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Noise-induced hearing loss in firefighters: an audiological evaluation

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Abstract

Background The aim of this study was to evaluate the hearing thresholds, speech understanding abilities, and otoacoustic emissions tests of firefighters to determine the effects of occupational noise exposure on auditory health. This descriptive study consisted of 25 firefighters and 25 healthy individuals with normal hearing as the control group. Firefighters exposed to noise outside of working hours, those using ototoxic medications, or those with other health risk factors were excluded from the study. Hearing functions of all participants were assessed using pure-tone and high-frequency audiometry, speech tests, and otoacoustic emissions measurements.

Results Firefighters' pure-tone hearing thresholds were significantly higher compared to the control group, and hearing loss was observed, particularly at high frequencies (4000 Hz and above). In the speech test results, SRT thresholds were also found to be statistically significantly higher in the study group ($p<0.05$). Dynamic range was found to be narrower in the study group. DPOAE and TEOAE results showed that firefighters exposed to noise at certain frequencies had significantly lower SNRs.

Conclusions These findings support similar studies in the literature, demonstrating that long-term noise exposure has potential negative effects on hearing health in firefighters, particularly high frequencies indicate that hearing thresholds can be affected.

Keywords Occupational noise, Noise pollution, Vulnerable occupations, Workplace exposures

Background

Firefighters are the professionals responsible for extinguishing fires and ensuring the safety of citizens in extraordinary situations such as earthquakes, floods, landslides and explosions within the fire department, which is the organization that carries out firefighting activities. Firefighting is among the most difficult and dangerous professions. In addition to encountering various burning products, employees are also exposed to heat and noise [1]. Due to the harsh conditions that firefighters are exposed to, it is observed that they encounter serious health problems such as heat stroke, hearing loss, visual impairment, musculoskeletal disorders, and exposure to toxic substances. Studies show that firefighting is one of the most critical professions in terms of hearing health, as firefighters are routinely exposed to hazardous noise levels [2]. Hong et al. (2008) reported that firefighting equipment such as water pumps and saws along with firefighters shouting loudly to communicate with each other, are sources of noise for firefighters [3]. In addition, it was reported that 73.9% of firefighters were exposed to urban noise, 68.0% to vehicle noise, and 38.2% to telephone noise [4]. Neitzel et al. (2013) measured the noise levels to which firefighters were exposed. 105–109 dBA was obtained in ventilation activities such

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as metal, concrete, wood, and drywall cutting, and over 106 dBA was obtained with the pneumatic chisel used in vehicle rescue missions [5]. The measurements of the fire truck's horn and siren were determined to be approximately 98 dBA in the interior of the vehicle and 115 dBA in the exterior. In addition, an average sound level of 101 dBA was detected during routine alarm tests. It was also reported that the duration of these operations, therefore the duration of noise exposure, lasted approximately 5.5 to 33 min. These measurements shows that the noise levels to which firefighters were exposed were quite high. Additionally, it is known that firefighters may have difficulty understanding speech because the acoustics of their work environment are quite complex [6].

Based on the literature, firefighters appear to be at risk of hearing loss due to prolonged exposure to occupational noise. Therefore, the purpose of this study was to evaluate the hearing health and speech tests of firefighters. There are studies in the literature that evaluate the hearing thresholds and otoacoustic emission measurements of firefighters [7–9]. However, studies on the speech perception of firefighters are, to our knowledge, limited. In our study, in addition to applying pure tone audiometry, high-frequency audiometry, and speech tests, the dynamic range, a parameter in the evaluation of acoustic reflexes and cochlear sensitivity, was also evaluated, aiming to examine the hearing of firefighters within a broader framework.

Methods

This study is a descriptive study. The study included firefighters from a metropolitan municipality in Türkiye, and written permission was obtained from the institution for their participation. Additionally, voluntary consent forms were obtained from all participants. The study was conducted in the Audiology Laboratory of Biruni University. This study was approved by the Non-Interventional Ethics Committee of Biruni University with the decision numbered 2021/60–7 dated 22.10.2021.

Participants

The study sample size was calculated using the G*Power 3.1.9.4 (Universitat Düsseldorf) package, considering the speech discrimination results from the study by Nada et al. (2014), with 95% power and a 0.05 margin of error, resulting in a minimum of 36 participants (study group: 18, control group:18) [10, 24]. Exclusion criteria included having risk factors such as exposure to noise outside of working hours, use of ototoxic drugs, hypertension, diabetes, history of meningitis, family history of hearing loss, history of acute or chronic ear infection, head and neck injuries, history of cancer, smoking, and alcohol use. 25 volunteer firefighters meeting these criteria were contacted, and to ensure equal participant numbers, 25 controls meeting the exclusion criteria but not working in a job involving noise exposure were included.

