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ASSESSMENT OF ANNOYANCE FROM LOW FREQUENCY AND BROADBAND NOISES

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Abstract
Objectives: It has been shown that low frequency noise (LFN), defined as broadband noise with dominant content of low frequencies (10–250 Hz), may be annoying to exposed subjects. The aim of the study was to compare the degree of annoyance caused by LFN with that caused by broadband noise (BBN) without dominant low frequency components at similar A-weighted sound pressure levels. **Materials and Methods:** Subjects included in the study were 145 male employees of the control rooms. They were exposed to noise through headphones at gradually increasing dB A-weighted sound pressure levels within the range of 62–84 dB. Annoyance rating was based on a 100-score graphical scale. **Results:** LFN was rated as significantly more annoying than BBN at the comparable A-weighted sound pressure levels. The annoyance assessment of either noise did not depend on age, length of employment or the level of exposure to noise at a current workplace. **Conclusions:** LFN represents a higher risk of influencing human well-being than regular BBN and should be considered in the occupational exposure assessment.

Key words:
Low frequency noise, Broadband noise, Annoyance rating

INTRODUCTION

Low frequency noise (LFN) is usually defined as a broadband noise (BBN) with the dominant content of 10–250 Hz or 20–250 Hz frequencies [1,2]. It is ubiquitous in both general and occupational environments. The common sources of LFN are ventilation installations, pumps, compressors, diesel engines, gas turbine power stations and means of transport. The occurrence of LFN in dwellings, offices and control rooms is mainly caused by indoor ventilation or air conditioning systems. The outdoor sources of noise could also be important because of poor attenuation of low frequency components by the walls, floors and ceilings [2,3]. Since LFN includes both infrasonic and low audible frequencies, many effects attributed earlier to infrasound are also believed to be exerted by LFN [1,2,4,5]. The primary and the most frequent effect of the LFN exposure on human subjects is annoyance [1,2,4]. By definition, annoyance is a feeling of displeasure associated with any agent or condition known or believed to have an adverse effect on human subjects [1]. Several studies have shown the differences in the degree of annoyance caused by exposure to low and medium or high frequency noise at the same A-weighted sound pressure levels. The annoyance experienced from LFN seems to

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be higher than that from noise without dominant low frequency components. Moreover, that effect is frequently present at relatively low sound pressure levels that comply with guidelines based on ordinary environmental noise [1,2].

It has been shown that exposure to LFN is often accompanied by many subjective effects such as tiredness, feelings of irritation, unease or stress, headache, pulsating feeling or feeling of pressure on the eardrum, nausea or dizziness. Some of these symptoms, especially fatigue, concentration problems, headache and irritation, can reduce working capacity [1,2,6].

Low frequency noise may also affect work performance. Although the results of previous performance investigations, mainly laboratory experiments, were equivocal [2,4,5,7,8], the recent investigations have shown that LFN at relatively low A-weighted sound pressure levels (about 40 dB) could be perceived as annoying and adversely affecting the performance, particularly when mentally demanding tasks are executed [9–11].

The aim of this study was to compare annoyance related to LFN and BBN without the dominance of low frequency components at both comparable A-weighted sound pressure levels.

MATERIALS AND METHODS

Study population

The study population comprised 145 male workers, aged 26–55 years, employed in the control rooms of two Polish electric power stations and one cement plant. The majority of them were high school graduates (Table 1). The subjects were exposed to LFN at moderate sound pressure levels, significantly lower than Polish maximum admissible intensities (MAI) for audible and infrasonic noise [12], thus safe from the view point of hearing conservation. Moreover, about 52% of subjects were employed in control rooms for at least half of the total length of work. None of the subjects reported any hearing problems. Table 1 shows the characteristics of the study group.

