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A Study of Annoyance Caused by Low-Frequency Noise During Mental Work

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This article presents the results of an analysis of annoyance caused by low-frequency noise (including infrasonic noise) that occurs at work stations located in offices. The tests covered measurements of acoustic parameters specific for this type of noise and a survey conducted in the working environment and in laboratory conditions at a model of a work station.

low-frequency noise   annoyance   working environments

1. INTRODUCTION

Low-frequency noise (including infrasonic noise) is one of the most harmful and annoying factors that occurs in human working and living environments [1, 2, 3].

Infrasonic noise values permissible in the work environment (especially for industrial conditions), included in the regulation of the Minister of Labor and Social Policy regarding the highest permissible concentrations and intensities of health damaging factors in the work environment, were established due to the health damaging effect of this sound (mainly the influence of infrasound on hearing and the entire body). Permissible values of infrasonic noise at work stations in Poland are as follows: equivalent G-weighted sound pressure level normalized to a nominal 8-hr working day, $L_{\text{G eq, 8 hr}}$ = 102 dB, unweighted peak sound pressure level, $L_{\text{LIN peak}}$ = 145 dB [4]. These values are valid for all work stations irrespective of the character of the work. Lower permissible values ($L_{\text{G eq, 8 hr}}$ = 86 dB, $L_{\text{LIN peak}}$ = 135 dB) are only valid for pregnant women and young persons [5].

At the moment there are no criteria concerning annoyance caused by low-frequency and infrasonic noise in the work environment. This is especially noticeable at work stations where mental work takes place or attention is required.

The effect of annoyance that occurs even when the audibility threshold is only slightly exceeded is the dominating effect of the influence of low-frequency and infrasonic noise on the human body during occupational exposure [2].

Tests of the influence of infrasound and low-frequency sound on the human body have been conducted in Poland for many years at the Nofer Institute for Occupational Medicine in Łódź, the Building Research Institute in Warsaw, the AGH

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University of Science and Technology in Kraków and the Central Institute for Labour Protection – National Research Institute (CIOP-PIB) in Warsaw. Those conducted at CIOP-PIB will be discussed later in this paper.

2. METHODOLOGY

The study included tests of the effect of annoyance caused by infrasound and low-frequency noise, mainly in office/administration rooms at work stations for mental work, which requires attention. The tests of the effect of annoyance caused by low-frequency noise in the work environment and in laboratory conditions were conducted concurrently (Figure 1).

As tests and own observations show, approximately 50% of complaints of noise in office facilities are related to low-frequency noise from equipment and machines installed inside or outside the building. Low-frequency noise that causes those complaints is usually generated by the air conditioning or ventilation systems (operation of fans and ice water pumps, etc.), IT network equipment and hardware (crossover cabinets, servers, etc.), transformers located inside the building, lifts and street traffic, especially if it is heavy. Significant effects of annoyance at work caused by low-frequency noise are especially experienced and reported by employees performing mental work, precision work or work that requires attention, e.g., WAN (wide area network) administrators (administrators of information and signal transfer networks in banks, cellular telephony operators, etc.), air traffic controllers, white-collar employees executing responsible and complex analytical processes (e.g., financial and legal advisors in banks), researchers [6, 7].

