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DOES LOW FREQUENCY NOISE AFFECT HUMAN MENTAL PERFORMANCE?

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To study the influence of low frequency noise (LFN) on mental performance and subjective well-being, 192 male subjects, categorised in terms of sensitivity to noise in general, and to LFN in particular, worked with four standardised psychological tests. Three different acoustic conditions were used in the experiment: the background laboratory noise, LFN, and the broadband noise without dominant low frequency content (reference noise) at a level of 50 dB(A).

The influence of exposure and/ or noise sensitivity on the tests' results or their interaction were found in three of the four performed tests. Poorer results in the LFN (compared to other noise conditions) were observed in person classified as high-sensitive to noise in general and low-sensitive to LFN in the Signal Detection Test (more erroneous responses). The annoyance of LFN and reference noise was rated higher than that of the background noise. Subjects high-sensitive to noise in general reported the highest annoyance due to LFN. In conclusion, LFN at moderate level could be perceived as annoying and adversely affecting attention and visual perception, particularly in subjects high-sensitive to noise.

1. Introduction

Although the international definition of low frequency noise (LFN) is missing, LFN is usually defined as a broadband noise with the dominant content of low frequencies from 10 (20) Hz to 250 Hz. Exposures to LFN are ubiquitous both in the general and the occupational environment (in dwellings, control rooms, office-like area etc.) [1, 2].

Annoyance seems to be the primary and the most frequent effect of the LFN exposure. It is often suffered at relatively low sound pressure levels and subjects sensitive to this type of noise were not necessarily sensitive to noise in general. Furthermore, some symptoms related to LFN annoyance, especially fatigue, concentration problems, headache and irritation could reduce working capacity [1–3]

Over the years, a great deal of research has been carried out to evaluate adverse effects on performance from different kind of noises, but most of them have been based on noise at rather high levels. Considerably fewer studies were concerned with noise at moderate levels, including moderate levels of low frequency noise. Moreover, their results are rather inconsistent, probably due to considerable differences in the individual sensitivity to noise [4, 5].

Generally, little is known about LFN effects in the occupational environment. Only a few previous studies indicated that LFN might reduce performance at levels that could occur in the occupational environment [6–8]. While recent investigations showed that LFN at relatively low A-weighted sound pressure levels (about 40–45 dB) could be perceived as annoying and adversely affecting the performance, particularly when more demanding tasks were executed. Moreover, persons classified as sensitive to LFN may be at the highest risk [9–11].

The aim of the study was to investigate the influence of LFN on human mental performance. An attempt was made to answer the following questions:

- Can LFN at levels normally occurring in the industrial control rooms affect attention, visual perception, logical reasoning and subjective well-being?
- Does a relationship exist between sensitivity to noise and noise effects?

2. Material and methods

2.1. Study population

Subjects of the study comprised 192 male volunteers, with an average age of 35.2 years (SD $=$ 13.7), not occupationally exposed to noise. The majority of them were high school graduates. All persons did not report any hearing problems (see questionnaire quoted below). They were recruited by advertisement and received financial compensation for their participation in the experiment.

2.2. Study design

Subjects performed a series of standardised psychological tests designed for assessment of attention, visual perception and logical reasoning. Three different acoustic conditions were used in the experiment: a background laboratory noise, LFN, and a reference noise. Persons were assigned to various experimental conditions randomly, i.e. in arrival order to background noise, LFN, and reference noise. After test session, they completed questionnaires aimed at: (i) subjective rating of annoyance and effort put into performing tasks, (ii) symptoms experienced during test session, (iii) evaluation of individual sensitivity to the noise in general and to LFN in particular, (iv) self-assessment of hearing status.

A 100-score graphical rating scale was used for the annoyance assessment. The local ethics committee approved the study.

2.3. Exposure conditions

The experiment was performed in a special chamber for psychological tests (6.8 m^2 area) furnished as an office environment. The noise was generated from a set of loud-speakers placed in the corners of the room.

