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Articles

The association between occupational noise exposure, hearing loss, and metabolic syndrome among workers in a textile factory: a cross-sectional study

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Rationale: Previous studies have examined the relationship between noise exposure and hearing loss with metabolic syndrome (MetS), but the results have been inconsistent.
Aim: To assess an association between noise exposure, hearing loss, and the status of MetS.
Methods: This cross-sectional study was carried out in 950 employees of a textile factory in 2023. Participants were categorized into two groups based on their noise exposure: under 85 dB versus 85–90 dB. Hearing loss was defined as a mean hearing threshold exceeding 25 dB in either or both ears within the relevant frequency ranges. MetS was diagnosed with the National Cholesterol Education Program Expert Panel and Adult Treatment Panel III criteria. Demographic, medical, and occupational data were collected during periodic examinations. Then, the relationship between MetS and its components with noise exposure and hearing loss was examined.
Results: The median age of the study population was 33 years (IQR 28 to 38 years) and the median work experience was 3 years (IQR 2 to 9 years). 864 (90.9%) of the subjects were male, 774 (81.5%) were married, and 848 (89.3%) had shift work. 10.8% (n = 103) of the participants were diagnosed with MetS, and 72% (n = 684) had exposure to noise levels greater than 85 dB. Increased waist circumference (odds ratio (OR) = 1.61; 95% confidence interval (CI) 1.20–2.17, p = 0.002), elevated triglycerides (OR = 2.03; 95% CI 1.36–3.02, $p < 0.001$), and reduced high-density lipoprotein (HDL) levels (OR = 1.71; 95% CI 1.28–2.29, $p < 0.001$) were significantly associated with the noise exposure. There was also a significant relationship between MetS components and high-frequency hearing thresholds. Specifically, hearing loss at higher frequencies in both ears was linked to elevated fasting blood sugar, diastolic blood pressure, triglycerides, and low HDL.
Conclusion: Our study showed a significant association between noise exposure and components of MetS including increased waist circumference, high triglycerides, and low HDL cholesterol. In addition, based on initial analysis, there was a significant association between MetS and its components, including dysregulated glucose and lipids, and elevated diastolic blood pressure, with the median hearing threshold at higher frequencies.

Key words: hearing loss, metabolic syndrome, occupational noise exposure, textile factory

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Metabolic syndrome (MetS) encompasses a cluster of metabolic disorders, characterized by central obesity, glucose metabolism impairment, dyslipidemia, and elevated blood pressure. Its diagnosis requires meeting at least three of five criteria: increased waist circumference, elevated fasting blood sugar, high triglycerides, raised blood pressure, or decreased high-density lipoprotein (HDL) cholesterol [1]. This condition has emerged as a significant global health concern, affecting approximately 20–25% of the world's population, with our country, Iran, reporting a prevalence of 31.02% as of 2018 [2, 3].

The development of MetS is multifactorial, influenced by lifestyle factors such as excessive caloric intake and physical inactivity, as well as genetic predisposition, environmental toxins, and occupational conditions [4, 5]. Among workplace factors, noise exposure has been hypothesized to be as a significant contributor to metabolic health [6].

Noise exposure produces both auditory and non-auditory health effects. While hearing loss is the primary auditory consequence, affecting roughly 20% of the global population and potentially leading to reduced quality of life through social isolation, recent research suggests a complex relationship between hearing impairment and MetS [7–16]. However, the underlying pathophysiological mechanisms connecting these conditions remain inadequately understood.

The available evidence indicates that chronic noise exposure may increase the risk of metabolic disorders through various pathways. Noise pollution triggers pathophysiological changes by activating the hypothalamic-pituitary-adrenal axis and autonomic nervous system, leading to elevated stress hormone levels that can affect lipid and glucose metabolism [17]. However, epidemiological studies have yielded conflicting results regarding the relationship between noise exposure and MetS. While some research suggests that moderate to severe workplace noise exposure contributes to MetS, other studies have found no significant association [6, 18–22].

Given the high prevalence of MetS and the inconsistent findings regarding its relationship with occupational noise exposure and hearing loss, further investigation is warranted. Previous studies have been limited by the presence of additional occupational hazards that could confound the relationship between noise exposure and MetS. Additionally, specific noise exposure levels, particularly in the 85–90 dB range, have not been adequately studied. This research aims to examine the impact of occupational noise exposure and hearing loss on MetS status among textile factory workers, where noise represents the primary occupational hazard.