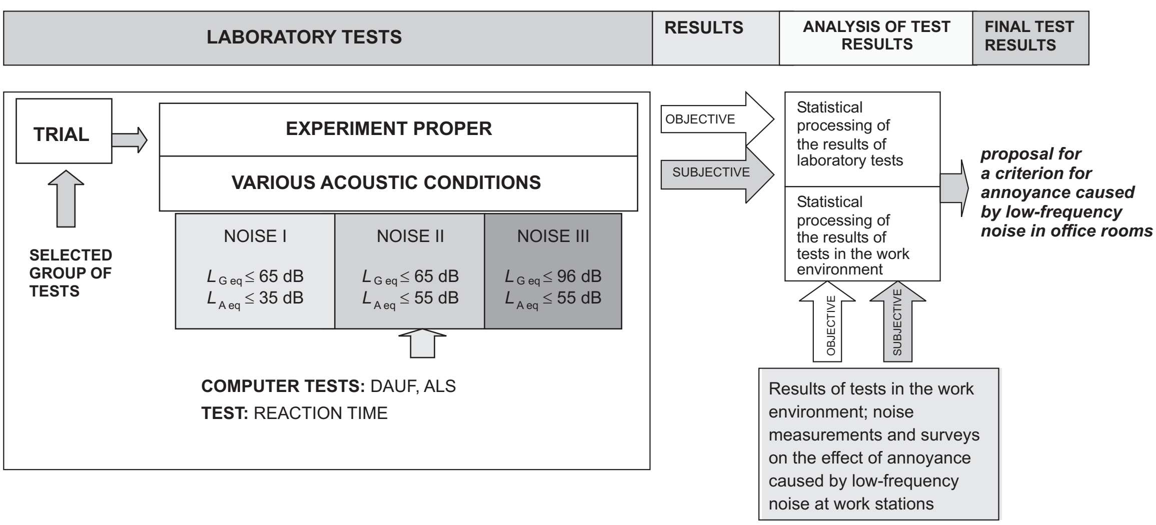

Figure 1. A general diagram of the study of the effect of annoyance caused by low-frequency noise. *Notes*. Noise I—computer noise, noise II—low-frequency noise, noise III—noise with infrasound components

3. PILOT TESTS OF LOW-FREQUENCY NOISE IN OFFICE FACILITIES

Pilot tests of noise conducted by CIOP-PIB in office buildings showed that many employees complained about annoying, irritating, disturbing and tiresome infrasound or low-frequency noise, which also caused excessive sleepiness, even though permissible values were not exceeded.

Figure 2 shows examples of noise spectra for two work stations, where the effect of annoyance resulting from low-frequency noise was reported. Lines A and A1 show the spectra of noise generated by air conditioning equipment. Once

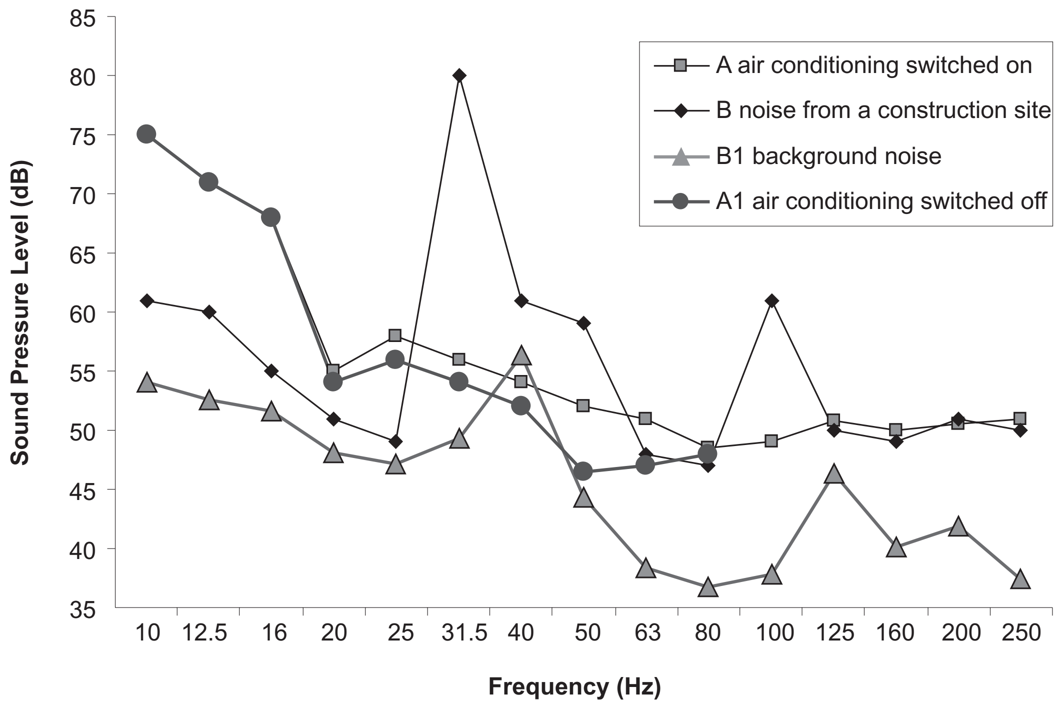

Figure 2. Spectra of low-frequency noise at work stations. *Notes*. A, A1—the level of acoustic pressure in the one-third octave bands at a work station for mental work with air conditioning switched on and off, respectively; B—the level of acoustic pressure in the one-third octave bands at a work station for mental work, noise generated at a nearby construction site; B1—the level of acoustic pressure in the one-third octave bands at a work station for mental work, background noise.