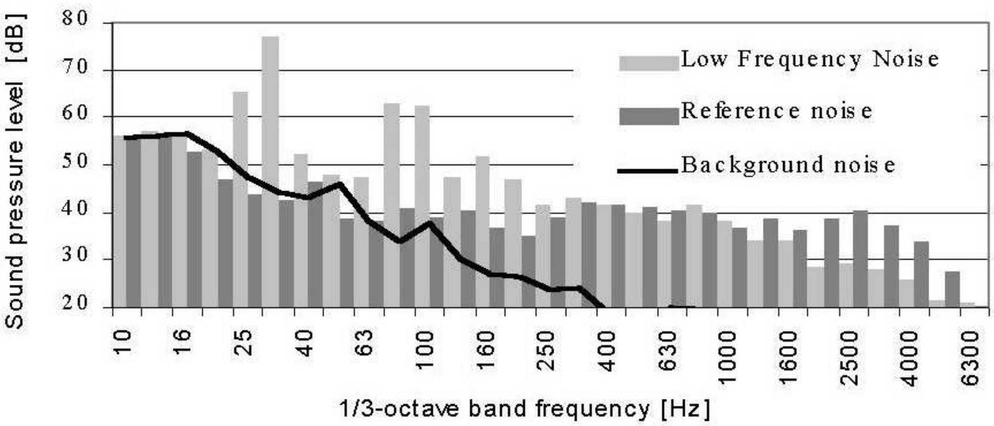


Fig. 1. Noise exposure conditions during test session – results of the frequency analysis.

Table 1. Noise exposure parameters during test session at the subject's ear.

Noise parameters	Type of exposure			
	Background noise		Low frequency noise	Reference noise
	Mean value ±SD			
Equivalent-continuous A-weighted sound pressure level L_{AeqT} [dB]	29.9±1.4[1]	40.7±3.7	50.9±1.7	50.6±1.2
Equivalent-continuous level C-weighted sound pressure L_{CeqT} [dB]	53.6±1.8[1]	55.8±2.2	74.4±0.8	56.9±1.4
L_{CeqT}-L_{AeqT} [dB]	23.5±2.0	16.0±7.1	23.5±1.6	6.2±1.3
Equivalent-continuous level G-weighted sound pressure L_{CeqT} [dB]	68.3±1.9[1]	68.1±1.8	75.6±0.8	67.9±2.1

[1] Measurements in empty chamber at the subject's head.

LFN was of a tonal character with dominant components centred at 1/3-octave bands of 25, 31.5, 80 and 100 Hz (Fig. 1). The reference noise was the broadband noise without dominant low frequency components of a predominantly flat frequency character. Both noises were of an artificial origin and rather steady-state character. Moreover, they were at the same an equivalent-continuous A-weighted sound pressure levels of approx. 50 dB, corresponding to levels normally occurring in industrial control rooms [12]. The background noise consisted of noise accompanying computer and air conditioning operation. Noise exposure parameters were monitored during the test session (Table 1).

2.4. Performance tasks

Subjects performed four standardised tests, i.e.: the Signal Detection Test (test I), the Stroop Colour-Word Test (test II), the Math Reasoning Test (test III) and the Comparing of Names Test (test IV).

Test I and II involved working with a computer, but test III and IV – with pen and paper. Before the test session the subjects were informed how to perform the first two tests. Instructions concerning test III and IV took place just before performing them.

The Signal Detection Test is a computerised test applied to measure the ability of visual differentiation. The screen is covered with dots, and then, one after another, they are faded out apparently by pure chance and are substituted by new ones. Subjects are expected to detect cases when four dots represent the shape of square. The main variables include the amount of correct and delayed reactions as a measure for reliability of the detection process, and the median detection times as a measure for the speed of the detection process [13, 14].

The Stroop Colour-Word Test is used for registration of the colour-word interference tendency, i.e. impairment of the reading speed or colour recognition due to interfering information. Therefore, it is useful in determining the individual susceptibility to stimulus disturbing mental processes. Test consists of four parts:

- the first – in which the names of colours (RED, GREEN, YELLOW or BLUE) are exposed in grey on the screen and subject is expected to push the button corresponding to the name – "reading in the baseline conditions";
- the second – in which colour rectangles are shown and subject is asked to press the button in the same colour – "naming in the baseline conditions";
- the third – in which the names of colours are presented in different colours (e.g. name "GREEN" is written in red, blue or yellow) and subject is expected to push the button corresponding to the name – "reading in the interference conditions";
- the fourth – in which names of colours are shown in similar way as in a preceding part, but person is told to respond to the colour of fonts – "naming in the interference conditions".

The main evaluated variables are:

- the reading interference, i.e. the difference between the median reaction times of reading in the interference and baseline conditions;
- the naming interference, i.e. the difference between the median reaction times of naming in the interference and baseline conditions;

- the median reaction times and the number of incorrect answers for each individual test part [13].

