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PROPOSALS OF CRITERIA FOR ASSESSMENT OF LOW FREQUENCY NOISE ANNOYANCE IN THE WORK ENVIRONMENT

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Abstract

The aim of the study was to recommend methods for assessing low frequency noise (LFN) in the occupational environment to prevent annoyance and its effects on work performance. Three different measuring methods were proposed: (i) method I – frequency analysis in 1/3-octave bands from 10 to 250 Hz, (ii) method II – determination of equivalent-continuous A-weighted sound pressure level (SPL) in the frequency range 10-250 Hz and introduction of the penalty for tonal character of noise, and (iii) method III – based on equivalent-continuous A-weighted SPL corrected due to the presence of low frequencies and tonal character of LFN. As recommended noise limits for method II and III, 50 and 55 dB were proposed, respectively. On the other hand, various criterion curves were assumed for method I.

The proposed criteria were verified in the laboratory and field investigations. The laboratory study included 55 volunteers, aged 21.8±2.1 years, with normal hearing (<25 dB HL). Subjects listened to different noises at SPL of 45–65 dBA, and evaluated annoyance using a 100-score graphical rating scale. In the field study, the subjects, 28 male workers, aged 43.1±5.1 years, exposed to LFN at SPL of 48–61 dBA, were asked to rate noise annoyance at workplace using similar graphical scale.

The subjective ratings of LFNs were compared to objective results from various assessing methods. The relations between annoyance and excesses of proposed limits were analyzed using Pearson correlation coefficient (r). The obtained results show that the subjective ratings were correlated with all proposed criteria ($0.51 \leq r \leq 0.63$ $p<0,01$). However, in the laboratory exposure conditions the best relation was found in case method I and criterion curve based on hearing threshold level (r=0.61), while during field study – method II (r=0.63).

INTRODUCTION

Although the international definition of low frequency noise (LFN) is missing, it is usually defined as a broadband noise with the dominant content of low frequencies from 10 (20) Hz to 250 Hz. LFN is ubiquitous not only in the general environment but also at workplace, especially in industrial control rooms and offices [2], [5].

Generally, LFN effects are less recognized when compared to the effects of noises at higher frequencies. However, the importance of LFN in the general environment was pointed out in the WHO document on community noise [3]. The specific regulations on its control in the general environment are in use in some European countries. However, no guideline for working environment has existed so far. Only outline recommendations for LFN in the occupational environment to prevent annoyance and effects on work performance have already been proposed in Sweden [11].

Whereas, there is a growing body of data showing that LFN at levels normally occurring in control rooms and office-like areas (40−50 dB) can be perceived as annoying and adversely affecting the human mental performance, particularly when more demanding tasks were executed. Moreover, subjects recognized as high-sensitive to LFN may be at higher risk [1], [8], [9], [10]. Thus, the LFN could possibly lead to work impairment, particularly in case of jobs requiring selective attention and/or processing high load of information.

Many studies have indicated that A-weighted sound pressure level is a less suitable descriptor for assessing effects of LFN [5]. Thus, attempts have been made to replace the A-weighting with the alternative measures that better predict the effects of LFN.

The main aim of the study was to recommend methods for assessing LFN and propose limits to prevent its annoyance and effects on work performance in the occupational environment. A further objective was to verify the proposed exposure criteria in the laboratory and field investigations.

CRITERIA FOR ASSESSMENT OF LFN

Review of Existing Evaluation Methods

Over the years many different methods have been suggested for the assessment of LFN in the general environment (dwellings). Exposure criteria are in use or are proposed in Germany, Sweden, Denmark, the Netherlands, the United Kingdom and Poland [6].

Generally, all of them are based on frequency analysis in 1/3-octave bands in various frequency ranges from 8 Hz to 250 Hz. In majority cases, measured sound pressure levels are compared with criterion curves (tab. 1). However, in the Danish method the nominal A-weighting corrections are added to the spectra, and the weighted spectrum is summed to form the A-weighted sound pressure level (SPL) in the frequency range 10-160 Hz ($L_{pA,LF}$). Moreover, it specifies a 5 dB penalty for impulse noise. On the other hand, in German method if the noise is not tonal, the A-weighted SPL in the frequency range 10-80 Hz is calculated based only on bands exceeding the hearing threshold. Whereas, for tonal noise, the level of the 1/3-octave band with the tone is compared to the hearing threshold modified by penalty depending on frequency and time of day.

An outline Swedish recommendations for assessing LFN at workplaces are based on 1/3-octave band measurements in the frequency range of 25-200 Hz and three criterion curves (S40, S60 and S80) representing noise level groups 40 dBA, 60 dBA and 80 dBA [11].