Methods

This cross-sectional investigation was carried out among employees (N = 1020) of a textile manufacturing facility in 2023. All workers who underwent annual periodic health examinations during this period and met the inclusion criterion of a minimum of one year's employment at the facility were included in the study. The exclusion criteria were as follows: a history of known baseline conditions such as MetS or its components, cardiovascular diseases, renal failure, etc. (n = 9), a history of non-occupational or secondary job-related noise exposure (n = 12), incomplete occupational health records (n = 45), or refusal to participate in the study (n = 5). The final analytical sample comprised 950 workers.

Data collection utilized a comprehensive approach during periodic health examinations, employing structured interviews and standardized measurement protocols. The investigative framework encompassed multidimensional data acquisition, including demographic, medical, and occupational variables. Demographic information systematically captured participants' characteristics, including chronological age, biological sex, anthropometric measurements, marital status, tobacco consumption (operationalized as daily cigarette intake exceeding one cigarette over the preceding six-month period), and physical activity levels (quantified as ≥ 150 minutes of weekly engagement). Occupational data acquisition focused on participants' professional trajectories, encompassing work experience, shift work patterns, use personal protective equipment regularly, and job-related physical demands. All examinations were conducted by a certified occupational medicine specialist, ensuring standardized and rigorous assessment protocols. Anthropometric and physiological measurements adhered to the internationally recognized standardization guidelines. Waist circumference was meticulously assessed according to the World Health Organization's precise anatomical definition, measuring the midpoint between the iliac crest and lowest rib along the mid-axillary line [23]. Biochemical parameters, including fasting blood glucose, triglyceride levels, and HDL cholesterol, were obtained through venous blood sampling during routine periodic examinations, with samples collected following a fasting state to ensure metabolic consistency.

The diagnostic criteria for MetS were established in accordance with the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) framework. This standardized classification system incorporates five distinct physiological parameters: (1) sex-specific waist circumference thresholds (≥ 102 centimeters for men; ≥ 88 centimeters for women); (2) elevated blood pressure readings (≥ 130/85 millimeters of mercury); (3) serum triglyceride concentrations (≥ 150 milligrams per deciliter); (4) gender-specific HDL cholesterol thresholds (< 40 milligrams per deciliter for males; < 50 milligrams per deciliter for females); and (5) fasting blood glucose levels (≥ 100 milligrams per deciliter). The presence of MetS was confirmed when participants manifested three or more of these defined clinical parameters.

The environmental noise exposure assessment was conducted by a qualified occupational health technician across various operational units within the facility. Based on these quantitative measurements, the study participants were stratified into two distinct exposure categories: those with occupational noise exposure ranging from 85 to 90 dB constituted the exposure group, while individuals exposed to ambient noise levels below 85 dB were classified as the non-exposure group. Comparative analysis was subsequently performed to evaluate the differential prevalence of MetS between these two exposure categories.

The audiometric assessment was conducted by a certified audiologist in a standardized acoustic environment to evaluate bilateral air conduction thresholds. The examination protocol encompassed frequency-specific measurements at 500, 1000, 2000, 3000, 4000, and 6000 Hertz. Hearing threshold calculations were stratified into two distinct frequency ranges: low-frequency thresholds were computed as the arithmetic mean of measurements at 500, 1000, and 2000 Hertz, while high-frequency thresholds were derived from the mean values at 3000, 4000, and 6000 Hertz for each ear independently. The operational definition of hearing loss was established as a mean hearing threshold exceeding 25 dB in either or both ears within the respective frequency ranges.

Statistical Analysis

The analytical framework of this investigation examined the interrelationships between MetS, including its constituent components, and two primary variables: occupational noise exposure (85–90 dB) and frequency-specific hearing impairment (categorized as high and low frequencies) in both ears.

The normality of data distribution was evaluated using the Kolmogorov–Smirnov test. Given the non-parametric nature of the data distribution, descriptive statistics for continuous variables were reported as median values with corresponding interquartile ranges (IQR), while categorical variables were expressed as absolute frequencies and relative percentages.

