Do we need psychoacoustics within soundscape?

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Abstract

For the evaluation of soundscape the perception by the human being with respect to the auditory sensation is very important, which is also influenced by expectation, experience and context. The well-known A-weighted sound pressure level is a suitable predictor at higher levels to estimate a possible damage of the human hearing by sound. But at lower sound pressure levels annoyance cannot be sufficiently predicted by the A-weighted sound pressure level. Especially in complex sound situations with different spatially distributed sound sources the human hearing is able to focus on single sound sources and to judge the sound quality depending on loudness, sharpness, roughness, fluctuation strength separately. This means that for the acoustical investigation of soundscape the use of binaural recording and psychoacoustic analysis is strongly recommended, which is currently described as informative in the new working item proposal for ISO 12913-2.

Keywords: soundscape, psychoacoustics
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1 Introduction

Environmental noise is a leading environmental nuisance. Thus, the World Health Organization WHO estimates that one million healthy life years are lost every year from traffic related noise in the western part of Europe [1]. These estimations make clear that in spite of long-term endeavours to protect humans from harmful noise and to reduce noise annoyance in cities by comprehensive regulations, a great deal of persons is still suffering from environmental noise [2]. Thus, the adequacy of common environmental noise assessment concepts must be questioned. In contrast to it, the soundscape approach as based on perception by people in context [3] is an approach to holistically grasp the issue of environmental noise perception and assessment. The fundamental difference to traditional environmental noise assessment concepts is that the soundscape approach implicitly assumes that acoustic environments can evoke different emotions and feelings and that the perception of environmental noise is not limited to the annoyance dimension only. Soundscapes can be restorative, vibrant, pleasant, eventful, monotonous or chaotic. This goes beyond the consideration of mere annoyance level only. It is obvious that a valid classification of soundscapes in terms of affective quality cannot be achieved by sound pressure level interpretations interpreted in the light of more or less annoyance. Of course, A-weighted sound pressure level indicators are adequate for assessing the risk of physical damage of the human hearing. But, such indicators do not allow distinguishing a soundscape which is perceived as vibrant, pleasant and eventful from a soundscape being perceived as chaotic and bothering. To illustrate the insufficiency of the A-weighted sound level indicators, the result of a within-subjects design of experiment is shown, where several typical environmental noise sources of one minute were presented to and assessed by participants with respect to some evaluation criteria. In total, 20 participants with normal hearing took part in the experiment. Among other environmental noise stimuli, five typical environmental noises were presented, which all had the same $L_{Aeq}$ of 70 dB(A), see figure 1.

![Figure 1: Level (A) vs. time analysis of different environmental noises](image-url)
It was observed that the assessments of annoyance as well as loudness differed statistically significant ($F_{(4,76)}$ loud = 9.4, $p<0.01^{**}$, $F_{(4,76)}$ annoying = 3.4, $p<0.05^{*}$) as figure 2 and 3 display [4]. As expected, the environmental sounds of constant $L_{Aeq}$ were not assessed as equally loud and equally annoying. The loudness and in particular the annoyance of environmental noise do not depend on the sound level only.

![Figure 2: Box-whisker plot: Overall annoyance assessment of different environmental noises shown in figure 1](image)

![Figure 3: Box-whisker plot: Overall loudness assessment of different environmental noises shown in figure 1](image)

Moreover, although the overall loudness and overall annoyance assessments of environmental noises are not completely independent, these dimensions are not congruent [5]. For example, overall loudness and overall annoyance were statistically significant assessed with respect to the fountain noise stimulus (Wilcoxon signed-rank test, $p<0.05^{*}$). This means that the psychoacoustic loudness is able to predict more reliably loudness assessments than sound level indicators, but the consideration of loudness is not sufficient to explain noise annoyance. Other (psychoacoustic) properties of environmental noises, besides loudness, influence annoyance assessments as well.

### 2 Psychoacoustics and its importance to soundscapes

Psychoacoustics provides knowledge about the relationship between acoustical stimuli and provoked hearing sensations for specific “one-dimensional” sensations like loudness, sharpness, roughness or fluctuation strength [6]. All psychoacoustic parameters are of prothetic...
nature quantifying how much or how intense a certain auditory sensation is. For example, the psychoacoustic parameter loudness describes the perception of volume considering the most important human signal processing phenomena like distribution of critical bands and spectral and temporal masking properties in detail. The psychoacoustic loudness parameter shows a higher correspondence with the sensation of volume (loudness) than simple sound level indicators, since the psychoacoustic loudness is mimicking closely the human signal processing [7]. The sharpness parameter describes the weighted first moment of distribution of critical band rates of specific loudness, relating the proportion of high-frequency spectral components to the total loudness. In contrast to it, roughness and fluctuation strength interprets the temporal structure of signals; low modulations lead to a perception of a fluctuating noise, whereas fast modulations result in a kind of roughness sensations. The magnitude of these psychoacoustic sensations depends mainly on the rate and level of modulation. The psychoacoustic sensation of tonality describes generally the magnitude of perception of tonal content in broad-band noises and is influenced by several aspects. According to Sottek et al. [8] correlates the perception of tonality with the partial loudness of the tonal components. Consequently, psychoacoustic elements of (annoying) sound can be described in detail by a combination of hearing sensations [6].