air conditioning was switched off, the acoustic pressure decreased for the frequency of 50 Hz by approximately 5 dB. This is a component of the spectrum which is often indicated by persons exposed to low-frequency noise as particularly annoying. Figure 1 also clearly illustrates significant low-frequency components for the frequency of 31.5 Hz which caused complaints of employees working in the surveyed rooms.

The results of the pilot survey on the tiresomeness of noise in office facilities, which was conducted during the tests in office building showed that most subjects complained about problems with concentration (57.4%), discomfort (44.7%), headaches (21.3%), sleepiness (10.6%) and fatigue (8.5%).

The subjects (23 women and 28 men) were exposed to noise with the equivalent sound pressure level corrected by the frequency-weighting characteristic: A from 41.4 to 65.3 dB (M = 55.3) and G from 64.6 to 82.9 dB (M = 74.2).

4. TESTS IN LABORATORY CONDITIONS

From a group of 189 volunteers, 60 persons (30 women and 30 men) were selected for studying the effect of annoyance caused by low-frequency noise. The subjects were under 26. They had normal hearing and different levels of reactivity, which is a temperamental feature; 30 persons from the selected group were classified as low-reactive, the other 30 as high-reactive.

The subjects (60 persons) took part in an experiment that consisted in completing psychological tests in three different acoustic conditions. The psychological tests checked work performance during intellectual tasks (ALS test [8]) and continuous attention (DAUF test [9]).

A 100-point noise annoyance scale (NAS) [10] (Figure 3) and a survey of sensations and complaints related to exposure to noise (for qualitative assessment) were used to subjectively evaluate sensations related to the influence of low-frequency and infrasonic noise during the course of the experiment [10, 11].

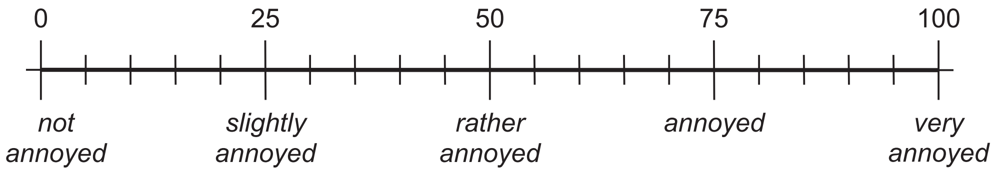

Figure 3. A 100-point noise annoyance scale (NAS) [10].

4.1. Acoustic Signals During Tests in Laboratory Conditions

The subjects performed the aforementioned psychological tests in different acoustic conditions inside a sound-insulated cabin. During the experiment the sources of noise were located outside the cabin. Table 1 and Figure 4 illustrate the acoustic parameters for the consecutive options of acoustic conditions (signals) inside the cabin during the course of the experiment. A single session lasted aproximately 60 min.

4.2. Statistical Analysis

The influence of noise exposure, subjective sensitivity and subjective annoyance ratings were analysed with ANOVA. However, the differences in rates of registered sensations and complaints due to various noise conditions were evaluated with the Kruskal-Wallis one-way ANOVA by ranks test. All statistical tests were done with an assumed significance level of $p < .05$. Statistical analysis was performed with Statistica version 6.0 (StatSoft).