Data collection tools

Each test was performed separately on each ear.

Tympanometry and acoustic reflex threshold

Tympanometric examination was performed to examine the middle ear status of the participants with the Otometrics brand Otoflex model device. Participants with Type A tympanogram were included in the study. For acoustic reflex threshold measurements, ipsilateral and contralateral recordings were taken with the same brand and model device at 500, 1000, 2000, 4000 Hz.

Pure tone and high frequency audiometry

Hearing thresholds of the participants were determined with Otometrics brand Astera 2 model device. Air conduction hearing thresholds were measured in the frequency bands 125–250–500–1000-2000–4000-6000–8000 Hz using supraaural headphones. Again, with the same brand and model device, pure tone stimuli were sent through circumaural headphones in the frequency bands 10000–12500–14000–16000 Hz to determine the participants' high frequency thresholds.

Speech tests

Participants' speaking tests were performed with Otometrics brand Astera 2 model device. Speech Recognition Test (SRT) was performed by asking the participants to repeat the words they heard with a spondaic word list and the lowest level at which they heard the speech at 50% was accepted as the threshold. In addition, the level at which speech was most comfortable level (MCL) and the level at which it was uncomfortable level (UCL) were determined. The Speech Discrimination (SD) test was administered by presenting participants with 25 monosyllabic words at their most comfortable listening level (MCL) and asking them to repeat the words they heard. Each correctly repeated word was scored as 4% (maximum score 100%). The dynamic range, which is the usable listening range and provides information about cochlear sensitivity, was calculated using the UCL-SRT formula.

Otoacoustic emission measurements

Distortion Product Otoacoustic Emissions (DPOAE) at 996, 1191, 1416, 1679, 2001, 2382, 3359, 4003, 4755, 5654, 6728 and 7998 Hz; Transient Otoacoustic Emissions (TEOAE) at 1000, 1500, 2000, 3000 and 4000 Hz were measured and Signal-Noise Ratio (SNR) were recorded using an Otometrics brand Capella model device.

Statistical analysis

SPSS 27.0 was used for analyses. Analyses were performed separately for the right and left ears for all collected data. Descriptive statistics included means and standard deviations for continuous quantitative variables. Frequencies and percentages were presented for qualitative variables. Quantitative data were analyzed for normal distribution using the Shapiro–Wilk test. Quantitative variables did not show a normal distribution, and intergroup comparisons were made using the Mann–Whitney U test. The chi-square test was used for qualitative data analysis. $p<0.05$ was considered statistically significant.

Results

Age and gender information of the groups is shown in Table 1. The mean age of the study group was 39.12 ± 5.44 years, and that of the control group was 36.48 ± 8.02 years, and the ages of the two groups were statistically similar ($p>0.05$). All participants in both groups were male (100%).

Figure 1 shows the comparison of pure tone and high frequency hearing thresholds of the groups in the right (a) and left (b) ears. Hearing thresholds of the firefighters were significantly higher than the control group at 125, 250, 500, 1000, 6000 and 8000, 10000, 12500, 14000, 16000 Hz in the right ear and 125, 250, 1000, 4000, 6000, 8000, 10000, 12500, 14000, 16000 Hz in the left ear ($p<0.05$). No significant difference was found between the groups in the hearing thresholds of 2000 and 4000 Hz in the right ear and 500 and 2000 Hz in the left ear ($p>0.05$).

Figure 2 shows the comparison of ipsilateral and contralateral acoustic reflex thresholds of the groups. No significant difference was found between the right (Fig. 2a) and left (Fig. 2c) ipsilateral acoustic reflex thresholds in both groups ($p>0.05$). Right ear (Fig. 2b) contralateral 500, 1000, 4000 Hz; left ear (Fig. 2d) contralateral 500, 1000, 2000, 4000 Hz acoustic reflex thresholds were significantly higher in the study group than in the control group ($p<0.05$).

Table 1 Sociodemographic information of the groups

		Study Group (n = 25) X ± SD n, %	Control Group (n = 25) X ± SD n, %	p
Age (Year)		39.12 ± 5.44	36.48 ± 8.02	0.056
Gender	**Female**	0 (0.00%)	0 (0.00%)	1.000
	Male	100 (100.0%)	100 (100.0%)	

