



**Acoustics'08
Paris**
June 29-July 4, 2008

www.acoustics08-paris.org

The noise induced harmful effects assessment using psychoacoustical noise dosimeter

Jozef Kotus^a, Bozena Kostek^a, Andrzej Czyzewski^a, Krzysztof Kochanek^b and Henryk Skarzynski^b

^aGdansk University of Technology, Multimedia Systems Department, 11/12 Gabriela Narutowicza Street, 80-952 Gdansk, Poland

^bThe Institute of Physiology and Pathology of Hearing, Pstrowskiego 1, 01-943 Warsaw, Poland

joseph@sound.eti.pg.gda.pl

A new way of assessment of noise-induced harmful effects on human hearing system was presented in the paper. Employing the developed psychoacoustical noise dosimeter the new indicators of noise harmfulness were verified on the basis of hearing examinations and noise measurement results. The indicators were based on some psychoacoustical properties of the human hearing system and, at the same time, on evaluation of the time and frequency characteristics of noise. Additionally, time properties of the Temporary Threshold Shift are calculated during the noise exposure. The evaluation of the proposed indicators were conducted on the basis of hearing examinations in the real noise exposure situations and also on the basis of simulation results employing standard test signals (such as: white, pink and brown noise). The standard noise dose analysis results were also presented for the purpose of comparison. The performed analysis and obtained results confirmed correctness and practical usefulness of the proposed indicators.

1 Introduction

Today's methods of hearing impairment risk evaluation are mostly based on the equal energies hypothesis. Such approach focuses mainly on the assessment of the amount of energy having direct impact on the human hearing system. The time characteristics of signals are ignored while the main emphasis is put to the equivalent noise level. In many cases, such approach turns to be insufficient. As many literature sources [1], [2], [3] available on the subject of noise exposure to different types influence state, both time characteristics and the spectrum significantly contribute to hearing loss [4], [5]. Having this in mind the authors designed, implemented and evaluated a new method of hearing impairment risk estimation. The method is based on modeling the consequences of a particular type of noise impact on hearing. The method and the effects are presented in this study.

2 Psychoacoustical noise dosimeter

Currently a noise dose is determined based on the aggregate acoustic energy that a person experiences in a certain acoustic environment. The proposed method constitutes quite a different approach. It concentrates on the prediction

of the results that the person incurs due to specific noise. The method takes into account the processes occurring in the inner ear. Based on the measurement of the instantaneous acoustic pressure, the Temporary Threshold Shift (TTS) is determined. In the proposed solution, a modified Johnston's psychoacoustic model is used [6]. It enables to determine the global/maximal basilar membrane motion.

Figure 1 depicts a general block diagram of the psychoacoustic model of a noise dosimeter. Its performance is based on the analysis of the basilar membrane response to the noise in the critical bands of hearing [6]. In the first step, a spectrum of the signal power is determined using the Fast Fourier Transform (FFT) (block 2). Then (in block 3), the spectrum is corrected by the outer to the inner ear transfer function. In step 4, spectral factors are grouped into critical bands using Bark scale. Next, signal levels in different bands are determined, and the result reflects the excitation of the basilar membrane. Its response is calculated through multiplexing levels of instantaneous excitation by the characteristics of the auditory filters relevant to particular critical bands. The obtained value of the basilar membrane deflection is then exponentially averaged. Such operation reflects the inertia of the processes occurring in the inner ear. The averaged values are used to resolve the Asymptotic Threshold Shift (ATS) level [7].

