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Evaluation of Noise Exposure and Hearing Threshold Levels Among Call Centre Operators

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The aim of this study was to evaluate the hearing status of call centre operators in relation to their noise exposure. Conventional pure-tone audiometry and extended high-frequency audiometry were performed in 49 workers, aged 22–47 years (mean ± SD: 32.0 ± 6.0 years), working in call centre from 1.0 to 16.5 years (mean ± SD: 4.7 ± 2.9 years).

Questionnaire inquiry aimed at collecting personal data, the information on communication headset usage habits, self-assessment of hearing ability and identification of risk factors for noise-induced hearing loss were also carried out. Sound pressure levels generated by the communication headset were determined using the artificial ear technique specified in CSA Z107.56-13 (2013) standard. The background noise prevailing in offices was also measured according to PN-N-01307 (1994) and PN-EN ISO 9612 (2011).

Personal daily noise exposure levels in call centre operators varied from 66 to 86 dB (10–90th percentile). About half of the study subjects had normal hearing in the standard frequencies (from 250 to 8000 Hz) in both ears, while only 27.1% in the extended high-frequencies (9–16 kHz). Moreover, both high-frequency and speech-frequency hearing losses were observed in less than 10% of audiograms, while the extended high-frequency threshold shift was noted in 37.1% of analysed ears. The hearing threshold levels of call centre operators in the frequency of 0.25–11.2 kHz were higher (worse) than the expected median values for equivalent (due to age and gender) highly screened population specified in ISO 7029 (2017). Furthermore, they were also higher than predicted for 500–4000 Hz according to ISO 1999 (2013) based on the results of noise exposure evaluation.

Keywords: communication headsets; occupational exposure to noise; hearing threshold levels; hearing loss; noise-induced hearing loss.

1. Introduction

Nowadays communication headsets are widely used in many work environments (Nassrallah *et al.*, 2016). Call centres belong to the fastest growing branches where such devices are necessary to perform the basic duties.

The wide range of variability of the sound level produced by the communication, headsets, the diversity of external acoustic conditions and the ability to generate in headphones sudden, short-term, loud sounds (so-called acoustic shocks) are associated with the risk of auditory and non-auditory effects of noise. In particular, the professional headsets users may experience unwanted reactions and discomforts due to acoustic shock, i.e., acoustic shock disorder (ASD), whose typical symptoms are transient 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 (Westcott, 2006). In turn, the long-term exposure – through headphones – to noise (sounds) at levels above 85 dB is associated with the risk of noise-induced hearing loss (ISO 1999, 2013).

However, despite the rapid development of the call centre sector, there is scarce research on the noise-induced hearing loss among call centre operators. Such a situation has probably been in part due to the difficulties in the measurement set-up and in the evaluation of the exposure itself.

Traditional methods for measuring occupational noise exposure with the use of a sound level meter or noise dosimeter (e.g. those described in (PN-EN ISO 9612, 2011)) are not suitable for noise assessments under communication headsets. For measurements when sound sources are close, or occlude the ears, specialized methods have been specified by the International Standards Organization such as the microphone in a real ear (MIRE) technique (PN-EN ISO 11904-1, 2008) and manikin technique (PN-EN ISO 11904-2, 2009). 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 single number corrections to convert measurements to the equivalent diffuse field (AS/NZS 1269.1, 2005; CSA Z107.56-13, 2013).

Regarding the risk of NIHL due to the use of communication headsets, for instance, earlier Mazlan *et al.* (2002) examined the hearing status among young Malaysian call centre operators and found that the prevalence of NIHL among this professional staff was comparable to the prevalence in normal subjects.

More recently, Ayugi *et al.* (2015) carried out a descriptive cross-sectional study in 1351 call centre operators (aged 19–55 years) to study the prevalence of symptoms of acoustic shock syndrome. However, despite the numerous symptoms of acoustic shock syndrome among 13% of the examined subjects, they noted NIHL only in case of 21 (i.e. 1.6% of 1351) workers. Twelve females had mild hearing losses while only one man had a severe hearing loss.

Meanwhile, extremely alarming information comes from the recently published paper presenting a case report of diagnosed noise-induced hearing loss in a 30-years old man, who has been working as a home agent for 50 months, 8 hours a day and 6 days a week (Beyan *et al.*, 2016).

Nowadays in Poland the evaluation of noise exposure from communication headsets, especially in call centre operators, is not routinely performed. Only a few studies have, to date, been performed and the data concerning the risk of NHIL are scarce (Smagowska, 2010; Smagowska *et al.*, 2012; Pawlaczyk-Łuszczyńska *et al.*, 2019). Therefore, the overall purpose of this study was to evaluate the hearing threshold levels (HTLs) of call centre operators in relation to their noise exposure due to the use of communication headsets.

2. Methodology

Noise measurements and hearing tests were performed in call centre operators. All subjects were also inquired about their: a) age and gender, b) education and/or profession, c) work history, including time of employment/exposure to noise and/or use of headsets at previous workplaces, and d) current job (details of the work pattern and equipment used, preferred volume control setting, type of calls typically handled, etc.).

The study group comprised 49 workers employed in one call centre. They were recruited by advertisement and received financial compensation for their participation in the study. The study design and methods were approved by the Bioethical Commission of the Nofer Institute of Occupational Medicine, Lodz, Poland (resolution no. 17/2018 of 20 November 2018).

2.1. Hearing tests

The conventional pure-tone air conduction audiometry (PTA) and extended high-frequency audiometry (EHFA) were performed in all subjects of the study. The auditory rest before the audiological evaluations lasted 14 hours.

Hearing threshold levels (HTLs) for each ear were determined for both standard frequencies from 0.125 to 8 kHz and extended frequencies from 8 to 18 kHz with 5 dB steps. The bracketing method as specified in PN-EN ISO 8253-1 (2011) has been used in case of PTA. A similar methodology has been applied for EHFA. But 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 into analysis due to many missing data.

Standard pure-tone audiometry was always determined first, followed by the EHFA. In both cases, the right ear was tested first. The hearing examinations were conducted with the VIDEOMED Smart Solution (Poland) clinical audiometer, model AUDIO 4002 with the Holmberg GMBH & CO. KG Electroacoustik (Germany) headphones type HOLMCO PD-81 for the PTA, and the Sennheiser Electronic GmbH & Co. KG (Germany) headphones type HAD 200 for EHFA. Prior to the audiological evaluations, otoscopy was performed.

The prevalence of normal audiograms, high- and speech-frequency hearing losses and extended high-frequency hearing threshold shifts were analysed in the study subjects (ears). Normal hearing was defined as having HTLs between 0.25 and 8 kHz lower than or equal to 20 dB HL. The speech- and high-frequency hearing loss was defined as a pure-tone mean of >20 dB HL at 0.5, 1, 2 and 4 kHz, and 3, 4 and 6 kHz, respectively. In turn, the participants with the mean hearing threshold at 9, 10, 11.2, 12.5, 14 and 16 kHz above 20 dB HL were considered as having the extended high-frequency hearing threshold shift.