Study design

Exposures to LFN and BBN were preceded by a questionnaire survey to collect: (i) basic information concerning age, education, workplace, length of employment; (ii) sources of noise and its character in control rooms; (iii) subjective feelings and complaints associated with exposure to noise at workplace and assessment of its annoyance on a 100-score scale, and (iv) self-assessment

Table 1. Characteristics of the study group and noise at a current workplace

Total number of persons	145		
Age (years)	Range		Mean ± SD
	26–55		49.9 ± 5.9
Education (%)	University	High school	Other
	14.4	77.4	7.5
Total length of employment (years)	8–37		19,8 ± 6.3
Length of employment in control rooms (years)	0.5–27		10.6 ± 6.4
Noise parameters (dB)	Range	Mean ± SD	MAI**
Equivalent-continuous A-weighted SPL*, $L_{A\,eq,\,T}$	47.7–65.2	58.3 ± 3.3	85***
Maximum A-weighted SPL, $L_{A\,max}$	60.0–79.5	71.6 ± 4.2	115***
Peak C-weighted SPL, $L_{C\,peak}$	82.4–108.6	95.1 ± 4.7	135***
Equivalent-continuous G-weighted SPL, $L_{G\,eq,\,T}$	58.7–84.3	75.0 ± 4.5	102****
Peak unweighted SPL, $L_{LIN\,peak}$	88.9–113.1	100.9 ± 5.7	145****

* SPL – sound pressure level.
** MAI – maximum admissible intensity.
*** MAI for audible noise [12].
**** MAI for infrasonic noise [12].

of hearing status. The results of the questionnaire survey have been described in detail elsewhere [13].

Eight various samples of noise were used (Table 2). The first four signals were those of BNS, the other four of LFN. An example of the LFN and BBN spectrum is given in Fig. 1. Prior to the exposure, the sound pressure levels of noise were calibrated with type 4144 Bruel & Kjaer (B&K) pressure microphone, type 4152 B&K artificial ear, type SV01A SVANTEK microphone preamplifier, type SVAN 912E sound and vibration analyzer and type 4231 B&K sound level calibrator.

Noise was reproduced in quiet rooms, outside the control rooms, using a set of instruments consisting of type 7005 B&K tape recorder, type LV120 LUXMAN stereo integrated amplifier and type MRD-CD 270 SONY headphones. A-weighted sound pressure levels gradually increased within the range of 62–84 dB. Each signal was presented during 20 s.

The annoyance was assessed immediately after completing the exposure using a 100-score graphical rating

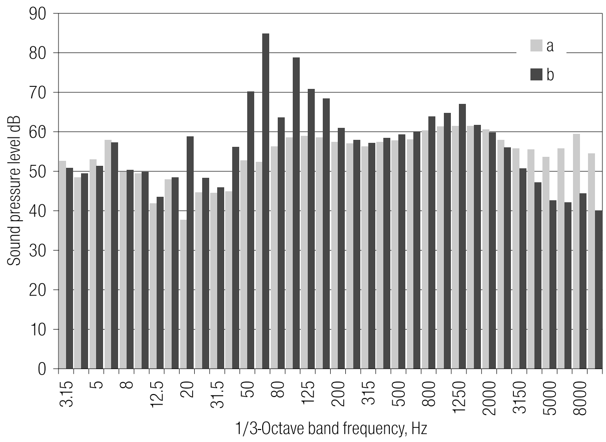

Fig. 1. Examples of reference noise spectrum at approximately equivalent-continuous A-weighted sound pressure level of 72 dB; a – broadband noise no. 2; b – low frequency noise no. 6.

scale with verbally labeled two poles (not annoying and very annoying) and three other positions (Fig. 2). For example, the ratings “somewhat annoying” and “quite annoying” were scored 25 and 75 on the scale, respectively. Similar rating scales were applied in earlier studies [14,15].