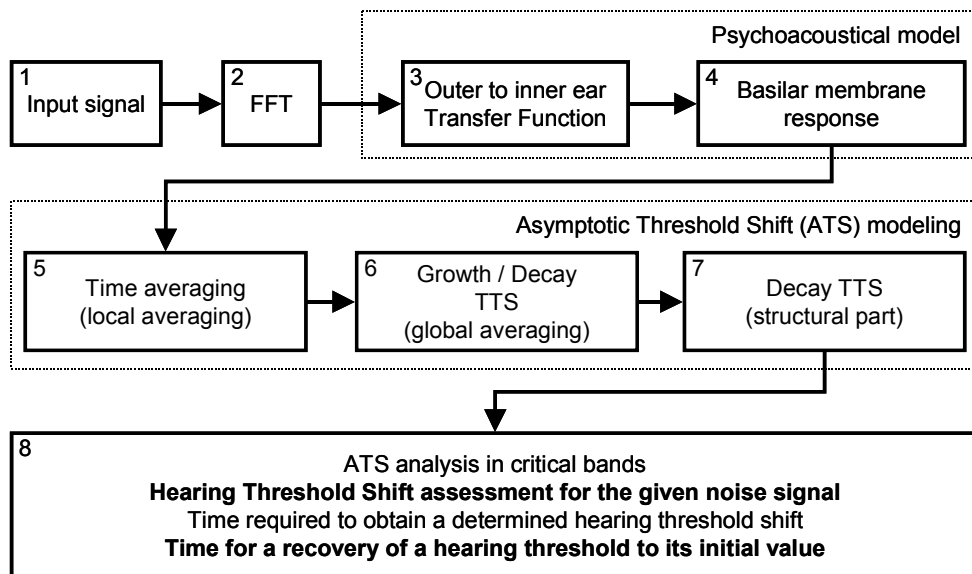


Fig. 1 Block diagram of the psychophysiological noise dosimeter.

The ATS modeling block consists of three parts (blocks 5, 6, 7). In the following step, the instantaneous ATS values are fed to bloc 5 which simulates the acoustic reflex mechanism. The algorithm used in this block averages the ATS level locally, operating accordingly to the time of the acoustic reflex duration. In practice, this enables to temporarily maintain the ATS level (local averaging), especially when the ATS level changes are abrupt. Such situations happen when a sudden change of a signal level occurs in a sound. This way, the processed ATS values are eventually exponentially averaged (block 6), which reflects the process of Temporary Threshold Shift of hearing (global averaging) during the noise exposure [7]. Block 7 is activated right after the exposure is finished, when the level of noise does not cause TTS effect any more. The block's task is to reflect the changes in the process of TTS fading in response to mechanic strain put on delicate cochlea structures. The block is activated by the level of TTS existing at the moment the exposure is stopped.

Block 8 produces final results, ready to be presented and stored in a file. Thus, the model enables to determine TTS values in critical bands, the time elapsing till the specified hearing threshold occurs, and the time necessary to restore the initial value of the hearing threshold. The proposed dosimeter has also a very important feature which is its ability to specify the shift of the hearing threshold already at the time of exposure to a specified type of noise.

3 The proposal new kind of noise harmfulness indicators

The new concept of noise dosimetry uses a simple psychoacoustic model to determine the effects of exposure to excessive levels of noise. Such result-based approach to dosimetry leads to the assumption that the occurrence of the TTS effect is an inexpedient reaction. This assumption was the basis for the definition of two new indicators of noise-induced damages. The first one links the values of the hearing threshold shift with the time of noise exposure. The second one relates to the time necessary for the TTS effect to fade. As already mentioned, the TTS effect is determined independently in different critical bands. Thus, during the exposure to noise the characteristic of hearing threshold becomes variously deflected for different frequencies. The indicator is expressed by formula 1. Indicator L_{JK} is constructed through summing up the values of the threshold shift for particular frequencies at time intervals of one minute. The time during and after the exposure is considered. The process of restoring the hearing to its state from before the exposure to noise may occur only if the person who experienced a temporary hearing threshold shift stays in the acoustic environment that is appropriate for this process. In practice, it is means silence [3]. The $1/N$ factor was introduced to make the results independent from the number of considered bands.

The proposed indicator needs summing the thresholds over all critical bands. In general, however, it is possible to perform necessary calculations based on the analysis of noise in octave bands. The result expressed through the value of this indicator is the aggregated, linear shift of the hearing threshold caused by the exposure to noise. Subtracting 1 from the result of TTS level change to linear scale assures that 0 TTS value on a linear scale is equal to 0

TTS on the decibel scale [8]. Moreover, small values expressed in dB are also small on a linear scale. Thanks to this mathematical operation, it was possible to better expose greater TTS values as more dangerous even during short exposures. Subtracting 1 from TTS has also some very important physical meaning. If the values were added without subtracting 1, then 0 dB TTS would be 1 on a linear scale. Adding the value of 1, when TTS does not occur leads to false values of the indicator that mistakenly suggest great threat to hearing. Thus, subtracting 1 from TTS solves the problem. Such approach is also present in the referenced literature [8].

$$L_{JK} = \frac{1}{N} \sum_{t=0}^{T+T_R} \sum_{i=0}^N \left(10^{\frac{L_{TTS}(i,t)}{10}} - 1 \right) \quad (1)$$

where:

N – the number of analysed critical bands (24 critical bands),

T – exposure time (expressed in minutes),

T_R – resting time (time required for hearing recovery),

$L_{TTS}(i,t)$ – instantaneous value of the TTS level for i -th critical band and for time t .

