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INFLUENCE OF LOW FREQUENCY NOISE ON COGNITIVE PERFORMANCE TASKS

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To study the influence of low frequency noise (LFN) on cognitive performance tasks, 96 subjects, categorised in terms of sensitivity to LFN, worked with four standardised psychological tests during exposure to LFN or broadband noise without dominant low frequency content (reference noise) at a level of 50 dB(A).

It was found that the test results were influenced by exposure and/or noise sensitivity. Regardless of sensitivity to noise, poorer results in the LFN (compared to reference noise conditions) were noted in the Comparing of Names Test (a tendency to more erroneous responses). High-sensitive subjects achieved poorer results than others during exposure to LFN in the Stroop Colour-Word Test (a significant interaction between noise and noise sensitivity in case of reading interference) and in the Continuous Attention Test (a tendency to more erroneous reactions). These findings suggest that LFN at moderate levels could adversely influence cognitive performance tasks and subjects high-sensitive to LFN may be at highest risk.

1. Introduction

There is growing body of data showing that low frequency noise (LFN) differs in its nature from other noises at comparable levels. LFN is ubiquitous not only in the general but also in the occupational environment, especially in industrial control rooms, office-like area etc. Ventilation systems, pumps, compressors, diesel engines, gas turbine power stations, means of transport, etc., may be quoted as some examples of the common sources of LFN. Its prevalence in offices and control rooms is mainly due to indoor network installations, ventilation, heating and air-conditioning systems as well as by outdoor sources of noise and poor attenuation of low frequency components by the walls, floors and ceilings [1–4].

The new working conditions for personnel in control rooms and offices have led to a change of demands, involving a high element of unpredictability, selective attention, processing of a high load of information and the work that to a large extent is paced by computers. The knowledge on how LFN affects performance in these types of work situations is rather scarce. A few previous studies indicated that LFN might reduce performance at levels that could occur in the occupational environment [5–7]. 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 [8–10]. Thus, the LFN could possibly influence the working capacity of personnel in control rooms and offices.

The aim of the study was to investigate whether exposure to LFN at levels normally occurring in the industrial control rooms can influence cognitive performance tasks and subjective well-being. A further objective was to analyse the relationship between LFN effects and subjective sensitivity to this type of noise.

2. Material and methods

2.1. Study population

Subjects of the study comprised 49 male and 47 female pre-selected volunteers, aged 19–26 (mean value $= 21.7$ SD $= 1.7$), high school or university graduates.

Candidates were selected from 402 persons, recruited by advertising, on the basis of their scores on Weinstein noise sensitivity evaluation questionnaire [11]. This questionnaire was used in earlier studies for evaluation of individual sensitivity to noise in general (for example see [9, 12]). Only subjects who were recognised as highly or less sensitive (i.e. obtained more than 86 or less than 76 points) were included to the study. Additionally, each person underwent a hearing test and only subjects with normal hearing (< 25 dB HL) were allowed to participate. All subjects received financial compensation for their participation in the experiment.

2.2. Study design

Subjects performed a series of standardised psychological tests during exposure to LFN or reference noise. They were randomly assigned to different noise conditions. After the test session, subjects completed questionnaires aimed at: (i) subjective rating of annoyance and effort put into performing tasks, (ii) symptoms experienced during test session, (iii) temperament assessment [13]. These latter data will be reported elsewhere.

A 100-score graphical rating scale was used for the assessment of annoyance and effort. Subjects' sensitivity to LFN was rated prior to experiment, during selection of candidates. 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.

