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RESEARCH ARTICLE

Impact of age and solvent exposure on audiometric abnormalities among automotive production workers: A cross-sectional study from Türkiye

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Abstract

Objectives: This study investigates the relationship between occupational noise, solvent exposure, and audiometric abnormalities in male automotive industry workers, focusing on factors associated with audiometric abnormalities, including age, body mass index, and biochemical markers.

Methods: This cross-sectional study was conducted among 500 male workers who were admitted to the outpatient clinic of Ankara Occupational and Environmental Diseases Hospital for periodic health examinations between September 1, 2020, and July 1, 2021. Audiometric results and biochemical markers, including hippuric acid, trichloroacetic acid, and manganese, were assessed alongside demographic and occupational variables. Multivariate logistic regression was used to identify predictive factors for abnormal audiometry results.

Results: Among the participants, 61.2 % exhibited abnormal audiometry results, and 11.4 % had noise-induced hearing loss. Age strongly predicted abnormal audiometry (OR = 1.11, 95% CI: 1.07–1.15, $p < 0.001$), with an 11% increase in odds per year. Elevated trichloroacetic acid (TCA) levels were also associated with a 9% increase in odds of abnormal audiometry (OR = 1.09, 95% CI: 1.01–1.18, $p = 0.027$). No significant associations were found for body mass index, duration of work, or hippuric acid levels.

Conclusions: Age and TCA levels were significantly associated with audiometric abnormalities among workers exposed to occupational noise and solvents. These findings highlight the need for targeted interventions, including regular audiometric evaluations and minimizing solvent exposure, to reduce the risk of hearing loss in industrial settings. Further research is needed to explore the underlying mechanisms linking solvent exposure and auditory dysfunction.

Keywords: noise-induced hearing loss, occupational solvent exposure, audiometric abnormalities, automotive industry workers, Trichloroacetic Acid (TCA), predictive risk factors

Introduction

Occupational noise is a common physical hazard in many industrial workplaces. It is mainly generated by machinery, metal processing, and other manufacturing activities, and workers may be exposed to sound levels that exceed recommended safety limits during routine operations. To reduce the health risks associated with excessive noise exposure, several international organizations have established regulatory frameworks and exposure limits for occupational settings. For instance, the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) recommend

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exposure limits of approximately 85–90 dB over an 8-hour work shift, with preventive measures required when these limits are exceeded [1,2]. Prolonged exposure to high levels of occupational noise may lead to noise-induced hearing loss (NIHL), a progressive sensorineural hearing disorder that typically begins at high frequencies. Studies show the relationship between workplace exposure to noise and noise-induced hearing loss (NIHL). Over time, prolonged exposure to high sound levels can cause permanent inner ear damage, called noise-induced hearing loss. This sensorineural hearing loss begins in the high-frequency range and progresses gradually with continued exposure to extreme sound levels [3]. It has been found in animal experiments that heavy metals and organic solvents are ototoxic [4-6]. Various chemicals with ototoxic properties have been identified, and organic solvents have been shown to increase hearing loss synergistically with noise [7]. In a study conducted among printing workers, it was found that there was a significant relationship between hippuric acid level and hearing loss [8]. The concentrations of methyl hippuric acid in urine and pure-tone thresholds (2 to 8 kHz) were positively correlated in xylene-exposed workers. In the same study, subjects with a high cumulative dose of xylene exposure had poorer test results than subjects with a low cumulative xylene exposure [9].

In the literature, there are studies in the form of case reports supporting that chronic exposure to manganese may be associated with hearing impairment [10,11]. A mouse study determined that the level of manganese accumulated in the inner ear of the subject who was injected subcutaneously for three days and remained in the inner ear for at least 2 weeks after the treatment. This is important as a study demonstrates manganese accumulation in the inner ear due to systemic exposure [12].

After diagnosing occupational diseases in Turkey, it is mandatory to report them to SGK (Sosyal Güvenlik Kurumu, Social Security Institution). According to the latest published 2021 SGK Occupational Diseases and Occupational Accidents Data, the total number of reported occupational diseases in Turkey is 1207, 55 of which have been reported as occupational hearing loss [13]. A significant relationship was found between age, duration of exposure to noise at work, and hearing loss in forestry workers using chainsaws in Turkey [14]. In another case-control study, no correlation was found between blood arsenic levels and hearing loss levels in miners [15]. It has been found that there is a loss of capacity for the vestibular-ocular reflex, which shows vestibular dysfunction in patients with hearing loss due to exposure to noise in industrial workers [16]. Work-related noise and hearing loss were also associated with carpenters [17].

