DOI: 10.61782/fa.2025.0717

FORUM ACUSTICUM EURONOISE 2025

PSYCHOACOUSTICS, THE LONG WAY TO BE CONSIDERED INTO INTERNATIONAL STANDARDS

Klaus Genuit[1*]
[1] HEAD-Genuit-Foundation, Herzogenrath, Germany

ABSTRACT

For several decades the A-weighted sound pressure level has been used for the evaluation of sound. But sound character is determined by the spectral composition and the temporal patterns. For this reason, the discipline of psychoacoustics has established itself, which can provide more differentiated analyses describing the sound character. With the help of psychoacoustics parameters such as loudness, sharpness, tonality, roughness, fluctuation and impulsiveness, the auditory impression of sound events can be viewed in a more differentiated way than just with the A-weighted sound pressure level. The first standards were developed for stationary loudness DIN 45632 and ISO 523. In the meantime, we have standards by ECMA-418-2 describing different psychoacoustical parameters based on a hearing model like tonality, roughness and fluctuation strength. The international standard ISO 12913 "Soundscape" describes this relationship of perceived sound quality considering the context.

Keywords: *psychoacoustics, standardization, soundscape*

1. INTRODUCTION

The noise nuisance of the population has increased in recent years, despite numerous measures to reduce the noise emissions of individual noise sources. According to the German Federal Environment Agency (UBA), more than 50% of the population is affected by traffic noise [1]. Although psychoacoustics was introduced by ZWICKER [2] in the middle of the last century, first with the parameter loudness, the A-weighted sound pressure level still dominates all legal regulations with respect to noise measurements. The advantage of the A-weighted SPL is the option to calculate with these data. If you know the level of two sources, a calculation of the superposition is possible. It is not possible to predict the psychoacoustical parameters by superposition of different sound sources, the time signal is necessary. The absence of standardization for a long time was another disadvantage of the introduction. It has been a long way to overcome this handicap.

2. WHAT IS NOISE

Noise is caused by the perception of humans and describes the effect of sounds. Consequently, noise cannot be measured with sound level meters, but sound only becomes noise if it is undesirable for those affected or is likely to affect them psychologically, physically, socially or economically [3]. Noise represents a negatively assessed sound immission, i.e. it does not exist without the perceiving subject. This understanding is also shared by the DEGA (German Acoustical Society) Noise Working Group (ALD) and explains that noise is an evaluative term and therefore cannot be measured with physical devices alone [4]. Consequently, a physically unambiguously describable sound event can certainly lead to different auditory events. The context, the attitude of the exposed person to the source of the noise or to its originators, as well as the experience and expectations of the noise exposure, influence the perception and assessment of sounds. According to this understanding, noise cannot be validly determined based on an A-weighted sound pressure level alone, as is suggested by terms such as "noise measurement" and "noise map". A so-called "noise map" is so far only a map that shows sound pressure levels based on calculated data. A sound pressure level map is certainly necessary for the discussion of noise exposure, but it is not sufficient for the valid determination of nuisance caused by noise, i.e. in the context of noise [5].

3. PSYCHOACOUTSICS

Usually when noise effects are considered with respect to well-being and health, A-weighted sound pressure level indicators are analyzed. However, several decades ago researchers started to use measurement methods to quantify auditory sensations in more detail. Later the soundscape pioneer SCHAFER [6] described acoustics and