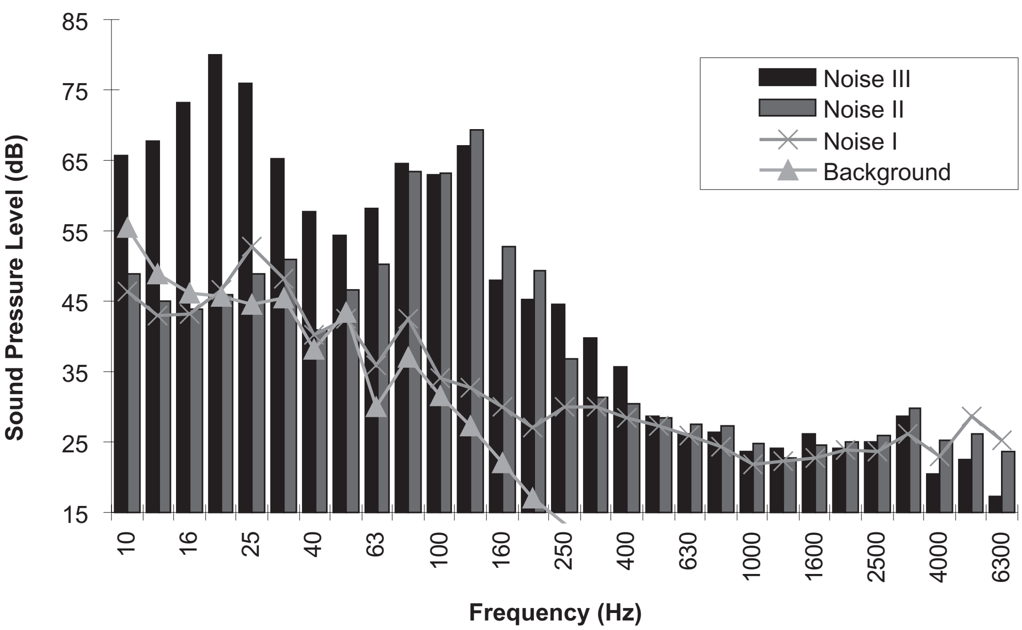

Figure 4. Noise spectra inside the cabin for different experiment options.

TABLE 1. Acoustic Parameters for Individual Acoustic Conditions During Laboratory Tests

Conditions	Parameters Inside the Cabin (dB)		
	$L_{A\ eq,\ T}$	$L_{C\ peak}$	$L_{G\ eq,\ T}$
Acoustic background inside the cabin	22.0	63.5	61.8
Noise I: computer noise	35.0	64.6	62.0
Noise II: low-frequency noise	53.2	82.8	62.1
Noise III: noise with infrasound components	52.9	88.4	90.3

Notes. $L_{G\ eq,\ T}$—equivalent G-weighted sound pressure level over duration T, $L_{C\ peak}$—C-weighted peak sound pressure level, $L_{Aeq,\ T}$—equivalent continuous A-weighted sound pressure level over duration T.

4.3. Results of Subjective Tests in Laboratory Conditions

There was a significant diversification of the subjective assessment of noise annoyance in the individual options of the experiment. Detailed results of statistical analysis show two statistically significant differences in the perception of noise depending on gender and reactivity. The first case relates to the difference between average values on NAS collected after the experiment with noise in a group of women and men. The difference in the perception of noise III (i.e., noise with infrasound components) was 10.73 points and was statistically significant ($F = 6.415$, $p = .014$). Thus, noise III was more tiresome for women than for men. The results of the subjective assessments of the effect of noise annoyance taking into consideration the subjects' gender are shown in Table 2.

The second case relates to the results of the subjective assessments of the effect of noise annoyance by women taking into consideration their reactivity (Table 3).

Detailed results of variance analysis show statistically significant differences in the perception of noise by women with different reactivity. The difference in their perception of the same noise was 14.33 points for noise II and 19 points for noise III, and it was statistically significant ($p = .036$ and $p = .002$, respectively). Thus, persons with different reactivity evaluated the tiresomeness of noise II and noise III differently; it was more tiresome for women with high reactivity than for those low reactivity. However, there were no differences in the assessment of the tiresomeness of low-frequency noise (noise II) and noise with infrasound components (noise III) in groups of women with the same reactivity.

TABLE 2. Basic Results for the Noise Annoyance Scale (NAS) [10] After Three Experiments, and Gender ($N = 30$)

	NAS					
Statistical Parameter	**N I (W)**	**N I (M)**	**N II (W)**	**N II (M)**	**N III (W)**	**N III (M)**
M	16.10	18.13	43.50	34.60	43.50	32.77
Variance	296.71	276.26	359.98	255.56	318.67	220.05
SD	17.23	16.62	18.97	15.99	17.85	14.83
Median	10	19.5	43.5	35	46.5	27.5
Min–Max	0–50	0–80	10–75	13–75	20–75	7–60
Range	50	80	65	62	55	53

Notes. N I—results of tests conducted after the experiment, without the influence of noise I, computer noise; N II—results of tests conducted after the experiment, with the influence of noise II, low-frequency noise; N III—results of tests conducted after the experiment, with the influence of noise III, noise with infrasound components. W—women, M—men. Analysis has shown that the empirical distributions of NAS scores can be approximated with normal distribution. Variances were homogenous.