Table 2. Acoustic parameters of low frequency and broadband noise

No. of reference noise	Noise parameter (dB)/ equivalent-continuous	Range	Mean ± SD
	Broadband noise (BBN)		
1	A-weighted SPL $L_{A\,eq.,\,Te}$	62.0-63.7	62.5 ± 0.8
	C-weighted SPL $L_{C\,eq,\,Te}$	63.3-65.2	64.1 ± 0.9
2	A-weighted SPL $L_{A\,eq,\,Te}$	69.1-72.1	71.4 ± 1.5
	C-weighted SPL $L_{C\,eq,\,Te}$	70.2-73.3	72.4 ± 1.5
3	A-weighted SPL $L_{A\,eq,\,Te}$	77.4-78.8	78.1 ± 0.6
	C-weighted SPL $L_{C\,eq,\,Te}$	78.3-79.6	79.1 ± 0.6
4	A-weighted SPL $L_{A\,eq,\,Te}$	82.2-84.0	83.0 ± 0.8
	C-weighted SPL $L_{C\,eq,\,Te}$	83.1-84.9	83.9 ± 0.8
	Low frequency noise (LFN)		
5	A-weighted SPL $L_{A\,eq,\,Te}$	66.6-68.0	67.5 ± 0.6
	C-weighted SPL $L_{C\,eq,\,Te}$	80.1-81.2	80.9 ± 0.5
6	A-weighted SPL $L_{A\,eq,\,Te}$	71.9-72.3	72.1 ± 0.2
	C-weighted SPL $L_{C\,eq,\,Te}$	84.9-85.1	85.0 ± 0.1
7	A-weighted SPL $L_{A\,eq,\,Te}$	76.6-77.6	77.1 ± 0.4
	C-weighted SPL $L_{C\,eq,\,Te}$	89.0-90.2	89.6 ± 0.5
8	A-weighted SPL $L_{A\,eq,\,Te}$	80.4-81.3	80.8 ± 0.4
	C-weighted SPL $L_{C\,eq,\,Te}$	92.5-93.4	92.9 ± 0.4

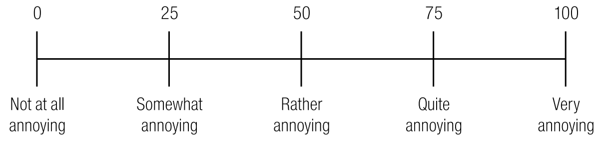

Fig. 2. Noise annoyance rating scale.

Statistical analysis

The differences in the noise-related annoyance rating were analyzed using standard non-parametric methods, including Friedman ANOVA and the Wilcoxon matched-pairs test.

Relationships between age, length of work, exposure to noise at the workplace, and the annoyance assessment of reproduced signals were analyzed using Pearson's correlation coefficient (r). A value of $p < 0.05$ was considered to indicate statistical significance.

RESULTS

The subjective annoyance assessments of low frequency and broadband noises are presented in Fig. 3. A considerable di-

