider binaural signal processing phenomena.

The fact, that annoyance resulting from the listener’s surrounding soundscape is also depending on the personal attitude of the listener, further increases the intricacy of the soundscape approach, which has to integrate important aspects, such as the physical situation, experience and interpretation of the environment into one broad concept [8]. Even visual information of the location affects noise evaluation [9]. Abe et al. concluded that the influence of visual and verbal information on the auditory evaluation of environmental sounds is considerable [10]. In order to capture the mentioned difficulties with respect to human sensation and evaluation of environmental noise, the transformation of a sound event (the physical situation) into the perceived sound event has to be considered. This transformation is influenced by different aspects: first of all, the physical aspect; secondly, the psychoacoustic aspect: the human hearing processes sound depending on the time structure and frequency distribution. And thirdly, the psychological aspect, including context, the kind of information, the individual expectation and attitude to the sound, is finally leading to the evaluation of the sound event.

Therefore, a multi-dimensional approach, considering these different aspects adequately, is necessary to meet the requirements of the soundscape approach, the “[…] total appreciation of the acoustic environment” [2].

2.2. The application of psychoacoustics in the context of environmental noise

Different calculation methods and models, which, according to the rule of distance for SPL reduction, and by taking into account propagation properties, reflections against objects, damping factors, are an attempt in predicting how A-weighted SPL evolves as a function of distance, however, neglecting time and frequency information. In reality though, the calculated LAeq and the expected corresponding noise annoyance, often differ widely from the evaluations made by the concerned residents [11]. This explained with the fact that the human hearing, in contrast to a sound level meter, is not an absolute measuring instrument. It shows a differentiated sound perception due to its non-linearity and adaptivity as well as its signal processing characteristics, paying attention to further factors than only to the averaged intensity of the sound event [12].

It could be established that the time structure of occurrence of sound events in the context of traffic noise has a major influence on the noise annoyance. A high traffic load noise can be evaluated as more pleasant than low traffic load noise because of the perceivable single vehicle pass-by’s penetrating the quietness, which “startled” permanently the exposed persons. For example, traffic noise was measured and analyzed for the understanding of exterior vehicle noise perception and resulting effects on man in the European research project “Sound Quality of Exterior Vehicle Noise” (SVEN). There, traffic noise recorded in L-shaped and U-shaped streets was analyzed and evaluated. The noise for the “L-shaped building” street was judged by the majority to be a bit or much louder and more dangerous, unpleasant and annoying compared with the U-shaped street. With respect to the general judgements the “L-shaped building” traffic noise was again judged less favourable. Therefore, the street shape – U-shaped, L-shaped – affects also the noise situation (because of different reflection patterns and time structure) and the noise annoyance respectively [13].

Another ongoing European research project is “Quiet City Transport” (QCity), which underlines the endeavour to further explore the connection between urban noise and its perception and evaluation [14]. It was observed that many hot-spots regarding complaints cannot be explained with data from noise maps alone. The L_Aeq does not sufficiently describe the environmental noise and its perception.

Figure 1 illustrates the behaviour of different parameters in dependency on distance in free field. It schematically depicts on the basis of tonal and broadband noise the behaviour of different parameters in dependency on the distance. It makes clear the different behaviour of psychoacoustic parameters compared with the decrease of the SPL.

Figure 2 shows the calculation of these parameters of a vehicle’s pass-by noise recorded in different distances from the moving source. In contrast to the principle of the SPL distance dependency, the psychoacoustic parameters
are also less dependent from the distance and from the SPL respectively [15].

The vehicle pass-by noise is further analyzed in Figures 3 and 4. The occurrence and the persistence in particular of disturbing patterns in the noise event can be observed, too. The modulation spectra clearly shows the unchanged particularities of the vehicle’s pass-by noise, although the $L_{Aeq}$ decreases with distance (Figure 3, Figure 4).

Moreover, the diagram depicting the “Relative Approach”, a pattern measurement algorithm, underlines this conclusion. (Figure 4) This calculation method identifies changes in the short time spectrum with respect to frequency and time domain applying the difference calculation between current signal values and estimated values. The estimated value is derived from the signal known up to the current time. The determined difference can be interpreted as the short time signal change [12].