TABLE 3. Basic Results for the Noise Annoyance Scale (NAS) [10] After Three Experiments, and the Females Subjects' Reaction Level ($N = 15$)

	NAS					
Statistical Parameter	**N I (W LR)**	**N I (W HR)**	**N II (W LR)**	**N II (W HR)**	**N III (W LR)**	**N III (W HR)**
M	13.2	19.0	36.3	50.7	34.0	53.0
SD	15.39	18.97	15.67	19.75	12.83	17.38
Min–Max	0–41	0–50	15–67	10–75	20–50	25–75
Range	41	50	52	65	30	50

Notes. N I—results of tests conducted after the experiment, without the influence of noise I, computer noise; N II—results of tests conducted after the experiment, with the influence of noise II, low-frequency noise; N III—results of tests conducted after the experiment, with the influence of noise III, noise with infrasound components. W LR—women with low reactivity, W HR—women with high reactivity. Analysis has shown that the empirical distributions of NAS scores can be approximated with normal distribution. Variances were homogenous; $B = 1.045$, $P(3.251) = .66$. The calculations show that the values of NAS are statistically significantly different ($F = 13.79$, $p = 0.0000$).

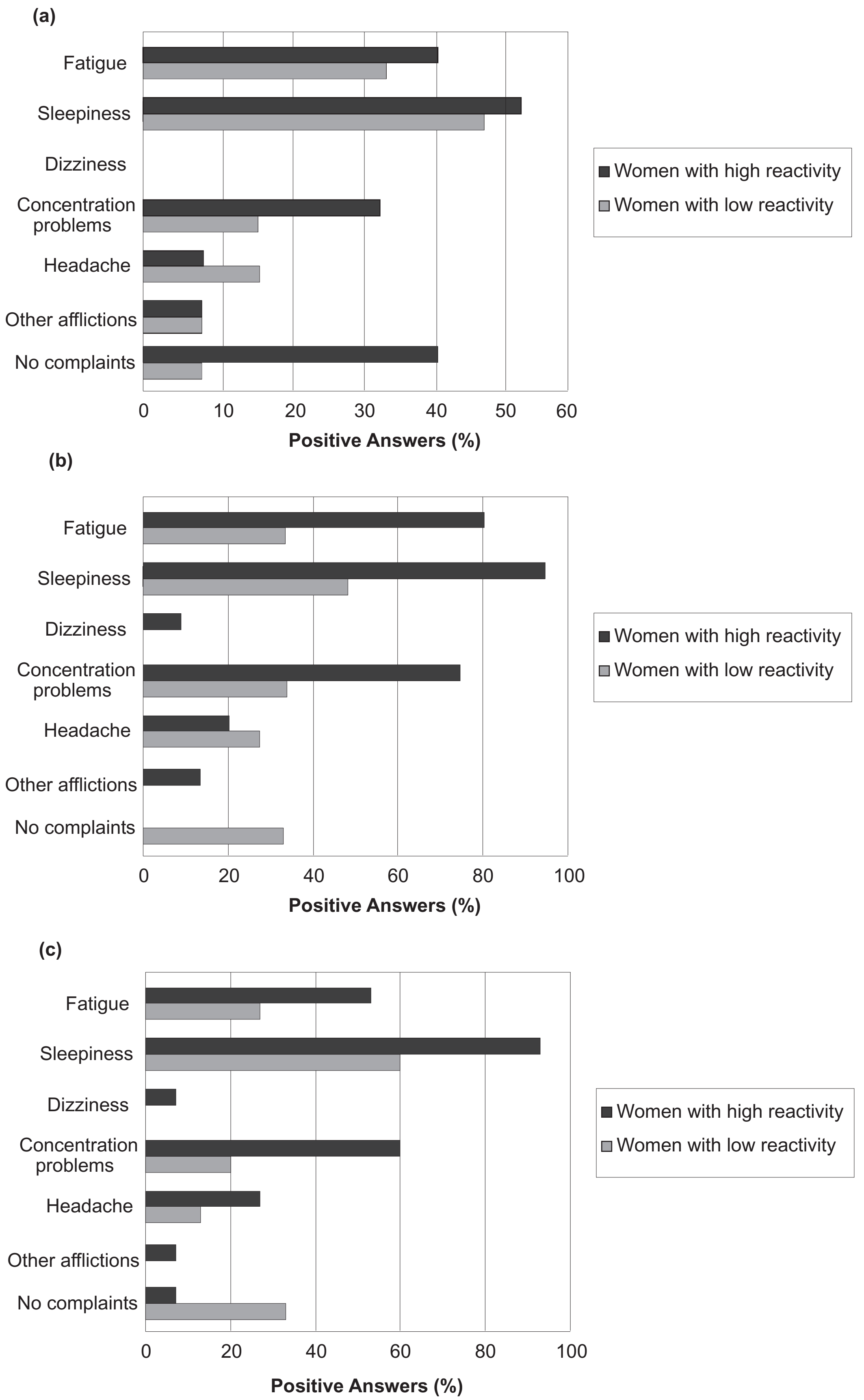

Figure 5. Complaints related to exposure to (a) noise I, (b) noise II, (c) noise III, inside the cabin, subjectively defined during the experiment by female subjects. *Notes.* noise I—computer noise, noise II—low-frequency noise, noise III—noise with infrasound components.