The Math Reasoning Test (test III) is the sub-test of the General Aptitude Test Battery (GATB) adapted to Polish population [15]. It consists of 25 mathematical tasks and is designed to measure of skills in the four basic arithmetic operations and ability to perform them quickly and accurately. Number of correct and erroneous answers given within 7 minutes period are the main test results.

The Comparing of Names Test (test IV) is a second sub-test of the GATB [15]. It consists of two columns of words (names). Respondent decides whether couples of words (names) in both columns are exactly the same. This test is designed to measure the ability to see pertinent detail in verbal material. Test results are number of correct and incorrect answers given within 6 minutes period.

2.5. Subjective sensitivity to noise

Individual sensitivity to noise in general and to LFN in particular was assessed separately. Weinstein noise sensitivity evaluation questionnaire [16], consisting of 21 statements with proposed degrees of the agreement (from "do not agree at all" to "agree completely"), graded from 1 to 5, was adopted in order to assess subjects' sensitivity to noise in general. The questionnaire had a total of 105 points; the higher the score, the higher sensitivity to noise. Thus, persons who obtained more than median score were categorised as highly sensitive (high-sensitive) to noise in general (NG+). Others were recognised as less sensitive (low-sensitive) to noise in general (NG−).

In order to evaluate sensitivity to LFN, three following statements were used:

- "I feel relief when refrigerator, fan or computer turns off";
- "When I am listening to loud music, I often perceive additional sensations, e.g. pressure on the eardrum, vibrations in chest or throat etc.";
- "I like to listen music when bass (low tones) are turned on".

All statements had five response alternatives ranging from "do not agree at all" to "agree completely". Subjects who answered "agree" or "agree completely" to at least one statement were recognised as highly sensitive (high-sensitive) to low frequency noise (LFN+). The others were categorised as less sensitive (low-sensitive) to low frequency noise (LFN−).

In the group, 96 persons were classified as high-sensitive to LFN and 109 – as high-sensitive to noise in general, but the two sensitivity distributions were not identical. Thus, the categorisation of subjects in terms of subjective sensitivity to noise in general and to LFN in particular formed the basis for the classification of the study group into four sensitivity sub-groups, i.e. persons who were:

- low-sensitive to noise in general and low-sensitive to LFN (NG−LFN−),
- high-sensitive to noise in general and low-sensitive to LFN (NG+LFN−),
- high-sensitive to noise in general and high-sensitive to LFN (NG+LFN+),
- low-sensitive to noise in general and high-sensitive to LFN (NG−LFN+).

2.6. Statistical analysis

The influence of noise exposure and subjective sensitivity on the different performance tests and subjective annoyance ratings were analysed using covariance analysis, ANCOVA (in majority variables) and log-lin analysis (only in case of discrete variables, e.g. amount of delayed reaction in test I).

In the first stage of ANCOVA two main effects, i.e. noise exposure (3 noise conditions) and sensitivity to noise (4 sensitivity sub-groups) were analysed with two covariates, i.e. age and education. In the second stage of ANCOVA, each group performing tasks in different noise conditions was considered separately and only the main effect of sensitivity to noise was analysed, while the covariates were unchanged.

The relationships between subjective annoyance rating and symptoms reported during the test session were analysed using Pearson's correlation coefficient (r). However, the differences in rates of registered sensations and complaints due to various noise conditions were evaluated using Fisher test.

All statistical tests were done with assumed significance level $p < 0.05$, while p-value up to 0.10 was reported as a tendency. The statistical analysis employed SPSS for Windows software.

3. Results

3.1. Performance tests

Signal Detection Test

ANCOVA. No significant main effect of noise exposure on the test results was found. There was a weak main effect of noise sensitivity on median detection time ($p = 0.071$). Regardless of noise conditions, subjects categorised as NG+LFN+ showed tendency to higher median detection time compared to the others. This effect was pronounced in the background noise conditions ($p = 0.016$) (Table 2, Fig. 2). However, during exposure to LFN and reference noise there were no significant differences among subjects of different noise sensitivity.