Table 1. Reference curves used in various criteria concerning environmental exposure to LFN together with outline Swedish recommendations for workplaces

1/3-octave bands Hz]	German	Swedish	Dutch	Polish	British	S40	S60	S80
	Sound pressure level [dB]							
8	$103^{+5/0}$*							
10	$95^{+5/0}$			80.4	92			
12,5	$87^{+5/0}$			73.4	87			
16	$79^{+5/0}$			66.7	83			
20	$71^{+5/0}$		74	60.5	74			
25	$63^{+5/0}$		64	54.7	64	70	80	90
31,5	$55.5^{+5/0}$	56	55	49.3	56	61	71	81
40	$48^{+5/0}$	49	46	44.6	49	54	64	74
50	$40.5^{+5/0}$	43	39	40.2	43	48	58	68
63	$33.5^{+5/0}$	41.5	33	36.2	42	46.5	56.5	66.5
80	$28^{+10/5}$	40	27	32.5	40	45	55	65
100	$23.5^{+15/10}$	38	22	29.1	38	43	53	63
125		36		26.1	36	41	51	61
160		34		23.4	36	39	49	59
200		32		20.9		37	47	57
250				18.6				
* A penalty for equivalent levels of the tones in the day/night period								

Proposals of Assessment Criteria for Work environment

The difference between C- and A-weighted sound pressure levels (L_C-L_A) is commonly used for identifying the frequency composition of noise. It is assumed that the difference exceeding 15 dB indicates the occurrence of LFN.

Three different measuring methods were proposed:

- method I – a frequency analysis in 1/3-octave bands from 10 to 250 Hz,
- method II – the determination of equivalent-continuous A-weighted sound pressure level (SPL) in the frequency range 10-250 Hz and introduction of the penalty for tonal character of noise using following formula (1):

$$L_{A10-250Hz} = 10log\sum_{f} 10^{0,1(L_f+K_{fA})} + K_1 \qquad [dB] \qquad (1)$$

Where:

L_f – is the SPL in the 1/3-octave bands from 10 Hz to 250 Hz, in dB;

K_{fA} – is the relative response of the A-weighting frequency characteristics for the f-th 1/3-octave band, in dB;

K_1 – is the penalty for tonal character of noise, K_1=5 dB; the noise is said to be tonal if the level in a particular 1/3-octave band is 5 dB or more above the level in the two neighboring bands;

- method III – based on an equivalent-continuous A-weighted SPL corrected due to presence of low frequencies (K_2) and tonal character of noise (K_1), expressed by equations (2):

$$L_{A,LFN} = L_{A\,eq,Te} + K_1 + K_2 \quad \text{[dB]} \tag{2}$$

Where:
$L_{A\,eq,Te}$ – is the equivalent-continuous A-weighted SPL, in dB;
K_1 – is the penalty for tonal character of noise;
K_2 – is the penalty for presence of low frequency components in the spectrum, K_2=8 dB for 15 dB ≤ L_C-L_A<20 dB, K_2=10 dB for L_C-L_A≤20 dB.
As a recommended noise limits for method II and III, there were proposed 50 dB and 55 dB, respectively. On the other hand, five various criterion curves were assumed for method I, i.e.:

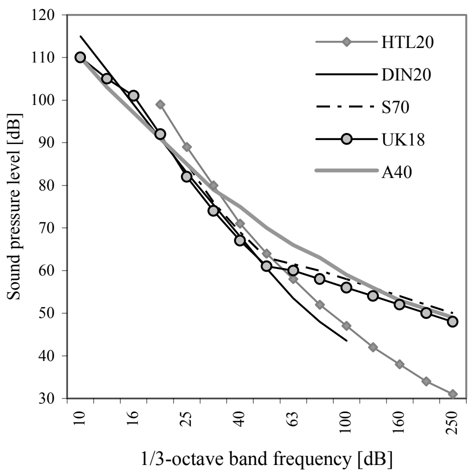

Figure 1 – Comparison of proposed criterion curves

- curves HTL20 and DIN20 – exceeding by 20 dB the hearing threshold level according to ISO 226: 2003 and German method, respectively;
- curve S70 – corresponding to outline Swedish recommendations for workplaces (lying 5 dB above curve S60);
- curve UK18 – developed on British proposals but 18 dB higher,
- curve A40 – curve based on A-weighting characteristics and expressed as $L_f=40-K_{fA}$, where: L_f is the sound pressure level for the f-th 1/3-octave band, in dB; K_{fA} is the relative response of the A-weighting frequency characteristics for the f-th 1/3-octave band, in dB (*Figure 1*).

It is worth noting that the A-weighted SPL in the frequency range 10–250 Hz ($L_{A\ 10\text{–}250\ Hz}$) corresponding to all above mentioned criterion curves is approx. 50 dB.