According to the data for 2021, there are 16 million insured employees in Turkey, 238,000 of whom work in the automotive production sector [13]. In Turkey, workers in automobile manufacturing plants typically work 5 days a week, at least 8 hours a day. The total weekly working time is at most 45 hours. The automobile manufacturing sector has main occupational groups such as painters, assemblers, and welders [18]. In the production sector, the sound of metals hitting and rubbing against each other creates noise in the work environment. Paint, solvents, and welding fumes, used extensively in the automobile industry, can also cause inner ear damage, as mentioned above [4,11].

Previous research has found that these chemicals can cause damage to the inner ear. However, little evidence suggests a relationship between workplace manganese and solvent exposure and hearing. Studies on the effect of paint and welding fume exposure on hearing in the automotive manufacturing sector are minimal. Therefore, this study aims to determine the relationship between urinary manganese levels, solvent degradation metabolites (urine TCA, hippuric acid), and audiometric abnormality levels among automotive manufacturing workers.

Methodology

Study design

This cross-sectional study examines the patient files of the automotive factory employees who applied to the occupational outpatient clinic of Gazi Hospital for periodic health examinations between September 1, 2020, and July 1, 2021. xx University Human Research Ethics Committee granted the study exemption from full ethical approval (approval no: 20.10.2022-E-77082166). All the workers included in the study are men in different occupations in the same automotive manufacturing factory. The entire universe is included in the study. An otolaryngologist examined all employees, and those with chronic otitis media were excluded from the study. Individuals with personal or familial deafness in their anamnesis, those who had ear surgery, those who used ototoxic drugs, and those with type 2 diabetes mellitus and hypertension for more than 5 years were excluded from the study. Workplace noise levels were not measured. Workplace noise levels were not directly measured in this study. However, all participants were employed in the automotive production environment, where routine processes such as metal processing, welding, and assembly are known to generate substantial occupational noise. Therefore, workers were considered to be exposed to workplace noise based on their job roles and the characteristics of the production environment. According to the audiometry results, the groups were divided into those with normal and abnormal audiometry results. To diagnose NIHL, Klockhoff-modified criteria for a history of occupational noise exposure, bilateral hearing loss, and a threshold level greater than 25 dB at frequencies between 1,000 Hz and 8,000 Hz were used [19].

Data collection

Age, gender, height, weight, BMI (Body Mass Index), current and past occupations, working years, workplace exposures, smoking and alcohol use status, chronic diseases and drug use, previous ear diseases, and operations were obtained from the medical anamnesis form. The employees' audiometer analysis reports, hemogram, biochemistry, and toxicological marker results were examined from the patient files. Due to the small number of participants in some occupational categories (assembler and quality control officer), these groups were not included as separate categories in the comparative analyses. Body mass index (BMI) was calculated by dividing body weight in kilograms by the square of height in meters (kg/m^2), according to the standard anthropometric definition recommended by the World Health Organization [20]. The employees' audiometry reports, hemogram results, biochemical parameters (glucose and thyroid-stimulating hormone [TSH]), and toxicological markers (urinary hippuric acid, TCA], and whole-blood manganese levels) were obtained from patient records and included in the analysis.

Audiometric examination

An otolaryngologist examined all of the employees after a pure tone audiometry was performed using a pure tone manual diagnostic audiometer (Model GSI 61, Grason-Stadler, Inc.) by a single audiologist at the Audiology Laboratory of Ankara Occupational and Environmental Diseases Hospital. Pure tone audiometry was conducted with the subjects at frequencies of 0.5, 1, 2, 3, 4, and 6 kHz using air and bone conduction in a sound-isolated chamber. The participants were informed to differentiate between low sound levels of several frequency pure tones and react by pressing a button. The lowest tone heard at each frequency was evaluated as the hearing threshold level. A normal audiogram was described as findings consistent with normal hearing sensitivity, typically consisting of air conduction and bone conduction shown for the right and left ear, respectively, with <25 dB HL values at each tested frequency level [21]. In this study, "abnormal audiometry" referred to any audiometric finding deviating from normal hearing thresholds. In contrast, NIHL was defined using the Klockhoff-modified criteria, which identify hearing loss patterns compatible with occupational noise exposure. Therefore, NIHL represents a specific subset of abnormal audiometric findings. Workplace environmental noise measurements were not performed.