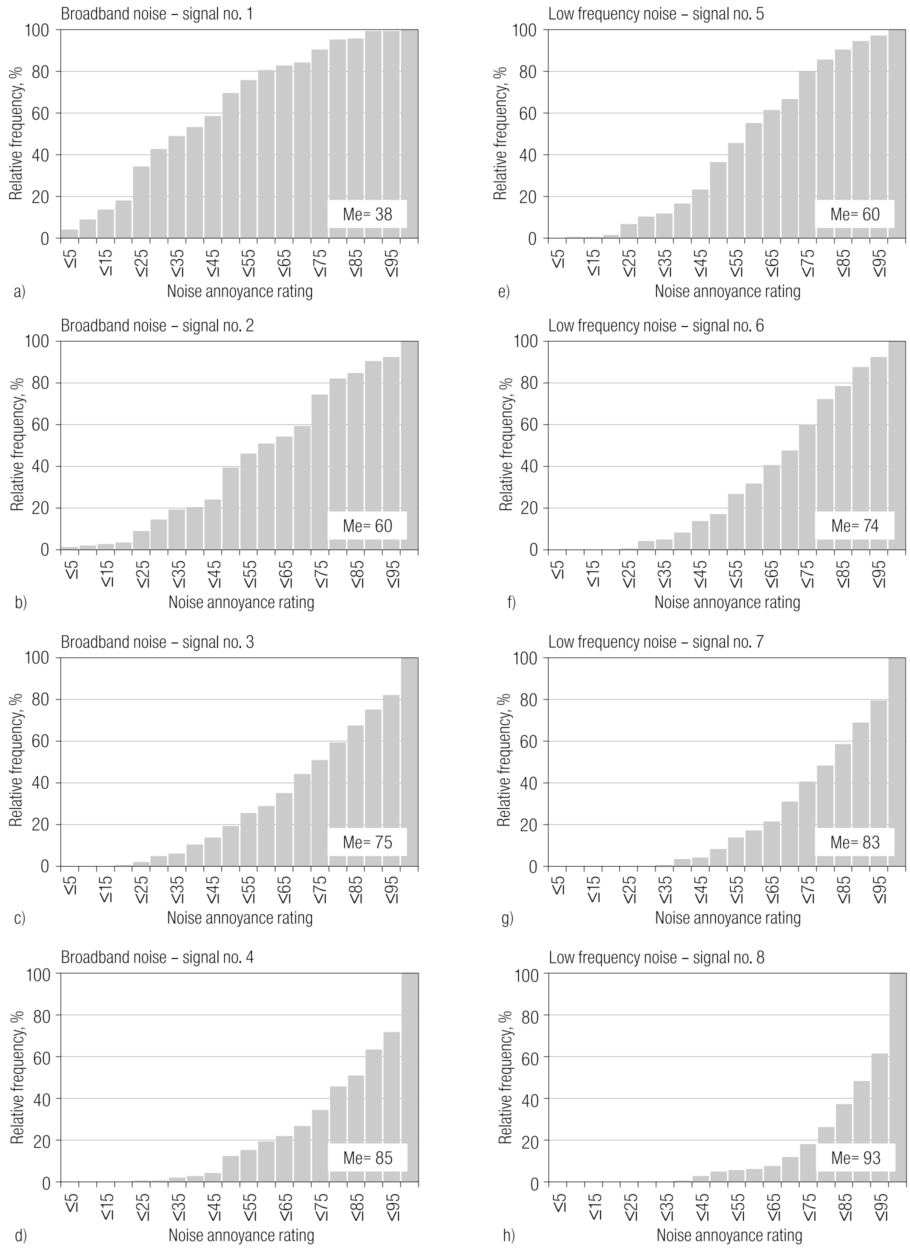

Fig. 3. Cumulative distributions of annoyance rating of eight types of reference noise (M_e – median values of annoyance ratings).

versity of the noise-related annoyance rating was observed, particularly at low A-weighted sound pressure levels (see signals nos. 1, 2 for BBN and no. 5 for LFN in Fig. 3).

The results of Friedman ANOVA (χ^2ANOVA (N = 145, df = 7) = 665.686, p = 0.000; Kendall coefficient of concordance 0.656, r mean rank 0.653, p = 0.0000) proved that the distribution of annoyance ratings for each of eight signals was different, and the differences in its shape (for both LFN and BBN) decreased with increasing A-weighted sound pressure levels. The median values of annoyance ratings for LFN ranged from 60 to 93, and were higher than those for BBN, which remained within the range of 38–85 (Fig. 3).

Both noises at relatively low A-weighted sound pressure levels (62–67 dB) were rated by considerable fraction of subjects as more than "rather annoying", which corresponds with more than 50 scores on the 100-score scale. However, for LFN it was over twice as many as in case of BBN (63.4% vs. 30.3%) (Fig. 3a, f). LFN and BBN at the highest A-weighted sound pressure levels were assessed as "very annoying" (100 scores on the scale) by 26.9 and 18.6 % of subjects, respectively (Fig. 3d, h).

Linear relationship between mean values of noise annoyance rating and A-weighted sound pressure level were found in both types of reference signals (Fig. 4). However, LFN was in general rated as more annoying than BBN at comparable A-weighted sound pressure levels (Wilcoxon matched-pairs test, $p < 0.05$).