VERIFICATION OF PROPOSED EXPOSURE CRITERIA

The proposed criteria were verified in the laboratory and field investigations concerning noise annoyance rating.

Laboratory Study

The study included 55 pre-selected female and male volunteers, mainly high school or university graduates, aged 21.8±2.1 years, with normal hearing (<25 dB HL) categorized in terms of individual sensitivity to noise in general and to LFN, in particular. The way of the categorization subjects in terms of sensitivity to noise was described in detail elsewhere [8].

Study subjects listened to different noises, at SPL of 45−65 dBA. They were asked to imagine that in such noise conditions they have to perform jobs requiring increased mental processing and selective attention. Immediately after completion of each noise sample, they assessed the noise annoyance, loudness and the degree of disturbing effect of noise in case of routine tasks and more demanding tasks involving mental processing and selective attention. They gave their evaluations of noises on paper form using 100-score graphical rating scales. Prior to the exact listening tests, the subjects were trained using four noise examples. After the test session they were asked to complete a questionnaire aimed at symptoms experienced during the tests and subjective rating of fatigue related to noise.

The experiment was performed in a special chamber for psychological and audiometric tests (6.2 m^2 area). Four stationary noises of artificial origin with different frequency contents were chosen for the listening tests, including three LFNs and one noise without dominant content of low frequencies (*Figure 2*). They were presented at nominal equivalent-continuous A-weighted SPLs of approx. 45, 50, 55, 60 and 65 dB, corresponding to levels normally occurring in industrial control rooms and office–like areas [7]. All presentations lasting 30 seconds were made once and the sequence of presentation was randomized.

The noises were generated using a set of loudspeakers and subwoofer. Noise exposure conditions during listening session were monitored and evaluated using proposed assessing methods.

Field Study

Generally the subjects of the study comprised 215 male workers aged 26−62 years, employed in the control rooms of two Polish electric power stations and one cement plant. The majority of them were high school graduates.

A questionnaire was applied as a main tool of the study. The subjects were asked to assess the annoyance related to noise at workplace on a 100-score graphical rating scale. Noise conditions in the control rooms were verified by *in situ* measurements and evaluated according to proposed assessment criteria.

The noise annoyance rating was preceded by a questionnaire survey to collect:
(i) basic information concerning age, education, workplace, years of employment; (ii) sources of noise and its character in control rooms; (iii) the subjective feelings and complaints related with exposure to noise at workplace and the assessment of its annoyance on the 100-score scale, and (iv) the self-assessment of hearing status. Results of the questionnaire have been described in detail elsewhere [7].

Generally, the inquired persons were exposed to noise at moderate equivalent – continuous A-weighted sound pressure levels (48-66 dB) with diversified content of low frequency components (10-250 Hz) in the spectra (the difference L_C-L_A ranged from 4.9 to 20.3 dB). However, only 28 subjects, aged 43,1±5,1 years, without any hearing problems (see the questionnaire mentioned above) who were exposed to actual LFN noise with the dominant content of low frequencies (L_C-L_A>15 dB) (*Figure 3*) were selected for the further analysis.

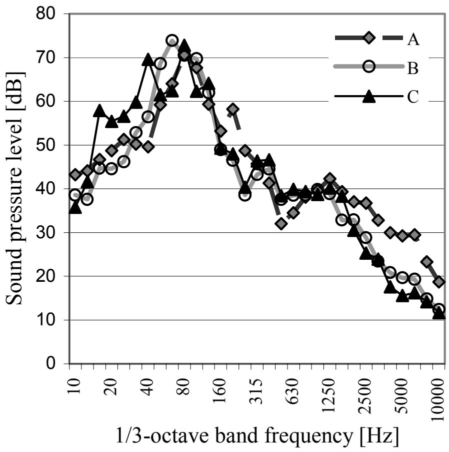

Figure 1– Frequency spectrums of the LFN examples at approx. SPL of 55 dBA

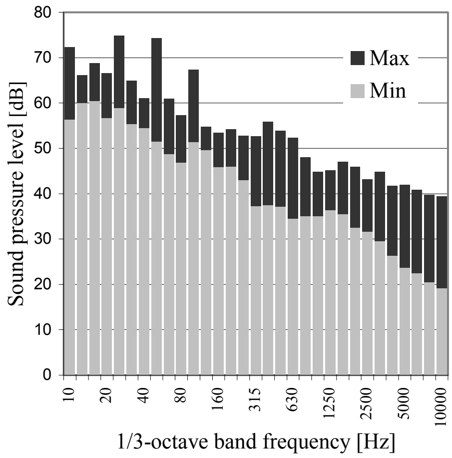

Figure 2– Frequency spectrums of LFNs occurring in control rooms

Statistical Analysis

Both in the laboratory and field studies, the subjective ratings of LFNs were compared to objective results from various proposed assessment criteria as well as “ordinary” method based on the equivalent-continuous A-weighted SPL ($L_{Aeq,T}$) and exposure limit equal to 55 dB. Relationships between excesses of limits corresponding to each measuring method and noise-related annoyance assessments as well as relations between other variables were analyzed using Pearson’s correlation coefficient (r). Probability values (p) below 0.05 were considered statistically significant.

