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NOISE EXPOSURE AND HEARING STATUS AMONG EMPLOYEES USING COMMUNICATION HEADSETS

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Abstract
Objectives: The objective of this study was to assess the hearing of employees using communication headsets with regard to their exposure to noise. **Material and Methods:** The study group comprised 213 employees, including 21 workers of the furniture industry, 15 court transcribers and 177 call center operators, aged 19–55 years, working with headsets for a period of up to 25 years. All the participants underwent a standard pure-tone audiometry, extended high-frequency audiometry (EHFA) as well as transient-evoked otoacoustic emissions (TEOAEs) and distortion-product otoacoustic emissions (DPOAEs). Noise exposure from headsets was evaluated using the microphone in a real ear technique according to PN-EN ISO 11904-1:2008. **Results:** Personal daily noise exposure levels ranged 57–96 dB and exceeded 85 dB only in 1.4% of the call center operators. Forty-two percent of the participants had bilateral normal hearing in the standard frequency range of 250–8000 Hz, and 33% in the extended high-frequency range of 9–16 kHz. It was found that DPOAEs were present bilaterally in 59% of the participants. Reproducibility of TEOAE at >70% and signal-to-noise ratio at >6 was exhibited by 42% and 17% of them, respectively. The 3 subgroups of workers differed in age, gender, noise exposure and type of headsets in use. However, after adjusting for age and gender, significant differences between these subgroups in terms of hearing were mostly visible in EHFA. A significant impact of age, gender, daily noise exposure level and current job tenure on hearing tests results was also noted among the call center operators and the transcribers. The most pronounced were the effects of age and gender, whereas the impact of the daily noise exposure level was less evident. **Conclusions:** It seems that EHFA is useful for recognizing early signs of noise-induced hearing loss among communication headset users. However, further studies are needed before any firm conclusions concerning the risk of hearing impairment due to the use of such devices can be drawn. Int J Occup Med Environ Health. 2022;35(5):585–614

Key words:
noise-induced hearing loss, pure-tone audiometry, otoacoustic emissions, communication headsets, occupational exposure to noise, extended high-frequency audiometry

INTRODUCTION

Nowadays, more and more people regularly use wired and wireless communication headsets and other wearable hearing devices at work. They are found in call centers, retail stores, drive-through restaurants, airport ground and control tower operations, industrial and construction sectors, military sites, as well as occupations such as radio operator, pilot and transcriber [1].

Some workers, such as call center operators, use hands-free communication headsets or low attenuation devices in an environment where the background noise is not so significant. Others, as exemplified by airline pilots or military personnel, wear noise-reducing headsets or advanced technologies, to attenuate very loud ambient noise and enhance the communication signal [1]. What's more, in both cases, workers are not only exposed to

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the surrounding workplace noise, but also to the internal audio communication signals from the devices they are wearing. When active, the audio channel is the dominant source of exposure.

Traditional methods for measuring noise levels in occupational settings (e.g., those described in PN-EN ISO 9612:2011 [2]) are not suitable for evaluating noise exposure under communication headsets. Specialized methods applicable to measurements under occluded ears have been specified by the International Organization for Standardization, such as the microphone in a real ear (MIRE) technique (PN-EN ISO 11904-1:2008) and the manikin technique (PN-EN ISO 11904-2:2009) [3,4]. In addition, simpler methods have also been proposed in some national standards such as the use of general purpose artificial ears and ear simulators in conjunction with a single number or one-third-octave band procedure to convert measurements to the equivalent diffuse or free field (AS/NZS 1269.1:2005, CSA Z107.56-18) [5,6].

Results from field studies indicate that, depending on the type of communication headsets, job tasks carried out and background noise levels, the A-weighted equivalent continuous sound pressure levels (SPLs) measured under headphones may vary from several dozen to >100 dB and could exceed regulatory limits in some cases, especially in noisy environments [7,8].

The wide range variability of the sound level produced by the communication headsets, the diversity of external acoustic conditions and the ability to generate some sudden, short-term, loud sounds (so-called acoustic shocks) in the headphones are associated with the risk of auditory and non-auditory effects of noise. In particular, professional users of communication headsets may experience involuntary response and discomforts due to acoustic shock, i.e., acoustic shock disorder (ASD), the typical symptoms of which are temporary earaches, tinnitus, auditory hypersensitivity (phonophobia), headaches and dizziness, feelings of blocking ears, numbness or burning around the ears, as well as emotional reactions, including anxiety and depression [9]. In turn, the long-term exposures, through headsets, to noise (sounds) at levels of >85 dB, similar to such exposures from other sources, are associated with the risk of noise-induced hearing loss (NIHL). A number of previous reports, presenting the results of noise measurements under communication headsets, suggested the potential for, but did not confirm the occurrence of, hearing damage among workers exposed to noise generated by communication headsets.

The golden standard in the diagnosis of NIHL is a standard pure-tone audiometry (PTA) usually performed in the frequency range of 250–8000 Hz. However, this test enables detection of the hearing loss no sooner than when the cochlea damage is irreversible. It has been shown that hearing thresholds in the extended high-frequency range (>8 kHz) might, in fact, be affected by noise earlier, which means that extended high-frequency audiometry (EHFA) may identify individuals with an initial hearing loss not yet visible in the conventional audiometry. Therefore, it can be useful for diagnosing early signs of NIHL [10,11]. Another method that could be used to monitor early signs of NIHL – in addition to PTA rather than instead of it – can be the measurement of otoacoustic emissions (OAEs), since they can give information about weakened functions of cochlea before the problems are seen in audiograms [12].

Otoacoustic emissions are weak acoustic signals generated in the inner ear and registered in the outer ear, whose measurement is used as an objective hearing test. They occur either in response to an acoustic stimulus or spontaneously [12]. However, it has not been adequately established yet if OAEs, especially the transient-evoked otoacoustic emissions (TEOAEs) and distortion-product otoacoustic emissions (DPOAEs), can be applied as diagnostic tools for communication headsets users.

However, despite the wide use of communication headsets in various occupational settings, a relatively small number of studies have, to date, been performed concerning the risk of NIHL among their users [13–20]. The majority of these investigations were focused on call center operators and their outcomes are rather inconclusive.

For example, alarming data come from the recently published paper presenting a case study of a 30-year-old man who was diagnosed with NIHL after 50 months of work as a home agent for 6 days/week 8 h/day [16]. In contrast, a different conclusions can be formulated from a study by Ayugi et al. [17], who surveyed 1351 call-center operators in East Africa for symptoms of acoustic shock syndrome and noticed NIHL in <2% of workers.

Therefore, the main objective of the present study was to evaluate the hearing of employees of 3 different branches using communication headsets in relation to their exposure to noise. The further purpose was to explore the factors which have an impact on hearing assessed with conventional PTA and EHFA as well as TEOAEs and DPOAEs.

MATERIAL AND METHODS

A cross-sectional study including noise measurements, questionnaire surveys and hearing tests was carried out among employees of 3 call centers, a court and a furniture factory, who regularly used communication headsets. The study group comprised 213 subjects in total, including furniture industry workers (N = 21), court transcribers (N = 15) and call center operators (N = 177).

The participation in the study was voluntary. The subjects were recruited by advertisement. They obtained some remuneration and certified in writing their consent to participate in the research. The study design and methods were approved by the Ethics Committee of the Nofer Institute of Occupational Medicine of Lodz, Poland (decision No. 17/2018 of November 20, 2018).

Hearing tests

All participants underwent standard PTA and EHFA, as well as otoacoustic measurements, specifically TEOAEs and DPOAEs. Prior to hearing examinations, otoscopy was performed. Only the subjects who met the inclusion criteria, i.e., a normal otoscopy picture, a lack of a history of chronic ear diseases, head injury and ototoxic drugs, were included into the study.

Hearing threshold levels (HTLs) for each ear were determined for both standard frequencies of 0.125–8 kHz and extended frequencies of 9–18 kHz with 5 dB steps. The bracketing method as specified in PN-EN ISO 8253-1:2011 [21] was used in the case of PTA. A similar methodology was applied for EHFA. However, in the latter case, the initial familiarization was performed using a tone of 11.2 kHz. The order of tones was from 11.2 upwards to 18 kHz, followed by the lower frequency range, in the descending order (i.e., from 11.2 to 8 kHz). However, HTLs at 18 kHz were not included in the analysis due to many missing data.

The prevalence of normal and high-frequency notched audiograms, as well as high-frequency and speech-frequency hearing losses, and extended high-frequency hearing threshold shifts were analyzed in the study subjects (and, more specifically, in their ears). Normal hearing was defined as having HTLs of 0.25–8 kHz ≤20 dB HL. The speech-frequency and high-frequency hearing loss was defined as the pure-tone mean of >20 dB HL at 0.5 kHz, 1 kHz, 2 kHz and 4 kHz, and 3 kHz, 4 kHz and 6 kHz, respectively. In turn, the participants with the mean permanent hearing threshold at 9 kHz, 10 kHz, 11.2 kHz, 12.5 kHz, 14 kHz, and 16 kHz of >20 dB HL were considered to have the extended high-frequency hearing threshold shift. According to Cole's recommendation, a high-frequency notch was defined as a hearing threshold level at 3 and/or 4 kHz and/or 6 kHz of ≥10 dB HL greater than at 1 kHz or 2 kHz and at 6 kHz or 8 kHz [22].

The standard PTA was always determined first, followed by EHFA. In both cases, the right ear was tested first. The hearing examinations were conducted with the VID-

EOMED Smart Solution (Szczawno-Zdrój, Poland) clinical audiometer, model AUDIO 4002 with the Holmberg GmbH & Co. KG Electroacoustics (Berlin, Germany), headphones type HOLMCO PD-81 for the PTA, and the Sennheiser Electronic GmbH & Co. KG (Wedemark, Germany) headphones type HAD 200 for EHFA.

A Scout Otoacoustic Emission System v. 3.45.00 (Biologic System Corp., Mundelein, IL, USA) was applied to record and analyze otoacoustic emissions. For TEOAE measurements, standard click stimuli at the SPL of about 80 dB were generated. Each response was windowed 3.5–16.6 ms post stimulus and band-pass filtered at 0–6000 Hz. The total number of stimuli was 260. The artifact rejection level was set at 20 mPa. The amplitude and reproducibility of the response, as well as the noise floor during measurements of TEOAEs and corresponding signal-to-noise ratios (SNRs), were determined for the overall frequency range and for half-octave bands with central frequencies of 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz. The SNR of >6 dB and reproducibility of >70% were adopted as the criteria of the TEOAE presence.

For DPOAE testing, a stimuli in a form of a 2-tone was used with the fixed ratio of frequencies f_1 and f_2 ($f_1/f_2=1.22$), and the intensity levels L_1 and L_2 of 65 dB and 55 dB, respectively. The amplitudes of registered signals were determined at the $2f_1–f_2$ frequencies as a function of f_2 frequencies (ranging approx. 1500–10 000 Hz in one-fourth-octave intervals), together with the noise floor and corresponding SNR. The DPOAE signals were considered present if the SNR was >6 dB.

The presence and absence of TEOAEs and DPOAEs, as well as the mean values of the TEOAE and DPOAE parameters (i.e., amplitude of responses, SNRs and reproducibility, where applicable) were analyzed in the study subjects.

Hearing examinations were carried out by the same investigator in the quiet rooms located close to the participants' workplaces (where the A-weighted equivalent-continuous SPL of the background noise level did not exceed 35 dB). The auditory rest before audiological evaluations lasted 14 h.

Questionnaire surveys

The study subjects were asked to fill in a questionnaire developed to enable identification of risk factors for NIHL and self-assessment of the hearing status. In particular, the questionnaire consisted of items on:

- demographic data;
- education and/or profession;
- work history, including duration of employment/exposure to noise and/or use of headsets at current and previous workplaces;
- data concerning the current job (details of work pattern and equipment used, preferred volume control setting, type of calls typically handled, etc.);
- medical history (past middle-ear diseases, and ear surgery, hereditary disorders, cholesterol levels, arterial hypertension, head trauma, etc.);
- physical features (body weight, height, skin pigmentation);
- lifestyle (smoking, noisy hobbies, using portable media players, attending discobars, rock concerts etc.);
- hearing-related symptoms such as hearing impairment, difficulties in hearing or understanding whisper, normal speech and speech in noisy environment, as well as the presence of tinnitus and hyperacusis.

In addition, subjects' hearing ability was assessed using a (modified) Amsterdam Inventory for Auditory Disability and Handicap ([m]AIADH) [23]. This questionnaire is divided into 5 parts (subscales) assessing separately:

- the ability of discrimination of sounds (subscale I),
- auditory localization (subscale II),
- understanding speech in noise (subscale III),
- intelligibility in quiet (subscale IV),
- detection of sounds (subscale V).

However, the results of the aforesaid questionnaires will be presented elsewhere.

Noise exposure evaluation

In order to evaluate the noise exposure of the study subjects, noise levels generated by their headsets and background noise levels were measured, and data on typical working patterns were gathered as well. The following noise parameters were determined according to PN-N-01307:1994 [24] and PN-EN ISO 9612:2011 [2]:

– A-weighted equivalent-continuous SPL,
– A-weighted maximum SPL with S (slow) time constant,
– C-weighted peak SPL.

The SPLs emitted by communication headsets were determined using the MIRE technique and artificial ear technique according to PN-EN ISO 11904-1:2008 [3] and CSA Z107.56-18 [6], respectively. However, the latter method was only applied for some of the study subjects, namely for some call center operators and all transcribers. The results of noise exposure evaluation using the artificial ear technique will be presented elsewhere.