In the context of the COST Action "TUD Action TD-0804 [9]" soundwalks were repeatedly performed to investigate the city centre of Aachen, Germany. Eight urban locations were repeatedly visited, recorded binaurally and evaluated with respect to different criteria by in total 57 participants, which were subdivided into 8 groups. The soundwalk participants were requested to listen to the sound of a location and they should experience the location with all senses for at least 3 minutes. After listening they were asked to fill out a questionnaire and provide assessments on different category scales. Table 1 shows that the psychoacoustic loudness indicator is able to explain more variance of in-situ assessments of loudness and unpleasantness than the commonly used A-weighted equivalent continuous sound level $L_{Aeq}$. The psychoacoustic loudness explains 6% more variance regarding the in-situ judgments of unpleasantness than the $L_{Aeq}$ and even 9% more variance of unpleasantness data obtained during soundwalking. The better prediction performance of the psychoacoustic loudness compared to the sound level indicator is close to statistical significance. This observation underlines the benefit of a detailed modeling of loudness sensation by the psychoacoustic parameter loudness compared to simple sound level indicators. Finally, it is possible to explain more variance by considering further psychoacoustic parameters quantifying further auditory sensations.

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<th>$L_{Aeq}$</th>
<th>Psychoacoustic Loudness</th>
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<td>0.80**</td>
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<tr>
<td>Assessed unpleasantness in-situ</td>
<td>0.54**</td>
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3  Psychoacoustics and its limitation regarding calculation

Noise maps are usually based on calculations considering the contributions of different noises in terms of A-weighted sound pressure level. For the calculation of sound pressure levels simple rules can be applied. The overall sound pressure level due to the superposition of sources (e.g. for uncorrelated noise sources: 60 dB + 60 dB = 63 dB) as well as distance effects can be easily predicted (-6 dB per doubling of distance for a point source in free-field). Such simple calculation rules without considering the time signal cannot be applied for psychoacoustic parameters. For the calculation of psychoacoustic parameters the time signals are needed. In particular, for superposed sources based on single source parameters there are no simple rules and laws to predict the resulting sum. In general, it is possible for an existing sound source of high annoyance to be masked by a second sound source of more preferred sound quality. For example, a perceived high impulsiveness of an individual sound source, often leading to annoyance reactions, can be reduced by adding noise of more comfortable sound quality. This means that unpleasant noise components can be masked by more positive sounds. However, if sound is added to another noise, annoying psychoacoustic phenomena can result as well. For example, modulations or fluctuations can be generated, which can result in increased noise annoyance [11].

Figure 4 provides an example of two superposed sources, namely a time-variant scooter pass-by noise event and a steady-state fountain noise. These sounds are analysed with respect to parameter values as single sources and as superposed sources. First of all, it is clear that the superposition of two incoherent signals with the same LAeq results in a level increase of 3 dB. In contrast to the prediction of sound pressure level, the overall loudness of two single loudness values cannot be simply calculated without considering the resulting time signal of the superposed sources. The resulting loudness based on the loudness values of superposed single sources is not possible, since the psychoacoustic parameter loudness takes into account aspects such as spectral and temporal masking, which cannot be determined without considering the time signals. Moreover, according to the ISO 532-1 leads the consideration of the statistical mean of time varying loudness, in general, to results that are too low in comparison to the evaluated loudness, and the percentile loudness N₅ should be given when stating the overall loudness perceived [12]. Fastl concluded that this relationship is caused by an “overemphasis” of single loud events, which contribute greatly to the overall perception [13]. The 5th percentile loudness value is the loudness value which is reached or exceeded only in 5 % of the total measurement interval. The scooter noise has a greater N₅ value than the fountain noise and if both single sources are combined, the N₅ is mostly influenced by the scooter pass-by event. Thus, if mainly the loudest parts within a noise sequence are important for the overall loudness impression, the exact run of the loudness over time of the different sources and their resulting sum must be known in detail. For sharpness as the measurement technique for the simulation of the auditory sensation of sharpness, which is here calculated on the basis of DIN 45692 [14], it can even be observed that the resulting overall sharpness turns out to be lower than the sharpness of the single source fountain. Thus, the sum sharpness can be lower than the maximum of the sharpness of the single sources.
Figure 4: Analysis of different parameters of two single sources (left: scooter pass-by (30 km/h constant speed), middle: fountain noise) and their resulting sum signal (right). From top to bottom: Level (A) vs. time, Loudness vs. time according to ISO 532-1 [12], Sharpness vs. time according to the DIN 45692 [14], Roughness vs time according to Sottek [18], Relative Approach vs. time [15]
A comparable effect occurs for the psychoacoustic parameter roughness. The considerable roughness impression of the single scooter pass-by noise is "disturbed" by superposed broadband steady-state fountain noise resulting in a lower overall roughness in case of the superposed sources. Moreover, if temporal and spectral noise patterns are analyzed, e.g. based on the Relative Approach analysis [15], a similar observation can be made. The Relative Approach analysis parameter is related to perceivable patterns in acoustic signals and detects specific, obtrusive, attention-attracting noise features, since it is often observed that human auditory impression is dominated by patterns, and in such situations largely ignores absolute values [16]. The algorithm forms a moving average in time and frequency and subtracts it from each of series of instantaneous measurements; the difference between instantaneous value and the updating moving average is interpreted as pattern strength. It is the difference between the estimate and the actual content in a signal [17]. It can be seen that due to the superposition of the two single sources, the presence of the fountain with its pseudo-stationary noise caused by the water plashing resulting in low amount of remarkable noise patterns is reducing the amount of perceivable patterns caused by the scooter-pass-by event. Then, the scooter noise is less clear in its pattern.