Percentages of ears with hearing threshold levels exceeding 20 dB HL at any of the speech frequencies (0.5, 1, 2, and 4 kHz), high frequencies (3–6 kHz) and extended high frequencies (9–16 kHz) were also calculated. In addition, to identify early signs of noise-induced hearing loss, the prevalence of high frequency notched audiograms was also analysed. According to Coles' recommendation, a high-frequency notch was defined as a hearing threshold level at 3 and/or 4 and/or 6 kHz at least 10 dB HL greater than at 1 or 2 kHz and at 6 or 8 kHz (Coles *et al.*, 2000).

Hearing tests were carried out in a quiet room located in the call centre where the A-weighted equivalent-continuous sound pressure level of the background noise did not exceed 35 dB. Figure 1 presents the 1/3-octave band noise spectrum measured in the aforesaid room at the same place where the subject's head was positioned during his hearing test. According to PN-EN ISO 8253-1 (2011), such background noise conditions enabled the testing of hearing threshold levels down to 0 dB HL, with the maximum uncertainty (due to ambient noise) of +5 dB HL.

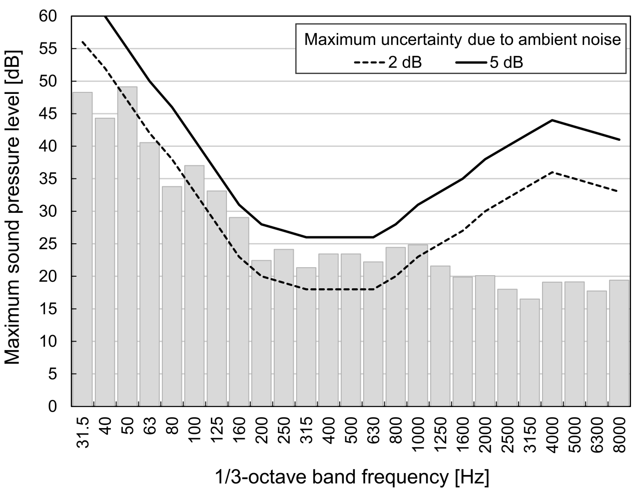


Fig. 1. Noise spectrum measured in test room located in the call centre (at a time when conditions were representative of those existing when audiometric tests were carried out) together with maximum permissible ambient sound pressure levels enabling testing of air conduction hearing threshold levels (from 125 to 8000 Hz) down to 0 dB HL with permitted maximum measurement uncertainty due to ambient noise equal to +2 or +5 dB specified in PN-EN ISO 8253-1 (2011).

2.2. Noise exposure evaluation

In order to evaluate the noise exposure of call centre operators, noise levels generated by headsets and background noise levels were measured and data on typical working pattern were gathered as well. The following noise parameters were determined according to PN-N-01307 (1994) and PN-EN ISO 9612 (2011): a) A-weighted equivalent-continuous sound pressure level (SPL), b) maximum A-weighted SPL with S (slow) time constant, and c) peak C-weighted SPL.

Noise exposure from communication headsets was evaluated using the artificial ear technique as specified in CSA Z107.56-13 (2013) standard. This method involved the use of two identical headsets, one placed on the subject's head, the other connected in parallel with the headset in use. The parallel headphone was placed on an artificial ear, the GRAS type 43AG-2 (with pinna), that was connected to the SVANTEK sound analyser type SVAN 958, and the aforesaid noise parameters together with sound pressure levels in 1/3-octave bands (from 20 to 10 000 Hz) were measured.

Simultaneously, the SVANTEK dual channel noise dosimeter type SV102 (equipped with standard 1/2-inch microphone type SV25D) was used for measurement of background noise occurring outside the headphone or close to ear without a headphone.

According to the CSA Z107.56-13 (2013) standard, results of the frequency analysis under headphone were then converted into corresponding diffused-field levels to obtain the diffuse-field related A-weighted sound pressure levels.

A task-based measurement strategy according to PN-EN ISO 9612 (2011) was applied for exposure evaluation from both the headsets and background noise. In general, 590 (2×295) random samples of the sound pressure level (lasting in total approx. 59 hours) were collected. Since a number of subjects used single-ear headsets, noise exposure was separately assessed for ear without and with a headphone.

2.3. Data analysis

Audiometric hearing threshold levels in call centre operators were compared to the theoretical predictions calculated in accordance with ISO 1999 (2013). The aforesaid standard specifies the method for determining a statistical distribution of hearing threshold levels in adult populations after a given exposure to noise based on four parameters: age, gender, noise exposure level (i.e., A-weighted equivalent continuous SPL normalized over a 8-h working day or a 40-h working week) and time (duration) of noise exposure in years).

Subjects' hearing thresholds (in the frequency range of 0.250–12.5 kHz) were also compared to age-related reference data from highly screened (otologically normal) non-noise-exposed population specified in the ISO 7029 (2017) standard.

Differences in HTLs between subjects' left and right ears as well as between the ears exposed and non-exposed to noise from headsets were also explored using t-test for dependent data or Wilcoxon singed-rank test, where applicable. Similar tests were used for comparison of hearing threshold levels in call centre operators with reference data from the highly screened non-noise-exposed population and noise-exposed population. On the other hand, t-test for independent data or Mann-Whitney U-test test was applied for assessment of the differences between noise levels under headsets in case of lower and higher volume settings.

The main effects ANOVA was used to analyse the first-order (non-interactive) effects of multiple factors such as: noise exposure, gender, age or tenure on HTLs. For this purpose the study group was divided into subgroups according to gender (females and males), age (younger and older subjects), tenure (shorter and longer) and noise exposure (lower- and higher-exposed). Median values of age, tenure and daily noise exposure level were used as the basis for the aforesaid subjects classification. In turn, the possible relations between variables (e.g. subjects' age and tenure) were evaluated using the Pearson's correlation coefficient.

The prevalence of high- and speech-frequency hearing losses, extended high-frequency hearing threshold shifts and high-frequency notched audiograms was analysed in study subjects (ears) and was presented as proportions with 95% confidence intervals (95% CI). The differences between subgroups of participants (e.g. females and males) and their ears in the incidence of these outcomes were analysed using the Fisher's exact test.

The STATISTICA (version 9.1. StatSoft, Inc.) software package was used for statistical analysis. All tests were conducted with assumed significance level $p < 0.05$.