Statistical comparisons employed non-parametric methodologies. The Mann–Whitney U test was utilized for continuous variable analyses, while categorical variable associations were assessed using the chi-square and Fisher's exact tests. Variables showing significant results in univariate analysis were further examined using logistic regression analysis to adjust the effect of confounding factors. Statistical analyses were performed using SPSS, version 27.0 statistical software. Statistical significance was established at an alpha level of 0.05, with confidence intervals (CI) set at 95%.

Ethical Considerations

The study adhered to rigorous ethical protocols throughout its execution. Prior to enrollment, comprehensive informed consent was obtained from all participants. The research protocol, including its objectives, methodological procedures, potential risks, and anticipated benefits, was thoroughly elucidated to each worker to ensure informed decision-making. The voluntary nature of participation was emphasized, with explicit assurance that withdrawal from the study was permissible at any stage without adverse consequences. All data management procedures were conducted in strict compliance with established ethical guidelines, ensuring the preservation of participant confidentiality and anonymity throughout the research process. The study protocol received formal ethical approval from the institutional Ethics Committee (approval code: IR.IUMS.FMD.REC.1402.124) on June 3, 2023.

Results

The study population comprised 950 textile industry workers, characterized by a median age of 33 years (IQR 28 to 38 years). Eight hundred and sixty four (864, 90.9%) of the participants were male and 86 (9.1%) were female. The median duration of their employment was 3 years (IQR 2 to 9 years). Regarding demographic characteristics, the majority of the participants were married (n = 774, 81.5%), with a smaller proportion being single (n = 176, 18.5%). Only 1.3% of the participants were smokers, and 89.3% had shift work. None of the workers were using personal protective equipment regularly. In total, 10.8% (n = 103) of the participants were diagnosed with MetS. Additionally, 72% of participants experienced noise levels exceeding 85 decibels (Table 1).

The audiometric analysis revealed distinct patterns of frequency-specific hearing impairment across the study population. In the right ear, the prevalence of low-frequency hearing loss was minimal (0.8%), while the high-frequency hearing loss was more prevalent (11.9%). Similarly, left ear assessments demonstrated the low-frequency hearing loss in 1.4% of participants, with a higher proportion (13.2%) exhibiting high-frequency hearing loss. Aggregate bilateral hearing assessment indicated that 1.7% of the study population manifested with low-frequency hearing impairment, whereas a substantially higher proportion (17.4%) demonstrated high-frequency hearing loss.

Statistical analyses revealed significant associations between MetS and several demographic variables. Specifically, age demonstrated a strong association ($p < 0.001$), while occupational tenure ($p = 0.04$) and marital status ($p = 0.03$) showed moderate associations with MetS prevalence. Conversely, no statistically significant relationships were observed between MetS and other variables, including gender, tobacco consumption, shift work patterns, occupational requirements, or physical activity levels (Table 2).

The analysis of occupational noise exposure revealed significant associations with several metabolic parameters. Specifically, elevated triglycerides ($p < 0.001$), increased waist circumference ($p = 0.002$), and reduced HDL levels ($p < 0.001$) demonstrated their strong associations with noise exposure. The risk assessment analyses indicated that the noise-exposed individuals exhibited higher prevalence ratios for metabolic alterations: elevated triglycerides (odds ratio [OR] = 2.03, 95% CI 1.36–3.02), reduced HDL levels (OR = 1.71, 95% CI 1.28–2.29), and increased waist circumference (OR = 1.61, 95% CI 1.20–2.17) compared to their unexposed counterparts (Table 3). In the regression analysis adjusting the effects of contextual variables, the relationship between exposure to noise and triglyceride, waist circumference, and HDL remained significant (Table 4). However, no significant associations were observed between the noise exposure