X: Mean, *SD:* Standard Deviation, *n:* Number, *%:* Percentage

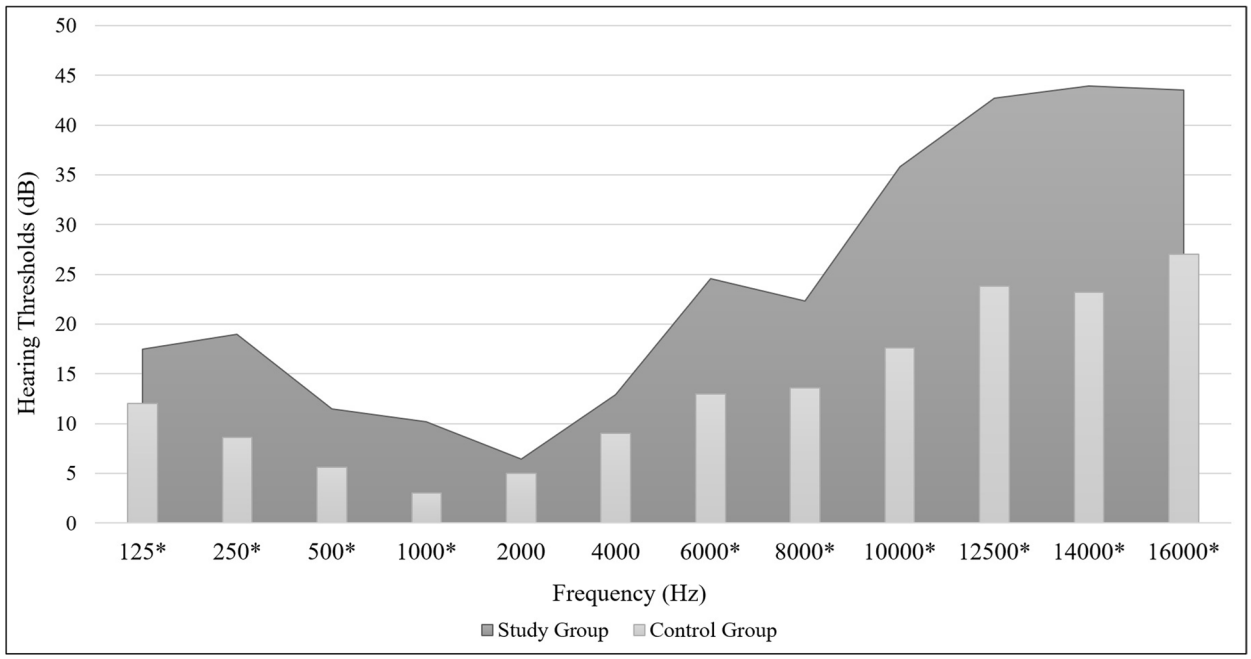
Figure 3 shows the comparison of the speech test results of the groups. Right and left ear SRT (Fig. 3a) values were significantly higher in the study group than in the control group ($p<0.05$). There was no significant difference between the groups in SD (Fig. 3b), MCL (Fig. 3c), UCL (Fig. 3d) results ($p>0.05$).

Figure 4 shows the dynamic ranges of the right ear (Fig. 4a, b) and left ear (Fig. 4c, d) of the groups. In the right ear, the dynamic range of the study group was 80.40 ± 11.62, while the dynamic range of the control group was 87.20 ± 8.30. It was observed that the right ear dynamic range of the study group was significantly narrower than the control group ($p<0.05$). In the left ear, the dynamic range of the study group was 80.00 ± 11.72, while the dynamic range of the control group was 87.40 ± 8.79. It was observed that the left ear dynamic range of the study group was significantly narrower than the control group ($p<0.05$).

Figure 5 shows the comparison of DPOAE and TEAOE SNR results of the groups. The DPOAE SNR results at 4003, 5654, 6728, 7998 Hz in the right ear (Fig. 5a) and 4755, 5654 Hz in the left ear (Fig. 5b) were significantly lower in the study group than in the control group ($p<0.05$). There was no significant difference between the groups in DPOAE SNR results at other frequencies ($p>0.05$). The TEOAE SNR results at 3000 and 4000 Hz in the right ear (Fig. 5c) and 4000 Hz in the left ear (Fig. 5d) were significantly lower in the study group than in the control group ($p<0.05$). There was no significant difference between the groups in TEOAE SNR results at other frequencies ($p>0.05$).