Collection of biological samples

Ten millilitres of venous blood were poured into tubes (BD Vacutainer, USA) by venipuncture from each subject and processed within the following 3 days. After centrifuging the samples at 3,500 g for 10 minutes at +4 ^{o}C, the serum was separated and stored at -80 °C until analysis. Whole blood was used for manganese analysis. Urine was collected into a clean urine container. After collecting the urine, it was stored in the refrigerator at +4°C. It was sent to the analytical toxicology laboratory for analysis and frozen before analysis.

Biochemical measurements

Complete blood counts were analysed using the Coulter Gen-S haematology analyser. Whole blood manganese was analysed with certified reference material (Seronorm Trace Elements Billinstod, Norway) by Inductively Coupled Plasma—Mass Spectrometer on Agilent 7700 (Agilent Technologies, USA). Urine hippuric acid rates were analysed using "Chromosystems, Agilent 1200 series equipped with a UV detector, HPLC with reagent kit for the HPLC-Analysis. Urinary TCA was measured with a commercial kit (FAR, Verona, Italy). Briefly, TCA in the sample reacts with pyridine in an alkali medium and forms a colour complex that can be photometrically determined at 526 nm. The assay principle is the colorimetric endpoint.

Statistical analysis

Statistical analyses were performed using the SPSS software version 26 (Statistical Package for the Social Sciences by IBM). The variable was investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov-Smirnov/Shapiro-Wilk's test) to determine whether or not they are typically distributed. Descriptive analyses were presented using medians for the non-normally distributed and ordinal variables. Since the age, weight, height, BMI, duration of work, hippuric acid, manganese, TCA, TSH, and glucose levels were not normally distributed, nonparametric tests were conducted to compare these parameters and the ordinal variables. The Mann-Whitney U test was used to compare the differences between workers with normal and abnormal audiometry for age, weight, height, BMI, duration of work, hippuric acid, manganese, TCA, TSH, and glucose levels. The proportions of workers with abnormal and standard audiometry were presented by smoking status and occupations using cross-tabulations. The Chi-square test was used to compare these proportions in different groups. Multivariate logistic regression was employed to assess the independent effects of predictors (age, BMI, duration of work, hippuric acid, and TCA levels) on the likelihood of abnormal audiometry results, with odds ratios (OR) and 95% confidence intervals (CI) calculated to quantify associations, and p-values used to determine statistical significance. Multicollinearity among the independent variables included in the regression model was assessed using the variance inflation factor (VIF). All VIF values were below the commonly accepted threshold, indicating no significant multicollinearity.

Results

A total of 500 male workers employed in the automotive production sector were included in the study. The median age of the participants was 33 years, and the median body mass index (BMI) was 26,1 kg/m^2. More than half of the workers (62.4%) were current smokers. The median duration of employment in the sector was 6 years. The most common occupations were welding (50.8%) and painting (43.8%). Overall, abnormal audiometry findings were observed in 61.2% of the workers. The detailed sociodemographic and biochemical characteristics of the study population are presented in Table 1. All subjects in the study group recruited in the automotive industry were male. The median age of the subjects was 33. The median height was 175 cm, and the median weight was 80 kilograms. The median BMI calculated with the kg/m^2 formula was determined as 26.1. More than half of the employees were smokers (62.4%). While the maximum working period of the employees in the same sector is 17 years, the average working year has been determined to be 6 years. While reviewing the occupations of the employees, it was determined that 56.2% were welders and 43.8% were painters. When the data of all employees were examined, it was determined that 61.2% of the individuals had abnormal findings in audiometry. In toxicological analyses, the median value of hippuric acid was 521.5 mg/L, the median value of TCA was 4.4 µg/L, and the median value of manganese was 9.9 µg/L among all workers. In biochemical analyses, the median glucose level was 96 mg/dl, and the median TSH level was 1.86 mIU/L.