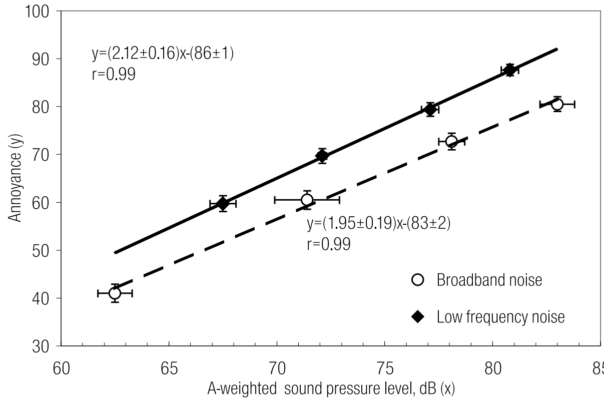

Fig. 4. Relationship between A-weighted sound pressure level and mean annoyance rating of reference noise (horizontal and vertical whiskers mark 95% confidence intervals).

No significant relation was found between the annoyance assessment of eight various samples of noise and age, length of employment or level of exposure to noise at workplace (Table 3).

DISCUSSION AND CONCLUSIONS

Eight samples of reference noises of two various spectral shapes were applied in the study. The first four were samples of BBN without prominent low frequency components, the other four were those of LFN containing dominant components of 10–250 Hz. The difference between C- and A-weighted sound pressure levels ($L_{C-}L_A$) is commonly used to identify the frequency composition of noise. It is assumed that the difference exceeding 15 dB indicates the occurrence of LFN [1]. In our study, the $L_{C-}L_A$

Table 3. Correlation coefficients between annoyance rating of eight types of reference noise and age, length of employment and level of exposure to noise in control rooms (all values not statistically significant, $p > 0.05$)

	Correlation coefficient r							
	Reference noise (no.)							
	1	2	3	4	5	6	7	8
Age	-0.06	-0.06	-0.04	-0.06	-0.01	0.01	-0.04	-0.02
Total time of employment	-0.03	-0.02	0.01	-0.02	0.07	0.07	0.02	0.02
Time of employment in control rooms	0.07	0.06	0.02	0.03	0.04	0.03	-0.04	-0.02
Equivalent-continuous A-weighted SPL $L_{A\,eq,\,Te}$	-0.07	-0.03	0.05	0.05	-0.09	-0.11	-0.06	-0.04

difference ranged from 12.1 dB to 13.5 dB for LFN, thus it was close to 15 dB, while for BBN it remained within the range of 0.9–1.3 dB. This confirms a substantial difference in frequency spectrum between reference noises.

The annoyance assessment of the reproduced noise did not depend on age, length of employment and the level of exposure to noise at the workplace. Generally, the annoyance ratings of exposure to low frequency and broadband noises differed significantly. LFN was assessed as more annoying than BBN at the comparable A-weighted sound pressure levels. These results confirm the previous observations that the A-weighted sound pressure level is not an appropriate measure in LFN annoyance assessment and may lead to underestimation of that effect. For example, Kjellberg and Goldstein [16] found that the A-weighted sound pressure levels underestimated the annoyance due to noise with dominant low frequency components by 5 dB at 50 dB(A) and by 8 dB at 86 dB(A).

It is worth noting that the A-weighting characteristics, commonly used to assess occupational exposure to noise, was established to predict loudness of sounds, but not their annoyance. Thus, no wonder that attempts have been made to replace A-weighting by alternative measures that better predict the effects of LFN. So far, the most popular solution is frequency analysis. For instance, current Polish, Swedish and German recommendations concerning the exposure to LFN in general environment are based on the frequency analysis in 1/3-octave bands [17–19]. However, there are no specific regulations for controlling occupational exposure to LFN in Europe. In 1998, the American Conference of Governmental Industrial Hygienists established the permissible sound pressure levels in 1/3-octave bands for infrasound and low frequency sound in the frequency range of 1–80 Hz [20].

Taking into account the results of this study, it may be concluded that LFN represents a higher risk of influencing human well-being than regular BBN. The occupational hygiene criteria for LFN need to be established in the near future. Outline recommendations for LFN in the occupational environment to prevent annoyance and effects on work performance have already been proposed in Sweden [21].

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