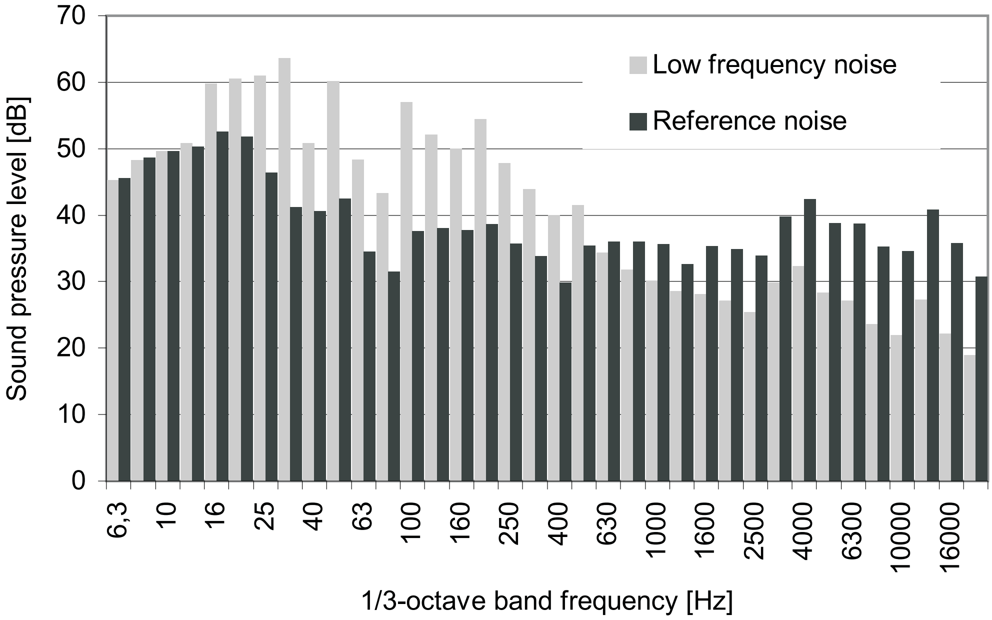


Fig. 1. Noise exposure conditions during performing tests – results of the frequency analysis.

Table 1. Noise exposure parameters during test session.

Noise parameter	Exposure conditions	
	Low frequency noise	Reference noise
	Mean value ± SD	
Equivalent-continuous A-weighted sound pressure level L_{AeqT} [dB]	49.7±1.1	49.9±1.1
Equivalent-continuous C-weighted sound pressure level L_{CeqT} [dB]	66.0±0.7	53.5±0.7
L_{CeqT}-L_{AeqT} [dB]	16.4±1.1	3.6±0.6
Equivalent-continuous G-weighted sound pressure level L_{GeqT} [dB]	72.8±0.6	64.5±1.4

LFN simulated noise occurring in the industrial control rooms (Fig. 1). The reference noise was the broadband noise without dominant low frequency components of a predominantly flat frequency character. Both noises were at the same equivalent-continuous A-weighted sound pressure level (SPL) of approx. 50 dB, but they differed in C- and G-weighted sound pressure levels (Table 1). Earlier study showed that sound pressure levels normally occurring in industrial control rooms remained within the range of: (i) 47.7–66.0 dB(A) (*mean 58.5 dB(A)*), (ii) 59.4–79.0 dB(C) (*mean 68.6 dB(C)*), (iii) 58.7–92.1 dB(G) (*mean 75.4 dB(G)*) [14]. Thus, SPL of 50 dB(A) corresponded with the lower limit of the measured levels. Moreover, it was 15 dB lower than the currently admissible levels established in Poland to ensure suitable working conditions for operators of control equipment in control booths, remote control rooms, etc.[15].

2.4. Performance tasks

Subjects performed four standardised tests: the Signal Detection Test (test I), the Stroop Colour-Word Test (test II), the Comparing of Names Test (test III) and the Continuous Attention Test (DAUF, test IV). Test I, II and IV involved working with a computer, while test III – with pen and paper. Before the test session 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 [16, 17].

The Stroop Colour-Word Test is computerised realisation of the Colour-Word interference paradigm by STROOP [18]. It is based on the assumption that reading speed of a colour-word is slower, if the word is written in a differently coloured font. There is always a delay in naming the colour of this word, if colour and colour-word do not match.

This 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 [16].

The Comparing of Names Test (test IV) is a sub-test of the General Aptitude Test Battery (GATB) adapted to Polish population [19]. 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.