Table 1. Description of study variables

Variables	Me [IQR] / N (%)
Age, years	33 [28; 38]
Body mass index	24 [21.1; 27]
Work experience, years	3 [2; 9]
Systolic blood pressure, mmHg	110 [100; 120]
Diastolic blood pressure, mmHg	70 [70; 80]
Fasting blood sugar, mg/dl	80 [75; 87]
Triglyceride, mg/dl	89 [67; 128.2]
High density lipoprotein, mg/dl	47 [39; 53]
Waist circumference, cm	92 [86; 102]
Pack year	1.1 [0.5; 2.6]
Gender:	
Female	86 (9.1)
Male	864 (90.9)
Marital status:	
Single	176 (18.5)
Married	774 (81.5)
Smoking status:	
Yes	12 (1.3)
No	938 (98.7)
Noise exposure:	
Yes	684 (72)
No	266 (28)
Shiftwork:	
Yes	848 (89.3)
No	102 (10.7)
Work demand:	
Sedentary	32 (3.4)
Light	817 (86)
Medium	85 (8.9)
Heavy	16 (1.7)
Physical exercise:	
Yes	39 (4.1)
No	911 (95.9)
Metabolic syndrome:	
Yes	103 (10.8)
No	847 (89.2)
Triglyceride:	
High	196 (20.6)
Low	754 (79.4)
Fasting blood sugar:	
High	85 (8.9)
Low	865 (91.1)
Systolic blood pressure:	
High	66 (6.9)
Low	884 (93.1)
Diastolic blood pressure:	
High	170 (17.9)
Low	780 (82.1)
Waist circumference:	
High	308 (32.4)
Low	642 (67.6)
High-density lipoprotein:	
High	628 (66.1)
Low	322 (33.9)

IQR, interquartile range; Me, median; N, patients' number

Table 2. Comparison of demographic and occupational characteristics between two groups with and without metabolic syndrome

Variable	Metabolic syndrome, Me [IQR] / N (%)		P-value	OR [95% CI]
	Yes	No		
Age, years	36 [31; 41]	33 [27; 37]	< 0.001	
Work experience, years	3 [2; 11]	3 [2; 8]	0.046	
Gender:			0.804	0.91 [0.45–1.83]
Female	10 (11.6)	76 (88.4)		
Male	93 (10.8)	771 (89.2)		
Marital status:			0.031	2.02 [1.05–3.86]
Single	11 (6.3)	165 (93.8)		
Married	92 (11.9)	682 (88.1)		
Smoking status:			0.772	1.34 [0.17–10.50]
Yes	1 (8.3)	11 (91.7)		
No	102 (10.9)	836 (89.1)		
Shiftwork			0.185	0.67 [0.37–1.21]
Yes	88 (10.4)	760 (89.6)		
No	15 (14.7)	87 (85.3)		
Work demand:			0.234	
Sedentary	6 (18.8)	26 (81.3)		
Light	90 (11)	727 (89)		
Medium	5 (5.9)	80 (94.1)		
Heavy	2 (12.5)	14 (87.5)		
Physical exercise:			0.513	1.48 [0.44–4.89]
Yes	3 (7.7)	36 (92.3)		
No	11 (11)	811 (89)		

CI, confidence interval; IQR, interquartile range; Me, median; N, patients' number; OR, odds ratio

The Mann–Whitney U test was utilized for continuous variable analyses, and the chi-square and Fisher's exact test for categorical variables.

and overall MetS (p = 0.84), fasting blood glucose (p = 0.84), or blood pressure parameters (diastolic: p = 0.29; systolic: p = 0.47).

Further investigations revealed a significant association between MetS and audiometric parameters, specifically with high-frequency hearing thresholds. Participants diagnosed with MetS demonstrated significantly elevated median hearing thresholds at high frequencies in both the right and left ears compared to those without the syndrome (p = 0.031 and 0.042, respectively) (Table 5). However, after logistic regression analysis has been performed, this relationship was not significant (p = 0.335 and 0.124, respectively).

The component-specific analysis of MetS revealed distinct patterns of association with hearing impairment. High-frequency hearing loss in both ears showed significant associations with multiple metabolic parameters, including elevated fasting blood glucose, diastolic blood pressure, triglycerides, and reduced HDL levels. Additionally, there was a significant association between low-frequency hearing loss in both ears and increased waist circumference.

Demographic and lifestyle variables also emerged as significant factors associated with the hearing function. High-frequency hearing loss in both ears showed substantial associations with smoking status, marital status, chronological age, and work experience (Table 6). These findings suggest a complex interplay between metabolic, environmental, and demographic factors in hearing impairment. Logistic regression analysis revealed that the relationship between age and hearing loss at low frequencies in the right ear (p = 0.009) and at high frequencies in the right (p = 0.003) and left (p < 0.001) ears was significant. The relationship between gender and hearing loss at high frequencies in the left ear (p = 0.023) was also significant. However, the relationship between hearing loss and components of MetS was not significant.