Discussion

Although the presence of noise in life is important in terms of affecting hearing thresholds, it is not sufficiently recognized that it poses a threat to health [11]. Firefighters who are exposed to noise excessively during their professional work are at great risk for hearing loss. In this regard, it has been reported in the literature that 74% of firefighters are not concerned about hearing loss, while 82% are concerned about developing mild to severe hearing loss in the long term. Additionally, it has been reported that firefighters concerned about their hearing health are using more hearing protection equipment [12]. In this context, our study evaluates the effects of high-level noise that firefighters are exposed to throughout their professional lives on hearing thresholds, speech understanding abilities, dynamic range and outer hair cells, and provides evidence showing the potential risks of occupational noise exposure on auditory health. As far as we have encountered, our study is the first study in which speech tests, dynamic



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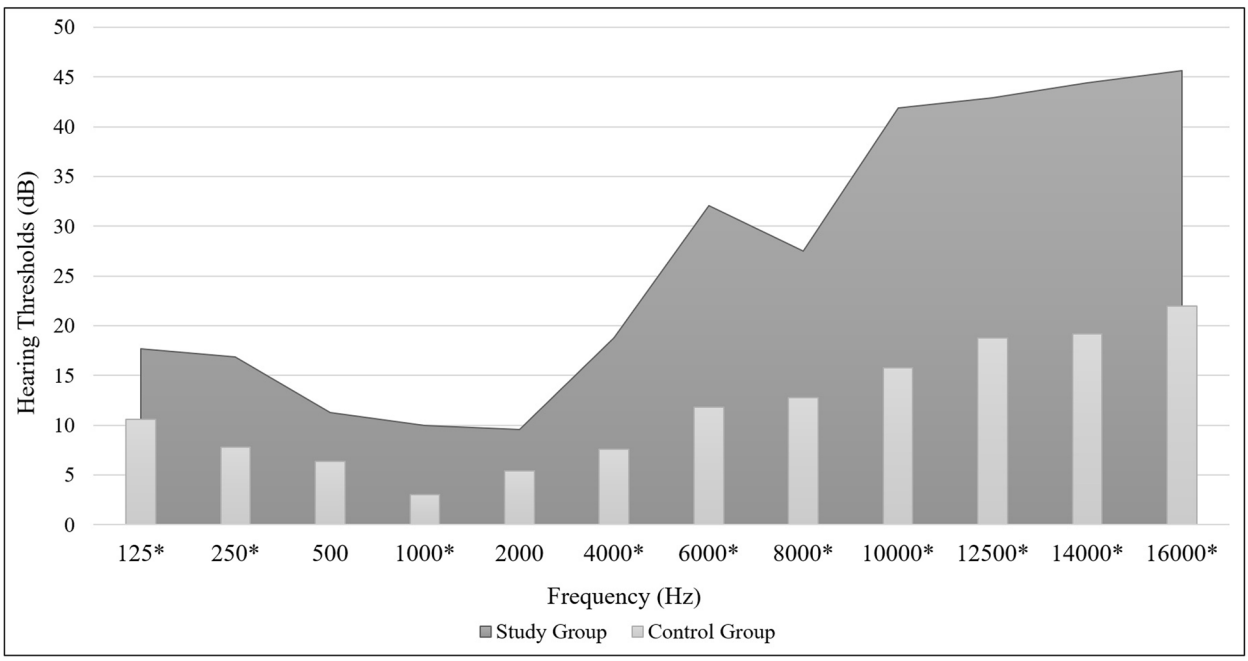

b

Fig. 1 Comparison of right (a) and left (b) ear pure tone and high frequency pure tone thresholds of groups (*:$p<0.05$)

range and acoustic reflex thresholds were also evaluated in firefighters.

Prolonged exposure to noise damages the cochlea, particularly the organ of Corti [13]. As a result of exposure to noise, cochlear blood flow is disrupted, hair cells and supporting structures are destroyed, nerve fibers innervating the hair cells are also lost, and the basal region of the cochlea is first affected [14]. As an effect of noise, vasoconstriction occurs in the capillaries of the basilar membrane and stria vascularis [15]. Moderate noise exposure causes swelling in the nuclei of outer hair cells and afferent nerve fibers extending to inner hair cells. Long-term