The Continuous Attention Test (DAUF) is applied to measure of "long-term attention and concentration performance". According to a basic definition, attention is selection: perception and visualisation are adjusted and limited to a part of stimuli acting upon the organism simultaneously. The continuous aspect emphasises the fact that with continuous repetition it becomes more difficult to carry out attention processes. Thus, the measurement of continuous attention mainly records aspects of "general performance and/or performance readiness" which are to a large extent independent of intelligence.

For thirty minutes rows of triangles are presented on screen under time-critical conditions; the tips of the individual triangles can point either up or down. When a previously determined amount of triangles points down, the subject has to press the reaction button. The main tested variables are: number of correct and incorrect responses, amount of omitted stimuli and mean reaction time [16].

The test session lasted in total about 95 minutes.

2.5. Subjective sensitivity to LFN

To assess sensitivity to LFN, the subjects were asked to answer a questionnaire, including three following statements:

- "I am not sensitive to noise with bass (low tones)",
- "I think that even low, monotonous humming (e.g. from a transformer) is unpleasant",
- "I like to listen music when bass are turned on".

It is worth noting that, in some recent studies, sensitivity to LFN was also based on similar statements or questions (e.g. "Are you sensitive to low frequency noise?" or "I am sensitive to rumbling noise from ventilation system") [9, 10].

All statements had five response alternatives ranging from "do not agree at all" to "agree completely, graded from 1 to 5. On the basis of subjects' score, subjects were categorised as highly sensitive (high-sensitive) or less sensitive (low-sensitive). The higher the score, the higher sensitivity to noise. Thus, persons who obtained more than median score were categorised as high-sensitive to low frequency noise (LFN+). The others were classified as low-sensitive to low frequency noise (LFN−).

2.6. Statistical analysis

Covariance analyses, ANCOVA, were performed to evaluate the influence of noise exposure, sensitivity to LFN and their interaction on the different performance tests and subjective ratings. Two main effects, i.e. exposure conditions (2 noises) and LFN sensitivity (2 sensitivity sub-groups) were analysed, taking into consideration two covariates, i.e. gender and sensitivity to noise in general. These covariates were introduced to the model to avoid their possible influence on test results and subjective ratings.

To evaluate the influence of exposure and noise sensitivity on answers given in the questionnaire concerning symptoms experienced during test session, a log-lin model was applied. However, the relationships between subjective ratings and reported symptoms were analysed using Pearson's correlation coefficient (r).

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 software for Windows.

3. Results

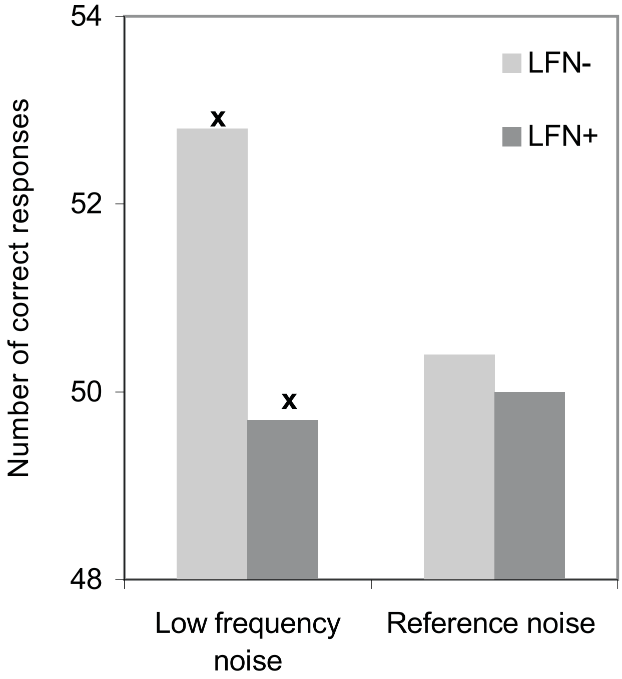
3.1. Performance tests

Signal Detection Test

Results from the Signal Detection Test are shown in Table 2. A significant main effect of noise conditions on the median reaction time was found ($p = 0.015$). Regardless of LFN sensitivity, higher values of median reaction time were reported during exposure to reference noise (Table 2). No significant differences in other test results were noted between noise exposures. Generally, the results were not influenced by the subjective sensitivity. However, during exposure to LFN, a weak simple effect of LFN sensitivity was found in case of the number of correct responses ($p = 0.065$). In the LFN conditions, subjects categorised as high-sensitive to LFN obtained poorer results than low-sensitive subjects (Fig. 2).