3. Results

The study group comprised 24 females and 25 males aged 22–47 years (mean ± SD: 32.0 ± 6.0 years, median: 31.5 years) employed from 1.0 to 16.5 years in a call centre (mean ± SD: 4.7 ± 2.9 years, median: 4 years). The majority of participants (89.8%) used the single-ear headsets with microphone. About one-fourth of them put the headphone alternately on both ears, while the others put it always on the same preferred right (39.5%) or left (34.9%) ear.

3.1. Noise exposure evaluation

Table 1 summarizes measurement results of the background noise (i.e. noise occurring outside the headphone or close to ear without a headphone) and the noise from communication headsets. In particular, it presents both uncorrected and corrected (diffuse-field related) A-weighted equivalent-continuous sound pressure levels measured using the artificial ear technique.

According to the collected data, headsets generated noise at diffuse-field related A-weighted equivalent-continuous SPLs ranging from 67 to 87 dB (10–90th percentile), with 14.2% and 40.8% of cases exceeding 85 and 80 dB (Fig. 2a). On the other hand, the background noise remained within the range of 58–82 dB (10–90th percentile) (Fig. 2b). Noise levels occurring under headsets were higher than the recommended A-weighted equivalent-continuous SPL ($L_{Aeq,T}$ = 65 dB) to ensure proper working conditions at workplaces in observational dispatcher cabins, telephone remote control rooms used in management procedures, on premises for precise works, etc. (PN-N-01307, 1994). Similar noise exposure conditions were also observed in almost all (91.8%) cases outside headsets or close to ear without a headphone.

The higher volume settings of communication headsets were associated with both significantly higher le-

Table 1. Summary results of noise measurements at workplaces in call centre.

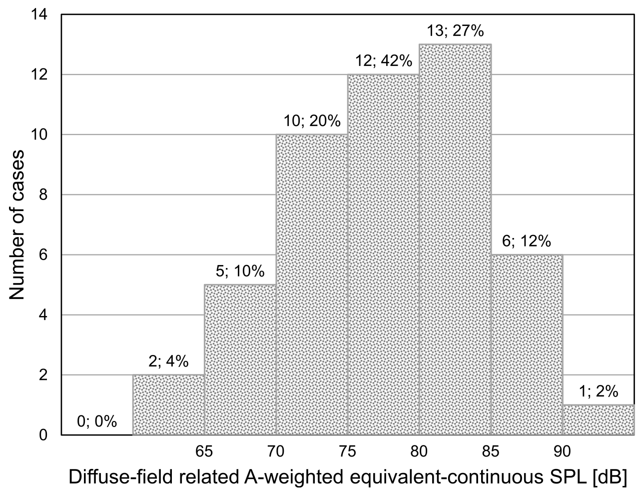
Noise parameters [dB]	Total	Headset volume setting	
		≤ 73%	> 73%
	Mean ± SD (median)		
Artificial ear technique			
Diffuse-field related A-weighted equivalent-continuous SPL	78.0 ± 7.5 (78)	74.0 ± 6.4 (74)*	82.3 ± 4.0 (83)*
A-weighted equivalent-continuous SPL	82.6 ± 7.2 (82)	78.8 ± 6.4 (78)*	86.7 ± 4.1 (87)*
Maximum A-weighted SPL	97.2 ± 6.4 (98)	94.5 ± 6.4 (95)*	99.7 ± 4.1 (100)*
Peak C-weighted SPL	115.9 ± 4.9 (117)	114.2 ± 5.3 (115)*	117.6 ± 2.9 (119)*
Background noise**			
A-weighted equivalent-continuous SPL	72.6 ± 4.9 (73)	70.7 ± 4.7 (71)*	75.5 ± .8 (76)*
Maximum A-weighted SPL	88.6 ± 5.3 (89)	87.5 ± 5.7 (87)	90.4 ± 4.3 (91)
Peak C-weighted SPL	109.3 ± 5.7 (109)	107.8 ± 5.9 (106)*	111.7 ± 4.9 (112)*

SD – standard deviation, SPL – sound pressure level.

* Significant differences between sound pressure levels corresponding to various volume settings of communication headsets ($p < 0.05$).

** Outside the headphone or close to ear without a headphone.

a)



b)

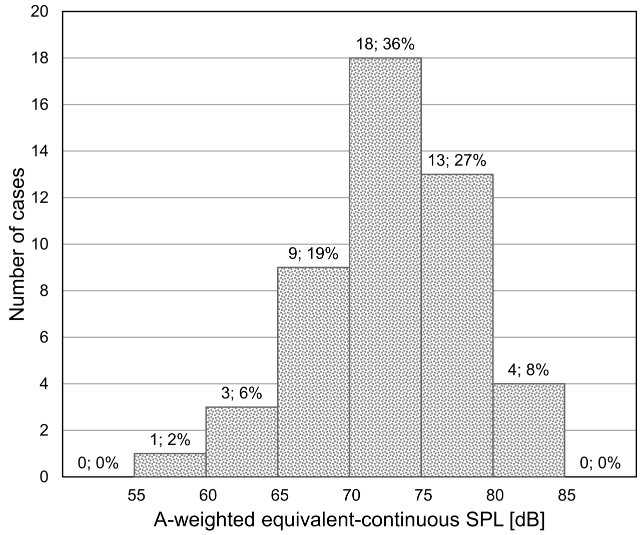
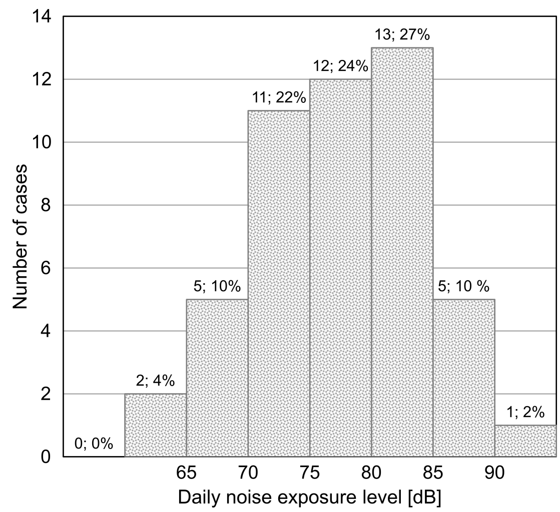


Fig. 2. Distributions of sound pressure levels measured (a) under communication headsets and (b) outside the headsets or close to ears without headphones.

vels of produced sounds (74.0 ± 6.4 dB vs 82.3 ± 4.0 dB at volume setting ≤73% and >73%, respectively) and higher noise level measured outside the ear without headphone (70.7 ± 4.7 dB vs 75.5 ± 4.0 dB, $p < 0.05$).