RESULTS

In the laboratory study the subjects categorized in terms of sensitivity to noise were asked to assess annoyance related to LFN as well as loudness and the degree of its disturbing effect in case of routine and more demanding tasks. The influence of sensitivity to noise on these ratings will be analyzed elsewhere. Nevertheless, it has been found that there are close relations between all subjective assessments (correlation coefficient r varies from 0.81 to 0.93, $p<0.001$). Thus, in the following part only the annoyance rating is considered.

The subjective assessments of annoyance related to LFN in the laboratory and field conditions are summarized in tab. 2, while examples of objective results from various assessment criteria are presented in tab. 3.

Table 2. Subjective evaluations of LFN in the laboratory and field conditions

Laboratory study	Annoyance rating (mean value±SD)				
Noise spectrum/ nominal SPL	45 dBA	50 dBA	55 dBA	60 dBA	65 dBA
A	31.1±23.4	43.2±22.3	54.3±20.8	61.8±21.7	78.1±17.8
B	22.9±20	35±21.7	49.5±22.5	52.8±23.8	73.9±18.8
C	23.9±21.5	36.4±23.6	49.4±21.2	50.2±25.1	76.8±20.3
Field study	Annoyance rating (mean value±SD)				
	48.7±25.1				

Table 3. Objective assessments of LFN based on proposed criteria

Method / exposure limit		Laboratory study (nominal SPL/ spectrum)									Field study
		50 dBA			55 dBA			60 dBA			
		A	B	C	A	B	C	A	B	C	
		Excesses [dB]									
I	HTL20	19.3	17.7	17.2	24.2	22.7	22.1	29.1	27.5	27.3	13.8–21.8
	DIN20	19.3	21.2	19.9	24.2	26.2	24.8	29.2	31	29.7	7.9–23.9
	S70	5.8	7.4	7.9	10.6	12.4	12.8	15.6	17.2	17.7	-4.2–11.3
	UK18	7.8	8.9	9.9	12.6	13.9	14.8	17.6	18.7	19.7	-2.2–13.3
	A40	3.8	5.7	4.9	8.7	10.7	9.8	13.7	15.5	14.7	-3.2–8.4
II	50 dB	3.9	-0.3	3.3	8.8	4.6	8.2	13.7	9.5	13.5	-3.0–7.0
III	55 dB	8.3	5.3	9.6	13	10.2	14.4	18	15	19.7	5.7–18.5

Generally, in both studies linear relationships between noise annoyance ratings and all proposed criteria for assessing LFN were found. Similar relation was noted also in case of the ordinary method based on equivalent-continuous A-weighted SPL and 55 dB exposure limit. Moreover, the correlation coefficients (r) and what follows the degree of explanation (r^2) were similar for all the above mentioned assessing methods (tab. 4). However, in the laboratory study method I (frequency analysis) and criterion curve HTL gave the highest value of correlation coefficient, while in the field study - method II. In the laboratory conditions, the next best methods were either the method II or the ordinary method based on $L_{A\ eq,T}$. On the other hand, in the field study the second best method was frequency analysis and criterion curve A40, while the smallest correlation gave method III and assessment criterion based on the equivalent-continuous A-weighted SPL.

CONCLUSION

Both in the laboratory and field exposure conditions, there was quite good agreement between the subjective annoyance rating and all proposed criteria for assessing LFN as well as ordinary method based on A-weighted SPL. In particular, relatively high value of correlation coefficient for the latter method was found in the laboratory study. Since under laboratory conditions subjects assessed the LNF samples of artificial origin, the relevance of these results for normal working conditions must be evaluated with care. Nevertheless, the obtained results, especially from the field study suggests that the method based on the equivalent-continuous A-weighted sound SPL and exposure limit 50 dB (method II) seems to be able to predict quite well annoyance experienced from LFN and to prevent its effects negative effects on the work performance in the occupational environment.

Table 4. The relation between the subjective annoyance ratings and excesses of limits corresponding to various assessment criteria

Exposure conditions	Method I					Method II	Method III	$L_{A\,eq,T}$
	HTL20	DIN20	S70	UK18	A40	50 dB	55 dB	55 dB
	Pearson correlation coefficient r (p<0,01)							
Laboratory	0.612	0.587	0.582	0.584	0.586	0.592	0.582	0.604
Field	0.577	0.613	0.597	0.597	0.621	0.632	0.511	0.511

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