Stroop Colour-Word Test

There were no significant differences in the test results between noise conditions (Table 3). However, a significant two-way interaction between type of exposure and subjective sensitivity to LFN was found ($p = 0.048$). Persons classified as high-sensitive to LFN had a higher value of reading interference in the LFN conditions than during exposure to reference noise, while the reverse was seen for low-sensitive subjects (Fig. 3).



x – a difference ($p = 0.065$)

Fig. 2. Number of correct responses in the Signal Detection Test – mean values adjusted for gender and sensitivity to noise in general.

Table 2. Results of the Signal Detection Test (mean values, in italics – mean values adjusted for gender and subjective sensitivity to noise in general).

Test parameter	Study group	Total	Noise conditions	
			Low frequency noise	Reference noise
Number of correct reactions	All subjects	50.54	51.00	50.06
	LFN−	51.83	53.10 / *52.76*[2]	50.68 / *50.36*
	LFN+	49.51	49.50 / *49.98*[2]	49.52 / *49.98*
Median reaction time [s]	All subjects[1]	0.80	0.77	0.82
	LFN−	0.77	0.74 / *0.76*[3]	0.80 / *0.82*[3]
	LFN+	0.82	0.79 / *0.78*[4]	0.86 / *0.83*[4]

[1] A significant main effect of noise conditions; ($p = 0.015$)
[2] A weak simple effect of LFN sensitivity during exposure to LFN ($p = 0.065$);
[3] A weak simple effect of noise condition in subjects LFN− ($p = 0.084$);
[4] A weak simple effect of noise condition in subjects LFN+ ($p = 0.090$).

Table 3. Results of the Stroop Color-Word Test (mean values, in italics – mean values adjusted for gender and subjective sensitivity to noise in general).

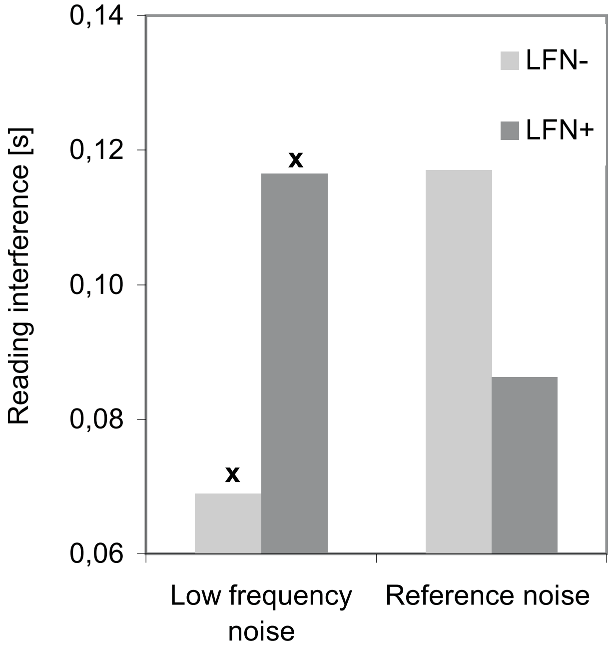
Test parameter	Study group	Total	Noise conditions	
			Low frequency noise	Reference noise
Reading interference [s]	All subjects [1]	0.099	0.098	0.099
	LFN−	0.094	0.070 / *0.069*[4]	0.116 / *0.117*
	LFN+	0.102	0.118 / *0.116*[4]	0.085 / *0.086*
Median reaction time of reading in the baseline conditions [s]	All subjects	0.75	0.74	0.76
	LFN−	0.73	0.73 / *0.73*	0.73 / *0.73*[5]
	LFN+	0.77	0.75 / *0.75*	0.79 / *0.79*[5]
Median reaction time of naming in the baseline conditions [s]	All subjects [2]	0.72	0.71	0.72
	LFN−	0.68	0.67 / *0.67*	0.68 / *0.68*[5]
	LFN+	0.75	0.74 / *0.75*	0.76 / *0.76*[5]
Median reaction time of naming in the interference conditions [s]	All subjects [3]	0.72	0.96	0.72
	LFN−	0.68	0.67 / *0.67*[4]	0.68 / *0.68*[6]
	LFN+	0.75	0.74 / *0.74*[4]	0.76 / *0.76*[6]
Number of naming errors in the baseline conditions	All subjects [2]	0.84	0.96	0.72
	LFN−	1.14	1.25 / *1.30*	1.05 / *1.12*
	LFN+	0.60	0.75 / *0.68*	0.44 / *0.39*
Number of reading errors in the interference conditions	All subjects	2.03	1.98	2.09
	LFN−	2.17	1.85 / *2.08*	2.45 / *2.77*[5]
	LFN+	1.92	2.07 / *1.80*	1.76 / *1.50*[5]