A two-way interaction of noise exposure and sensitivity to noise was also noted for the number of erroneous responses ($p = 0.050$). The subjects classified as NG+LFN− made more errors during exposure to LFN than during the exposure to background noise or reference noise (Table 2, Fig. 3). Moreover, they made significantly more errors than others in the LFN conditions ($p = 0.036$). During the reference and the background noises there were no differences in the number of erroneous reactions related to noise sensitivity.

Log-lin Analysis. No relation was proved between the following variables: amount of delayed reactions, noise conditions and sensitivity to noise.

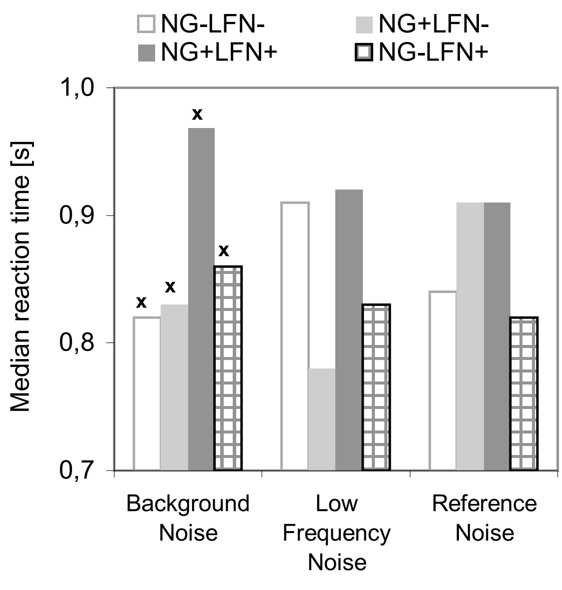
Stroop Colour-Word Test

ANCOVA. There was no significant main effect of noise conditions on the test results. However, a significant main effect of sensitivity to noise was found in case of the

Table 2. The results from the Signal Detection Test (mean values, in italics – mean values adjusted for age and education).

Test parameter	Study group	Total	Type of exposure		
			Background noise	Low frequency noise	Reference noise
Number of erroneous responses	All subjects [1]	1.66	1.56	1.63	1.73
	NG−LFN−	1.61	1.59 (*1.62*)	1.53 (*1.58*)[3]	1.68 (*1.71*)
	NG+LFN−	2.23	1.62 (*1.60*)	3.89 (*3.69*)[3]	1.44 (*1.51*)
	NG+LFN+	1.46	1.11 (*1.11*)	1.25 (*1.39*)[3]	2.00 (*2.01*)
	NG−LFN+	1.60	2.00 (*1.98*)	1.19 (*1.21*)[3]	1.60 (*1.50*)
Median reaction time [s]	All subjects [2]	0.88	0.87	0.88	0.87
	NG−LFN−	0.84	0.81 (*0.82*)[3]	0.91 (*0.91*)	0.82 (*0.84*)
	NG+LFN−	0.83	0.81 (*0.83*)[3]	0.79 (*0.78*)	0.89 (*0.91*)
	NG+LFN+	0.97	1.00 (*0.97*)[3]	0.95 (*0.92*)	0.96 (*0.91*)
	NG−LFN+	0.82	0.85 (*0.86*)[3]	0.79 (*0.83*)	0.81 (*0.82*)

[1] Interaction between noise exposure and sensitivity to noise ($p = 0.05$);
[2] A weak main effect of sensitivity to noise ($p < 0.10$);
[3] Significant differences between subgroups of various sensitivity to noise ($p < 0.05$).



X – significant differences ($p < 0.05$)

Fig. 2. Median reaction time in the Signal Detection Test – mean values adjusted for age and education.

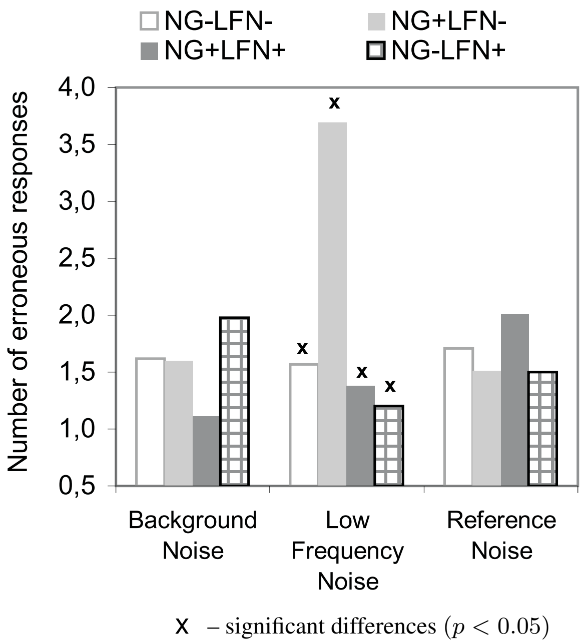


Fig. 3. Number of erroneous responses in the Signal Detection Test – mean values adjusted for age and education.