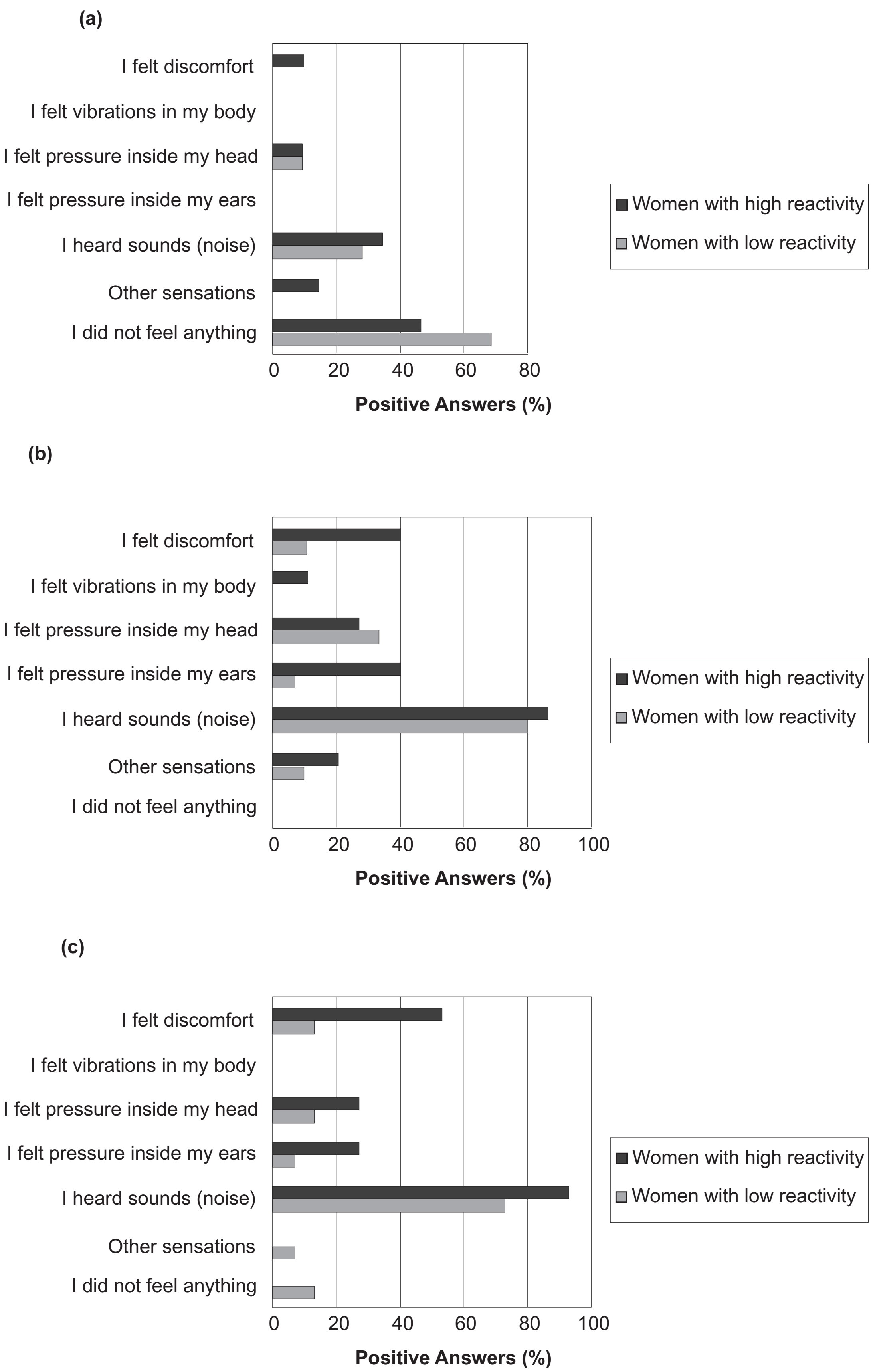

Figure 6. Sensations related to exposure to (a) noise I, (b) noise II, (c) noise III, inside the cabin, subjectively defined during the experiment by female subjects. *Notes*. noise I—computer noise, noise II—low-frequency noise, noise III—noise with infrasound components.

Figures 5 and 6 illustrate noise-related complaints and sensations defined subjectively by women during the experiment. Their distribution according to the reactivity of the women confirms that persons with high reactivity have a greater perception of noise and therefore report a greater number of sensations and complaints, e.g., sleepiness, fatigue, discomfort.

5. CONCLUSIONS

Poorer intellectual efficiency and decreased productivity can be the main results of annoyance caused by infrasound and low-frequency noise. Great individual differences that depend not only on acoustic factors can be observed in reactions to low-frequency noise.

Annoyance caused by noise is influenced by a number of factors, both acoustic and individual, subjective ones, such as personal attitude towards the source of noise (noise acceptance), becoming accustomed, hearing sensitivity and individual sensitivity. Some persons exposed to this type of noise complain of irritation, anxiety and stress.

Tests in laboratory conditions have shown that noise with infrasound components is perceived as more annoying (higher rating on the 100-point NAS) by women than by men.

Detailed tests in laboratory conditions have shown that low-frequency noise and noise with infrasound components is perceived as more annoying (a greater number of reported complaints and sensations, higher rating on the 100-point NAS) by women with high reactivity in comparison to persons with low reactivity.