According to PN-EN ISO 11904-1:2008 [3], a miniature probe microphone, the SVANTEK type SV25S (connected to 1 of the 2 available inputs of the dual-channel acoustic dosimeter type SV102) was placed at the entrance of the open ear canal of employees, and the aforesaid noise parameters together with SPLs in one-third-octave bands (20–10 000 Hz) were determined. Simultaneously, the second channel of dosimeter (equipped with a SVANTEK standard half-inch microphone type SV25D) was used for assessing noise exposure outside the headphone or close to the ear without a headphone.

Results of the frequency analysis in one-third-octave bands under headphones were then converted into corresponding free-field (and diffuse-field) levels to obtain the free-field-related (and diffuse-field-related) A-weighted SPLs. For each participant, 2 × 6 noise samples lasting approx. 2 ×30 min in total were collected separately for both headsets and background noise. Since a number of subjects used single-ear headsets, noise exposure was assessed separately for the left and right ear. A task-based measurement strategy according to PN-EN ISO 9612:2011 [2] was applied for noise exposure evaluation.

Data analysis

The frequency of specific answers given to the questionnaire in various subgroups of the study subjects, as well as the prevalence of some outcomes of hearing tests (e.g., incidence of absent DPOAEs or notched audiograms) were presented as proportions with 95% confidence intervals (95% CI), while the differences between them were compared in pairs using the χ^2 test.

Differences in hearing tests results (e.g., mean values of audiometric HTLs) between the subjects' left and right ears were explored using the t-test for dependent samples or the Wilcoxon singed-rank test, where applicable. In turn, the independent-samples t-test or the Mann-Whitney U test was applied for pairwise comparisons of the mean values of different variables such as age, tenure and daily noise exposure level in 3 subgroups of employees. In turn, the possible relations between variables (e.g., subjects' age and tenure) were evaluated using the Pearson's correlation coefficient.

A covariance analysis (ANCOVA) was applied to evaluate the differences in hearing tests' results in 3 subgroups of workers. One main effect, i.e., a type of work performed (3 occupational groups) was analyzed with age and gender as covariates, supplemented by the *post hoc* Tukey test for unequal N (or the Taman test where applicable).

On the other hand, the main effects analysis of variances (ANOVA) was used to analyze the first-order (non-interactive) effects of multiple factors such as: gender, age (or tenure) and daily noise exposure level on the results of hearing tests. For this purpose, a part of the study group (comprising call center operators and transcribers) was divided into subgroups according to gender (females vs. males), age (younger vs. older subjects), and noise exposure (subjects with lower vs. higher daily noise exposure levels) or tenure (a shorter vs. longer period of usage of communication headsets). The median values of age, daily noise exposure levels and tenure (at the current workplace) in the aforesaid subgroups of workers provided the basis for the classification of subjects. The differences between the aforesaid subgroups of the study subjects were assessed using the *post hoc* Tukey honestly significant difference test or the Taman test (if the assumption of variance homogeneity was not met).

The Statistica v. 9.1. (StatSoft Inc., USA) software package was used for statistical analysis. All the tests were conducted with an assumed $p < 0.05$ significance level, excluding the comparison in pairs (e.g., using the χ^2 test or the Mann-Whitney U test) where the p-value divided by the number of possible comparisons was set as the limit for statistical significance.

RESULTS

Study group characteristics

The study group comprised 213 regular users of communication headsets, including 177 call center operators, 15 transcribers, and 21 furniture industry workers employed in 3 call centers, in a district court and in a furniture factory. As to the gender, 54.5% of them were males. Their age ranged 19–55 years with the mean and standard deviation (SD) equal to 30.9 years and 7.5 years, respectively. The participants were employed at the current workplace for 1 month–25 years and used communication headsets regularly for 2–10 h/day (Table 1).

Generally, about a half of the study subjects had higher education. However, all the transcribers were university graduates, while only 1 furniture industry worker had higher technical education. The majority of the call center operators had high school education. The call center operators were considerably younger than the transcribers and the furniture industry workers. However, there were no significant differences in age between the transcribers and the furniture industry workers. The latter subgroup comprised only males equipped with communication headsets with a highly attenuated ear protection (i.e., hearing protection devices with a 2-way radio communication system). In turn, all the transcribers used binaural headphones or headsets, while the call center operators worked with binaural (32.8%) and monaural headsets (67.2%). About one-fourth of those using single-ear headsets put the headphone alternately on both ears, while the others put it always on the same preferred right (27.4%) or left ear (41.0%) (Table 1).

Basically, there were no significant differences between the subgroups in medical history and the prevalence of additional NIHL risk factors such as smoking, elevated blood pressure and light skin pigmentation [8]. Similar relationships were observed when analyzing some aspects of lifestyle, including frequent (at least a few times a month) attending music clubs, pubs or loud music concerts and having noisy hobbies (shooting, paintball, motor sports, use of a noisy tool, etc.) (Table 1). However, only a significantly higher percentage of call center operators, as compared to transcribers and furniture industry workers, declared frequent (several times a week or everyday) listening to music through the personal media players for at least 1 h/day (Table 1).

Noise exposure evaluation

Table 2 summarizes measurement results of the background noise (i.e., the noise occurring outside the headphone or close to the ear without the headphone) and the noise from communication headsets. In particular, it presents both uncorrected and corrected – free-field- and diffuse-field-related A-weighted equivalent-continuous SPLs measured using the MIRE technique.

According to the collected data, communication headsets generated noise at the free-field-related A-weighted

Table 1. Characteristics of employees using communication headsets, participating in the study carried out in 3 call centers, a court and a furniture company

Variable	Participants (N = 213)			
	call center operators (N = 177)	transcribers (N = 15)	furniture industry workers (N = 21)	total
Males [%]	48.6^{a}	60.0^{b}	100.0^{a,b}	54.5
Age [years] (M±SD)	29.2±6.8^{a,c}	38.0±0.8^{c}	39.2±7.8^{a}	30.9±7.5
Education [%]				
higher (university/others)	23.9	100.0	4.8	26.9
upper secondary (general/vocational)	58.5	0.0	47.6	53.3
others	4.0	0.0	47.6	8.0
Tenure [years] (M±SD)				
current	3.7±3.3^{a,c}	4.9±1.2^{b,c}	12.7±7.8^{a,b}	4.7±4.7
overall	6.6±5.8^{a,c}	13.4±3.8^{c}	16.7±6.0^{a}	8.3±6.7
Type of employment [%]				
full-time job	58.3	100.0	100.0	65.4
part-time job	26.3	0.0	0.0	21.8
others	14.3	0.0	0.0	11.8
Type of communication headsets [%]				
binaural headphones	32.8	100.0	100.0	44.3
monaural headphones	67.2	0.0	0.0	55.7
Use of communication headsets (M±SD)				
duration [years]	3.7±3.2^{a,c}	4.8±1.2^{b,c}	12.7±7.8^{a,b}	4.7±4.7
time				
h/day	5.8±1.8^{a}	6.3±1.1^{b}	7.9±0.2^{a,b}	6.1±1.8
h/week	28.5±9.9^{a}	32.5±5.1^{b}	38.2±4.5^{a,b}	29.7±9.7
volume settings [%]	69.1±22.3^{a}	77.5±16.0^{b}	40.0±18.1^{a,b}	66.1±23.6
Prevalence of risk factors for noise-induced hearing loss (NIHL) [%] (95% CI)				
frequently attending music clubs, pubs, loud music concerts, etc.	42.9 (35.9–50.3)	20.0 (6.5–46.1)	19.0 (7.3–40.7)	39.0 (32.7–45.7)
frequently using personal media player at least 1 h daily	34.5 (27.9–41.7)^{a,c}	6.7 (0.01–31.8)^{c}	9.5 (1.6–30.4)^{a}	30.0 (24.3–36.5)

Table 1. Characteristics of employees using communication headsets, participating in the study carried out in 3 call centers, a court and a furniture company – cont.

Variable	Participants (N = 213)			
	call center operators (N = 177)	transcribers (N = 15)	furniture industry workers (N = 21)	total
Prevalence of risk factors for noise-induced hearing loss (NIHL) [%] (95% CI) – cont.				
noisy hobby (shooting, practicing noisy motor sports, using noisy tools, etc.)	6.2 (3.4–10.9)	20.0 (6.5–46.1)	0.0	6.6 (3.9–10.9)
smoking	35.6 (28.9–42.9)	33.3 (15.2–58.5)	33.3 (17.2–54.8)	35.2 (29.1–41.9)
elevated blood pressure	8.5 (5.1–13.6)	6.7 (0.01–31.8)	0.0	7.5 (4.6–12.0)
light skin pigmentation	19.2 (14.1–25.7)	26.7 (10.7–52.5)	19.0 (7.3–40.7)	19.7 (14.9–25.6)

[a] Significant differences between the call centre operators and the furniture industry workers ($p < 0.05/3 = 0.0167$).
[b] Significant differences between the transcribers and the furniture industry workers ($p < 0.05/3 = 0.0167$).
[c] Significant differences between the call centre operators and the transcribers ($p < 0.05/3 = 0.0167$).
Generally, tests were conducted with an assumed $p < 0.05$ significance level. However, in the case of comparisons in pairs (e.g., using the χ^2 test and the independent-samples t-test or the Mann-Whitney U test), the p-value ($p < 0.05$) divided by the number N (N = 3) of possible comparisons was set as the limit for statistical significance.

equivalent-continuous SPLs ($L_{Aeq, T, FF}$) ranging 58–97 dB, while diffuse-field-related A-weighted equivalent-continuous SPLs ($L_{Aeq, T, DF}$) remained within the 57–95 dB range. In turn, the background noise levels ranged 50–95 dB. The highest $L_{Aeq, T, FF}$ levels (65–97 dB) were measured under headsets used by call center operators, while the lowest levels (58–81 dB) under those used by transcribers. The latter subgroup of the study subjects were working in the lowest background noise level conditions, whereas furniture industry workers – in the most noisy environment (50–63 dB vs. 82–95 dB, $p < 0.05/3 = 0.0167$).

As mentioned earlier, the subjects worked with communication headsets for 2–10 h/day and some of them (i.e., a number of call center operators) used single-ear headsets with the headphone worn alternately on both ears or always on the same preferred ear. Subsequently, the individual daily noise exposure levels ($L_{EX, 8h}$), calculated separately for the right and left ears of all study subjects based on the free-field-related headset and background noise levels, ranged 57–96 dB. There were no significant differences between the $L_{EX, 8h}$ levels determined for the left and right ears of the study subjects.

The Polish maximum admissible intensity (MAI) value for occupational noise ($L_{EX, 8h} = 85$ dB) [25] was exceeded (for at least 1 ear) in the case of 1.4% of the call center operators. The $L_{EX, 8h}$ levels higher than the lower exposure action value ($L_{EX, 8h} = 80$ dB) based on Directive 2003/10/EC [26] were noted in the case of 7.3% of the call center operators. None of the furniture industry workers was exposed to noise at levels >85 dB, while only 9.5% of them were exposed to the $L_{EX, 8h}$ levels of >80 dB. In turn, the noise levels of <80 dB were noted in the case of all transcribers (Figure 1).

The A-weighted maximum SPLs ($L_{A max}$) and C-weighted peak SPLs ($L_{C peak}$) measured outside the headphone or close to ear without the headphone did not exceed the MAI values which are equal to 115 dB and 135 dB,

Table 2. Noise measurements in call centre operators, transcribers and furniture industry workers involved in the study

Variable	Noise parameters [dB]											
	call center operators (N = 177, 354 ears)			transcribers (N = 15, 30 ears)			furniture industry workers (N = 21, 42 ears)			total (N = 213, 426 ears)		
	M±SD	Me	L_{eq}	M±SD	Me	L_{eq}	M±SD	Me	L_{eq}	M±SD	Me	L_{eq}
A-weighted daily noise exposure level	73.2±4.6^{a}	73	77.1	67.0±7.7^{a,b}	68	72.9	73.9±4.1^{b}	74	75.8	72.8±5.1	73	76.8
MIRE technique												
free-field-related A-weighted equivalent-continuous SPL	77.0±4.0^{a}	77	80.2	68.1±7.5^{a}	69	73.9	74.0±4.1	74	75.9	76.1±5.0	77	79.7
diffuse-field-related A-weighted equivalent-continuous SPL	76.3±3.9^{a}	77	79.0	67.4±7.5^{a,b}	68	73.2	73.6±4.1^{b}	74	75.5	75.4±4.8	76	78.5
uncorrected A-weighted equivalent-continuous SPL	78.8±3.7^{a,c}	79	80.3	69.9±7.5^{a}	70	75.6	75.0±4.0^{c}	76	76.8	77.8±4.8	78	79.8
uncorrected maximum A-weighted SPL	91.0±5.8^{a}	91	-	80.3±6.1^{a,b}	81	-	90.7±4.0^{b,c}	90	-	89.3±6.7	90	-
uncorrected peak C-weighted SPL	112.9±8.2^{a,c}	111	-	104.9±6.2^{a,b}	105	-	128.4±4.1^{b,c}	129	-	115.0±10.5	112	-
Background noise (outside the headphone or close to ear without a headphone)												
A-weighted equivalent-continuous SPL	69.5±3.7^{a,c}	68	71.6	56.0±3.4^{a,b}	55	57.3	88.4±3.4^{b,c}	88	89.6	70.4±7.8	68	80.1
A-weighted maximum SPL	88.6±5.3^{a,c}	89	-	74.0±7.4^{a,b}	72	-	103.8±6.7^{b,c}	104	-	89.8±11.5	90	-
C-weighted peak SPL	109.3±5.7^{a,c}	109	-	102.8±6.8^{a,b}	103	-	129.0±8.7^{b,c}	128	-	113.1±11.7	109	-

L_{eq} – energy average of the samples measured with A-weighted equivalent-continuous SPL; MIRE – microphone in a real ear; SPL – sound pressure level.