However, sounds are processed on the basis of semantic features (meaning) rather than of some abstracted sensory properties only. Psychoacoustic parameters describing several auditory sensations in detail are necessary, but not sufficient to explain responses to (meaningful) noises. According to ISO 12913 part 1, soundscape means “acoustic environment as perceived or experienced and/or understood by a person or people, in context” [3]. This implies that the context is relevant for sound perception. In particular, the context includes the interrelationships between person and activity and place, in space and time. Therefore, some environmental noises, which were described in chapter 1, were repeatedly judged regarding annoyance under different experimental conditions. By providing additional visual input the context was modified to a certain extent. In fact, only a freeze picture of the respective noise source was shown.

Figure 5: Box-whisker plots: Comparison of annoyance assessments provided in laboratory context on a 9-point category scale without and with additional visual input
The participants were explicitly requested to assess the annoyance of the presented sound only. Due to a greater temporal separation of the provided assessments collected under different conditions (>20 minutes), it was prevented that the previous assessments of the same acoustical stimulus could be recollected.

The annoyance assessments were found to be highly statistically significant different with respect to the fountain noise (paired two-tailed t-tests, p<0.01**) and at least close to statistical significance in the case of the train noise stimulus (paired two-tailed t-tests, p=0.19). These observations confirm the occurrence of audio-visual interaction. As expected, there is an influence of visual input on sound perception. Interestingly, if visual input is provided than fountain noise is perceived as less annoying, whereas a train picture did not reduce annoyance. In consideration of the fact, that the visual input was minimal (only a freeze image), which did not allow a strong multi-modal immersion into the environmental sequence, it is expected that in real-life even larger effects on sound assessment due to visual data occur. This simple example illustrates that in the context of soundscape investigations the applications of psychoacoustics is necessary, but not sufficient.

4 How to Consider Psychoacoustics for Soundscape?

Psychoacoustics must be considered in the context of soundscapes investigations at different places. It is very evident that a general rethinking is needed to change from addressing only the symptoms to treating the causes in the context of environmental noise. A detailed knowledge in psychoacoustics with respect to the relations between certain acoustic features and human responses can help to describe accurately noise exposure with its specific psychoacoustic properties. In order to consider psychoacoustics in the context of soundscape some important steps must be taken.

Firstly, measurements of acoustical environments must be realized by means of measurement devices allowing aurally-accurate recordings. This allows listening to the measurements in an aurally-accurate way and is also a requisite for subsequent psychoacoustic analyses.

Secondly, in the context of the assessment of acoustical environments psychoacoustic parameters - in particular the standardized parameters loudness, sharpness and prominence (tonality) - should be considered to determine the character and quality of noise in a detailed way. In this context, it was observed that temporal effects, e.g. variation of psychoacoustic parameters over time, are meaningful as well, since strong variations of noise attract attention beyond its absolute level [17].

Thirdly, psychoacoustic analysis results can be used to classify locations and areas. The results of certain psychoacoustic parameters could be interpreted with respect to adequate limits and ranges to estimate the effect of soundscape on people at least from the perspective of signal properties.
5 Conclusions

Soundscape should be used as a “shell” discipline including the consideration of environmental, natural and artificial sounds influenced by context, experience, expectations and landscape. It is already clear for decades that the effect of noise on humans cannot be measured or calculated by the consideration of the A-weighted sound level only. A low sound pressure level is not a guarantee for a better sound quality or a low noise annoyance and vice versa. In contrast to the simple sound pressure level approach, by means of psychoacoustics and “sound quality” state-of-art-knowledge various hearing sensations can be meticulously described and their implications regarding sound assessments estimated. However, blind time averaging of (psycho-)acoustic parameters leads to wrong assumptions with respect to perceived sound quality or annoyance. For the analysis and classification of soundscapes it is necessary to listen to the sound of the environment and to listen to the comments of the people living in this soundscape. In order to draw the correct conclusions in soundscape investigations there is a strong need for transdisciplinary actions, since the consideration of sound perception beyond physics and noise control requires a constructive collaboration of several disciplines.

References