This regularity occurred in both noise II (noise level: $L_{\mathrm{A\ eq}}$ = 53 dB and $L_{\mathrm{G\ eq}}$ = 62 dB) and in noise III experiment conditions (noise level: $L_{\mathrm{A\ eq}}$ = 53 dB and $L_{\mathrm{G\ eq}}$ = 90 dB). However, we did not observe any significant diversification in the assessment of noise with higher infrasound components in its spectrum (noise III: $L_{\mathrm{A\ eq}}$ = 53 dB and $L_{\mathrm{G\ eq}}$ = 90 dB) and noise with lower infrasound components in its spectrum (noise II: $L_{\mathrm{A\ eq}}$ = 53 dB and $L_{\mathrm{G\ eq}}$ = 62 dB) with groups of women with the same reactivity level.

During laboratory tests a significant number of the subjects (over 50%) complained of problems with concentration, sleepiness and fatigue when working in low-frequency noise. Over 50% of the subjects also reported problems with concentration in the work environment.

Generally one can state that noise which is not tolerable even at low levels (near threshold levels), and which is present in a room occupied by a person with highly sensitive hearing or high reactivity, or a person under stress or internal tension, during mental work, has a great influence on the mental condition and can cause different problems, such as the vibroacoustic disease [3, 7]. This disease is defined as systemic pathology observed as a result of excessive and long-term exposure to high intensity infrasound and low-frequency noise [12]. It can lead to disorders of complex intellectual processes, which can in turn result in decreased intellectual efficiency and disturbances of the said intellectual efficiency [13]. This problem requires further studies.

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