When the differences between the group with abnormal audiometry and the group with normal audiometry results were examined, age was statistically significantly

Table 1. Sociodemographic and biochemical characteristics of male industry workers

Age (years), median (Q1–Q3)		33 (27-43)
Height (cm), median (Q1–Q3)		175 (171-180)
Weight (kg), median (Q1–Q3)		80 (74-90)
BMI (kg/m^2), median (Q1–Q3)		26.1 (24.2-28.7)
Current smoking, n (%)		312 (62.4)
Duration of work (years), median (Q1–Q3)		6.0 (4-17)
Occupation, n (%)	Welder	254 (50.8)
	Painter	219 (43.8)
	Assembler	22 (4,4)
	Quality control officer	5 (1,0)
Abnormal audiometry, n (%)		306 (61.2)
NIHL, n (%)		57 (11.4)
Hippuric acid (mg/L), median (Q1–Q3)		528 (295-924)
TCA (µg/L), median (Q1–Q3)		4.4 (3.2-6.3)
Manganese (µg/L), median (Q1–Q3)		9.8 (7.9-12.4)
Glucose (mg/dL), median (Q1–Q3)		96 (90-104)
TSH (mIU/L), median (Q1–Q3)		1.79 (1.29-2.52)

N: number, BMI: body mass index, NIHL: Noise-Induced Hearing Loss, TCA: Trichloroacetic Acid, TSH: Thyroid-Stimulating Hormone, mg/L: Milligrams per Liter, µg/L: Micrograms per Liter, mIU/L: Milli-International Units per Liter.

higher in the group with abnormal audiometry results (p<0.001). The BMI value in the group with abnormal audiometry results is higher than in the group with standard audiometry. This difference was also found to be statistically significant (p=0.009). The groups had no significant difference regarding height, weight, and smoking status. There is a statistically significant difference between the groups regarding working years in favor of those with abnormal audiometry (p<0.001). There was no significant difference between the groups in terms of occupations. Hippuric acid and TCA levels were statistically significantly higher in the group with abnormal audiometry (p=0.015, p=0.040, respectively). There was no significant difference between the groups regarding manganese, glucose, and TSH levels (Table 2).

When the differences between those with and without sensorineural hearing loss were examined, the median age was 40 in those with sensorineural hearing loss and higher than in those with no NIHL. This difference is statistically significant. Those with NIHL had a statistically higher BMI than those without. There was no significant difference between the groups regarding height and weight. When evaluated in terms of smoking, 54.2% of those with NIHL and 64.4% of the No NIHL audiometry group were smokers. This difference is not statistically significant. Considering the median working years, this period was 8 years in patients with sensorineural hearing loss, statistically significantly higher than in the group with other audiometry. The groups showed no significant difference in the hippuric acid, TCA and manganese median. The median TSH level was 1.76 mIU/L and statistically significantly lower in the NIHL group. There was no significant difference between the groups regarding glucose levels (Table 3).

The factors associated with abnormal audiometry results among male industry workers exposed to occupational noise are presented in Table 4. Multivariate logistic regression analysis showed that age and TCA levels were significantly associated with abnormal audiometry results. Age was strongly associated with abnormal audiometry results, with an odds ratio (OR) of 1.11 (95% CI: 1.07–1.15, p < 0.001), indicating that for every one-year increase in age, the odds of having abnormal audiometry results increased by 11%. Similarly, TCA levels were significantly associated with abnormal audiometry results, with an OR of 1.09 (95% CI: 1.01–1.18, p = 0.027), suggesting that for each unit increase in TCA concentration, the odds of abnormal audiometry results increased by 9 %. Other variables, including body mass index (BMI) (OR = 1.01, 95% CI: 0.96–1.07, p = 0.626), duration of work (OR = 0.98, 95% CI: 0.94–1.02, p = 0.448), and hippuric acid levels (OR = 1.00,