The diagrams show that specific acoustic properties (tonal components, pattern in the time and frequency domain, etc.) attracting attention, remain nearly unchanged in a case of a tenfold increase of the distance and decrease of $L_{Aeq}$. In case, those properties are not evaluated as pleasant in the context of environmental noise – presumably the car pass-by noise is rarely evaluated as pleasant – the noise annoyance does not decrease in the same way compared with the decline of the $L_{Aeq}$.

The evaluation of tram noise is also often complex. The next example, recorded in Brussels, shows the insufficiency of averaged SPL descriptions for the understanding of noise annoyance. Although the A-weighted $L_{eq}$ is almost identical, the evaluations, given by a small sample of test subjects, differ widely. Two curves squeal noise events were compared. Tram 1 and tram 2 do not considerably differ in $L_{Aeq}$ (left 80.05 dBA / right 75.0 dBA to 80.3 dBA / 73.9 dBA) and loudness (46.2 sone / 30.4 sone to 49.3 sone / 35.0 sone). The difference in the sharpness gives first information (3.29 acum / 2.31 acum to 4.38 acum / 3.26 acum) about relevant features of the sound events for the evaluation. Tonal components as well as temporal variations could also be identified. The Relative Approach clearly shows pattern in the time domain, which finally led to the different evaluations (Figure 5).
Impressive sound features contribute to overall judgments regardless of their sound pressure levels [16].

To sum up, the examples mentioned above point out the necessity of new approaches, measurement techniques and new parameters in order to adequately grasp the particularities of a soundscape and to sufficiently consider the mechanism of sound perception. Conventional parameters and analysis techniques are not sufficient. A new approach has to be applied involving aurally-accurate measurements and psychoacoustic analyses, where the characteristics of the human auditory apparatus are taken into account.

3. Evaluation of soundscapes

3.1. “Questions and answers”

Human hearing can classify complex soundscapes into single sound events because of its binaural hearing and its consequential directional hearing and selectivity. Single contributions to a soundscape can be selected by human hearing and decisively influence the individual evaluation. Thus, if people are complaining about noise annoyance, the actual reasons for noise objection have to be explored first. Physical, psychoacoustic and binaural signal processing as well as cognitive aspects affect the evaluation of environmental noise. (Figure 6)

Relevant questions may be: Which of the existing sound sources causes the noise annoyance? Which kinds of signal attributes like modulation or specific patterns in the time and frequency domain are creating the annoyance? Is the time structure responsible for the complaints? Are informative features relevant with respect to the annoyance? Is the noise unpleasant or conspicuous due to modulation or are there noticeable patterns in the time or frequency range? What kind of attitude and expectation has the listener?

Answers to those questions can already give significant information about the actual causes for complaints. On the one hand, these answers already allow first successful measures in order to improve the perceived environmental noise quality [17]. The phrase sound/noise quality in the context of environmental noise is also frequently used by other authors [18].
On the other hand, the acoustic analysis of the soundscape can be carried out in a more goal-oriented manner, if the exposed persons give reasons for their annoyance.

3.2. Measurement of soundscapes – Aurally-equivalent sound measurement

With conventional one-channel measurements it is not possible to sufficiently determine environment noise quality and the annoyance caused by a complex environmental sound situation constituted by several spatially distributed sound sources. Important aspects, which influence the subjective impression, are masking effects, sound impression, spatial distribution and complex phase relations. Conventional measurement and analysis technique only partly take into account these aspects. The use of binaural technology is recommended to bridge this gap. The artificial head accurately simulates acoustically relevant components, and it is able to obtain aurally-accurate binaural recordings of sound events. The playback of binaural recordings creates an auditory impression for the listener which is the same as it would have had if the listener had been present at the original sound event [19]. The results of listening tests, realistically playing-back the noise situations, are highly valid and reliable. Measurements with binaural technology are necessary if subsequent reproductions of noise are required, e.g. in the case of further examination in laboratories (listening tests). This insight has become widely accepted; the use of binaural technology and psychoacoustic analyses, considering both channels, in acoustic engineering win slowly recognition [20] (Figure 7).

3.3. Calculations models and analyses

Generally, environmental noise is perceived by the sound perception mechanisms of human hearing. The perceived sound event can be described and analyzed in terms of psychoacoustic parameters, such as loudness, sharpness, roughness, and fluctuation strength. These parameters describe the environmental noise situation better than the simple A-weighted SPL and capture relevant, “ear-catching” phenomena of the noise.