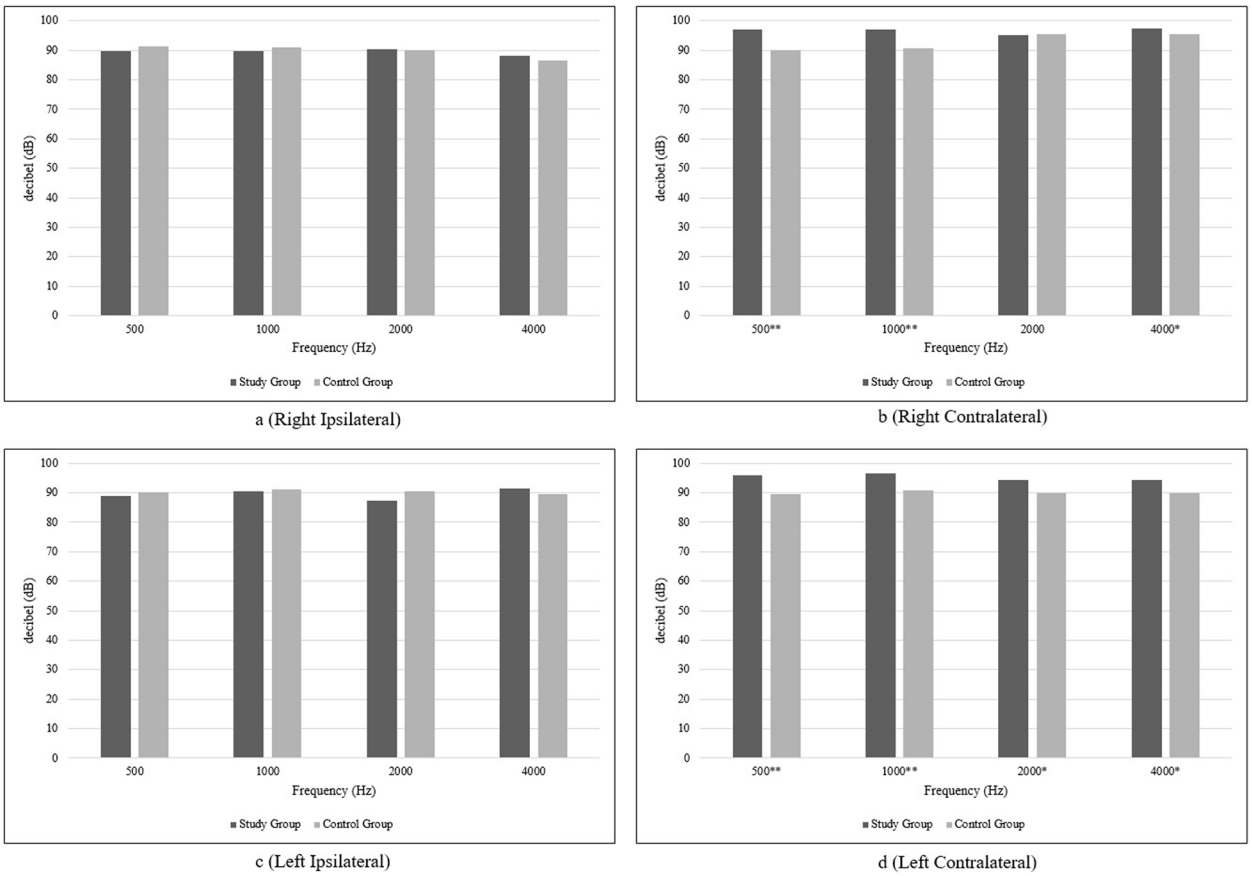

Fig. 2 Comparison of Right (a,c) and Left (b,d) Ear Ipsilateral and Contralateral Acoustic Reflex Thresholds of the Groups (*:$p < 0.05$, **:$p<0.001$)

noise exposure, however, can cause degeneration in the mitochondria at the efferent nerve endings of outer hair cells, in addition to changes in synaptic vesicles [16]. Therefore, hearing loss is first observed at high frequencies. Our findings, in line with this information, show that the hearing thresholds of firefighters, including high frequencies, deteriorate significantly. We observed that hearing thresholds deteriorate more especially at frequencies of 4000 Hz and above. There are various studies in the literature that are consistent with our findings. In a study involving 214 firefighters, approximately 30% of firefighters were found to have mild to severe hearing loss, and it was reported that this rate was too high to be explained by age-related hearing loss alone [12]. In the literature, it has been reported that 40% of firefighters experience hearing loss at 4000 Hz and 6000 Hz [17]. A study conducted in Korea reported that the hearing thresholds of Korean firefighters were significantly worse than those of the otologically normal Korean population [2]. These findings indicate that the high levels of noise that firefighters are exposed to throughout their professional lives may cause irreversible damage to cochlear structures. Therefore, it can be considered that hearing loss observed in firefighters, especially at high frequencies, is directly related to occupational noise exposure. This situation emphasizes the importance of regular audiological evaluations and hearing conservation programs for firefighters.

From our speech test results, there was similarity between the groups in MCL, UCL and SD tests, while SRT thresholds were significantly higher in the study group. However, we believe that this difference will not cause a speech comprehension difficulty severe enough to affect the daily lives of the study group, and therefore is not clinically significant. Although we do not think that the minimal increase in SRT thresholds is clinically significant, we think that in the long term, firefighters' speech understanding skills are more prone to deterioration due to noise-induced hearing loss compared to those without any otological problems. In addition, despite the significant difference in SRT results, the similarity between the groups in SD scores suggests that the current hearing loss is cochlear in origin. In individuals with cochlear pathology, a decrease in dynamic range occurs with a moderate SD score [18]. Our findings, similar to the SRT results, showed that the dynamic range was