Table 2. Comparison of characteristics according to audiometry results

		Audiometry		
Variable		**Normal**	**Abnormal**	**p-value**
Age (years), median (Q1–Q3), (n=500)		28.5 (26.0-36.3)	39.0 (29.0-45.0)	**<0.001***
BMI (kg/m^2), median (Q1–Q3), (n=496)		25.7 (24.0-28.0)	26.8 (24.3-29.0)	**0.018***
Smoking status	Current smoker, n (%), (n=312)	128 (41.0)	184 (59.0)	0.188†
	Nonsmoker, n (%), (n=188)	66 (35,1)	122 (64,9)	
Occupation	Welder, n (%), (n=254)	99 (51.0)	155 (50.7)	0.810†
	Painter, n (%), (n=219)	83 (42.8)	136 (44.4)	
Duration of work (years), median (Q1–Q3), (n=500)		5 (3-8)	7 (4-20)	**<0.001***
Hippuric acid (mg/L), median (Q1–Q3), (n=485)		453.0 (282.0-851.0)	600.0 (322.0-991.5)	**0.015***
TCA (µg/L), median (Q1–Q3), (n=489)		4.2 (3.1-6.2)	4.7 (3.4-6.5)	**0.040***
Manganese (µg/L), median (Q1–Q3), (n=486)		9.7 (8.0 -12.6)	9.8 (7,9-12.3)	0.757*
Glucose (mg/dL), median (Q1–Q3), (n=490)		96 (90-101)	96 (90-105)	0.250*
TSH (mIU/L), median (Q1–Q3), (n=470)		1.75 (1.31-2.50)	1.80 (1.27-2.54)	0.866*

For significance testing, a Chi-square† was formed for the differences in group numbers, and a Mann-Whitney-U* was performed.
N: number, BMI: body mass index, NIHL: Noise-Induced Hearing Loss, TCA: Trichloroacetic Acid, TSH: Thyroid-Stimulating Hormone, mg/L: Milligrams per Liter, µg/L: Micrograms per Liter, mIU/L: Milli-International Units per Liter.

95% CI: 1.00–1.00, p = 0.365), did not show statistically significant associations with abnormal audiometry results in this model.

Discussion

It was observed that audiometry evaluations were not within normal limits in 61.2% of the workers in our study. Hearing loss is present in 19.2% of all participants. In a study evaluating the hearing level of workers exposed to noise and organophosphates in the workplace, an abnormality was found in the audiometry results of 53.1% of the participants [22]. In a study conducted among employees of 22 automobile factories, the prevalence of noise-induced hearing loss was 28.8% [23]. A survey conducted to determine the level of hearing health and noise exposure among workers in the automotive industry determined that 26.8% of the participants had various levels of hearing loss [18]. In a study conducted on 2647 people working in an automobile factory, the prevalence of high-frequency hearing loss was 17.2% among the participants [24]. All these results show that a significant portion of the

Table 3. Comparison of characteristics according to the presence of NIHL

		Audiometry		
Variable		**No NIHL**	**NIHL**	**p-value**
Age (years), median (Q1–Q3), (n=500)		32 (27-43)	40 (29-45)	0.016*
BMI (kg/m²), median (Q1–Q3), (n=496)		26.0 (24.2-28.4)	27.5 (24.7-29.2)	0.083*
Smoking status	Current smoker, n (%), (n=312)	281 (90.1)	31 (9.9)	0.184†
	Non-smoker, n (%), (n=188)	162 (86,2)	26 (13,8)	
Occupation	Welder, n (%), (n=254)	230 (90.6)	24 (9.4)	0.147†
	Painter, n (%), (n=219)	189 (86.3)	30 (13.7)	
Duration of work (years), median (Q1–Q3), (n=500)		5 (3-16)	8 (6-20)	0.006*
Hippuric acid (mg /L), median (Q1–Q3), (n=485)		525.0 (294.0-925.0)	585.0 (319.8-909.8)	0.891*
TCA (µg/L), median (Q1–Q3), (n=489)		4.5 (3.3-6.4)	4.3 (2.8-6.0)	0.145*
Manganese (µg/L), median (Q1–Q3), (n=486)		9.8 (7.9-12.5)	9.7 (7.9-11.7)	0.480*
Glucose (mg/dL), median (Q1–Q3), (n=490)		96 (90-104)	97 (89-103)	0.927*
TSH (mIU/L), median (Q1–Q3), (n=470)		1.80 (1.31-2.52)	1.73 (1.11-2.65)	0.438*

For significance testing, a Chi-square† was formed for the differences in group numbers, and a Mann-Whitney-U* was. N: number, BMI: body mass index, NIHL: Noise-Induced Hearing Loss, TCA: Trichloroacetic Acid, TSH: Thyroid-Stimulating Hormone, mg/L: Milligrams per Liter, µg/L: Micrograms per Liter, mIU/L: Milli-International Units per Liter.