The study subjects spent from 5 to 9 hours per day (7.4 ± 0.7 hours, median: 7.5 hours) on phone calls. Furthermore, 66.7% of them usually set the volume of communication headset at over 50.0% of the maximum value, including 19.0% at 100% of the maximum volume. Subsequently, the personal daily noise exposure level ($L_{\mathrm{EX,8h}}$) determined on the basis of the data from the artificial ear technique remained within the range of 66–86 dB (10–90th percentile) (mean ± SD: 77.6 ± 7.4 dB, median: 78 dB) with 12.2% of cases exceeding the Polish maximum admissible intensity (PMAI) value for occupational noise ($L_{\mathrm{EX,8h}}$ = 85 dB) according to the Ordinance by the Minister for the Family, Labour and Social Policy (2018). In turn, the lower exposure action value ($L_{\mathrm{EX,8h}}$ = 80 dB) from Directive 2003/10/EC (2003) was exceeded in 38.8% of call centre operators (Fig. 3a).

a)



b)

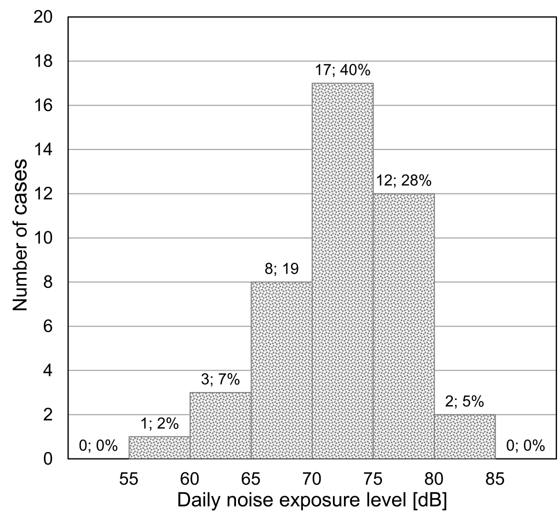


Fig. 3. Distributions of daily noise exposure levels ($L_{\mathrm{EX,8h}}$) in call centre operators. The data represents the $L_{\mathrm{EX,8h}}$ levels determined for ear (a) with and (b) without a headphone.

The $L_{\mathrm{EX,8h}}$ levels obtained for the ear without a headphone reached values of 66–78 dB (10–90th percentile) (mean ± SD: 72.3 ± 4.9 dB, median: 72 dB). Daily noise exposure levels exceeding 80 dB were noted in 4.7% of the analysed cases (Fig. 3b).

It is worth stressing that the A-weighted maximum SPLs ($L_{\mathrm{A\,max}}$) and C-weighted peak SPLs ($L_{\mathrm{C\,peak}}$) measured outside the headphone or close to ear without headphone did not exceed the MAI values which are equal to 115 dB and 135 dB, respectively (Ordinance by the Minister for the Family, Labour and Social Policy (2018)). Furthermore, the $L_{\mathrm{A\,max}}$ and $L_{\mathrm{C\,peak}}$ levels determined directly under headphones (without correction to diffuse-field related sound pressure levels) were also lower than the aforesaid limit values.

3.2. Results of audiometric tests

Generally, 57.1% (95% CI: 43.3–69.9%) of the study subjects had normal hearing in the standard frequency range (HTLs ≤ 20 dB HL between 0.25 and 8 kHz for both ears), while only 27.1% (95% CI: 16.5–41.2%) in the extended frequency range (HTLs ≤ 20 dB HL between 9 and 16 kHz for both ears). It is not surprising that a higher percentage of younger than older subjects had standard pure-tone hearing thresholds within normal limits (70.8% (95% CI: 50.6–85.2%) vs 44.0% (95% CI: 26.7–62.9%), $p < 0.05$).

High-frequency hearing loss (mean HTL at 3, 4, and 6 kHz > 20 dB HL) and speech-frequency hearing loss (mean HTL at 0.5, 1, 2, and 4 kHz > 20 dB HL) were noted in 3.1% (95% CI: 0.7–9.1%) and 4.1% (95% CI: 1.3–10.4%) ears, respectively (Table 2). In turn, the high-frequency notched audiograms were found in the 10.2% (95% CI: 5.5–18.0%) of the analysed ears. All of them occurred at 4 or 3 kHz.

Neither the prevalence of the hearing loss nor the high-frequency notching differed significantly between the left and the right ear. However, high-frequency notches at 3 kHz were more frequent among the subjects with longer (> 4 years) than with shorter (≤ 4 years) tenure (10.4% (95% CI: 4.2–22.7%) vs 0.0% (95% CI: 0.0–8.7%), $p < 0.05$).

The extended high-frequency threshold shift (mean HTL at 9, 10, 11.2, 12.5, 14, and 16 kHz > 20 dB HL) was found in 37.1% (95% CI: 28.2–47.1%) of the analysed ears. Its prevalence was higher in older (age > 31.5 years) than in younger (age ≤ 31.5 years) subjects (46.0% (95% CI: 33.0–9.6%) vs 27.7% (95% CI: 16.9–41.9%), $p < 0.05$). Furthermore, the high-frequency threshold shift was more often observed in the case of the left ear as compared to the right ear (50.0% (95% CI: 36.4–63.6%) vs 24.5% (95% CI: 14.5–38.3%), $p < 0.05$). However, neither noise exposure level nor gender had a significant impact on the aforesaid outcomes of the extended high-frequency audiometry.

Figure 4 presents the standard pure-tone hearing thresholds and extended high-frequency hearing thresholds determined in 49 call centre operators (98 ears) together with the expected HTLs (in the frequency range of 0.250–12.5 kHz) for the comparable highly screened non-noise-exposed population specified in the ISO 7029 (2017) standard. In turn, Fig. 5 shows the results of the audiometric tests together with the hearing losses predicted for call centre operators according to ISO 1999 (2013) based on their noise exposure.

As demonstrated, the call centre operators' HTLs in the frequency range of 0.25–11.2 kHz were significantly higher than the expected median values for a comparable (due to age and gender) highly screened non-noise-exposed population, while at 12.5 kHz they were close to predictions (Fig. 4). Furthermore, in the frequency range of 500–4000 Hz (Fig. 5), the actual HTLs were also higher (worse) than those expected from noise exposure ($p < 0.05$), while at 6 kHz they were comparable ($p > 0.05$).

There were significant differences in the mean hearing thresholds between the left and the right ear at 1.5,

Table 2. Summary results of standard pure-tone audiometry (PTA) and extended high-frequency (EHFA) in 49 call center operators (98 ears).