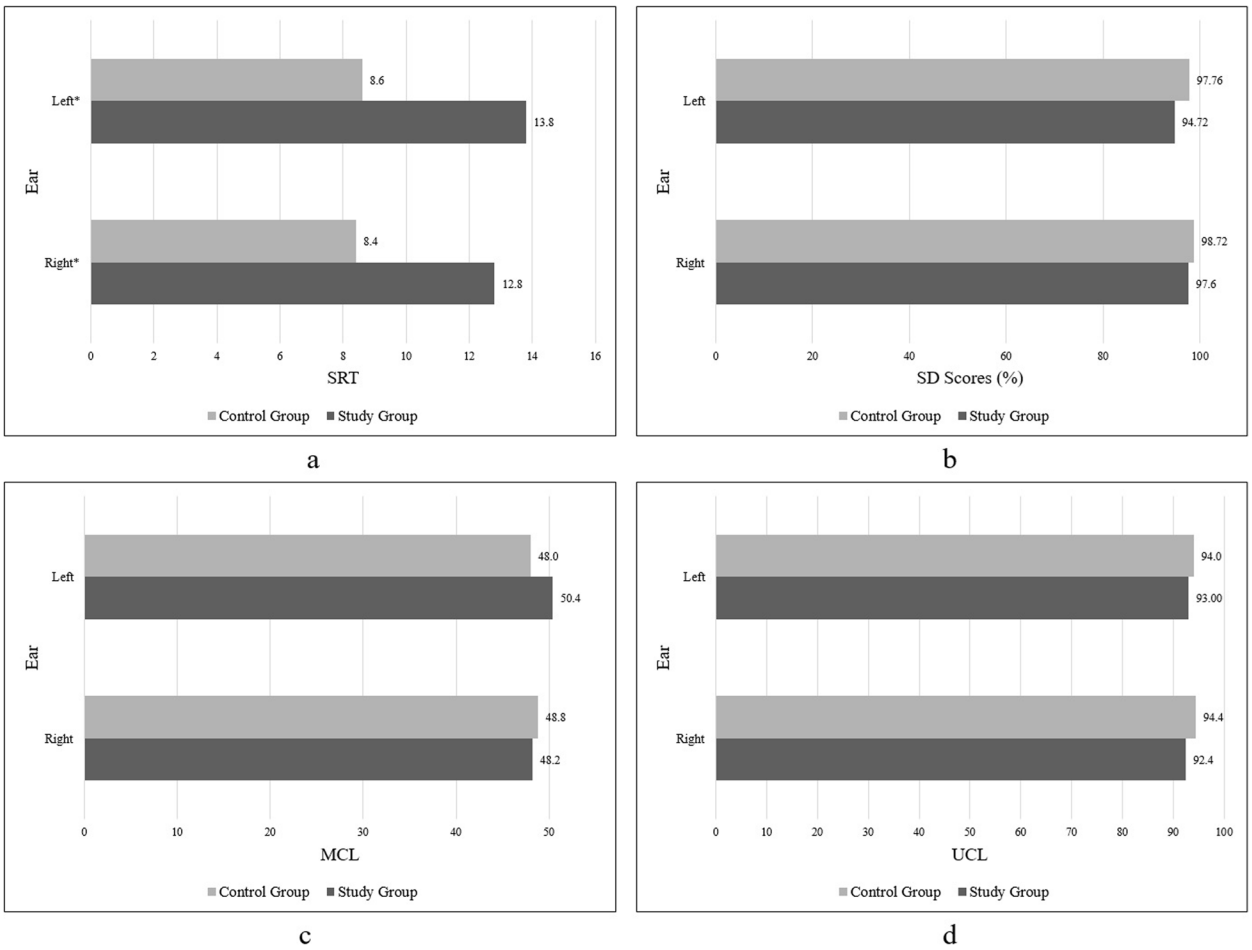

Fig. 3 Comparison of the Speech Test Results of the Groups (a: SRT, b: SD, c: MCL, d: UCL)

significantly narrower in firefighters than in the control group, but this was not clinically significant. Nevertheless, it should be kept in mind that long-term occupational noise exposure may lead to further narrowing of the dynamic range and auditory performance losses in the future. Therefore, it is important to implement hearing protection measures and to perform regular hearing screenings. In future studies, it is recommended to conduct research in larger populations using speech understanding tests in noise in our population.

Acoustic reflex results, bilateral ipsilateral measurements were similar between the groups. Contralateral acoustic reflex measurements showed significantly higher results in both ears in the study group. This statistically significant difference indicates that the noise to which firefighters are exposed may have a negative effect on the central auditory pathways in the long term. However, in a study involving 364 workers exposed to noise, it was reported that hearing complaints were not associated with acoustic reflexes [19]. This suggests that changes in acoustic reflexes may not always proceed in parallel with subjective auditory complaints and that the adaptation of the auditory system to noise may show individual differences. Further studies are recommended to better understand the relationship between acoustic reflex results and broader clinical symptoms in individuals exposed to noise.