Using indicator L_{JK} , it is possible to determine the absolute aggregate value of the hearing threshold shift caused by a defined exposure to noise, and it is done in conjunction with the time of the shift duration. The absolute value does not provide any direct information about the harmfulness of the particular exposure neither does it show the degree of exceeding the limit of the noise dose. For the clarity of interpretation, a parameter was introduced that reflects the amount of hearing threshold shift. It is expressed by formula 2. It directly links the value of L_{JK} for a considered exposure with the reference value. The D_{JK} parameter indicates the amount of hearing threshold shift caused by the following exposure:

$$D_{JK} = \frac{L_{JKExp}}{L_{JK100}} \cdot 100 \quad (2)$$

where:

L_{JKExp} – absolute value of the L_{JK} indicator for given noise exposure,

L_{JK100} – value of the L_{JK} indicator for the reference exposure (see chapter 4)

4 Results obtained using the psychophysiological noise dosimeter

4.1 The reference value

The experimental verification started with the evaluation of the reference value (i.e., the value of indicator L_{JK100}). The assessment of the L_{JK100} indicator required an appropriate type of noise characterized by relevant level, duration and spectral characteristic. The choice was based on current norms of the acceptable noise dose expressed using the equivalent level. It was decided that the level would be 85 dBA and the signal would be 8 hour-lasting. It is the maximum daily noise dose that is assumed not to cause

damages to hearing. Having in mind present recommendations for hearing protection, the authors did not exceed the 85 dBA level (obviously for a proportionally shorter duration) [9]. The only issue to decide on was the character of the signal. This is of crucial importance, due to the fact that the designed noise dosimeter operates using the spectral characteristic of noise. For this purpose three basic types of noise were selected: white, pink, and brown [10]. It was assumed that the best would be the noise with the distribution most similar to noises occurring in real day life. Thus, the comparison was made between the spectral distribution of all chosen ‘artificial’ noises with the noises registered in the observed clubs.

The procedure of comparison was as follows. The spectral characteristics of sounds registered in the clubs as well as those of selected noises were scaled linearly so, that the total value of the sound level was 85 dBA. Figure 2 depicts the graphs of the analyzed signals’ spectra. To estimate which of the noises was closest to the spectra of the noises registered in the clubs, the Pearson’s test was carried out. Additionally, the mean squared error was calculated for the signals. The results are shown in Table 1. The analysis was performed independently for the whole 1/3 octave band spectrum and additionally for the frequency above 50 Hz. Lower frequencies were rejected in order to show the character of the noise source. In the considered cases the sources were sound systems installed in the clubs.

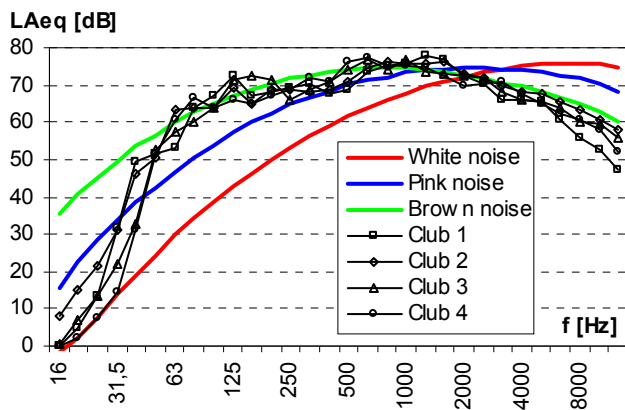


Fig. 2 The comparison of the 1/3 octave bands spectra for clubs and considered type of noise. All signals had the same L_{Aeq} value amount to 85 dBA.