[*] ***Corresponding author**: klaus.genuit@head-genuit-stiftung.de*

psychoacoustics as the cornerstones to understanding the physical properties of sound and the way sound is perceived. This approach emphasized that all aspects of soundscape are related to perception. Psychoacoustic data are considered for a more comprehensive evaluation of acoustic environments that goes beyond the simplified use of sound level indicators. Moreover, a key consideration is that acoustic environments are perceived binaurally by humans. Thus, measurement equipment that collects spatial information about the acoustic environments is increasingly being applied in soundscape investigations and consequently is suggested in soundscape standards. Following the soundscape concept, all measurements and analyses must reflect the way soundscape is perceived by people in the appropriate context. This insight led to an increase in research and applications of psychoacoustic measurements to understand the effects of acoustic environments on humans in more detail. Psychoacoustics deals with the description of the relationship between physical stimuli and the auditory perceptions they evoke. Experimentally observed relationships between stimuli and sensations result in mathematical descriptions and psychoacoustic models. This makes it possible to make statements about the acoustic properties of sounds and their perception. An extended assessment of environmental noise to predict noise pollution can be carried out by considering psychoacoustic characteristics of environmental noise. The most important psychoacoustical parameters are:

3.1 Loudness:

Consideration of distribution of critical bands and masking properties in the hearing, DIN 45631/A1, ISO 532-1. Studies [7] have shown that the 5% percentile loudness (N5) correlates highly with the perceived total loudness valid in cases of unsteady sounds, since the mean value of time varying loudness compared with the subjectively evaluated loudness provides a value, which is too low, the 5% percentile loudness (N5) has to be used with respect to the perceived overall loudness. Experiments have shown that the perception of loudness correlates better with the psychoacoustic parameter loudness than with the A-weighted sound pressure level [7]. Thus, the representative singular value, which considers human cognitive stimulus integration, is based less on a mean value than on the loudness peaks of the function of loudness over time. Basically, loudness depends on the spectral distribution, considers the level-dependent loudness perception of different tones and the duration as well as simultaneous-, pre- and post-masking properties of the human ear.

3.2 Sharpness:

Weighted first moment of distribution of critical band rates of specific loudness, relationship of high-frequency spectral components to total loudness, DIN 45692. The sharpness parameter covers the aspect that sounds with energetic focus in the high frequency range are perceived as sharp, which often leads to increased annoyance independent on level.

3.3 Roughness & Fluctuation:

Time structure of the sound signal, modulation factor and level difference determine roughness & fluctuation, amplitude- and frequency modulation, DIN 38455, ECMA 418-2 [8] (ECMA develops and publishes international standards for the information and communication industry). Roughness or fluctuation, deal with sensations that are evoked in sounds due to special temporal structures caused by modulation of tones or different tones in one frequency group.

3.4 Tonality:

Products emit tonally perceived noises due not only to pure tones but also to narrow noise bands, and to same-vicinity combinations of pure tones and narrow elevated noise bands, ECMA 418-2. The psychoacoustic parameters behave (almost) orthogonally, i.e. one psychoacoustic parameter can vary whereas another parameter remains constant. There is a gain in information compared to the sound pressure level and more differentiated statements about the characteristics and potential reactions of the listener become possible.

4. STANDARDIZATION OF PSYCHOACOUSTIC

Psychoacoustics will be more and more established: automotive field, office and appliance equipment, environmental noise and soundscape. The first standards within psychoacoustics were the loudness standards from stationary sound represented by the recommendation ISO 532-A and ISO 532-B (1966) “Method calculating loudness level”. ISO 532-A is based on octave spectrum in accordance with STEVENS [9], ISO 532-B is based on third octave spectrum in accordance with ZWICKER [10]. These recommendations became an ISO standard in 1975. This early introduction of the loudness standard has had some disadvantages: 1. the calculation was very complicate, 2. two standards instead of one, 3. the discussion that loudness is correct and A-weighted level is wrong has prevented a quick acceptance of this new approach, 4. ISO-