The role of TEOAE and DPOAE in the evaluation of cochlear damage in noise-exposed workers is well known [20, 21]. Our findings of both TEOAE and DPOAE indicate that outer hair cell mobility is affected in firefighters exposed to noise. There are limited studies examining the otoacoustic emission measurements of firefighters. In a cohort study including 176 young firefighters, it was reported that DPOAE amplitudes of firefighters decreased significantly and cochlear outer hair cell dysfunction increased as the duration of noise exposure increased [21]. Similarly, abnormal results were reported in both TEOAE and DPOAE tests of people exposed to noise [22]. It has been reported in the literature that

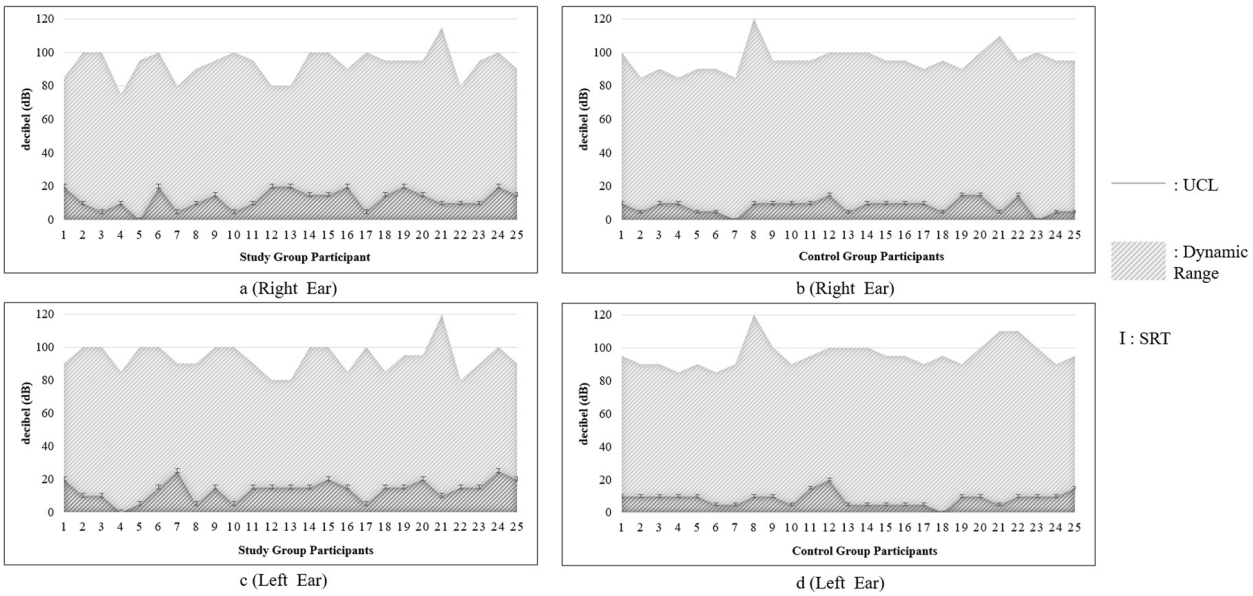

Fig. 4 Dynamic Ranges of the Groups (a: Right Ear, Study group; b: Right Ear, Control Group; c: Left Ear, Study Group; d: Left Ear, Control Group, *:p<0.05, **:p<0.001)