Audiometry results	Proportion of ears (95% CI)
Mean hearing threshold level	
at frequencies of 0.5, 1, 2 and 4 kHz > 20 dB	4.1 (1.3–10.4)
in frequency range 3–6 kHz > 20 dB	3.1 (0.7–9.1)
in frequency range 9–16 kHz > 20 dB	37.1 (28.2–47.1)
Hearing threshold level at one or more frequencies	
of 0.5, 1, 2 or 4 kHz > 20 dB	12.2 (7.0–20.4)
in frequency range 3–6 kHz > 20 dB	10.2 (5.5–18.0)
in frequency range 9–16 kHz > 20 dB	61.9 (51.9–70.9)
High-frequency notch	
total at 3 or 4 kHz	10.2 (5.5–18.0)
bilateral notch at 3 or 4 kHz	2.0 (0.0–11.9)

CI – confidential interval.

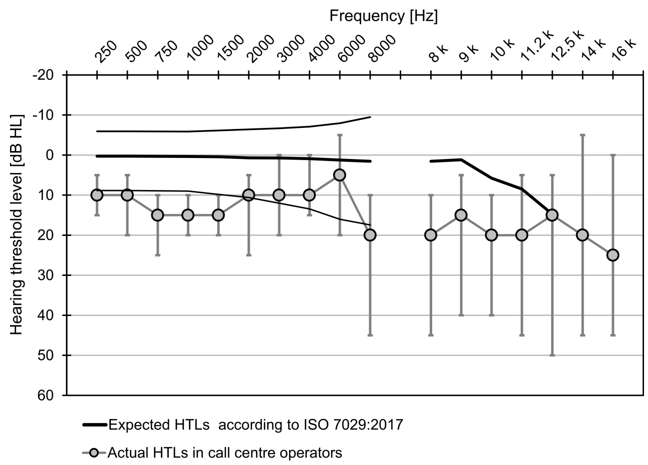


Fig. 4. Distribution of hearing threshold levels (HTLs) in call centre operators compared to hearing threshold levels in equivalent (due to age and gender) non-noise-exposed population specified in ISO 7029 (2017). Solid lines represent median values of the 10th, 50th and 90th percentiles of expected HTLs in reference population, while dots and whiskers represent the 10th, 50th and 90th percentiles of actual HTLs in call centre operators. (There were significant differences between mean values of actual and expected median HTLs in the whole analysed frequency range ($p < 0.05$) excluding 12.5 kHz).

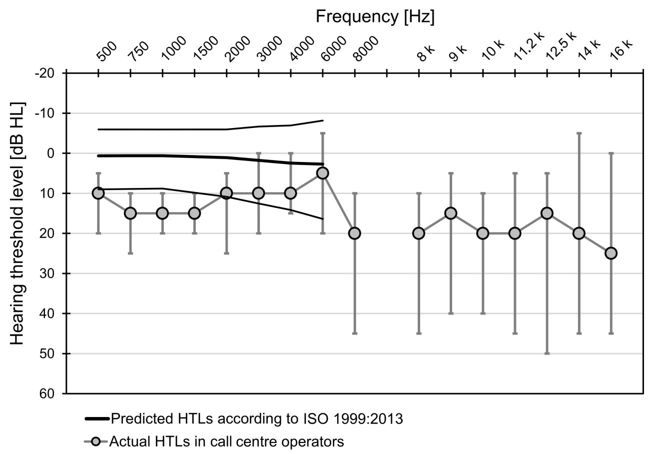


Fig. 5. Distribution of hearing threshold levels (HTLs) in call centre operators compared to expected hearing threshold levels according to ISO 1999 (2013) based on their daily noise exposure level and time of employment. Solid lines represent median values of the 10th, 50th and 90th percentiles of expected HTLs, while dots and whiskers represent the 10th, 50th and 90th percentiles of actual HTLs in call centre operators. (There were significant differences between mean values of actual and expected median HTLs in the whole analysed frequency range ($p < 0.05$) excluding 6000 Hz).

2, 6, 8, 9, 10, 11.2 and 12.5 kHz ($p < 0.05$) (Table 3). Both standard pure-tone speech hearing thresholds (1.5–2 kHz) and the extended high-frequency thresholds (8–11.5 kHz) were worse in the right ear as compared to the left ear. But there were no significant differences in HTLs (in the whole frequency range) between the ears without and with a headphone, when the analysis was limited to the subjects who reported the use of headsets on one ear only (Table 3).

Significant main effects of age and/or gender on HTLs at 4 kHz and 8, 9, 12.5, 14, and 16 kHz were observed when analysing a possible impact of multiple factors such as gender, age, and daily noise exposure level (Figs 6a–6c) using ANOVA. Since the tenure was correlated with age (Pearson's correlation coefficient $r = 0.40$, $p < 0.05$), thus its influence on hearing test results was analysed together with gender and daily noise exposure level. In the latter case, significant main effects of time of employment and gender were observed at 12.5 kHz (Fig. 6d) and 8–9 kHz, respectively. However, no significant main effects of the daily noise exposure on the hearing test results was noted.

Males, compared to females, showed considerably higher (worse) hearing threshold levels at 8, 9, 12.5,

Table 3. Standard pure-tone audiometry (PTA) and extended high-frequency audiometry (EHFA) hearing thresholds in call centre operators.