median reaction time of reading in the interference conditions ($p = 0.021$) as well as in case of the reading interference ($p = 0.008$). Despite the exposure conditions, subjects high-sensitive to noise in general (i.e. NG+LFN− and NG+LFN+) had a higher value of reading interference and longer median reaction compared to the others (Table 3).

During exposure to LFN there were no differences in the values of the reading interference between subjects with different noise sensitivities. However, in the reference noise, persons classified as NG+LFN− had the highest values of reading interference, while NG−LFN+ the lowest ($p = 0.055$). On the other hand, during the background noise conditions, subjects high-sensitive to noise in general (i.e. NG+LFN− and NG+LFN+) achieved higher values of the reading interference than others ($p = 0.036$) (Table 3, Fig. 4).

Log-lin Analysis. No relation was proved between the following variables: number of errors of reading and naming in the interference conditions, type of exposure and sensitivity to noise.

Math Reasoning Test

ANCOVA. No influence of exposure conditions, subjective sensitivity to noise and their interaction on test results was found.

Comparing of Names Test

ANCOVA. There was only a significant main effect of noise exposure on fractions of correct ($p = 0.012$) and erroneous marks ($p = 0.012$) (Table 4). Generally, the greatest fraction of errors was noted in the background noise conditions.

Table 3. The results from the Stroop Colour-Word Test (mean values, in italics – mean values adjusted for age and education).

Test parameter	Study group	Total	Type of exposure		
			Background noise	Low frequency noise	Reference noise
Median reaction time of reading in interference conditions [s]	All subjects[1]	0.94	0.93	0.95	0.95
	NG−LFN−	0.92	0.86 (*0.87*)	0.96 (*0.97*)	0.92 (*0.93*)
	NG+LFN−	0.97	0.96 (*0.98*)	0.96 (*0.96*)	1.00 (*1.01*)
	NG+LFN+	1.00	1.00 (*0.97*)	1.00 (*0.98*)	1.01 (*1.00*)
	NG−LFN+	0.87	0.90 (*0.90*)	0.87 (*0.88*)	0.85 (*0.84*)
Reading interference [s]	All subjects[1]	0.10	0.09	0.11	0.12
	NG−LFN−	0.08	0.04 (*0.04*)[2]	0.09 (*0.09*)	0.11 (*0.11*)[3]
	NG+LFN−	0.14	0.13 (*0.13*)[2]	0.11 (*0.10*)	0.19 (*0.19*)[3]
	NG+LFN+	0.13	0.15 (*0.15*)[2]	0.12 (*0.13*)	0.13 (*0.14*)[3]
	NG−LFN+	0.07	0.04 (*0.04*)[2]	0.11 (*0.11*)	0.05 (*0.05*)[3]

[1] A significant main effect of sensitivity to noise ($p < 0.05$);
[2] Significant differences between subgroups of various sensitivity to noise ($p < 0.05$);
[3] Differences between subgroups of various sensitivity to noise ($p < 0.10$).

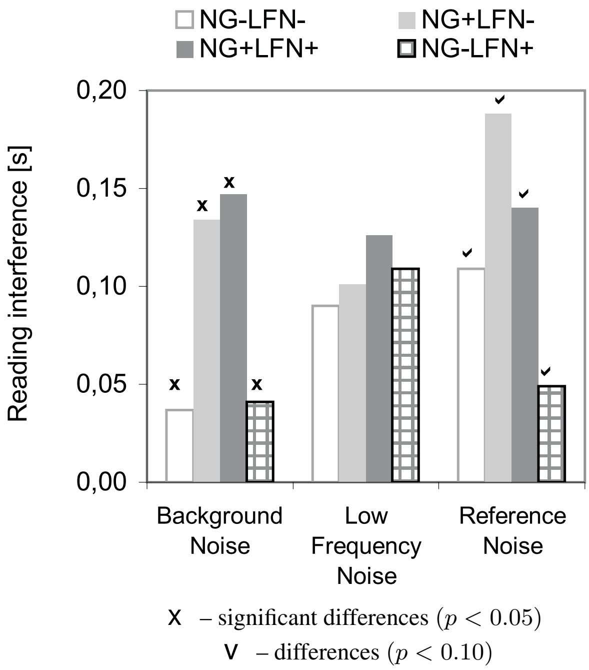


Fig. 4. Reading interference in the Stroop Colour-Word Test – mean values adjusted for age and education.