[a] Significant differences between the call centre operators and the transcribers ($p < 0.05/3 = 0.0167$).

[b] Significant differences between the transcribers and the furniture industry workers ($p < 0.05/3 = 0.0167$).

[c] Significant differences between the call centre operators and the furniture industry workers ($p < 0.05/3 = 0.0167$).

Generally, tests were conducted with an assumed $p < 0.05$ significance level. However, in the case of comparisons in pairs (i.e., using the independent-samples t-test or the Mann-Whitney U test), the p-value ($p < 0.05$) divided by the number N (N = 3) of possible comparisons was set as the limit for statistical significance.

respectively [25]. The $L_{A\ max}$ and $L_{C\ peak}$ levels determined directly under headphones were also lower than the aforesaid limit values (Table 2).

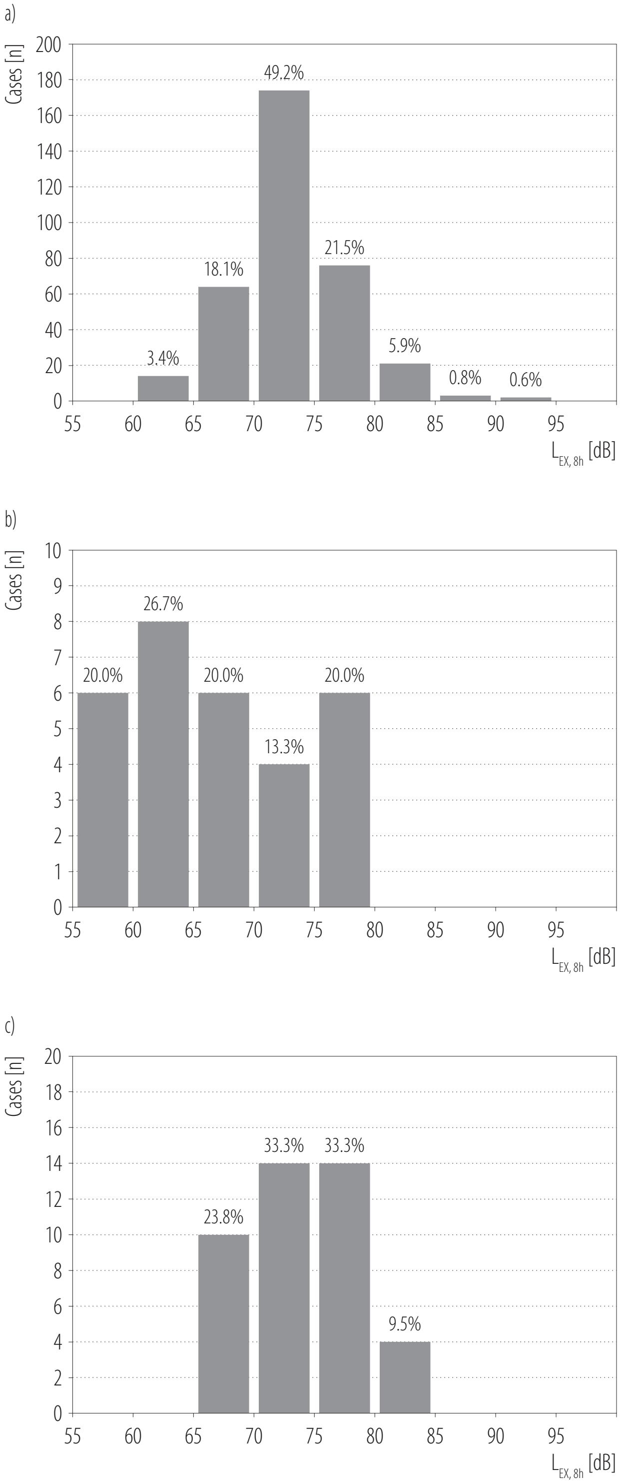


Figure 1. Distributions of the A-weighted daily noise exposure levels ($L_{EX, 8h}$) in 3 groups of employees regularly using communication headsets, i.e., a) call center operators (N = 177, 354 ears), b) transcribers (N = 15, 30 ears), and c) and furniture industry workers (N = 21, 42 ears)

Results of hearing examinations

Audiometric tests

Generally, 42.3% of the study subjects had bilateral normal hearing in the standard frequency range, while 32.9% in the extended high-frequency range. It is worth noting that none of the furniture industry workers had – either in the standard PTA frequency range or in the extended high-frequency range – HTLs within normal limits (Table 3).

High-frequency hearing loss and speech-frequency hearing loss were noted in 7.0% and 6.6% of the ears, respectively (Table 3). In turn, the high-frequency notched audiograms were found in 13.8% of the analyzed ears. The majority of them occurred at 4 kHz or 3 kHz. In contrast, the extended high-frequency threshold shift was found in 31.5% of the analyzed ears, and likewise high-frequency notches more often occurred in the case of the left ear as compared to the right ear. What's more, the prevalence of the high-frequency hearing loss, extended high-frequency threshold shift as well as the high-frequency notches was the highest in the case of the furniture industry workers (Table 3).

Figure 2 presents the mean values of the standard pure-tone hearing thresholds and extended high-frequency hearing thresholds (with 95% CI) determined for both ears in 3 subgroups of employees using communication headsets, while Table 4 summarizes the M±SD in the left and right ears of the study subjects.

Statistical analysis – ANCOVA with age and gender as covariates – showed significant differences in hearing thresholds between the 3 subgroups of the study subjects mainly in the extended high-frequency range. It turned out, on the one hand, that the furniture industry workers had significantly higher (worse) HTLs

Table 3. Prevalence of normal hearing, high-frequency hearing loss, speech-frequency hearing loss, high-frequency notched audiograms and extended high-frequency hearing thresholds in call centre operators, transcribers and furniture industry workers involved in the study

Variable	Prevalence							
	call center operators (N = 177)		transcribers (N = 15)		furniture industry workers (N = 21)		total (N = 213)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Bilateral normal hearing in the frequency range								
250–8000 Hz	48.6^{a}	41.3–55.9	26.7	10.7–52.5	0.0^{a}	–	42.3	35.8–49.0
9–16 kHz	39.0^{a,b}	32.1–46.3	6.7^{b}	0.01–31.8	0.0^{a}	–	32.9	15.6–32.8
Speech-frequency hearing loss	7.1	4.8–10.3	0.0	–	7.1	1.9–19.9	6.6	4.6–9.4
left ear	7.9	4.7–13.0	0.0	–	9.5	1.6–30.4	7.5	4.6–12.0
right ear	6.2	3.4–10.9	0.0	–	4.8	0.01–25.4	5.6	3.2–9.7
bilateral	3.4	1.4–7.4	0.0	–	0.0	–	2.8	1.2–6.2
High-frequency hearing loss	6.2^{a}	4.1–9.3	3.3	0.01–18.1	16.7^{a}	8.1–31.0	7.0	5.0–9.9
left ear	7.3^{a}	4.3–12.3	6.7	0.01–31.8	23.8^{a}	10.4–45.6	8.9	5.7–13.6
right ear	5.1	2.6–9.6	0.0	–	9.5	1.6–30.4	5.2	2.8–9.1
bilateral	2.3	0.7–5.9	0.0	–	4.8	0.01–25.4	2.3	0.9–5.6
Extended high-frequency hearing threshold shift	24.3^{b}	20.1–29.0	36.7^{c}	21.9–54.6	88.1^{a,c}	74.4–95.2	31.5	27.2–36.0
left ear	28.8^{a,b,d}	22.7–35.9	73.3^{b,d}	47.5–89.3	100.0^{a,d}	81.4–102.6	39.0	32.7–45.7
right ear	19.8^{a,d}	14.6–26.3	0.0^{c,d}	–	76.2^{a,c,d}	54.4–89.6	23.9	18.7–30.1
bilateral	15.3^{a}	10.7–21.4	0.0^{c}	–	76.2^{a,c}	54.4–89.6	20.2	15.3–26.1
High-frequency notching at 3, 4 or 6 kHz	12.1^{a}	9.1–16.0	6.7^{c}	0.9–22.6	33.3^{a,c}	21.0–48.5	13.8	10.9–17.5
left ear	14.1^{a}	9.7–20.1	13.3	2.7–39.4	47.6^{a,d}	28.4–67.6	17.4	12.9–23.1
right ear	10.2	6.5–15.6	0.0	–	19.0^{d}	7.3–40.7	10.3	6.9–15.2
bilateral	2.8^{a}	1.1–6.7	0.0	–	14.3^{a}	4.3–35.7	3.8	1.8–7.4

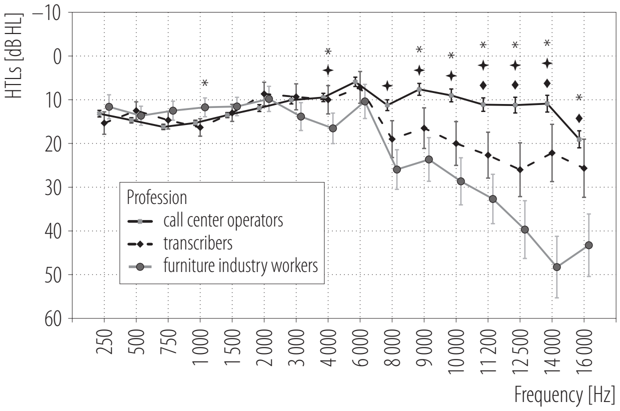
[a] Significant differences between the call centre operators and furniture industry workers ($p < 0.05/3 = 0.0167$).

[b] Significant differences between the call centre operators and the transcribers ($p < 0.05/3 = 0.0167$).

[c] Significant differences between the transcribers and the furniture industry workers ($p < 0.05/3 = 0.0167$).

[d] Significant differences between the right and left ears of the study subjects ($p < 0.05$).

Generally, tests were conducted with an assumed $p < 0.05$ significance level. However, in the case of comparisons in pairs using the χ^2 test, the p-value ($p < 0.05$) divided by the number N (N = 3) of possible comparisons was set as the limit for statistical significance.



✦ Significant differences between the call center operators and the transcribers (p < 0.05).
* Significant differences between the call center operators and the furniture industry workers (p < 0.05).
♦ Significant differences between the transcribers and the furniture industry workers (p < 0.05).
Data are given as mean values (adjusted for age and gender) with 95% confidence intervals and concern both ears.

Figure 2. Audiometric hearing threshold levels (HTLs) determined in a) call center operators (N = 177, 354 ears), b) transcribers (N = 15, 30 ears), and c) furniture industry workers (N = 21, 42 ears)

than the transcribes (at 4 kHz and 11.2–16 kHz) and the call center operators (at 1 kHz, 4 kHz and 8–16 kHz) (Figure 2). On the other hand, the transcribers obtained worse results of audiometric tests as compared to the call center operators in the frequency range of 8–14 kHz ($p < 0.05$).

There were some significant differences in the mean hearing thresholds between the left and the right ear at 1 kHz, 2 kHz, 3 kHz and 8–16 kHz in individual subgroups of the study subjects as well as in total (Table 4). The extended high-frequency threshold levels (9–14 kHz) were generally higher in the left ear, as compared to the right ear, in the 3 professional subgroups, excluding HTLs at 9 kHz and 14 kHz in the case of call center operators. However, a reverse relation was observed in the group of furniture industry workers for 16 kHz. As regards the standard PTA, apart from 8 kHz, significantly worse results in the left ear, in comparison with the right ear, were found among the transcribers at 1 kHz, 2 kHz and 3 kHz, among the furniture industry workers at 3 kHz, and among the call center operators at 1 kHz (Table 4).

Otoacoustic emissions

Transient-evoked otoacoustic emissions were present bilaterally in all analyzed frequency bands according to the criterion of reproducibility of >70% in 41.8% of the study subjects, while considering the SNR of >6 dB, in 16.9% of them (Table 5). As regards the reproducibility of total response and SNR, the aforesaid criteria were met in 97.9% and 74.2% of the employees under study, respectively. In turn, the DPOAEs were considered as present in both ears and in all analyzed frequencies in 59.2% of them (Table 5).

In contrast, 40.8% of the participants exhibited absent DPOAEs for at least 1 frequency in 1 or 2 ears (Table 5). The absence of TEOAEs (in at least 1 frequency band and in at least 1 ear) according to the reproducibility criterion (≤70%) was noted in 58.2% of the study subjects, while based on the SNR criterion (≤6 dB), in 83.1% of them.

As regards the presence and absence of OAEs, generally, there were no significant differences between the subjects' left and right ears. Similar relationships were also observed when the presence and absence of TEOAEs were analyzed in various groups of employees. Nonetheless, only a greater percentage of the furniture industry workers, compared to the call center operators, exhibited absent DPOAEs ($p < 0.05/3 = 0.0167$) (Table 5).