Frequency [Hz]		Hearing threshold level [dB HL]				
		Both ears	Left ear	Right ear	Ear without headphone*	Ear with headphone*
		Mean ± SD (median)				
PTA	125	13.0 ± 0.93 (15)	12.8 ± 4.3 (10)	13.3 ± 5.4 (15)	13.1 ± 5.0 (15)	13.9 ± 5.9 (15)
	250	11.0 ± 3.76 (10)	11.1 ± 5.2 (10)	10.9 ± 5.3 (10)	10.9 ± 4.8 (10)	11.1 ± 6.1 (10)
	500	12.4 ± 1.99 (10)	11.7 ± 4.7 (10)	13.1 ± 6.6 (10)	12.7 ± 5.4 (10)	12.7 ± 5.1 (10)
	750	14.7 ± 18.08 (15)	14.4 ± 4.2 (15)	15.1 ± 7.0 (15)	14.2 ± 4.8 (15)	14.8 ± 4.3 (15)
	1000	14.4 ± 5.82 (15)	14.0 ± 4.2 (15)	14.8 ± 6.3 (15)	13.9 ± 4.4 (15)	14.7 ± 4.6 (15)
	1500	13.0 ± 4.91 (10)	11.7 ± 3.6 (10)**	14.2 ± 6.8 (15)**	13.6 ± 7.7 (10)	13.1 ± 4.0 (10)
	2000	11.2 ± 7.20 (10)	9.9 ± 7.3 (10)**	12.6 ± 7.4 (10)**	12.2 ± 8.8 (10)	10.8 ± 6.7 (10)
	3000	9.3 ± 5.82 (8)	9.5 ± 7.4 (5)	9.2 ± 7.8 (10)	9.8 ± 8.7 (10)	9.5 ± 7.7 (10)
	4000	8.8 ± 7.20 (10)	9.4 ± 7.5 (10)	8.2 ± 6.3 (10)	9.5 ± 8.1 (10)	8.9 ± 5.9 (10)
	6000	5.8 ± 7.20 (5)	3.5 ± 7.9 (5)	8.2 ± 10.7 (5)	6.9 ± 12.1 (5)	7.0 ± 8.8 (5)
	8000	17.0 ± 7.44 (15)	11.6 ± 14.6 (10)**	22.4 ± 14.2 (20)**	18.9 ± 17.4 (15)	17.5 ± 17.5 (13)
EHFA	8000	17.2 ± 5.49 (15)	11.6 ± 14.6 (10)**	22.8 ± 14.8 (20)**	19.5 ± 18.3 (15)	17.5 ± 17.5 (13)
	9000	14.5 ± 6.62 (13)	9.8 ± 14.6 (5)**	19.3 ± 15.4 (15)**	15.9 ± 18.0 (15)	14.8 ± 17.6 (10)
	10000	16.6 ± 5.31 (13)	9.7 ± 15.5 (5)**	23.6 ± 15.6 (20)**	15.2 ± 18.3 (13)	18.3 ± 19.7 (13)
	11200	17.3 ± 5.71 (10)	12.0 ± 17.2 (10)**	22.6 ± 16.8 (20)**	17.0 ± 17.5 (13)	18.8 ± 22.0 (10)
	12500	17.3 ± 6.40 (15)	11.8 ± 18.9 (5)**	22.8 ± 17.8 (15)**	17.0 ± 19.0 (13)	17.0 ± 23.0 (8)
	14000	18.1 ± 4.88 (15)	17.1 ± 20.7 (15)	19.0 ± 17.0 (20)	15.8 ± 20.4 (13)	17.8 ± 21.5 (15)
	16000	23.2 ± 6.62 (25)	21.8 ± 19.7 (25)	24.6 ± 15.6 (25)	22.7 ± 19.3 (25)	19.4 ± 18.9 (15)
Number of cases		98	49	49	32	32

SD – standard deviation.

* Data concerns participants who used headphone on one ear only.

** Significant differences between left and right ears ($p < 0.05$).

and 16 kHz (Fig. 6a). On the other hand, older subjects (age > 31.5 years) had higher hearing losses than younger ones (age ≤ 31.5 years) at 4, 12.5, 14, and 16 kHz (Fig. 6b), while the subjects with a longer (> 4 years) tenure had a worse hearing threshold than those with a shorter (≤ 4 years) tenure only at 12.5 kHz (Fig. 6d).

4. Discussion

The overall objective of this study was to analyse the audiometric hearing threshold levels of call centre operators in relation to their noise exposure due to the use of communication headsets. Evaluation of noise exposure from such devices 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 Z107.56-13 (2013).

Recently, Nassrallah *et al.* (2016) 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 is not suited for the measurement of the 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 third-octave transformation preferable.

The aforesaid conclusions have been taken into account in the most recent, fifth edition of CSA Z107.56-18 (2018) which assumes that only type 2 or type 3.3 artificial ears may be used to provide a simpler assessment of sound exposure for sources close to the ear in some situations when a full manikin is not available or when a more compact instrumentation set-up is needed. Furthermore, it recommends that measurements with type 2 or type 3.3 artificial ears (under ITU-T Recommendation P.57) should be corrected by the free- or diffuse-field 1/3-octave band correction functions specified in PN-EN ISO 11904-2 (2009) and the A-weighting factors specified in IEC 61672-1 (2013). Meanwhile the previous edition of Canadian standard (CSA Z107.56-13 (2013) did not only allow to use the type 1 artificial ear, but it also specified (for

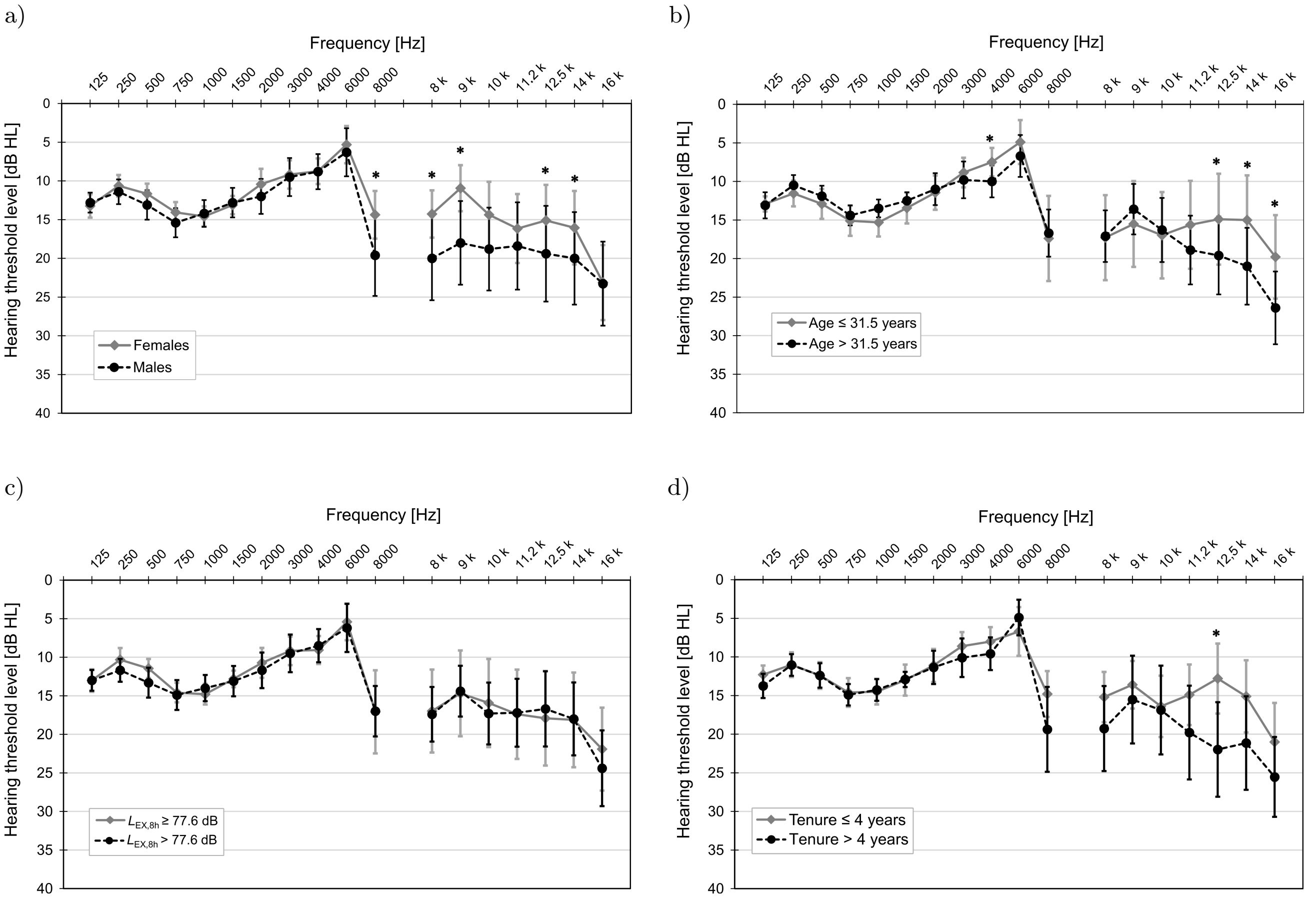


Fig. 6. Audiometric hearing threshold levels in various subgroups of call centre operators, i.e. females and males (a), younger and older subjects (b), lower- and higher-exposed to noise subjects (c), and subjects with longer and shorter time of employment in call centre (d). Data are given as mean values and 95% confidence intervals for both ears. Significant differences between subgroups are marked (*).