[1] A significant interaction of noise conditions and LFN sensitivity ($p = 0.048$);
[2] A significant main effect of LFN sensitivity ($p < 0.05$);
[3] A weak main effect of LFN sensitivity ($p = 0.056$);
[4] A weak simple effect of LFN sensitivity during exposure to LFN ($p < 0.10$);
[5] A weak simple effect of LFN sensitivity during exposure to reference noise ($p < 0.10$);
[6] A significant simple effect of LFN sensitivity during exposure to reference noise ($p = 0.031$).

Regardless of the noise exposure, differences related to LFN sensitivity were found in case of the median reaction time and the number of errors of naming in the baseline conditions ($p = 0.003$, $p = 0.034$), as well as in the case of the median reaction time of naming in the interference conditions ($p = 0.056$).

Comparing of Names Test

A significant main effect of noise conditions on the number of erroneous answers was found ($p = 0.015$). As can be seen in Table 4, regardless of the individual sensitivity to LFN, subjects made more errors during exposure to LFN than in the reference noise conditions.



x – a difference ($p = 0.082$)

Fig. 3. Reading interference in the Stroop Color-Word Test – mean values adjusted for gender and sensitivity to noise in general.

Table 4. Results of the Comparing of Names Test (mean values, in italics – mean values adjusted for gender and subjective sensitivity to noise in general).

Test parameter	Study group	Total	Noise conditions	
			Low frequency noise	Reference noise
Number of incorrect marks	All subjects [1]	2.57	3.23	1.92
	LFN−	2.95	3.80 / *3.48*	2.16 / *1.75*
	LFN+	2.28	2.82 / *3.21*	1.69 / *2.06*

[1] A weak main effect of noise conditions ($p = 0.066$).

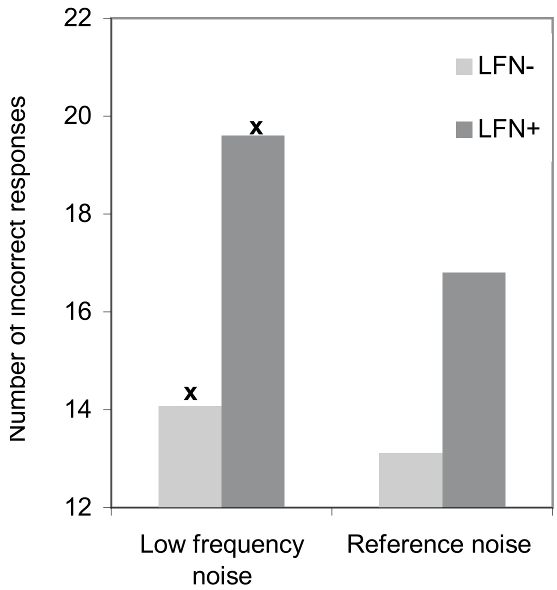
Continuous Attention Test (DAUF)

Generally, no significant differences in test results between low frequency and reference noises were found. Only a weak main effect of noise sensitivity was noted in case of number of incorrect responses ($p = 0.063$) (Table 5). In particular, this effect was observed during exposure to LFN. In those noise conditions, subjects high-sensitive to LFN showed tendency to larger number of errors compared to others ($p = 0.095$), while during reference noise there was no difference related to noise sensitivity.