Table 4. The results from the Comparing of Names Test (mean values, in italics – mean values adjusted for age and education).

Test parameters	Study group	Total	Type of exposure		
			Background noise	Low frequency noise	Reference noise
Fraction of erroneous answers [%]	All subjects [1]	5.68	7.73	5.16	4.19
	NG−LFN−	4.65	5.85 (*5.50*)	3.65 (*3.52*)	4.38 (*4.49*)
	NG+LFN−	6.03	8.35 (*9.32*)	4.93 (*5.75*)	3.76 (*4.24*)
	NG+LFN+	6.37	9.28 (*8.30*)	6.07 (*5.11*)	4.31 (*4.60*)
	NG−LFN+	5.61	7.47 (*7.83*)	5.34 (*5.62*)	4.04 (*3.16*)

[1] A significant main effect of exposure conditions ($p < 0.05$).

3.2. Annoyance assessment

ANCOVA. The significant main effects of both noise exposure ($p = 0.001$) and subjective sensitivity to noise ($p = 0.001$) on annoyance rating were found. Despite the noise sensitivity, the background noise annoyance was the lowest assessed (Table 5). On the other hand, subjects categorised as high-sensitive to noise in general assessed annoyance related to exposure conditions higher than other subjects.

Table 5. The subjective ratings of annoyance related to exposure conditions and efforts put into performing tests (mean values, in italics – mean values adjusted for age and education).

Subjective rating	Study group	Total	Type of exposure		
			Background noise	Low frequency noise	Reference noise
Annoyance	All subjects [1,2]	22.07	8.45	29.25	28.73
	NG−LFN−	17.14	9.18 (*8.33*)	21.73 (*22.18*)[3]	20.83 (*19.60*)[3]
	NG+LFN−	25.00	9.62 (*9.87*)	40.89(*37.91*)[3]	31.33 (*32.56*)[3]
	NG+LFN+	26.86	10.44 (*10.60*)	34.54 (*38.27*)[3]	32.14 (*37.47*)[3]
	NG−LFN+	18.91	4.50 (*4.94*)	21.33(*20.14*)[3]	31.87 (*26.55*)[3]
Effort	All subjects [2]	28.90	25.56	28.94	32.25
	NG−LFN−	26.36	23.94 (*25.46*)	25.47 (*25.97*)[3]	29.39 (*29.11*)
	NG+LFN−	29.03	22.77 (*21.18*)	40.11 (*36.59*)[3]	27.00 (*27.66*)
	NG+LFN+	33.40	32.61 (*33.88*)	32.00 (*36.54*)[3]	35.67 (*37.52*)
	NG−LFN+	25.41	21.63 (*20.43*)	20.80 (*19.27*)[3]	34.07 (*31.83*)

[1] A significant main effect of noise exposure conditions ($p < 0.05$);
[2] A significant main effect of sensitivity to noise ($p < 0.05$);
[3] Significant differences between subgroups of various sensitivity to noise ($p < 0.05$).

The annoyance due to LFN was highest rated by subjects high-sensitive to noise in general (i.e. NG+LFN− and NG+LFN+) ($p = 0.023$). However, the reference noise was rated highest by persons NG+LFN+, and lowest – by subjects NG−LFN− ($p = 0.014$). There were no differences in annoyance ratings of the background noise conditions among persons of different noise sensitivity (Table 5, Fig. 5).