532 was only valid for stationary sounds but in reality around 80% of daily sounds are time-variant. In 1996 the German Institute for Standardization (DIN) initiated a new working group "Psychoacoustical Measurement Technique" to standardize the time-variant loudness, sharpness and binaural measurement system (artificial head). The first result was the DIN 45692 (2009) for "Sharpness" which standardized a modified VON BISMARK sharpness [11] with a different weighting function. Informative was the AURES sharpness [12] mentioned which has a dependence on loudness. One year later the new time variant loudness DIN 45631/A1 was published 2010 based on the ZWICKER method. Parallel the ISO working group WG9 has started in 2007 to review the ISO 532 stationary loudness. In the meantime, another approach was established, the US ANSI S3.4-2007 "Procedure for the computation of steady sounds" in accordance with GLASBERG & MOORE loudness [13] using 40 equivalent rectangular bands instead of the 24 frequency groups by ZWICKER. The ANSI loudness was based on the new ISO 226 from 2003 (Equal Loudness Curves) whereas the ZWICKER loudness was based on the older ISO 226 from 1987. These differences led to a lengthy controversial discussion about which loudness should now be standardized. Unfortunately, the two calculation methods led to different results depending on the signal. It was questioned whether ISO 229 from 2003 is really better or more correct than the old ISO 229 from 1987 or whether it would be better to revise ISO 226 again. Finally, after many years, it was agreed to develop three new standards: ISO 532-1 (2017) according to the ZWICKER method for stationary as well as time-variant noises, ISO 532-2 as stationary loudness according to MOORE & GLASBERG [14] and later in 2023 ISO 532-3 for time-variant signals according to the MOORE & GLASBERG & SCHLITTENLACHER method [15]. In 2008, the first efforts were again made at DIN to standardize roughness. In the meantime, various software solutions were available for calculating roughness, but they yielded extremely different results. While the calculation of the roughness of pure, modulated sine tones was still quite uniform, large differences were revealed for broadband signals. Narrowband signals can cause roughness, but broadband noise cannot. Therefore, the calculation algorithm had to recognize whether the partial roughness occurring in the individual frequency groups correlates with each other or not. Numerous listening experiments with typical everyday noises also showed a large dispersion in terms of the assessment of roughness, even among experts. It was not until 2024 that DIN 38455 Roughness was published. In the field of office equipment manufacturers ECMA, the demand for the calculation of tonality and roughness came earlier, so that psychoacoustic parameters were standardized in parallel with ECMA-418-2 as early as 2022 based on SOTTEK's hearing model [16]. In addition to tonality, roughness has also been defined, and the fluctuation strength will also be standardized 2025.

5. SOUNDSCAPE

Psychoacoustics, sound quality and cognition provide information on how humans perceive and interpret their surrounding world. With psychoacoustics alone it is only possible to describe the sound character. Psychoacoustics can analyze in detail the acoustic composition of a soundscape and the signal properties that elicit specific auditory sensations; however, a comprehensive interpretation of the results requires feedback from the listeners. Whereas the perceived sound quality depends on the context how people experience the sound situation. While the overall noise measured at a specific location can be analyzed in terms of several acoustical parameters, the annoyance or pleasantness level of a complex soundscape composed of several sound sources cannot be determined solely from the values obtained through such analyses. Even if the acoustic contribution of a single sound source to the overall noise does not appear significant in a physical sense, the influence of this sound source on the soundscape can be relevant perceptually [17]. In 2008 a new working group WG54 at ISO started the development of the soundscape standard which was the basis of the first standard ISO 12913. The definition was part of ISO 12913-1 (2014): Soundscape is the acoustic environment as perceived or experienced and/or understood by a person or people, in context. Two major components like pleasantness and eventfulness describe soundscape. This concept allows considering sound quality aspects beyond noise annoyance, a good soundscape quality is not simply identical to the absence of annoyance. Judgments cannot be fully understood by only considering acoustical quantities, since contextual parameters and interactivity are relevant for assessment of a soundscape as well. The ISO/TS 12913-2 (2018) "Data collection and reporting requirements" is the first standard requesting normative the use of binaural measurement as the judgment of acoustical environment is multidimensional, the effects of superposition of several sound sources is not easy to predict and the human hearing is able to select a single sound source among others. Whereas ISO/TS 12913-3 (2019) "Data analysis" recommends the application of psychoacoustical parameters. The ISO/TS 12913-4 "Design and intervention" is under development.