Table 3. Comparison of metabolic syndrome and its components between two groups with and without exposure to noise

Variable	Noise exposure, N (%)		P-value	OR [CI 95%]
	Yes	No		
Metabolic syndrome:			0.908	1.04 [0.66–1.65]
Yes	75 (72.8)	28 (27.2)		
No	609 (71.9)	238 (28.1)		
Fasting blood glucose:			0.900	1.05 [0.63–1.73]
High	62 (72.9)	23 (27.1)		
Low	622 (71.9)	243 (28.1)		
Diastolic blood pressure:			0.295	1.22 [0.83–1.79]
High	128 (75.3)	42 (24.7)		
Low	556 (71.3)	224 (28.7)		
Systolic blood pressure:			0.474	0.82 [0.48–1.40]
High	45 (68.2)	21 (31.8)		
Low	639 (93.4)	245 (27.7)		
Triglyceride:			< 0.001	2.03 [1.36–3.02]
High	161 (82.1)	35 (17.9)		
Low	523 (69.4)	231 (30.6)		
Waist circumference:			0.002	1.61 [1.20–2.17]
High	201 (65.3)	107 (34.7)		
Low	483 (75.2)	159 (24.8)		
High-density lipoprotein:			< 0.001	1.71 [1.28–2.29]
High	476 (75.8)	152 (24.2)		
Low	208 (64.6)	114 (35.4)		

CI, confidence interval; N, patients' number; OR, odds ratio

The chi-square and Fisher's exact test were utilized for categorical variable analyses.

Table 4. Logistic regression analysis with adjustment of contextual variables for assessment the effects of noise exposure

Variable	β	P-value	OR [CI 95%]
Age	-0.060	< 0.001	0.94 [0.91–0.96]
Marital status	-0.034	0.876	0.96 [0.63–1.48]
Work experience	0.030	0.075	1.03 [0.99–1.06]
Triglyceride	0.839	< 0.001	2.31 [1.50–3.54]
Waist circumference	0.522	0.001	1.68 [1.22–2.31]
High-density lipoprotein	0.440	0.005	1.55 [1.14–2.11]

CI, confidence interval; OR, odds ratio

Table 5. Relationship between hearing loss and metabolic syndrome

P-value	Metabolic syndrome, Me [IQR] / N (%)		Hearing threshold
	No	Yes	
Right ear:			0.070
Low PTA	10 [10; 11.6]	10 [10; 10]	
High PTA	16.6 [13.3; 20]	15 [13.3; 18.3]	0.031
Left ear:			0.188
Low PTA	10 [10; 10]	10 [10; 10]	
High PTA	16.6 [13.3; 20]	15 [13.3; 20]	0.042
Total hearing loss:*			0.689
Low PTA	2 (12.5)	14 (87.5)	
High PTA	25 (15.2)	140 (84.8)	0.054

IQR, interquartile range; Me, median; N, patients' number; PTA, pure tone audiometry

The Mann–Whitney U test was utilized for continuous variable analyses, and the chi-square test for categorical variable.

* The total hearing loss is the mean hearing threshold exceeding 25 dB in either or both ears within the relevant frequency ranges (yes/no).

Table 6. Relationship between components of metabolic syndrome and other variables with hearing loss

Variables	RLPTA	RHPTA	LLPTA	LHPTA
	P-value			
Fasting blood sugar	0.120	0.003	0.553	0.023
Diastolic blood pressure	0.569	0.007	0.240	0.006
Systolic blood pressure	0.569	0.880	0.240	0.624
Triglyceride	0.214	0.010	0.914	0.005
Waist circumference	0.013	0.095	0.001	0.075
High-density lipoprotein	0.473	0.022	0.770	0.006
Age*	0.021	< 0.001	0.078	< 0.001
Work experience**	0.031	< 0.001	0.186	< 0.001
Gender	< 0.001	0.008	0.005	< 0.001
Marital status	0.196	< 0.001	0.895	< 0.001
Smoking status	0.752	0.010	0.709	0.003
Shiftwork	0.447	0.810	0.859	0.436
Work demand	0.017	0.273	0.054	0.324
Physical exercise	< 0.001	0.601	< 0.001	0.758

LHPTA, left high pure tone audiometry; LLPTA, left low pure tone audiometry; RHPTA, right high pure tone audiometry; RLPTA, right low pure tone audiometry

Here, hearing loss is considered a quantitative variable and its relationship with qualitative variables is examined through Mann-Whitney U test and with qualitative variables (age and work experience) through correlation.