Table 5. Results of the Continuous Attention Test (DAUF) (mean values, in italics – mean values adjusted for gender and subjective sensitivity to noise in general).

Test parameter	Study group	Total	Noise conditions	
			Low frequency noise	Reference noise
Number of incorrect reactions	All subjects	16.2	17.3	15.2
	LFN−	13.3	13.8 / *14.1*[1]	12.8 / *13.1*
	LFN+	18.6	17.7 / *19.6*[1]	17.2 / *16.8*

[1] A weak simple effect of LFN sensitivity during exposure to LFN ($p = 0.095$).



x – a difference ($p = 0.095$)

Fig. 4. Number of incorrect responses in the Continuous Attention Test (DAUF) – mean values adjusted for gender and sensitivity to noise in general.

3.2. Subjective ratings

There were no significant main effects of noise exposure, LFN sensitivity and their interaction on annoyance rating. Similar relations were found in case of the subjective assessment of effort put into performing tests.

Symptoms subjectively related to exposure conditions during test session are shown in Table 6. Regardless of noise conditions, drowsiness, fatigue, problems with concentration, discomfort and pressure in ears or head were the most frequently reported symptoms, but a significant difference between noises was only found in case of the drowsiness.

Table 6. The subjective sensations and complaints reported during test session.

	Low frequency noise	Reference noise
	Rates of answers (%)	
	Sensations	
No sensations	12.5	2.1
I heard sounds (noise)	72.9	83.3
I felt pressure in ears	25.0	20.8
I felt pressure in head	16.7	27.1
I felt vibrations in room	6.3	4.2
I felt vibrations in part of body	0	2.1
I felt discomfort	27.1	31.3
Others	20.8	22.9
	Complaints	
No complaints	18.8	12.5
Headache	12.5	14.6
Problems with concentrations	29.2	31.3
Dizziness	0	2.1
Drowsiness	52.1[1]	75.0[1]
Fatigue	47.9	43.8
Others	10.4	8.3

[1] A significant difference between groups at various exposure conditions ($p < 0.05$).

Noise (sounds) perceived during test session were significantly more often described as humming (58.3% versus 27.7%) and low (37.5% versus 17.0%) in the LFN conditions than in the reference noise.

Generally, the annoyance rating on the graphical scale was significantly correlated with the number of reported sensations ($r = 0.61$, $p = 0.000$) and complaints ($r = 0.73$, $p = 0.000$) subjectively related to exposure condition during performing tasks.

4. Conclusions

- It was found that the results of psychological tests were influenced by exposure and/or sensitivity to LFN.
- Differences related to exposure conditions were noted in two from four performance tests. Regardless the noise sensitivity, in the Comparing of Names Test,

subjects showed tendency to make more errors during exposure to LFN than in the reference noise conditions. On the other hand, in the Signal Detection Test, persons achieved longer median reaction times in the reference noise. Thus, during exposure to LFN, subjects reacted faster, but some of them, i.e. those categorised as high-sensitive to LFN, showed tendency to work less precise (achieved less number of correct responses) compared with subjects low-sensitive to LFN.
- A significant interaction of exposure conditions and sensitivity to LFN was found in the Stroop Colour-Word Test. In subjects categorised as high-sensitive to LFN was noted higher value of the reading interference index during exposure to LFN than in the reference noise, while in case of persons low-sensitive was observed reversed relation.
- Regardless of noise exposure, differences related to LFN sensitivity were found in the case of some variables from the Stroop Colour-Word Test as well as in the Continuous Attention Test. In the latter test, subjects classified as high-sensitive to LFN during exposure to LFN showed tendency to make more errors than other subjects, while in the reference noise there were no difference related to noise sensitivity.
- To sum up, LFN at levels normally occurring in the industrial control rooms may adversely affect cognitive performance tasks, and subjects classified as high-sensitive to LFN may be at highest risk. The findings presented here are thus in agreement with previous studies on the LFN effects on performance [8–10].

Acknowledgment

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