Contrary to EHFA, in the case of TEOAE and DPOAE testing, significant differences between the subjects' left and right ears were only observed for single frequencies or bands (Table 6). The DPOAE outcomes showed the left-right ear asymmetries in the furniture industry workers at 8391 Hz, in the transcribers at 3000 Hz, and in the call center operators at 1734 Hz and 2063 Hz (Table 6). At the same time, the TEOAE responses indicated a worse hearing in the left ear as compared to the right ear only

Table 4. Standard pure-tone audiometry (PTA) and extended high-frequency audiometry (EHFA) hearing threshold levels in call centre operators, transcribers and furniture industry workers involved in the study

Frequency	Hearing threshold level [dB HL] (M±SD)							
	call center operators (N = 177)		transcribers (N = 15)		furniture industry workers (N = 21)		total (N = 213)	
	left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear
500 Hz	14.7±5.9	14.7±5.8	12.7±4.6	12.3±5.0	13.8±4.2	15.2±8.3	14.4±5.7	14.6±6.0
750 Hz	16.5±5.6	15.9±6.0	14.7±4.0	14.7±5.2	12.4±4.1	14.3±6.2	16.0±5.5	15.7±6.0
1000 Hz	15.7±5.5[a]	14.9±5.7[a]	18.0±4.9[b]	14.7±7.4[b]	11.7±2.9	13.1±6.2	15.5±5.4[c]	14.7±5.9[c]
1500 Hz	13.6±5.0	13.4±5.9	13.3±5.2	12.7±8.2	11.7±2.9	13.6±5.7	13.4±4.9	13.4±6.0
2000 Hz	11.6±7.7	12.3±7.7	10.7±4.2[b]	6.7±5.2[b]	10.7±6.6	11.2±9.3	11.4±7.4	11.8±7.8
3000 Hz	10.4±7.8	9.7±8.7	13.0±7.3[b]	5.7±5.0[b]	16.0±8.9[d]	9.8±8.1[d]	11.1±8.0[c]	9.5±8.5[c]
4000 Hz	9.9±8.5	9.1±9.7	11.0±7.4	9.0±5.4	19.0±9.3	15.5±10.4	10.9±8.9	9.7±9.7
6000 Hz	5.6±9.5	6.1±10.6	6.0±9.3	8.3±9.8	12.1±11.8	13.8±11.2	6.3±9.8	7.0±10.8
8000 Hz	12.9±13.3[a]	10.3±11.8[a]	24.0±8.3[b]	14.0±5.1[b]	41.2±17.7[d]	24.0±12.0[d]	16.4±16.0[c]	11.9±12.1[c]
9000 Hz	8.6±15.0	7.4±12.9	20.0±9.8[b]	13.0±4.9[b]	41.4±19.6[d]	22.1±13.8[d]	12.6±18.1[c]	9.2±13.3[c]
10 000 Hz	11.6±15.7[a]	7.0±13.1[a]	27.3±12.1[b]	12.7±4.6[b]	44.3±15.8[d]	27.6±16.9[d]	16.0±18.5[c]	9.5±14.5[c]
11 200 Hz	13.1±15.9[a]	9.8±14.4[a]	30.7±12.4[b]	14.7±4.0[b]	48.6±18.5[d]	31.9±16.8[d]	17.8±19.4[c]	12.3±15.6[c]
12 500 Hz	13.6±18.0[a]	9.4±16.6[a]	34.0±18.6[b]	18.0±4.9[b]	49.3±24.3[d]	41.4±19.8[d]	18.2±21.7[c]	13.1±19.0[c]
14 000 Hz	11.2±17.8	11.0±19.0	31.0±16.6[b]	13.3±5.2[b]	58.9±15.7[d]	48.8±24.8[d]	16.7±22.3[c]	14.9±22.0[c]
16 000 Hz	18.7±17.9	19.4±19.7	40.7±9.2[b]	10.7±4.2[b]	39.0±12.9[d]	44.3±16.8[d]	20.9±18.5	21.3±20.3

[a] Significant differences between the right and left ears of the call centre operators ($p < 0.05$).

[b] Significant differences between the right and left ears of the transcribers ($p < 0.05$).

[c] Significant differences between the right and left ears all the study subjects ($p < 0.05$).

[d] Significant differences between the right and left ears of the furniture industry workers ($p < 0.05$).

among the call center operators. These were the TEOAE amplitude and SNR values in the frequency bands of 1000 Hz and 1500 Hz (Table 6).

Further statistical analysis of the TEOAE and DPOAE responses, adjusted for age and gender, showed significant differences between individual subgroups of the study subjects (Figure 3 and 4). However, these differences were limited to single frequencies. The furniture industry workers compared to the call center operators achieved a significantly worse TEOAE reproducibility for the total response and the 1500 Hz band (Figure 3c). They also had a lower, as compared to the call center operators, DPOAE amplitude and SNR values at 7031 Hz and 8391 Hz, respectively (Figure 4). Furthermore, the furniture industry workers vs. the transcribers exhibited a reduced TEOAE reproducibility for the total response and the DPOAE amplitude at 7031 Hz (Figures 3c and 4a).

Factors affecting the results of hearing tests

Taking into account the type of job performed by the participants, the effects of age, gender (or tenure), and the daily noise exposure level on the hearing tests results was evaluated according to the findings in the subgroups of the call center operators and the transcribers.

Table 5. Presence and absence of transient-evoked otoacoustic emissions (TEOAEs) and distortion-product otoacoustic emissions (DPOAEs) in call centre operators, transcribers and furniture industry workers involved in the study

OAEs criterion	Prevalence							
	call center operators (N = 177)		transcribers (N =15)		furniture industry workers (N = 21)		total (N = 213)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI
OAEs presence criterion								
TEOAE – SNR of >6 dB for all frequency bands	29.9	25.4–34.9	16.7	7.0–34.2	16.7	8.1–31.0	27.7	23.7–32.1
left ear	29.9	23.7–37.1	20.0	6.5–46.1	19.0	7.3–40.7	28.2	22.6–34.6
right ear	29.9	23.7–37.1	13.3	2.7–39.4	14.3	4.3–35.7	27.2	21.7–33.6
bilaterally	19.2	14.1–25.7	0.0	–	9.5	1.6–30.4	16.9	12.5–22.6
TEOAE – reproducibility of >70% for all frequency bands	60.7	55.6–65.7	53.3	36.2–69.7	42.9	29.2–57.8	58.5	53.7–63.0
left ear	61.0	53.7–67.9	40.0	19.9–64.3	42.9	24.5–63.5	57.7	51.0–64.2
right ear	60.5	53.1–67.4	66.7	41.5–84.8	42.9	24.5–63.5	59.2	52.4–65.5
bilaterally	43.5	36.4–50.9	40.0	19.9–64.3	28.6	13.7–50.3	41.8	35.4–48.5
DPOAE – SNR of >6 dB for all frequencies	68.6[a]	63.6–73.3	63.3	45.4–78.1	47.6[a]	33.4–62.3	66.2	61.6–70.5
left ear	70.6[a]	63.5–76.8	60.0	35.7–80.1	42.9[a]	24.5–63.5	67.1	60.6–73.1
right ear	66.7	59.4–73.2	66.7	41.5–84.8	57.1	36.5–75.5	65.7	59.1–71.8
bilaterally	61.6	54.2–68.4	53.3	30.2–75.1	42.9	24.5–63.5	59.2	52.4–65.5
OAEs absence criterion								
TEOAE – SNR of ≤6 dB for at least 1 frequency band	70.1	65.1–74.6	83.3	65.8–93.0	83.3	69.0–91.9	72.3	67.9–76.3
right ear	70.1	62.9–76.3	86.7	60.6–97.3	85.7	64.3–95.7	72.8	66.4–78.3
left ear	70.1	62.9–76.3	80.0	53.9–93.5	81.0	59.3–92.7	71.8	65.4–77.4
for at least 1 ear	80.8	74.3–85.9	100.0	75.7–103.3	90.5	69.6–98.4	83.1	77.4–87.5
TEOAE – reproducibility ≤70% for at least 1 frequency band	39.3	34.3–44.4	46.7	30.3–63.8	57.1	42.2–70.8	41.5	37.0–46.3
right ear	39.5	32.6–46.9	33.3	15.2–58.5	57.1	36.5–75.5	40.8	34.5–47.6
left ear	39.0	32.1–46.3	60.0	35.7–80.1	57.1	36.5–75.5	42.3	35.8–49.0
for at least 1 ear	56.5	49.1–63.6	60.0	35.7–80.1	71.4	49.7–86.3	58.2	51.5–64.6
DPOAE – SNR ≤6 dB for at least 1 frequency	31.4[a]	26.7–36.4	36.7	21.9–54.6	50.0[a]	35.6–64.4	33.6	29.3–38.2
right ear	33.3	26.8–40.6	33.3	15.2–58.5	42.9	24.5–63.5	34.3	28.2–40.9

left ear	29.4[a]	23.2–36.5	40.0	19.9–64.3	57.1[a]	36.5–75.5	32.9	26.9–39.4
for at least 1 ear	38.4	31.6–45.8	46.7	24.9–69.8	57.1	36.5–75.5	40.8	34.5–47.6

OAC – otoacoustic emission; SNR – signal-to-noise ratio.

[a] Significant differences between the call centre operators and the furniture industry workers ($p < 0.05/3 = 0.0167$).

Generally, tests were conducted with an assumed $p < 0.05$ significance level. However, in the case of comparisons in pairs using the χ^2 test, the p-value ($p < 0.05$) divided by the number N ($N = 3$) of possible comparisons was set as the limit for statistical significance.

Table 6. Transient-evoked otoacoustic emissions (TEOAEs) and distortion-product otoacoustic emissions (DPOAEs) measured in call centre operators, transcribers and furniture industry workers involved in the study carried out in June–July 2015, April–June 2016, and January–July 2019

Variable	Frequency [Hz] (M±SD)							
	call center operators (N = 177)		transcribers (N = 15)		furniture industry workers (N = 21)		total (N = 213)	
	left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear
TEOAE								
amplitude	6.7±5.4	7.1±5.3	5.3±5.0	5.7±5.1	4.6±4.9	4.5±4.9	6.4±5.3	6.7±5.3
1000 Hz	−3.6±4.8[a]	−2.5±5.3[a]	−2.7±5.5	−5.2±4.5	−3.7±4.7	−3.4±5.2	−3.5±4.8	−2.8±5.3
1500 Hz	1.8±5.8[a]	2.5±5.9[a]	1.0±5.6	0.8±5.8	0.1±5.5	0.7±5.7	1.6±5.8	2.2±5.9
2000 Hz	1.6±6.1	2.1±5.8	−0.1±5.7	0.5±5.3	0.0±5.5	−0.8±5.4	1.4±6.0	1.7±5.8
3000 Hz	0.1±5.2	0.2±5.5	−1.9±4.8	−2.1±5.6	−2.6±4.3	−2.8±4.1	−0.3±5.1	−0.3±5.5
4000 Hz	−4.4±6.1	−4.5±6.3	−6.9±5.2	−6.8±7.1	−8.5±6.4	−9.1±5.7	−4.9±6.2	−5.1±6.4
SNR	9.6±5.1	9.9±5.0	8.2±4.7	8.9±5.1	7.5±4.7	7.3±4.6	9.3±5.0	9.6±5.0
1000 Hz	6.2±4.6[a]	7.2±5.1[a]	7.0±5.2	4.8±4.5	5.9±4.5	6.0±4.7	6.2±4.6	6.9±5.0
1500 Hz	10.6±5.6[a]	11.2±5.5[a]	9.8±5.5	10.0±5.8	8.9±5.4	9.2±5.3	10.4±5.5	10.9±5.5
2000 Hz	9.2±5.7	9.6±5.5	7.5±5.3	8.5±5.3	7.8±5.3	6.8±5.0	9.0±5.7	9.3±5.4
3000 Hz	7.0±5.1	7.0±5.3	5.1±4.7	4.9±5.6	4.3±4.1	4.1±4.0	6.6±5.0	6.6±5.3
4000 Hz	8.5±4.4	8.6±4.4	7.3±4.4	8.2±5.5	6.1±4.0	5.5±4.2	8.2±4.4	8.3±4.5
reproducibility	94.4±6.4	94.0±10.1	91.6±12.2	95.9±4.7	87.7±17.6	86.2±23.1	93.5±8.8	93.4±11.9
1000 Hz	84.9±18.6	85.8±19.5	82.8±25.4	87.6±12.3	84.3±18.0	81.6±26.9	84.7±19.0	85.5±19.9
1500 Hz	92.8±12.9	93.1±13.4	88.2±22.2	96.0±3.9	87.3±17.0	84.0±26.8	92.0±14.2	92.4±15.0

Table 6. Transient-evoked otoacoustic emissions (TEOAEs) and distortion-product otoacoustic emissions (DPOAEs) measured in call centre operators, transcribers and furniture industry workers involved in the study carried out in June–July 2015, April–June 2016, and January–July 2019 – cont.