Table 4. Predictive factors of abnormal audiometry results among male industry workers exposed to occupational noise

Variable	**OR (% 95% CI)**	**p-value**
Age	**1.11 (1.07-1.15)**	**<0.001**
BMI (kg/m²)	1.01 (0.96-1.07)	0.626
Duration of work (years)	0.98 (0.94-1.02)	0.448
Hippuric acid (mg/L)	1.00 (1.00-1.00)	0.365
TCA (µg/L)	**1.09 (1.01-1.18)**	**0.027**

Multivariate logistic regression was used to calculate the means for each category. BMI: body mass index, TCA Trichloroacetic Acid, mg/L Milligrams per Liter, µg/L Micrograms per Liter.

workers in the automotive industry have hearing loss. Our findings are compatible with the literature. The differences between the frequencies may be due to the lack of similarity in characteristics such as age, gender, working unit, noise exposure, and personal protective equipment use of the individuals in the sample.

Our results showed that age and working time were statistically significantly higher in participants with abnormal audiometry results and those with noise-induced hearing loss. In our study, the odds of abnormal audiometry results increased by 11% for every one-year increase in age. In a survey of workers in automobile parts manufacturing factories, the frequency of hearing loss development in any ear is 33.3% for the participants with a working period of 10 years or more and 20.6% for those with less than 10 years. This frequency, which was 12.2% in the 20-30 age group, was determined as 27.5% in the 31-50 age group [25]. In a study investigating the effectiveness of earplugs in preventing noise-induced hearing loss in an automobile factory, it was observed that the hearing thresholds of workers exposed to noise increased significantly as age and exposure time increased [26]. A study investigating the characteristics of hearing loss in workers exposed to noise in the automotive manufacturing industry revealed that hearing loss is associated with working time [27]. In a prospective study that determined the 10-year incidence of workplace noise exposure and age-related hearing loss, evidence was found that age and exposure time have a potential multiplier effect on hearing function [28]. Undoubtedly, the findings in our study can be considered significant, considering that hearing loss occurs due to chronic exposure to noise and cumulative cochlear microtraumas [29]. In this study, increasing age was associated with abnormal audiometric findings. However, hearing impairment may also occur as part of the natural aging process (presbycusis), even in individuals without occupational exposures. Although NIHL was defined using the Klockhoff-modified criteria to identify audiometric patterns compatible with occupational noise exposure, the contribution of age-related hearing changes cannot be completely ruled out. Therefore, age should be considered a potential confounding factor when interpreting the association between occupational exposures and hearing impairment.

In this study, the mean body mass index of workers with abnormal audiometry results and noise-induced hearing loss was higher than that of workers with standard audiometry. In a study that included 48,549 employees aged 20-64 who did not have hearing loss at baseline and aimed to prospectively determine the link between obesity and hearing loss, overweight and obesity were found to be associated with an increased risk of hearing loss [30]. The findings of a meta-analysis to clarify further the potential relationship between body mass index and hearing loss contributed to the evidence that high body mass index may be positively associated with the risk of hearing loss [31]. In a longitudinal study of 249,000 Swedes that determined the estimated relative risks for sensorineural hearing loss, obesity was associated with doubling the risk of hearing loss [31]. Many different mechanisms can explain the relationship between obesity and hearing loss. Obesity can cause hearing loss by directly damaging hair cells through oxidative stress [32]. Obesity-related atherosclerosis may reduce blood flow to the cochlea by causing the narrowing of the artery and may result in decreased auditory sensitivity [8,33]. In addition, obesity-induced inflammation may contribute to target organ damage, and degeneration in hearing may be exacerbated by increased hypoxia and loss of spiral ganglion cells [28,34].

In this study, workers with hearing loss showed lower TSH levels compared with those with normal audiometry results. However, TSH levels alone are insufficient to determine the presence or type of thyroid dysfunction, as decreased TSH levels may also reflect hyperthyroidism. Since free T3 and free T4 measurements were not available in this study, the relationship between thyroid function and hearing impairment should be interpreted cautiously. Further studies including comprehensive thyroid hormone assessments are needed to better clarify this potential association.