Due to the limitations of these systems for typical sound emission of the lowest frequencies, high signal attenuation introduced by the correcting characteristics A, and a low influence on hearing these frequency levels were omitted. Three maximum values obtained from the Pearson’s test and minimum values of the mean squared error as well as the type of a signal for which the indicated values were obtained, are shown in Table 1 as specially marked. In all cases the brown noise turned to be the best.

Based on the results of the presented analysis, the 85 dBA brown noise lasting for 8h was selected as reference for calculating the reference value of the L_{JK100} indicator. This value is the daily acceptable time shift of the hearing threshold caused by noise.

	Results for whole band					
	Pearson’s test			Mean Squared Error.		
	White	Pink	Brown	White	Pink	Brown
Club1	0.761	0.866	0.967	17.3	10.2	12.3
Club2	0.834	0.918	0.967	16.4	7.2	9.2
Club3	0.822	0.909	0.976	15.6	9.0	12.6
Club4	0.814	0.909	0.969	15.7	10.4	14.4
Results for frequencies higher than 50 Hz						
Club1	0.168	0.418	0.884	16.0	8.7	4.7
Club2	0.430	0.640	0.920	14.8	6.6	2.4
Club3	0.311	0.551	0.938	15.3	7.3	2.7
Club4	0.261	0.507	0.934	15.5	7.6	2.9

Table 1 The corporation analysis results for spectra test signals and noise spectra for particular clubs

4.2 The experimental verification of the proposed indicators

The experimental verification of the proposed indicators was done based on real noise measurements carried out in selected music clubs [11], and on simulations using specially chosen test signals. The simulations used three types of noise (white, pink, and brown) of the levels and duration specified according to the principle of equal acoustic energy. The principle assumes that each signal carries the same amount of energy, which references the 8 hour working day and is expressed by the L_{Aeq} indicator. The result of analyses are presented in Fig. 3.

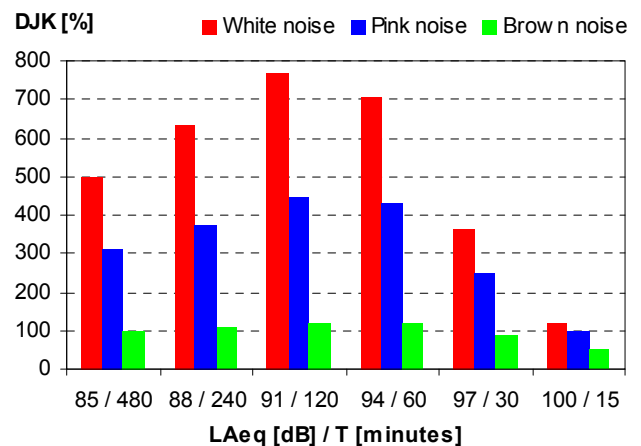


Fig. 3 The relative values expressed in D_{JK} indicator for different kinds of noise.

The tendency that noises having spectra with high frequencies of high levels are greater threat to outer ear than those of low-frequency character is clearly visible. It is consistent with the literature data concerned noise exposure [12]. The tendency does not depend on the level of noise.

Figure 4 presents the D_{JK} indicator value, which specifies the degree of noise harmfulness with respect to reference level, for noise levels measured in the clubs. The obtained values were compared with the noise dose evaluated by a traditional method based on L_{Aeq} level. Results denoted with L come from the analysis based on noise levels averaged over critical bands, while the results denoted with H relate to the analysis based on the history of noise level changes over time.

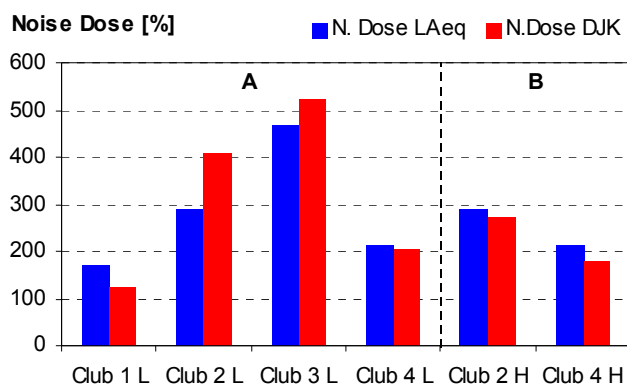


Fig. 4 The comparison of the D_{JK} indicator values with the noise dose evaluated by a traditional method based on L_{Aeq} level.