Variable	Frequency [Hz] (M±SD)							
	call center operators (N = 177)		transcribers (N = 15)		furniture industry workers (N = 21)		total (N = 213)	
	left ear	right ear	left ear	right ear	left ear	right ear	left ear	right ear
TEOAE – cont.								
reproducibility – cont.								
2000 Hz	90.7±13.8	91.5±12.8	87.5±14.9	94.2±9.4	83.6±27.7	85.6±19.3	89.8±15.8	91.1±13.5
3000 Hz	93.0±8.9	92.2±12.6	85.7±24.3	90.2±12.2	86.4±16.4	88.2±18.1	91.9±11.7	91.6±13.2
4000 Hz	74.0±19.1	74.1±21.2	67.6±27.1	66.9±35.8	62.6±24.7	57.8±27.6	72.5±20.6	72.0±23.6
DPOAE								
amplitude								
1453 dB	6.8±7.7	6.8±8.2	7.5±5.0	5.6±9.0	7.4±6.3	5.6±8.1	6.9±7.4	6.6±8.2
1734 dB	4.8±7.5^{a}	5.4±7.9^{a}	5.7±6.5	4.6±9.4	5.5±6.6	4.7±6.6	4.9±7.3	5.3±7.9
2063 dB	3.1±7.4^{a}	3.7±7.5^{a}	3.4±5.9	4.5±7.3	2.5±6.1	2.0±7.9	3.1±7.2	3.6±7.5
2531 dB	2.0±7.3	2.4±10.6	1.0±6.9	4.0±5.7	1.4±5.9	−1.2±8.8	1.9±7.2	2.2±10.2
3000 dB	2.8±6.4	2.5±6.7	−0.4±6.3^{b}	3.2±5.2^{b}	0.3±6.5	0.3±9.1	2.3±6.5	2.3±6.9
3563 dB	4.5±6.5	4.5±6.9	2.1±6.6	4.4±5.5	0.8±6.7	1.4±5.5	4.0±6.6	4.2±6.7
4219 dB	3.7±7.5	3.3±8.0	0.5±7.3	0.9±6.2	−1.6±6.1	−1.9±7.5	2.9±7.5	2.6±8.0
5016 dB	1.9±7.4	1.5±7.9	−0.9±8.2	−1.8±8.1	−5.1±8.1	−5.0±9.5	1.0±7.8	0.6±8.3
6000 dB	−1.2±8.6	−1.9±9.4	−6.2±12.1	−6.3±10.6	−11.2±10.7	−10.3±9.1	−2.5±9.5	−3.1±9.8
7031 dB	−3.5±9.7	−3.9±9.9	−6.2±9.4	−7.2±9.7	−14.4±10.1	−12.6±11.5	−4.8±10.2	−5.0±10.4
8391 dB	−9.6±9.9	−9.8±9.6	−13.9±9.9	−12.1±9.2	−17.8±7.3^{c}	−12.9±11.7^{c}	−10.7±10.0	−10.2±9.8
10 031 dB	−3.3±11.4	−3.6±11.6	−6.1±12.6	−6.5±11.5	−5.7±10.7	−6.7±10.1	−3.7±11.4	−4.1±11.4
SNR								
1453 dB	20.5±8.1	20.3±8.5	19.7±6.7	21.7±9.8	18.3±8.0	18.0±9.7	20.2±8.0	20.2±8.7
1734 dB	19.8±7.2	20.3±7.9	20.7±6.5	20.2±10.7	18.2±6.7	18.2±7.3	19.7±7.1	20.1±8.0
2063 dB	21.9±8.2^{a}	22.8±8.3^{a}	22.4±4.7	22.6±9.3	18.9±6.3	18.4±7.6	21.6±7.9	22.4±8.4

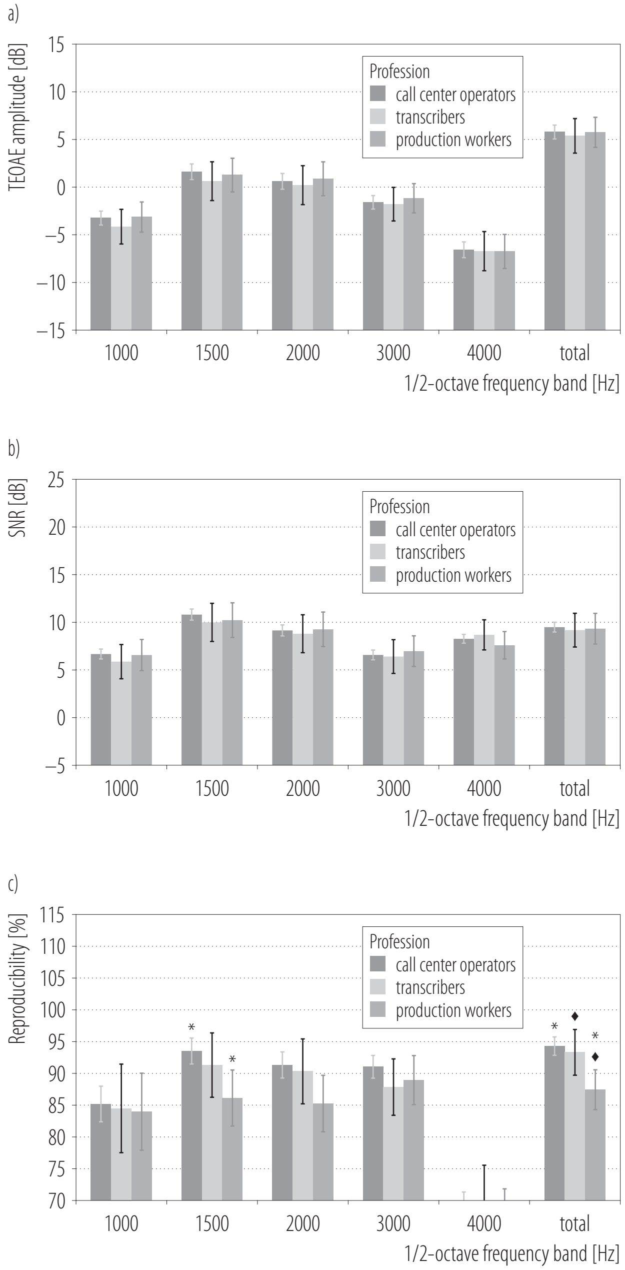
2531 dB	22.2±7.6	22.0±8.0	21.3±8.1	23.9±7.2	18.9±5.6	17.9±8.1	21.8±7.5	21.7±8.0
3000 dB	23.8±7.1	23.7±7.1	21.3±4.5	22.3±6.5	20.4±7.9	19.4±8.5	23.3±7.1	23.2±7.3
3563 dB	24.4±7.6	24.7±7.6	22.1±6.7	24.3±8.1	21.1±6.6	20.4±5.3	23.9±7.5	24.3±7.5
4219 dB	26.6±8.3	25.9±8.6	23.5±8.0	22.9±7.9	20.8±7.2	19.3±5.6	25.8±8.3	25.1±8.5
5016 dB	26.6±8.2	25.9±8.6	24.0±9.2	22.5±9.9	18.9±8.0	18.0±9.3	25.6±8.6	24.9±9.0
6000 dB	24.0±8.6	23.1±8.8	19.6±11.1	18.3±8.8	16.6±10.2	17.9±9.5	23.0±9.2	22.3±9.0
7031 dB	21.8±9.3	21.4±9.6	19.1±10.5	19.1±9.2	12.9±9.4	13.9±11.5	20.8±9.7	20.5±10.0
8391 dB	15.4±9.2	15.3±9.1	11.3±9.2	13.0±8.5	6.9±7.5[c]	11.7±10.3[c]	14.3±9.4	14.8±9.2
10 031 dB	18.2±10.7	17.8±10.9	15.0±11.8	15.3±10.8	14.7±9.1	15.9±9.7	17.6±10.7	17.4±10.7

SNR – signal-to-noise ratio.

[a] Significant differences between the right and left ears of the call centre operators ($p < 0.05$).

[b] Significant differences between the right and left ears of the transcribers ($p < 0.05$).

[c] Significant differences between the right and left ears of the furniture industry workers ($p < 0.05$).

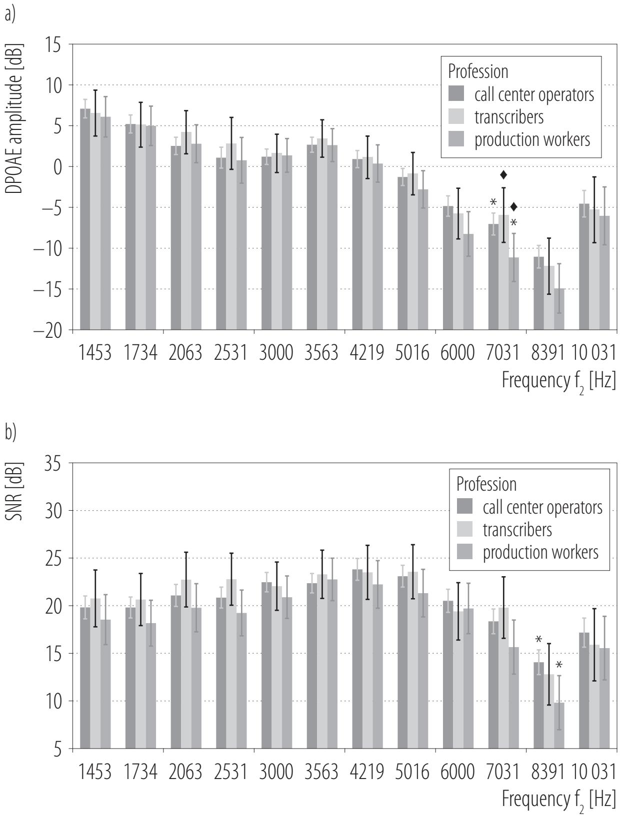


* Significant differences between the call center operators and the furniture industry workers ($p < 0.05$).

♦ Significant differences between the transcribers and the furniture industry workers ($p < 0.05$).

Data are given as mean values (adjusted for age and gender) with 95% confidence intervals and concern both ears.

Figure 3. Transient-evoked otoacoustic emissions (TEOAEs) measured in call center operators (N = 177, 354 ears), transcribers (N = 15, 30 ears), and furniture industry workers (N = 21, 42 ears): a) TEOAE amplitudes, b) signal-to-noise ratios (SNR), and c) reproducibility of responses



* Significant differences between the call center operators and the furniture industry workers ($p < 0.05$).

◆ Significant differences between the transcribers and the furniture industry workers ($p < 0.05$).

Data are given as mean values (adjusted for age and gender) with 95% confidence intervals and concern both ears.

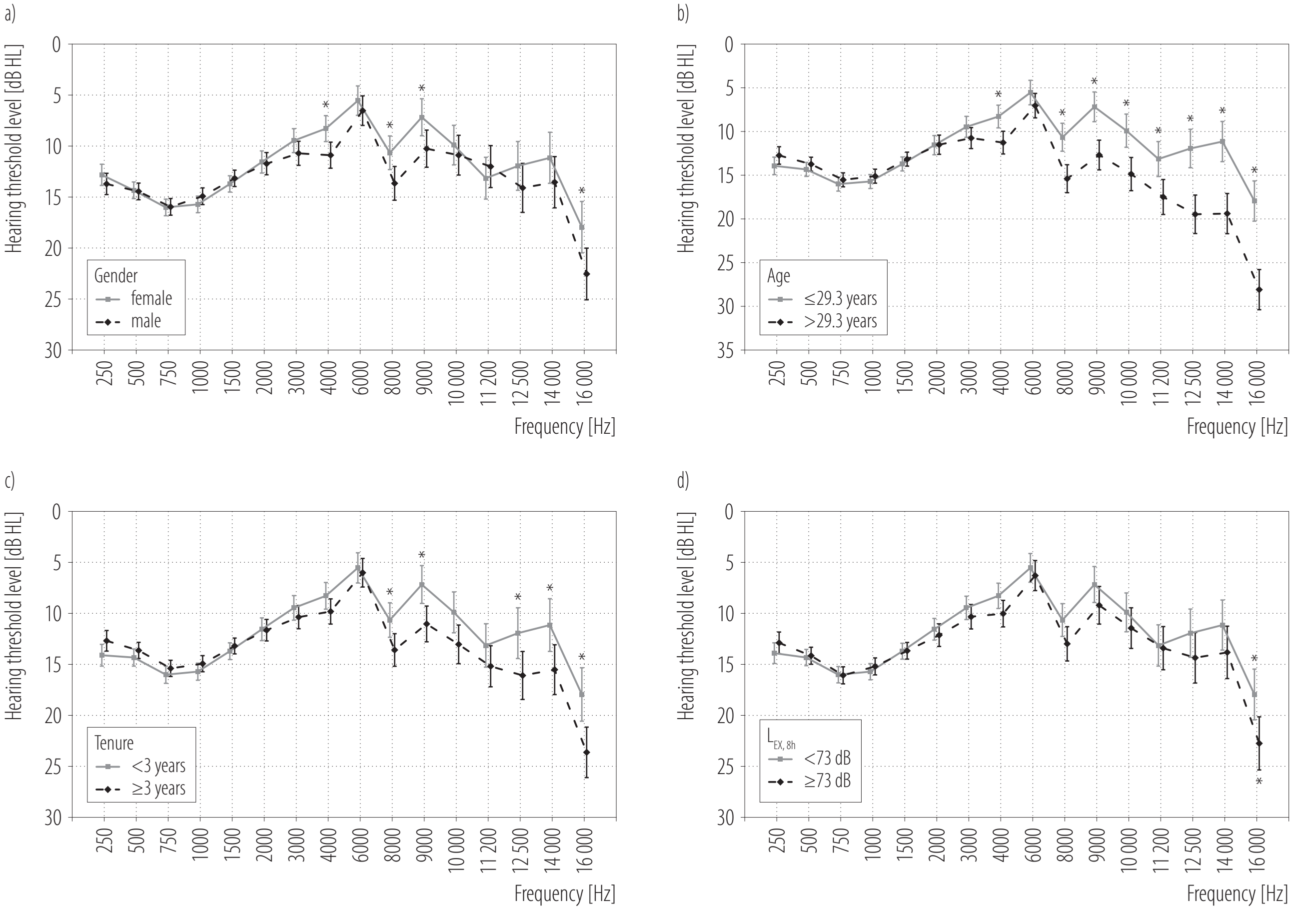
Figure 4. Distortion-product otoacoustic emissions (DPOAEs) measured in call center operators (N = 177, 354 ears), transcribers (N = 15, 30 ears), and furniture industry workers (N = 21, 42 ears): a) DPOAE amplitudes, and b) SNR

The aforesaid subgroup of communication headset users consisted of 95 (49.5%) men and 97 (50.5%) women, aged 21.9–38.6 years (10–90th percentile). They were exposed to noise at the $L_{EX,\,8h}$ levels ranging 67–79 dB (10–90th percentile) for the period of 0.8–8 years (10–90th percentile). Analysis of the prevalence of some outcomes of the hearing tests showed that a higher proportion of older subjects (aged >29.3 years), as compared to younger ones (aged ≤29.3 years), had the extended high-frequency threshold shift (37.4% vs. 11.6%, $p < 0.05$) and exhibited absent TEOAEs (in at least 1 frequency band) due to SNR ≤6 dB (75.8% vs. 66.3%, $p < 0.05$) and a reproducibility value of ≤70% (45.3% vs. 34.2%, $p < 0.05$). In turn, among men, more often as compared to women, were observed notched audiograms (16.8% vs. 6.7%, $p < 0.05$) and high-frequency hearing losses (9.5% vs. 2.6%, $p < 0.05$). Males vs. females also more frequently exhibited absent TEOAEs considering SNR (78.9 vs. 69.9%, $p < 0.05$) and reproducibility criterion (47.4 vs. 32.5%, $p < 0.05$).