each artificial ear) a correction expressed by a single number (8 or 5 dB) that could be applied directly to the A-weighted measurements. For this reason, in this study the noise exposure from communication headsets was measured using the type 3.3 artificial ear (a device combining a pinna simulator, the IEC 60318-4 (2010) ear simulator and a cheek-plate), and the 1/3-octave transformation was applied. Thus, in fact, the artificial ear technique fulfilling the recommendations of both editions of the aforesaid standard (i.e. CSA Z107.56-18 (2018) and CSA Z107.56-18 (2013)) was applied in this study.

The diffuse-field related A-weighted equivalent-continuous sound pressure levels measured under communication headset reached values of 67–87 dB (10–90th percentile), with 14.2% and 40.8% of cases exceeding 85 and 80 dB, respectively. On the other hand, the background noise (occurring outside the headphone or close to ear without a headphone) varied from 66 to 79 dB (10–90th percentile) and it was in majority (78%) cases higher than the – recommended in Poland – A-weighted equivalent-continuous sound pressure level (65 dB) to ensure proper working conditions at workplaces in observational dispatcher cabins, telephone remote control rooms used in management procedures, on premises for precise works, etc. (PN-N-01307 (1994)). Moreover, the background noise levels exceeded 80 dB in 8% of analysed workplaces. Such noise conditions seem to be rather unusual in the office environment. However, they can be explained by loud phone calls simultaneously performed by the subject under study and other call centre operators working in the neighbourhood.

It is worth noting that the A-weighted maximum SPLs and C-weighted peak SPLs measured both outside the headphone (or close to ear without headphone) as well as under the headphone did not exceed the MAI values (Ordinance by the Minister for the Family, Labour and Social Policy (2018)). Generally, in the latter case, the measured values of $L_{\mathrm{A\,max}}$ and $L_{\mathrm{C\,peak}}$ should be converted to their equivalent diffuse-field values, using the appropriate corrections, to allow comparisons to the applicable regulatory limits. However, neither CSA Z107.56-13

(2013) nor CSA Z107.56-18 (2018) include correction for peak C-weighted SPLs. Such correction has been specified by AS/NZS 1269.1:2005 (2005). According to the aforesaid standard a single number correction of 3–4 dB should be subtracted from the measured $L_{\mathrm{C\,peak}}$ values. It is obvious that after subtracting any value (> 0 dB) from the measured maximum A-weighted SPL and C-weighted SPL, the resultant sound pressure levels still did not exceed the Polish MAI values.

In this study almost all participants (89.8%) used single-ear headsets. Subsequently, the personal daily noise exposure levels remained within the range of 66–86 dB (10–90th percentile) and 66–79 dB (10–90th percentile) for ears with and without a headphone, respectively.

For example earlier, Patel and Broughton (2002) visited 15 call centres in the United Kingdom in order to evaluate whether or not there was a risk to hearing from working in a call centre. They measured a noise exposure in 150 operators and revealed that the corrected noise levels generated by headsets fitted on the KEMAR manikin varied from 65 to 88 dB, while the background noise levels were between 57 and 66 dB. Subsequently, taking into account the time spent by workers on phone calls, the estimated daily noise exposure level ranged from 67 to 84 or 87 dB in case of using for estimation the mean or maximum corrected noise levels, respectively. On that basis, Patel and Broughton (2002) concluded that the daily noise exposure level of call centre operators is unlikely to exceed 85 dB and therefore the risk of hearing impairment is extremely low (Patel, Broughton, 2002).

Later, Smagowska (2010) reported noise levels at 18 workstations in a call centre in Poland. Measurements were performed with a miniature microphone placed at the entrance of the external ear canal according to PN-EN ISO 11904-1 (2002), however, the measured levels were not corrected to obtain free- or diffuse-field related A-weighted equivalent-continuous sound pressure levels under headsets. Noise levels during phone calls varied from 68 to 91 dB, while anticipating a phone call they remained within the range of 55 to 65 dB. Subsequently, daily noise exposure levels ranged from 62 to 87 dB, showing that noise at call centre workstations can be an annoying factor contributing to a hearing loss in some cases.

More recently, Vergara *et al.* (2006) analysed the results of 166 noise level measurements in various call centres in Brazil. These measurements were also carried out according to the methodology described in PN-EN ISO 11904-1 (2002). However, contrary to our 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 it was removed at the end. Diffuse-field related A-weighted sound pressure levels determined on the basis of these measurements remained within the range from 71 to 85 dB, however, with only 14.4% of the cases exceeding 80 dB.

On the other hand, according to the latest study by Venet *et al.* (2018) comprising 39 French call centre operators (working with headsets), the mean value of the diffuse-field related A-weighted equivalent-continuous sound pressure level measured under a headset using manikin technique was 69.6 ± 3.7 dB. Consequently, both the maximum and the mean daily noise exposure level normalized for an equivalent 8-h exposure duration (equal to 75.5 dB and 65.7 ± 3.6 dB, respectively) was well below the lower action level ($L_{\mathrm{EX,\,8h}}$ = 80 dB) according to Directive 2003/10/EC.

It is worth underlining that in our study, 12.2 and 38.8% of the call centre operators were exposed through headsets to sounds at a daily noise exposure level exceeding 85 and 80 dB, respectively. Thus, the outcomes presented here are generally in agreement with the results of other investigations, although different methods were used to assess the sound immission from communication headsets (Patel, Broughton, 2002; Smagowska, 2010; Vergara *et al.*, 2006; Vent *et al.*, 2018). However, they do not fully confirmed some conclusions that call centre operators (Patel, Broughton, 2002; Vent *et al.*, 2018) are unlikely to be exposed to noise exceeding upper exposure action value ($L_{\mathrm{EX,\,8h}}$ = 85 dB) from Directive 2003/10/EC.