In our study, hippuric acid and TCA levels were higher in participants with abnormal audiometry. TCA levels were significantly associated with abnormal audiometry results, suggesting that for each unit increase in TCA concentration, the odds of abnormal audiometry results increased by 9 %. Hippuric acid and TCA are the primary metabolites of toluene, and trichloroethylene is among the most essential organic solvents [33]. A study evaluating hearing impairments in workers exposed to various levels of noise and solvents in a printing facility showed that occupational exposure to toluene caused an increase in hippuric acid, a nonspecific metabolite, in the urine. A rise of one gram of hippuric acid in the urine increased the probability of hearing loss by 1.76 times

[8]. Results of a study of workers exposed to solvents at concentrations below the occupational exposure limit values indicate that exposure to even moderate concentrations of occupational organic solvents increases the risk of hearing loss [35]. In a five-year study documenting the potential development of toluene and noise-induced hearing loss through repeated testing and measurement, the estimated relative risk of elevated hippuric acid levels for high-frequency hearing loss was 1.28 [34]. In a relatively old study of workers with chronic trichloroethylene poisoning, hearing loss was observed in 26 of 40 workers who were frequently exposed to high concentrations of trichloroethylene. Hearing loss in workers with urinary TCA levels between 40-200 mg/l was bilateral, affecting sensorineural and high frequencies [36]. In an animal study in four groups of rats exposed to trichloroethylene alone, the noise alone, a combination of trichloroethylene and noise, or control conditions, hearing loss due to exposure to a combination of trichloroethylene and noise at a frequency of 4 kHz was significantly greater than in the other groups [37]. The need for current data on the effects of solvent exposure on hearing function is noteworthy in the literature.

Limitation

This study has several limitations that should be acknowledged when interpreting the results. First, workplace noise levels were not directly measured using environmental noise monitoring; therefore, individual noise exposure levels could not be quantified precisely. Second, information on the use of personal hearing protection devices was not available, which may have influenced the audiometric outcomes observed among the workers. Third, due to the cross-sectional design of the study, causal relationships between solvent exposure, occupational noise, and hearing impairment cannot be established. Finally, although several relevant variables were included in the analysis, the possibility of residual confounding from unmeasured factors cannot be entirely ruled out.

Conclusion

This study highlights age and TCA levels significantly associated with audiometric abnormalities among male automotive industry workers exposed to occupational noise and solvents. The findings demonstrate an 11% increase in the odds of abnormal audiometry per year of age and a 9% increase per unit rise in TCA levels, emphasizing the cumulative impact of aging and chemical exposure on auditory health. In contrast, body mass index (BMI), duration of work, and hippuric acid levels did not show significant associations. These results underscore the importance of integrating regular audiometric evaluations, targeted interventions to reduce solvent exposure, and hearing conservation programs to mitigate the risks of occupational hearing loss in industrial settings. Further research is needed to explore the mechanisms linking solvent exposure to auditory dysfunction and develop evidence-based preventive strategies.

Author contribution

Conception: F.B., S.P.Ç., V.M., M.N.İ.; Design: F.B., S.P.Ç., M.N.İ.; Data acquisition: S.P.Ç.; Data analysis: F.B., S.P.Ç., V.M.; Data interpretation: S.P.Ç.; Drafting of the manuscript: F.B., S.P.Ç., V.M.; Critical revision of the manuscript: F.B., S.P.Ç., V.M., M.N.İ. All authors reviewed the results, approved the final version of the manuscript, and agreed to be accountable for all aspects of this study.

Ethical approval

This study was approved by the Gazi University Human Research Ethics Committe (Date: October 10, 2022, Decision/Protocol No: E-77082166). Informed consent was obtained from all participants involved in this study.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that this study was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Generative AI statement

The authors declare that during the preparation of this study, the following AI-assisted technology was used: ChatGPT and DeepL translate on between August and September 2025. Extent of Use: for translation assistance. The authors confirm that they have critically reviewed and edited any AI-generated content and take full responsibility for the integrity, accuracy, and originality of the publication. The authors certify that the original human contribution is maintained and that AI-assisted tools are not listed or cited as authors.

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