Furthermore, a greater percentage of subjects with higher noise exposure levels ($L_{EX,\,8h} \geq 73$ dB), compared to those with lower noise levels ($L_{EX,\,8h} < 73$ dB), had an extended high-frequency threshold shift (30.3% vs. 19.6%, $p < 0.05$). A similar relationship was observed between the subjects with a longer (≥3 years) vs. shorter tenure (<3 years) (30.7% vs. 17.8%, $p < 0.05$). Simultaneously, there were no significant differences in DPOAE responses between the higher- vs. lower-noise-exposed participants, older vs. younger ones, those with longer vs. shorter tenure, as well as males vs. females.

Further statistical analysis, i.e., the main effects analysis of variance (ANOVA) with the daily noise exposure level, gender and age (or tenure) as explanatory variables, revealed their impact on the audiometric HTLs (Figure 5) and measured OAEs (Figures 6 and 7). Since the tenure was correlated with age (Pearson's correlation coefficient $r = 0.46$, $p < 0.05$), the influence of these factors were analyzed separately, but together with gender and daily noise exposure levels.

On the one hand, significant main effects of gender or/and age on hearing threshold levels were observed in the extended high-frequency range of 9–16 kHz, as well as at 4 and 8 kHz (Figures 5a and 5b). On the other hand, a significant impact of the duration of employment (tenure) was noted at 8–9 kHz and 12.5–16 kHz (Figure 5c), while the influence of the daily noise exposure level on HTLs was visible only at 16 kHz (Figure 5d).

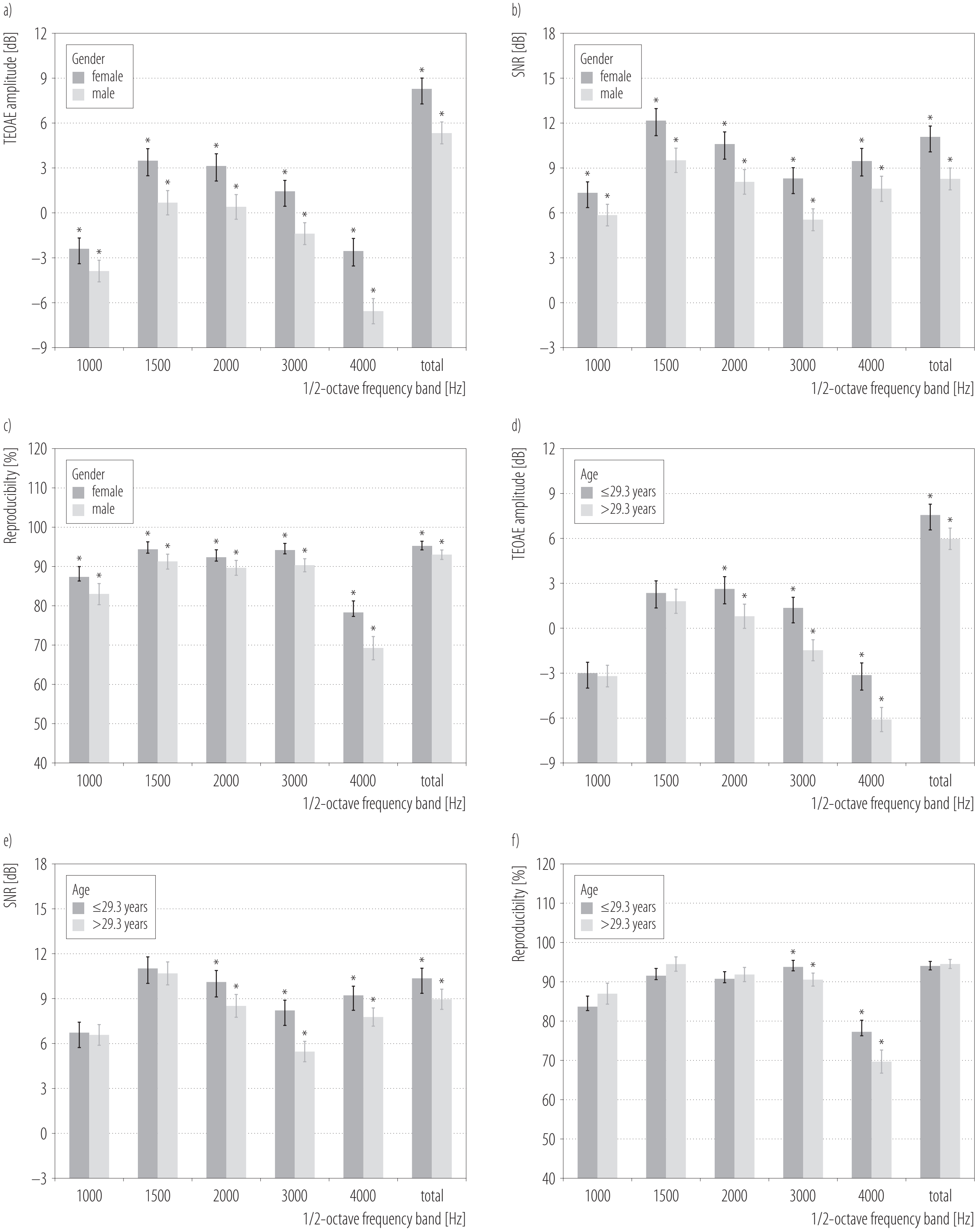


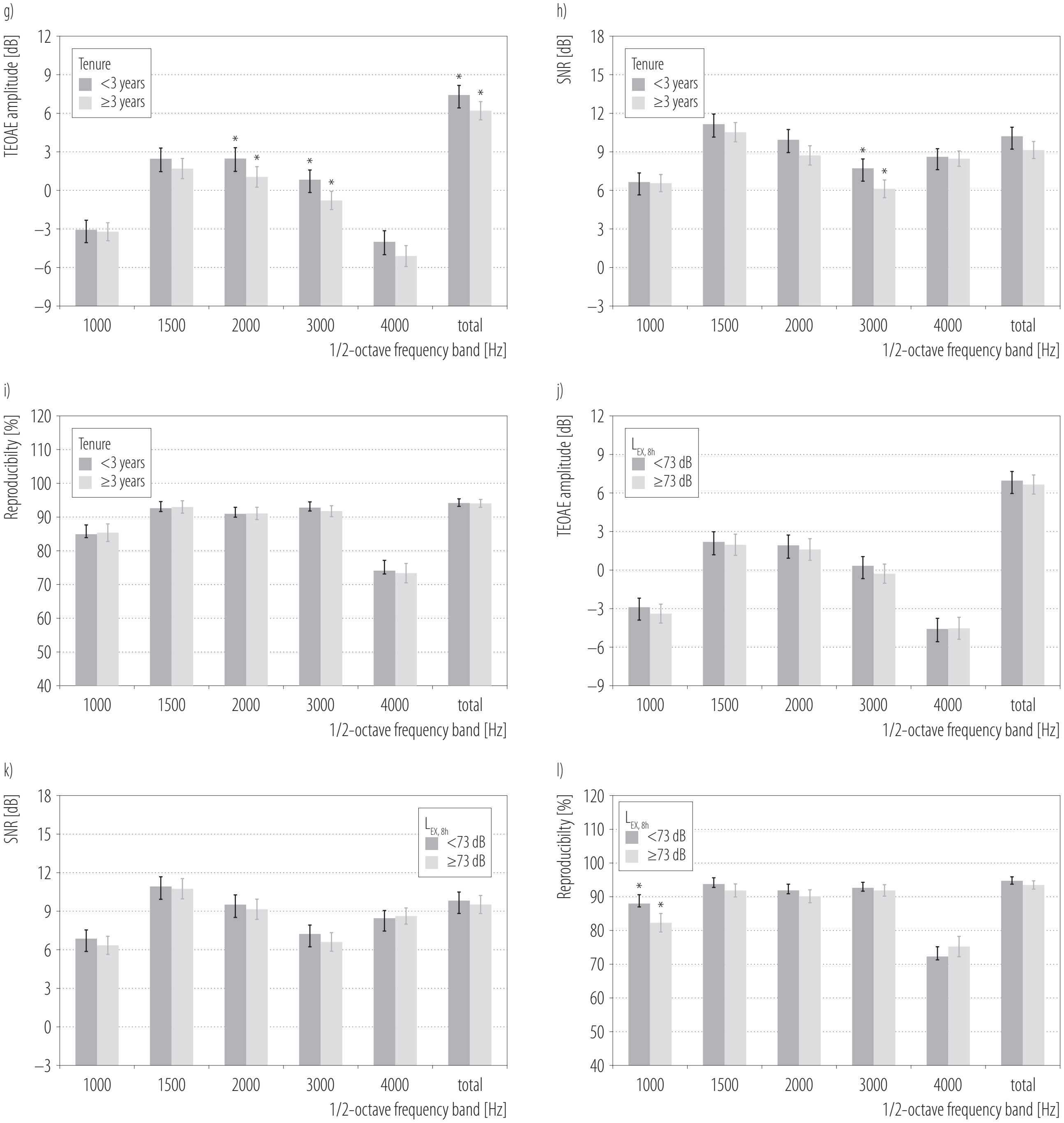
* Significant differences between various subgroups of call center operators and transcribers ($p < 0.05$).
Data are given as mean values with 95% confidence intervals and concern both ears.

Figure 5. Audiometric hearing threshold levels (HTLs) in various subgroups of call center operators (N = 177, 354 ears) and transcribers (N = 15, 30 ears): a) females (N = 97, 194 ears) vs. males (N = 95, 190 ears), b) younger (aged ≤29.3 years, N = 96, 192 ears) vs. older subjects (aged >29.3 years, N = 96, 192 ears), c) subjects with shorter (<3 years, N = 107, 214 ears) vs. longer tenure (≥3 years, N = 85, 170 ears), and d) subjects with lower ($L_{EX,\,8h}$ < 73 dB, N = 100, 200 ears) vs. higher daily noise exposure level ($L_{EX,\,8h}$ ≥ 73 dB, N = 92, 184 ears)

Generally, males, compared to females, showed considerably higher (worse) hearing threshold levels at 4 kHz, 8 kHz, 9 kHz and 16 kHz (Figure 5a). Older subjects (age >29.3 years) had higher hearing losses than younger ones (age ≤29.3 years) at 4 kHz, 8–16 kHz (Figure 5b), while the subjects with a longer tenure (≥3 years) exhibited a worse hearing threshold than those with a shorter (<3 years) tenure at 8–9 and 12.5–16 kHz (Figure 5c).

As regards OAEs, a significant impact of gender was noted for the total response and almost all frequency bands in the case of the TEOAE amplitude, the SNR and reproducibility (Figures 6a–6c). What's more, it was also observed for the majority of the analyzed frequencies in the case of the DPOAE amplitude and SNRs (i.e., at frequencies of 3000–7031 Hz) (Figures 7a and 7b). Basically, age, likewise gender, had a significant impact on most outcomes of the TEOAE (Figures 6d–6f) and DPOAE testing (Figures 7c and 7d). However, in the case of the TEOAE reproducibility, it was only observed in the frequency bands of 3 kHz and 4 kHz (Figure 6f).