Over a number of years, the golden standard in research and evaluation of a hearing handicap is the audiogram which is obtained from standard pure-tone audiometry usually performed in the frequency range from 250 to 8000 Hz. It has been shown, however, that hearing thresholds in extended high frequencies (above 8 kHz) might be affected by noise earlier (Porto *et al.*, 2004), which means that EHFA may identify individuals with an initial hearing loss not yet visible in the conventional audiometry. Since the extended high-frequency audiometry is useful in early diagnosis of noise-induced hearing loss (Somma *et al.*, 2008; Sulaiman *et al.*, 2015), it was applied together with standard pure-tone audiometry for assessment of hearing thresholds in call centre operators.

Regarding the hearing status, over half (57.1%) of our study subjects presented in both ears normal audiometry in the standard frequencies (from 250 to 8000 Hz), moreover, both high-frequency and speech-frequency hearing losses were observed in less than 5% of analysed audiograms. Thus, our findings are generally in line with the observations from a few earlier studies analysing hearing thresholds in the standard frequency range from 250 to 8000 Hz (Mazlan *et al.*, 2002; Ayugi *et al.*, 2015).

As mentioned above, Mazlan *et al.* (2002) examined call centre operators in Malaysia, among others, in order to analyse 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 hours. As in our study, the majority (47%) of Malaysian subjects have been working between 2–3 years and the longest duration of service was 8 years in 3 subjects. The average noise level from headphones was found to be 58 dB.

The results of pure-tone audiometry revealed that 78.8% of the examined call centre 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. (Normal hearing was defined as having a hearing threshold level between −10 dB HL to 20 dB HL for all frequencies from 250 to 8000 Hz. The hearing impairment was defined as having HTL of more than 20 dB HL in at least one frequency). 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 the hearing loss and the duration of employment. Thus, it was concluded that there was no evidence of noise induced hearing loss among call centre operators with prolonged exposure to noise from headphones and the duration of service (Mazlan *et al.*, 2002).

More recently, Ayugi *et al.* (2015) carried out a descriptive cross-sectional study in 1351 call centre operators (aged 19–55 years) to study the prevalence of symptoms of acoustic shock syndrome. They noted such symptoms in 384 (13%) of the study subjects. Blockage or fullness of the ears (27.7%), headache (25.8%), otalgia (24.9%), tinnitus (21.3%), hoarseness of voice (21.8%) and hyperacusis (19.5%) were the most common complaints. However, despite the numerous symptoms of acoustic shock syndrome, only 21 workers (i.e. 5.5% of 384 and 1.6% of 1351) had a form of a 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.* (2010) who analysed the prevalence of a sensory-neural hearing loss (SNHL) among older 58 telephone operators, including those using headphones (age: 46.3 ± 8.1 years, time of employment: 20.6 ± 9.1 years) in comparison with 30 administration staff workers (age: 47.2 ± 8.1 years, time of employment: 21.7 ± 8.2 years). They found that telephone operators had a significantly higher prevalence of acoustic shock symptoms and decreased hearing sensitivity compared to the controls. In particular, they noted 44.8% cases of SNHL among the telephone operators versus no cases among the controls; all of them were bilateral in distribution and concluded that among other analysed factors, only headset use (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.

More recently, in the above cited study, Venet *et al.* (2018) also analysed auditory fatigue among the call centre dispatchers working with headsets. However, due to much lower noise exposure levels (up to 75.5 dB, with mean value 65.7 ± 3.6 dB) no significant temporary changes in hearing were detected with either pure-tone audiometry or the EchoScan test. In conclusion, it was suggested that dispatchers' fatigue was probably due to duration of the work shift or to the tasks they performed rather than to the noise exposure under a headset.

Since over half of our study subjects had hearing thresholds within normal limits, to identify early signs of NIHL the prevalence of high-frequency notches in audiograms was analysed. Generally, various definitions of audiometric notches have been proposed. In this investigation according to Cole's recommendation, a high-frequency notch was defined as a hearing threshold level at 3 and/or 4 and/or 6 kHz at least 10 dB HL greater than at 1 or 2 kHz and at 6 or 8 kHz (Coles *et al.*, 2000). Such notches, occurring at 3 or 4 kHz, were found in 10.2% of analysed ears.

Recently, Corroll *et al.* (2017) analysed the prevalence of audiometric notches among the United States adult population (aged 20–69 years) based on the data collected within the 2011–2012 National Health and Nutrition Examination Survey. They found that generally nearly one-fourth (24%) of adults had bilateral or unilateral audiometric notches. Among the subjects who did not report any work exposure this number was estimated to be 20%. The presence of notches increased with age, ranging from 17.6% among the persons aged 20–29 years to 18.6% among those aged 30–39 years. That study defined the presence of a high-frequency notch when any threshold at 3, 4 or 6 kHz exceeded the averaged threshold at 0.5 and 1 kHz by ≥ 15 dB HL and the 8 kHz threshold was at least 5 dB HL lower (better) than the maximum threshold at 3, 4 or 6 kHz. Despite the difference in the notch definitions, our findings are comparable with those obtained by Corroll *et al.* (2017). Thus, the prevalence of high-frequency notches in call centre operators corresponded to that occurring in the population which is not occupationally exposed to noise.

It is worth emphasizing that nearly twice fewer examined subjects have normal hearing in the extended high frequency range in relation to the standard frequencies (27.1% vs 56.1%). Furthermore, the extended high-frequency threshold shift was noted in 37.1% of analysed ears, while both high-frequency and speech-frequency hearing losses were noted in less than 5% of analysed audiograms.

Generally, no significant impact of a daily noise exposure on the hearing threshold level was noted, while the subjects with a longer tenure had a worse hearing threshold than those with a shorter tenure only at 12.5 kHz. Males, compared to females, showed considerably higher (worse) hearing threshold levels at some extended high-frequencies range. In turn, the impact of age was additionally noticeable at 4 kHz.

The comparison of the call centre operators to the highly screened normal non-noise-exposed population (according to ISO 7029 (2017)) revealed that their hearing threshold levels in almost the whole analysed range from 0.250 to 11.2 kHz were higher than expected due to age and gender, while at 12.5 kHz they were close to predictions. Moreover, a similar tendency was observed in the frequency range below 6 kHz when HTLs of the call centre operators were compared to those predicted due to noise exposure according to ISO 1999 (2013). Only at 6 kHz the actual hearing thresholds were close to the predictions.

5. Conclusions

The findings presented in this paper suggest that call operators might be at risk of hearing impairments due to the use of communication headsets, and confirm the need to implement the hearing conservation program for this occupational group. However, further studies are needed, comprising a greater number of subjects, as well as a longer duration of employment, before firm conclusions concerning the risk of NIHL in the call centre operators can be drawn.

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