The results obtained with the D_{JK} indicator are close to the noise dose evaluated using the value of the L_{Aeq} equivalent level. The greatest discrepancies occur for clubs 2, 1, and 3, and they are observed for L -type results. In the case of H -type results, the discrepancies for club 2 are much lesser. High consistency of the results comes from the fact that the club noise spectra were quite similar to the spectrum of the reference signal (brown noise). For signals of different spectral characteristic (e.g., more close to pink or white noise) the values of the noise dose expressed through the D_{JK} indicator significantly differ from those evaluated based on the equivalent level (see Fig. 3).

5 Conclusion

It is worth emphasizing, that the indicators proposed by the authors illustrate a novel approach to noise threat assessment. The construction of the indicators is based on the analysis (namely the TTS effect occurrence) of noise influence on the hearing of an average listener. Although, the TTS effect depends on the level of noise, the way it forms and fades is related to the manner the acoustic energy is provided and it depends on a particular listener's vulnerability to acoustic harm.

The application of the presented Psychoacoustic Noise Dosimeter and new indicators may significantly enrich the knowledge on noise-induced effects. This was the main reason to implement the invented algorithm in a monitoring station of a Multimedia Noise Monitoring System designed in the Multimedia Systems Department [13].

Acknowledgments

This work was partially supported by the Polish Ministry of Science and Education within the project No. R0201001.

References

- [1] W. A Ahroon., R. P. Hamernik and R. I Davis., Complex noise exposures: An energy analysis, *J. Acoust. Soc. Am.*, vol. 93, no. 2, 997-1006 (1993)
- [2] E. Borg, B. Engstrom, Noise level, inner hair cell damage, audiometric features and equal-energy hypothesis, *J. Acoust. Soc. Am.*, vol. 86, no. 5, 1776-1782 (1989)
- [3] H. Irle, J. M. Hesse, H. Strasser, Physiological cost of energy-equivalent noise exposures with a rating level of 85 dB(A): Hearing threshold shifts associated with energetically negligible continuous and impulse noise, *Int. Journal of Industrial Ergonomics*, vol. 21, 451-463 (1998)
- [4] E. Emmerich, F. Richter, V. Linss, W. Linss, Frequency-specific cochlear damage in guinea pig after exposure to different types of realistic industrial noise, *Hearing Research*, vol. 201, 90-98 (2005)
- [5] H. Strasser, M.-C. Chiu, H. Irle, T. Grünig, Threshold Shifts and Restitution of the Hearing After Energy-Equivalent Narrow-Band And Wide-Band Noise Exposures, *INTER-NOISE 2007 Proceedings, ISTANBUL, TURKEY, 28-31.08. (2007)*
- [6] J. D. Johnston, Transform Coding of Audio Signals Using Perceptual Noise Criteria. *IEEE Journal on Selected Areas in Communications*, vol. 62, 314-323 (1988)
- [7] W. Melnick, Human temporary threshold shift (TTS) and damage risk, *J. Acoust. Soc. Am.*, vol. 90, no. 1, 147-154, (1991)
- [8] D. A. Bies, C. H. Hansen, An alternative mathematical description of the relationship between noise exposure and hearing loss, *J. Acoust. Soc. Am.*, vol. 88, no. 6, 2743-2754, (1990)
- [9] Criteria for a recommended standard, Occupational Noise Exposure, U.S. Department of Health and Human Services, June (1998)
- [10] <http://www.mediacollege.com/audio/noise/>
- [11] A. Czyżewski, J. Kotus, B. Kostek, Application of the psychoacoustic noise dosimeter for the determination of noise impact on hearing, *INTER-NOISE 2007 Proceedings, ISTANBUL, TURKEY, 28-31.08 (2007)*
- [12] R. Ordoñez, D. Hammershøi, Effects of frequency content from exposures with the same A-weighted equivalent level, *INTER-NOISE 2006 Proceedings, Honolulu, Hawaii, USA, 3-6.12 (2006)*
- [13] A. Czyżewski, J. Kotus, B. Kostek, M. Szczodrak, Multimedia Noise Monitoring System, *Bezpieczeństwo Pracy, nr 7-8, 8 – 11 (2007) (in Polish)*