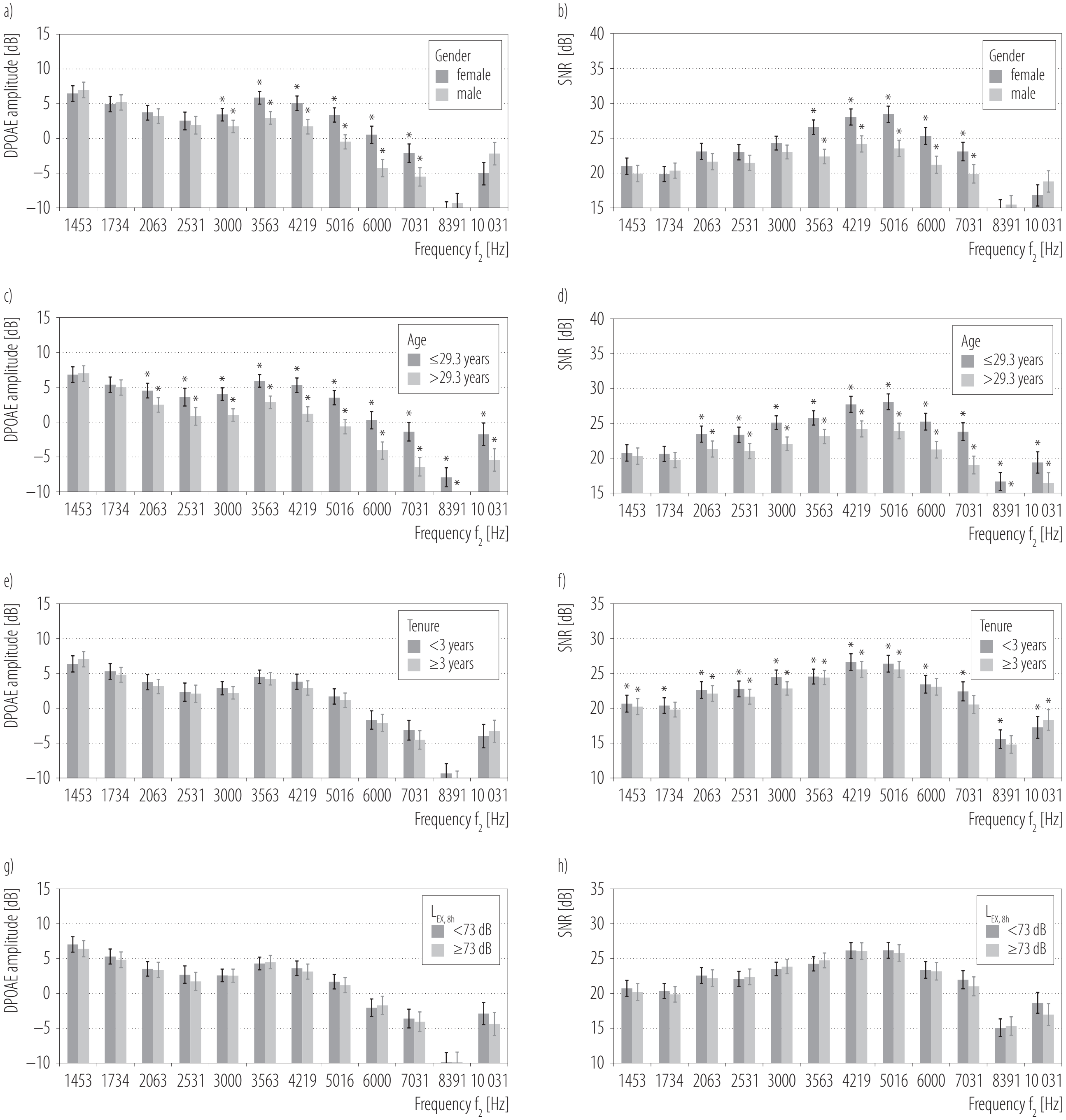

a)
TEOAE amplitude [dB]
12
9
6
3
0
−3
−6
−9
Gender
female
male
1000
1500
2000
3000
4000
total
1/2-octave frequency band [Hz]
b)
SNR [dB]
18
15
12
9
6
3
0
−3
Gender
female
male
1/2-octave frequency band [Hz]
c)
Reproducibilty [%]
120
110
100
90
80
70
60
50
40
Gender
female
male
1/2-octave frequency band [Hz]
d)
TEOAE amplitude [dB]
Age
≤29.3 years
>29.3 years
1/2-octave frequency band [Hz]
e)
SNR [dB]
Age
≤29.3 years
>29.3 years
1/2-octave frequency band [Hz]
f)
Reproducibilty [%]
Age
≤29.3 years
>29.3 years
1/2-octave frequency band [Hz]
*



* Significant differences ($p < 0.05$).

Data are given as mean values with 95% confidence intervals and concern both ears.

Figure 6. Transient-evoked otoacoustic emissions (TEOAEs) amplitudes, signal-to-noise ratios (SNR), and reproducibility of responses among the subgroups of call center operators (N = 177, 354 ears) and transcribers (N = 15, 30 ears), measured in: a), b) and c) females (N = 97, 194 ears) vs. males (N = 95, 190 ears), d), e) and f) younger (aged ≤29.3 years, N = 96, 192 ears) vs. older subjects (aged >29.3 years, N = 96, 192 ears), g), h) and i) subjects with shorter (<3 years, N = 107, 214 ears) vs. longer tenure (≥3 years, N = 85,170 ears), as well as j), k) and l) subjects with lower ($L_{EX, 8h}$ < 73 dB, N = 100, 200 ears) vs. higher daily noise exposure level ($L_{EX, 8h}$ ≥ 73 dB, N = 92, 184 ears)



* Significant differences ($p < 0.05$).

Data are given as mean values with 95% confidence intervals and concern both ears.

Figure 7. Distortion-product otoacoustic emissions (DPOAEs) amplitudes and signal-to-noise ratios (SNR) among the subgroups of call center operators (N = 177, 354 ears) and transcribers (N = 15, 30 ears) measured in: a) and b) females (N = 97, 194 ears) vs. males (N = 95, 190 ears), c) and d) younger (aged ≤29.3 years, N = 96, 192 ears) vs. older subjects (age >29.3 years, N = 96, 192 ears), e) and f) subjects with shorter (<3 years, N = 107, 214 ears) vs. longer tenure (≥3 years, N = 85; 170 ears), as well as g) and h) subjects with lower ($L_{EX, 8h}$ < 73 dB, N = 100, 200 ears) vs. higher daily noise exposure levels ($L_{EX, 8h}$ ≥ 73 dB, N = 92, 184 ears)

In turn, the effect of tenure reached statistical significance for the total response and frequency bands of 2 kHz and 3 kHz, in the case of the TEOAE amplitude as well as for both the DPOAE and TEOAE SNRs at 3 kHz (Figures 6g–i and Figures 7e and 7f). At the same time, the impact of the daily noise exposure level was only visible in the case of the TEOAE reproducibility in the frequency band of 1000 Hz (Figures 6j–l and Figures 7g and 7h).

Generally, the aforesaid outcomes of the TEOAE and DPOAE testing indicated a tendency to worse hearing in men vs. women, older vs. younger subjects, as well as those with a longer vs. shorter tenure, while the impact of the noise exposure level on OAEs was less evident.

DISCUSSION

The overall objective of this study was to explore the hearing function among employees regularly using communication headsets, with regard to their exposure to noise. Evaluation of noise exposure from communication headsets poses a methodological challenge. Therefore, for measurements under headsets, specialized methods have been established, including those based on the use of general purpose artificial ears and ear simulators as specified in AS/NZS 1269.1:2005 and CSA Z107.56–18 [5,6].

Nowadays in Poland, the evaluation of noise exposure from communication headsets is not routinely performed although such devices are widely used in many work environments. Only a few studies have been conducted so far, and they have been mainly focused on call center operators [8,27]. To the best of the authors' knowledge, not only in Poland but also in other countries, a relatively small number of studies have been conducted to date concerning the hearing status of employees using regularly communication headsets [13–20].

For example, Mazlan et al. [13] determined noise exposure and audiometric hearing threshold levels among young call center operators in Malaysia. Later on, El-Bastar et al. [14] assessed the incidence of hearing loss among employees of a communication company in Egypt. In turn, Müller and Schneider [20] analyzed results of both standard PTA and EHFA among airline pilots exposed to headset noise and ambient cockpit noise, while Vinodh and Veeranna [15] assessed the hearing functions of call center operators in India with the PTA and the distortion product otoacoutsic emissions. More recently, Myshchenko et al. [19] analyzed the hearing threshold levels among telephone operators in relation to their exposure to noise.

Thus, to explore hearing ability in regular headsets users, a cross-sectional study including noise measurements, hearing tests, and questionnaires was conducted among furniture industry workers (N = 21), court transcriptionists (N = 15), and call center operators (N = 177).

Noise exposure from communication headsets was evaluated using the MIRE technique. This technique provides the most direct estimate of noise exposure and likely has the best face validity [1]. According to the authors' evaluations, the study subjects were exposed to noise at the A-weighted daily noise exposure levels ranging 57–96 dB (M±SD 72.8±5.1 dB).

Recently, Nasrallah et al. [1] compared the results of the measurements carried out using acoustic manikin and various types of artificial ears, and concluded that the type 1 artificial ear was not suited for the measurement of sound exposure under communication headsets, while type 2 and type 3.3 artificial ears are in good agreement with the acoustic manikin technique. Single number corrections were found to introduce a large measurement uncertainty, making the use of the one-third-octave transformation preferable.

For example earlier, Patel and Brougthon [28] visited 15 call centers in the United Kingdom in order to evaluate whether or not there was a risk to hearing from working in a call center. They measured noise exposure in 150 operators and revealed that the corrected noise levels generated by headsets fitted on the KEMAR manikin ranged 65–88 dB, while the background noise levels were between 57–66 dB. Subsequently, taking into account the time spent by workers on phone calls, the estimated daily noise exposure level ranged 67–84 dB or 87 dB when, respectively, the mean or maximum corrected noise levels were used for estimation. On that basis, Patel and Broughton [28] concluded that the daily noise exposure level of call center operators was unlikely to exceed 85 dB and, therefore, the risk of the hearing impairment was extremely low.

Later, Smagowska [27] reported noise levels at 18 workstations in a call center in Poland. Measurements were taken with a miniature microphone placed at the entrance of the external ear canal according to PN-EN ISO 11904-1:2008 [3]. However, the measured levels were not corrected to obtain free- or diffuse-field-related A-weighted equivalent-continuous SPLs under headsets. Noise levels during phone calls varied 68–91 dB, while anticipating a phone call remained within the range of 55–65 dB. Subsequently, daily noise exposure levels ranged 62–87 dB, showing that noise at call center workstations can be an annoying factor contributing to a hearing loss in some cases.

More recently, Vergara et al. [29] analyzed the results of 166 noise level measurements in various call centers in Brazil. These measurements were also taken according to the methodology described in PN-EN ISO 11904-1:2008 [3]. However, contrary to this study, every single measurement lasted much longer and included the whole working shift. Therefore, the measuring equipment (with mini-microphone) was installed at the beginning of the subject's working day and removed at the end. Diffuse-field-related A-weighted SPLs determined on the basis of these measurements remained within the range of 71–85 dB, with only 14.4% of the cases exceeding 80 dB.

In turn, according to the study by Venet et al. [18] comprising 39 French call center operators (working with headsets), the mean value of the diffuse-field-related A-weighted equivalent continuous SPL measured under a headset using manikin technique was M±SD 69.6±3.7 dB. Consequently, both the maximum and the mean daily noise exposure level normalized for an equivalent 8-hour exposure duration (equal to 75.5 dB and M±SD 65.7±3.6 dB, respectively) was well below the lower action level ($L_{EX,\,8h} = 80$ dB) according to Directive 2003/10/EC [27].

On the other hand, in the latest investigation by Myshchenko et al. [19], noise exposure from communication headsets was evaluated using an artificial ear, the Brüel and Kjær type 4152. No procedure was applied to convert measurements to the equivalent diffuse or free field. According to the collected data, communication headsets generated noise at the A-weighted equivalent-continuous SPLs ranging 88–104 dB (M±SD 91.3±1.3 dB). However, these levels dropped to 80–96 dB (M±SD 83.1±1.3 dB) after the authors' correction using a single number of 8 dB as specified (for artificial ear, type 1) in AS/NZS 1269.1:2005 [5].

In this study, only 1.4% of the call center operators were exposed to noise at the A-weighted daily noise exposure level exceeding 85 dB, while 7.3% of them were exposed to the $L_{EX,\,8h}$ levels of >80 dB. Noise levels between 80–85 dB were noted in the case of 9.5% of the furniture industry workers. In turn, all the transcribers were exposed to noise at the levels of <80 dB. Thus, the outcomes presented here are generally in agreement with the results of other investigations although different methods were used to assess the sound exposure from communication headsets [18,27–29]. However, they do not fully confirm some conclusions that call center operators [18,28] are unlikely to be exposed to the noise exceeding the upper exposure action value ($L_{EX,\,8h} = 85$ dB) established in Directive 2003/10/EC [26].

The furniture industry workers were the only ones who used communication headsets with a high attenuation ear protection in noisy environment (with the A-weighted equivalent continuous SPLs ranging 82–95 dB). According to the authors' evaluations, none of the furniture industry workers was exposed to the daily noise exposure level of >85 dB. This proves that hearing protector devices with a 2-way radio communication system worn by furniture industry workers provided sufficient protection against noise. The real-life attenuation provided by the aforesaid hearing protectors ranged 8–24 dB (M±SD 14.4±4.8 dB).

As mentioned above, the golden standard in the diagnosis of NIHL is the standard PTA usually performed in the frequency range of 250–8000 Hz. However, since EHFA, DPOAE and TEOAE are believed to be useful for monitoring early signs of NIHL [10–12], these audiological tests were applied in the study together with the standard PTA for hearing assessment among communication headsets users.