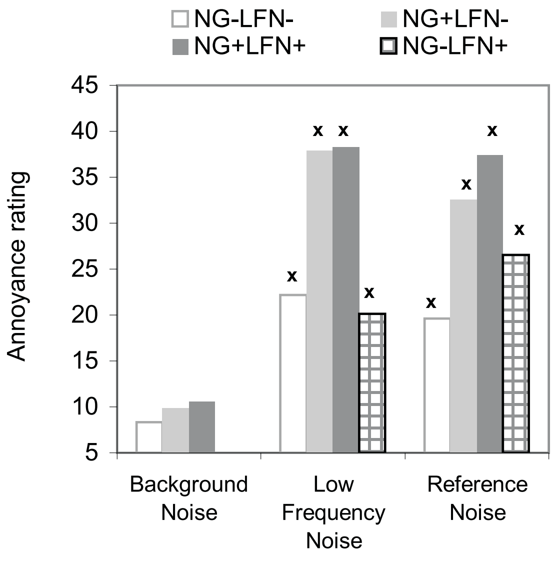


Fig. 5. Annoyance assessments of various noise exposure conditions - mean values adjusted for age and education.

Descriptive assessment. Regardless of exposure conditions, a considerable fraction of subjects (from 46.9 to 64.1%) reported no complaints during the test session. In the background noise, 57.8% of subjects did not report any sensations, while during exposure to LFN and reference noise – only 12.5% and 9.4% , respectively (significant differences between various exposure conditions). Noise present in the room was perceived nearly by all subjects exposed to reference noise and by over two-thirds of those exposed to LFN. On the other hand, in the background noise conditions, only 17.2% persons perceived sounds accompanying computer and air conditioning operation.

During exposure to reference noise, subjects most frequently reported problems with concentration (32.8%). Moreover, this rate of answers was significantly higher in comparison with the other exposure conditions. On the other hand, the LFN subjects most frequently reported fatigue (26.6%) and drowsiness (18.8%), but the complaints were not significantly more frequent than during other noise conditions.

Generally, the annoyance rating on the graphical scale was significantly correlated with the number of reported sensations (e.g. pressure in ears, vibrations in parts of body, discomfort) ($r = 0.49$, $p < 0.05$) and complaints (e.g. headache, fatigue) ($r = 0.36$, $p < 0.05$) subjectively related to exposure conditions during performing the tasks.

3.3. Effort

ANCOVA. A significant main effect of sensitivity to the noise on effort rating was found ($p = 0.033$). Regardless of the exposure conditions, subjective assessment was highest in persons high-sensitive to noise in general and to LFN in particular.

During exposure to LFN, subjects classified as high-sensitive to noise in general (i.e. NG+LFN− and NG+LFN+) put most effort into performing the tasks ($p = 0.016$) (Table 5). In the background and reference noise conditions, no differences were detected in effort ratings among subjects of different noise sensitivities.

4. Conclusions

- Results of subjects' categorisation in terms of noise sensitivity confirmed some earlier observations that higher sensitivity to noise in general was not necessarily connected with higher sensitivity to LFN.
- It was found that some of the test results were influenced by noise exposure and/or sensitivity to noise. Such relations were noted in three of the four tests, i.e. in case of the Signal Detection Test, the Stroop Colour-Word Test and the Comparing of Names Test.
- The differences related to exposure conditions were only found in the Comparing of Names Test. Regardless of the noise sensitivity, subjects committed relatively most errors in the background noise conditions, while in the reference noise circumstances the fraction of committed errors was relatively lowest.
- Poorer performance during exposure to LFN compared with other noise conditions was noted in the Signal Detection Test (two-way interaction between noise conditions and sensitivity to noise). In this task, persons classified as high-sensitive to noise in general, but low-sensitive to LFN, made more errors in the LFN conditions than during the background and reference noise. Moreover, their performance was poorer compared with other subjects in the same exposure conditions (i.e. in LFN).
- There was a relationship between noise sensitivity and performance results in the background noise with low frequency components in its spectrum. Subjects categorised as high-sensitive both to noise in general and to LFN in particular, showed the longest median reaction time in the Signal Detection Test and the highest value of reading interference in the Stroop Colour-Word Test, compared to others in the same exposure conditions.
- The annoyance assessment was related to both exposure conditions and subjective sensitivity to noise. Regardless of noise sensitivity, the background noise annoyance was the lowest rated. However, there was no significant difference between low frequency and reference noises. The LFN annoyance was assessed highest by subjects categorised as high sensitive to noise in general.
- To sum up, LFN at levels normally occurring in the industrial control rooms could be perceived as annoying and adversely affecting attention and visual perception,

especially in people particularly sensitive to noise. The findings presented here are thus in agreement with previous investigations concerning the LFN effects on performance [9–11], but further studies need to be carried out, especially in order to evaluate more specifically subjective sensitivity to LFN.

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