6. SUMMARY

It is astonishing that for many decades, the complexity of sounds and the perception by humans has only been described with a simple A-weighted sound pressure level measurement. Neither the temporal structures nor the spectral distributions are considered. For over 100 years, scientific investigations have been carried out within psychoacoustics, and for over 60 years there have been efforts to standardize these findings. Difficulties arose due to different scientific approaches, limited practical application and initially technically difficult implementations. In the meantime, standards are available for almost all relevant psychoacoustic parameters, unfortunately within different standardization committees such as ISO, DIN, ANSI, ECMA. However, with the standard for Soundscape ISO 12913, for the first time, the implementation of normative binaural measurement technology and informative use of psychoacoustics has been carried out. A long way! Psychological and cognitive aspects of sound are not physically measurable. The question is: How to measure sound? Very accurate with highest precision using a calibrated A-weighted sound pressure level meter class 1 or correct like the human hearing with consideration of context? A complete overview with respect to soundscape is given in [17].

7. REFERENCES

[1] Umweltbundesamt, 2022: https://www.umweltbundesamt.de/themen/laerm/laermwirkungen/laermbelaestigung

[2] E. Zwicker, „Über psychologische und methodische Grundlagen der Lautheit", *Acustica 8*, pp. 237–258, 1958

[3] R. Guski, „Lärm. Wirkungen unerwünschter Geräusche, *Hans Huber*, Bern, 1987

[4] ALD Arbeitsring Lärm der Deutschen Gesellschaft für Akustik (DEGA) Germany, https://www.ald-laerm.de/publikationen/laermlexikon/laerm

[5] K. Genuit, A. Fiebig, "Kritische Betrachtung zum Thema „Lärm"-Messung. Erweiterung von Lärmprognosen durch die Psychoakustik", *Zeitschrift für Lärmbekämpfung*, Nr. 1, 2014

[6] R.M. Schafer, "The Soundscape: Our Sonic Environment and the Tuning of the World". *Destiny Books*, 1994

[7] H. Fastl, E. Zwicker, „Psychoacoustics", *Springer Berlin Heidelberg*, 2007

[8] ECMA International - European association for standardizing information and communication systems, Genf

[9] S. S. Stevens, "Calculation of Loudness", *Journal of the Acoustical Society of America*, 33, pp. 1577-1585, 1961

[10] E. Zwicker, "A procedure for calculating loudness", *Acustica,* 10, 1960

[11] G. von Bismarck, "Sharpness as an attribute of the timbre of steady sounds", *Acustica*, Vol. 20, pp. 159-172, 1974

[12] W. Aures, "Berechnungsverfahren für den Wohlklang beliebiger Schallsignale. Ein Beitrag zur gehörrichtigen Schallanalyse", *Dissertation*, München, 1984

[13] B.R. Glasberg, B.C.J. Moore, "Prediction of absolute thresholds and equal-loudness contours using a modified loudness model". *J. Acoust. Soc. Am. 120*, pp. 585–588., 2006

[14] B.C.J. Moore, B.R. Glasberg, "A Revision of Zwicker's Loudness Model", *Acta Acustica,* Vol. 82, pp. 335-345, 1996

[15] B.C.J. Moore, B.R. Glasberg, A. Varathanathan, J. Schlittenlacher, "A Loudness Model for Time-Varying Sounds Incorporating Binaural Inhibition", *Trends in Hearing*, https://doi.org/10.1177/2331216516682698

[16] R. Sottek, "Loudness models applied to technical sounds", *Noise-Con*, Baltimore Maryland, USA, 2010

[17] B. Schulte-Fortkamp, A. Fiebig et.al., "Soundscapes: Humans and Their Acoustics Environment", *Springer,* (2023)