Regarding the hearing status, 42.3% of the study subjects presented normal audiometry in both ears, in the standard frequencies of 250–8000 Hz, while only one-third of them had the bilateral normal hearing within the extended high-frequency range of 9–16 kHz. Both high-frequency and speech-frequency hearing losses were noted in about 7% of the analyzed ears, while high-frequency notches were visible in the case of 13.8% of the audiograms. The prevalence of an extended high-frequency hearing threshold shift was >4 times higher than in the case of high-frequency and speech-frequency hearing losses. What's more, the extended high-frequency hearing threshold shifts as well as high-frequency hearing losses and high-frequency notches were most often observed among the furniture industry workers, while they were the least frequent in the call center operators or the transcribers (Table 3).

Transient-evoked otoacoustic emissions were present bilaterally in all analyzed frequency bands according to the criterion of reproducibility of >70% in 41.8% of the study subjects, and as for the SNR of >6 dB in 16.9% of them. In turn, the DPOAEs were considered as present (due to SNR of >6 dB) in 59.2% of the participants. In turn, 40.8% of the study subjects exhibited absent DPOAEs for at least 1 frequency in at least 1 ear. The absence of TEOAEs due to the reproducibility of ≤70% was noted in 58.2% of the participants, while based on the SNR criterion of ≤6 dB, in 83.1% of them. As regards the presence and absence of OAEs, in the majority of cases, there were no significant differences between the subgroups. Only a greater percentage of the furniture industry workers, compared to the call center operators, exhibited absent DPOAEs (Table 5).

It is worth noting, by the way, that the absence of DPOAEs in this study among the call center operators was close to that found earlier by Vinodh and Veeranna [15] who explored hearing functions in 340 call center operators in India (42% vs. 44%).

The subgroups of furniture industry workers, transcribers and call center operators differed in terms of age, gender, type of communication headsets used, and noise exposure levels. When the results of hearing tests (adjusted for age and gender) were analyzed, the differences between these subgroups were the most pronounced in the case of EHFA. In fact, for almost all tested frequencies, the furniture industry workers had significantly worse (higher) hearing thresholds than the call center operators and the transcribers, as well as the transcribers vs. the call center operators. Similar relationships were also observed in the case of the standard PTA and OAEs, but they were limited to few frequencies (or outcomes). They were visible in the case PTA for 1 kHz, 4 kHz and 8 kHz, DPOAE for 7031 Hz and 8391 Hz, and TEOAE for 1500 Hz. These results suggest that EHFA seems to be more useful than the standard PTA and OAEs for recognizing early signs of NIHL among communication headsets users.

Regarding the hearing status, it is worth noting that the left-right ear asymmetries were observed among the study subjects. Basically, both EHFA and PTA indicated worse (higher) HTLs in the left ear, compared to the right ear, in all subgroups. A reverse relationship observed for 16 kHz among the furniture industry workers can be explained by many missing data due to the limited SPL of the audiometer at this frequency.

However, again, the effect of the left-right ear asymmetries was most pronounced in the case of EHFA since it was noted for the majority of the analyzed frequencies of 9–14 kHz. In the case of the standard PTA, this effect was observed at 8 kHz as well as at single frequencies within the range of 1–3 kHz. Furthermore, both the extended high-frequency threshold shift and high-frequency notches were more often observed in the subjects' left ears than in their right ears.

Contrary to EHFA, in the case of TEOAE and DPOAE testing, significant differences between the subjects' left and right ears were only observed for single frequencies or bands. Nevertheless, these results are in line with the conclusions from some earlier studies concerning an increased susceptibility to hearing loss in the left ear, as compared to the right ear, which are independent of the occupation [20].

For example, recently, Müller and Schneider [20] checked the results of audiometric tests (in the frequency range of 125–16 000 Hz) among 487 German airline pilots who were exposed to the communication headset noise and ambient cockpit noise at the levels ranging 84–88 dB and 74–80 dB, respectively. They found the left-right threshold differences at 3 kHz, 4 kHz and 6 kHz, showing evidence of impaired hearing in the left ear, which deteriorates with pilots' age. What's more, the worse hearing in the left ear – by about 2–3 dB – was also observed among those subjects who mostly used the right ear for communication tasks. For comparison, in the older pilots (aged >40 years) who usually put the headphone on the left ear, the mean differences at 3–6 kHz were found to be of 6–10 dB. In conclusion, the authors suggested that the left ear was more susceptible to a hearing loss than the right ear.

Among the subjects involved in this study, the prevalence of normal hearing, both in standard frequencies (250–8000 Hz) and extended high-frequencies (9–16 kHz), was the highest in the subgroup of call center operators. In particular, nearly half of them presented – in both ears – standard pure-tone hearing thresholds of ≤20 dB HL. Moreover, the high-frequency hearing losses and high-frequency notches were only observed in about 6% and 12% of their ears, respectively. Thus, these findings are generally in line with the observations from some earlier studies analyzing the results of PTA among call center operators [13,17]

For example, the above cited Mazlan et al. [13] examined call center operators in Malaysia, in order to analyses the prevalence of the hearing loss in relation to the duration of service. Their study group comprised 136 workers, aged 18–35 years, wearing headphones and receiving calls continuously for 7 h. As in this study, nearly a half of the Malaysian operators have been working 2–3 years and the longest duration of service was 8 years in 3 subjects. In turn, the average noise level from headphones was found to be 58 dB. The results of PTA revealed that 78.8% of the examined call center operators had normal hearing in both ears and only 21.2% of them were found to have a hearing impairment in either one or both ears. That prevalence was comparable to the prevalence of hearing loss in normal subjects, used as controls in other Malaysian studies. Furthermore, there was no association between hearing loss and the duration of employment.

More recently, Ayugi et al. [17] carried out a descriptive cross-sectional study in 1351 call center operators (aged 19–55 years) to study the prevalence of symptoms of acoustic shock syndrome. They noted such symptoms in 384 (28%) of the study subjects. Blockage or fullness of the ears (28%), headache (26%), otalgia (25%), tinnitus (21%), hoarseness of voice (22%) and hyperacusis (20%) were the most common complaints. However, despite the numerous symptoms of acoustic shock syndrome, only 21 (i.e., 5.5% of 384 and 1.6% of 1351) workers developed a form of hearing loss. Twelve females had a mild hearing loss while only one man had a severe hearing loss.

However, different conclusions were formulated by El-Bestar et al. [14] who analyzed the prevalence of a sensory-neural hearing loss (SNHL) among older 58 telephone operators, including those using headphones (age: M±SD 46.3±8.1 years, duration of employment: M±SD 20.6±9.1 years) in comparison with 30 administration employees (age: M±SD 47.2±8.1 years, duration of employment: M±SD 21.7±8.2 years). They found that the telephone operators had a significantly higher prevalence of acoustic shock symptoms and decreased hearing sensitivity, as compared to the controls. In particular, they noted 44.8% of cases of SNHL among the telephone operators vs. no cases among the controls; all of them were bilateral in distribution and concluded that among the other analyzed factors, only headset use (the odds ratio [OR] = 5.2, 95% CI: 1.7–16.1) and age (OR = 1.1, 95% CI: 1.0–1.2) were significant risk factors for developing SNHL among telephone operators.

In turn, in the latest study by Myshchenko et al. [19], the exposure to noise and hearing ability in 75 telephone operators were evaluated, among other things. According to these evaluations, headsets generated noise at levels exceeding the upper exposure action value ($L_{EX,\ 8h} = 85$ dB) determined in Directive 2003/10/EC [26]. The hearing threshold levels (0.125–8 kHz) in the telephone operators surveyed appeared to be higher (worse) compared to HTL in an equivalent – due to age and gender – unscreened non-noise-exposed population according to ISO 7029:2017 [30]. Hearing sensitivity depended on the ear and, in most cases, was worse in the left ear as the operators preferred putting a headset on it. Moreover, hearing sensitivity was worse in the low frequency range which, according to Mishchenko et al., contradicts the theory that hearing loss begins in the high frequency range [19].

Much earlier, in a survey on the hearing acuity among telephone operators, Alexander et al. [31] did not find any significant relationship between a temporary threshold shift (TTS) and the number of hours worked. In turn, Idota et al. [32] demonstrated that loud signals transmitted through earphones used with communication systems in noisy workplace environments induced a TTS at 1500 Hz and 2000 Hz.

In turn, Venet et al. [18] analyzed auditory fatigue among call center dispatchers working with headsets. However, due to much lower noise exposure levels (≤75.5 dB, M±SD 65.7±3.6 dB) no significant temporary changes in hearing were detected with either PTA or the EchoScan test. (In the latter test, acoustic stimulation of the efferent reflexes is used alongside measurements of the distortion product otoacoustic emissions). In the opinion of these authors, the dispatchers' fatigue was probably due to the duration of the work shift or the tasks they performed, rather than to the noise exposure under a headset.

One of the goals of this study was to explore the factors which have an impact on the hearing status assessed with conventional PTA, EHFA, TEOAEs and DPOAEs. Given the similar character of the job being performed by call center operators and transcribers, the effects of age, gender, tenure and daily noise exposure level on hearing tests' results were evaluated according to the findings in these subgroups of communication headset users.

The statistical analysis revealed a significant impact of the subjects' age, gender, noise exposure and current job tenure on a number of hearing test results. Generally, both audiometric tests and OAEs indicated poorer hearing in older vs. younger subjects (aged >29.3 years vs. ≤29.3 years) and male vs. female subjects. Similarly, workers higher- vs. lower-exposed to noise ($L_{EX,\ 8h} \geq 73$ vs. $L_{EX,\ 8h} < 73$ dB) and subjects with longer vs. shorter tenure (≥3 years vs. <3 years) achieved worse results in some hearing tests.

However, the most pronounced were the effects of age and gender, since they were visible for the majority of outcomes of OAEs testing, as well as in the case of standard PTA (at 4 kHz and 8 kHz) and EHFA (for all analyzed frequencies in the case of age, and at 9 kHz and 16 kHz in the case of gender).

The impact of the daily noise exposure level was less evident, since it was only visible for a single frequency (or band) in the case of EHFA (at 16 kHz) and TEOAE reproducibility (in the 1 kHz band). The latter result is not surprising since the subgroups of call center operators and transcribers were exposed to noise at relatively low levels with the mean value of daily noise exposure level of M±SD 72.7±5.2 dB.

Contrary to noise exposure, the impact of tenure seems to be more evident as the persons with more years of experience, compared to those with less years, had higher hearing thresholds mainly within the extended high frequency range (8–9 kHz and 12.5–16 kHz). Furthermore, they had lower values of the TEOAE amplitude (for total response and frequency bands of 2 and 3 kHz) as well as lower SNR values (at 3 kHz) both in the case of DPOAEs and TEOAEs testing.

CONCLUSIONS

- According to results of this study, personal daily noise exposure levels in professional users of communication headsets calculated based on the results of measurements using the MIRE technique reached the values of 57–96 dB.
- The upper and lower exposure action values determined in Directive 2003/10/EC [26] were exceeded in 1.4% and 7.3% of the call center operators, respectively. None of the furniture industry workers using hearing protector devices with a 2-way radio communication system was exposed to a noise level of >85 dB, while only 9.5 of them were exposed to the $L_{EX, 8h}$ levels of >80 dB. However, the noise levels of ≤80 dB were noted among the transcribers.
- About 42% of the study subjects had bilateral normal hearing within standard frequencies of 250–8000 Hz, while only one-third of them exhibited bilateral normal hearing in the extended high-frequency range of 9–16 kHz. The high-frequency losses were noted in about 7% of the analyzed ears, while extended high-frequency threshold shifts were visible in the case of 29% of the audiograms. Moreover, the prevalence of the abnormal audiograms was the highest among the furniture industry workers.
- As regards DPOAEs, they were present bilaterally in 59% of the communication headset users. In turn, the TEOAE reproducibility of >70% and SNR of >6 dB were exhibited (in all frequency bands and both ears) by 42% and 17% of them, respectively. As regards the presence and absence of OAEs, generally, there were no significant differences between the subgroups of employees. Only a greater percentage of the furniture industry workers, compared to the call center operators, exhibited absent DPOAEs.
- Three subgroups of the study subjects differed in age, gender, noise exposure and type of headsets used. However, after adjusting for age and gender, significant differences between the subgroups – indicating worse hearing in the furniture industry workers as compared to the call center operators and the transcribers – were visible at all frequencies in EHFA. Similar relationships were also noted in the case of the standard PTA and OAEs, but they were limited to single frequencies.
- Given the similar character of the job performed by the call center operators and the transcribers, factors affecting the outcomes of hearing tests were evaluated based on the findings in these 2 subgroups of communication headset users.
- A significant impact of age, gender, daily noise exposure level and current job tenure on the results of audiological tests has been shown. The most pronounced were the effects of age and gender since they were visible in the majority of the outcomes of EHFA and OAEs. The noise level impact was less obvious because it was limited to the hearing threshold at 16 kHz and the TEOAE repro-

ducibility in the 1000 Hz band. Furthermore, workers with more years of experience had higher (worse) hearing thresholds for most frequencies in EHFA and reduced parameters of the DPOAE and TEOAE responses.

- To sum up, the findings presented in this paper suggest that employees using communication headsets might be at risk of hearing impairments, and confirm the need to implement the hearing conservation program. However, further studies are needed, in particular based on a longitudinal design, comprising a greater number of workers of different industries, as well as a longer duration of employment, before any firm conclusions concerning the risk of NIHL due to the use of communication headsets can be drawn. Meanwhile, EHFA seems to be a useful tool for recognizing early signs of NIHL among regular users of such devices.

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