Different preliminary calculation models integrating several parameters have been developed to determine annoyance. For example, Zwicker calculated the unbiased annoyance with loudness, sharpness and fluctuation strength [21], Terhardt developed a model for the determination of “Wohlklang” (pleasantness of noise) using loudness, sharpness, roughness and tonality [22], Preis worked with annoyance loudness (time-averaged value of the difference between loudness of the noise and background sound), intrusiveness including sharpness, and distortion of informational content in order to determine noise annoyance reception [23]. Further research must be carried out to determine a model integrating the relevant parameters, which considers the sound perception mechanism and correlates with annoyance evaluation respectively. Therefore, interaction effects of different parameters (e.g. psychoacoustic) with respect to annoyance caused by environmental noise have to be studied. The application of further parameters – besides the known psychoacoustic parameters – can be helpful regarding the description and evaluation of environmental noise as shown in some examples mentioned above.

3.4. Existing tools for the improved description of environmental noise

The intelligent use of already existing tools and analyses would be a step forward that would allow an improved...
The application of these opportunities – frequency filtering, variation of integration time – can already help to recognize disturbing patterns without much effort. Unfortunately, the legislators and decision makers often do not use these simple tools in the context of the evaluation of environmental noise.

However, questions concerning annoyance of environmental noise cannot be satisfactorily answered by the presented parameters alone. Both, the nature of the information in the acoustic environment and the attitude of exposed persons greatly affect the subjective impression and must be added to the (psycho-)acoustic analyses.

4. Conclusions

Conventional noise-maps listing only SPL values averaged over different time intervals cannot describe environmental noise quality adequately. Inevitably, such averaging measures are crude and hide the substantial exposure variation relevant for individual annoyance reactions [1].

One necessary measure is the increased application of artificial head technology in the environmental noise context. Only binaural recording technology, analog to human hearing, allows an objective sound recording and can register sound in relation to direction of the sound incidence. The binaural recordings allow the aurally-accurate reproduction of acoustic scenarios, which are directly comparable with respect to pleasantness or annoyance by listeners.

To sum up, the soundscape approach can help to bridge the explained gaps, which cannot be overcome with conventional methods alone. In order to achieve the common purpose of improving soundscapes with respect to pleasantness and reduced annoyance, “environmental sound design” with a multi-dimensional understanding must be carried out. This implies that the ultimate causes for complaints and high annoyance have to be identified, e.g. specific noise features caused by a certain sound source. Then, promising measures as a kind of sound design are feasible and, if possible, the modification of the responsible source.

Thus, physical aspects, psychoacoustic aspects, taking into account the human (binaural) signal processing, and cognitive, psychological aspects, regarding variables like information content, acceptance of sound sources, attitude of the listener, have to be adequately considered.

“From acoustics and psychoacoustics we will learn about the physical properties of sound and the way sound is interpreted by the human brain. From society we will learn how man behaves with sounds and how sounds affect and change his behaviour. From the arts, […] we will learn how man creates ideal soundscapes […]” [2]. Only the elaborate combination of those disciplines will allow the identification of promising measures against unwanted sound or better against unwanted sound features. The first step to meet this claim regarding the aspects of physical properties of the sound will be the extension from averaging energy descriptions (based on SPL values) to a more detailed acoustic description taking into account
acoustic properties of the sound events. To achieve an improved description of the soundscape, psychoacoustic parameters have to be applied. The use of psychoacoustic parameters and the detection of temporal and spectral patterns will advance soundscape evaluations as exemplarily shown and will considerably improve perceptually-related assessments of the environmental sound quality and its expected annoyance impact. Furthermore, new parameters, like the Relative Approach, must be developed to characterize the noise situation further. The use of simple tools, e.g. third octave analyzer, level meter with variable integration time, already give an improvement and the opportunity to identify disturbing components without much effort. Moreover, the idea of creating psychoacoustic maps integrating further parameters in conventional noise maps will allow, as a starting point, the application of the soundscape approach with psychoacoustics to the environmental and community noise context [25]. The demand and challenge is to “put some quality into environmental criteria” [26].

References