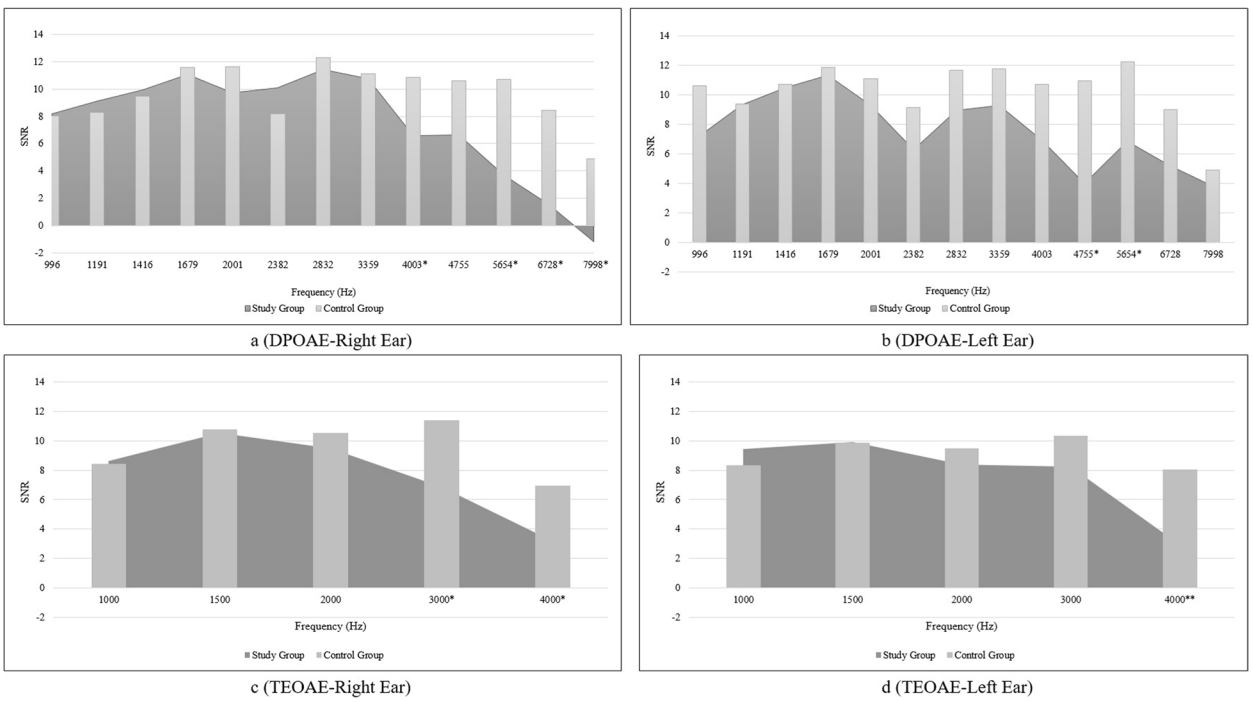

Fig. 5 Comparison of DPOAE (a: Right Ear, b: Left Ear) and TEOAE (c: Right Ear, d: Left Ear) Results of Groups

DPOAE results are more affected at frequencies of 4000 Hz and above in both noise-exposed and noise-exposed individuals [23]. In line with the literature, the results of our study also showed that DPOAE results of firefighters exposed to noise are more negatively affected at frequencies of 4000 Hz and above. In this context, based on our results and the literature, it is important to emphasize the necessity of early diagnosis and intervention in the deterioration of DPOAE and TEOAE results associated with long-term noise exposure in firefighters.

A significant limitation of this study is that firefighters were not questioned about their noise exposure levels, exposure durations, exposure frequency, and whether or not they used ear protection. These factors have significant effects on hearing health, and this omission made it impossible to assess the impact of these variables. However, the measurements made on the participants' hearing functions clearly reveal the potential effects of noise exposure with the available data and provide important evidence to the literature on this subject. Additionally, a significant limitation of this study was that our sample consisted only of male firefighters due to almost most of the active personnel being male. Therefore, we could not assess gender-based auditory differences and can not generalize the findings to female firefighters.

In future studies, it is recommended that firefighters be questioned about their noise exposure levels and hearing protection equipment usage habits. These data are critical for evaluating the effects of personal protective equipment usage on hearing health in more detail. In addition, it is thought that direct measurement of noise levels will reveal the relationship between hearing loss risk and occupational noise exposure more clearly. In addition, it is also of great importance to increase hearing awareness among firefighters. Trainings should be organized on the risk of hearing loss and awareness activities should be carried out on the effects of occupational noise exposure on hearing health. To reduce the risk of hearing loss, individuals at risk can be informed about the benefits and regular use of hearing protection equipment. Additionally, regular audiological evaluations are an important step in early detection of hearing loss.

Conclusions

This study indicates that long-term occupational noise exposure of firefighters has serious effects on auditory health. In addition, changes observed in tests such as speech understanding, dynamic range and acoustic reflex measurements indicate that occupational noise exposure has a broader auditory functional effect. These findings emphasize the importance of regular audiological screenings and hearing protection measures in firefighters. Hearing loss associated with noise exposure is a problem that requires early detection and intervention, and the findings of this study provide an important reference for the protection of hearing health.

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Authors' contributions
NNB was the project manager and played an active role in the conception, data collection, and drafting of the manuscript. HO was the project supervisor and played an active role in the conception and design of the study, participant recruitment, and writing of the manuscript, overseeing all processes. AAKK played an active role in data analysis and interpretation, and in the preparation of the manuscript. EA and VCH played an active role in data collection and drafting of the manuscript. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Non-Interventional Ethics Committee of Biruni University with the decision numbered 2021/60–7 dated 22.10.2021. Written permission was obtained from the a metropolitan municipality for the participation of firefighters. Additionally, voluntary consent forms were obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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