* The correlation coefficient for age and hearing loss is 0.07, 0.25, 0.05, and 0.23, respectively.

** The correlation coefficient for work experience and hearing loss is 0.07, 0.24, 0.04, and 0.22, respectively.

Discussion

This study examined the relationship between occupational noise exposure, hearing loss, and MetS among 950 textile factory workers, with 72% exposed to noise levels exceeding 85 dB. MetS was diagnosed in 10.8% of the participants in our investigation (n = 103). The prevalence of MetS has ranged from 17.5% to 19.8% in a variety of studies that have examined the correlation between occupational noise exposure and this syndrome [6, 12]. The higher prevalence rates of MetS in other studies could be attributed to older average ages and other lifestyle risk factors, such as a higher prevalence of smoking among the study populations, as well as differing conditions in the workplace, including exposure to various substances like metal fumes, acids/bases, and organic compounds.

Research has identified two primary mechanisms through which noise exerts detrimental effects on human health: a direct and an indirect pathway. The direct pathway operates through rapid transmission via the auditory nerve to the central nervous system, while the indirect pathway functions through cognitive processing of the auditory stimuli, eliciting emotional responses. Both mechanisms converge in their activation of the hypothalamic-pituitary-adrenal and sympathetic nervous system, resulting in elevated stress hormone secretion. This physiological stress response, which can manifest either acutely or chronically following noise exposure, may be mediated through various pathophysiological mechanisms, potentially contributing to MetS development [18].

Our investigation failed to demonstrate a statistically significant association between occupational noise exposure and MetS. The literature on this relationship has yielded inconsistent results, which may be attributed to variations in MetS diagnostic criteria and differences in noise exposure intensities. Several studies examining lower noise exposure levels (53–62 dB) have reported no significant association with MetS [21, 24]. However, the research involving higher noise intensities has produced contrasting results, with studies demonstrating significant associations at exposure levels above 90 dB [6, 18, 25–27]. Notably, recent research has identified a dose-response pattern at 93.4 dB (± 9.7), while studies of thermal power plant workers exposed to noise levels above 100 dB have shown strong correlations with MetS [25, 27]. The absence of a significant association in our study may be explained by several demographic and occupational factors. Our population was characterized by a relatively young median age (33 years), brief work history (median 3 years), and low smoking prevalence (1.3%). Additionally, the workplace environment lacked common confounding factors such as exposure to organic solvents, vibration, and heat [28]. Importantly, the maximum noise exposure in our study was 90 dB, which may fall below the threshold necessary to observe significant metabolic effects, particularly given the emerging evidence of a dose-response relationship between noise exposure and MetS. Furthermore, the healthy worker effect may have influenced our findings. Workers in this factory environment tend to request transfers to less hazardous settings due to various factors, including job demands, low wages, and health concerns. Consequently, our study population primarily consisted of young, healthy workers with limited exposure duration, potentially masking any long-term associations between noise exposure and MetS.

Our analysis revealed significant associations between noise exposure and several metabolic parameters. Specifically, we observed increased odds of elevated triglycerides (OR = 2.03; 95% CI 1.36–3.02, $p < 0.001$), enlarged waist circumference (OR = 1.61; 95% CI 1.20–2.17, $p = 0.002$), and reduced HDL levels (OR = 1.71; 95% CI 1.28–2.29, $p < 0.001$). These findings align with existing literature on the relationship between noise exposure and MetS components [18, 20, 29, 30]. Particularly noteworthy is the recent research demonstrating that prolonged exposure to moderate noise levels (75–85 dB) over 13.5 years was associated with the highest risk of dyslipidemia [31]. The underlying mechanism appears to involve noise-induced stress activation of the sympathetic autonomic nervous system and endocrine system, leading to alterations in serum lipid metabolism [30].

Our analysis failed to demonstrate statistically significant associations between noise exposure and several metabolic parameters, including fasting blood sugar, diastolic blood pressure, and systolic blood pressure. While these findings diverge from previous research that has established substantial correlations between noise exposure and elevations in both blood glucose and blood pressure, this discrepancy may be attributed to our study population's demographic characteristics, particularly their young age and limited occupational exposure duration [18, 20, 29]. This interpretation aligns with the hypothesis that blood pressure alterations during initial noise exposure are transient, whereas sustained exposure to high-intensity noise is necessary to induce persistent blood pressure elevation [31].

Our investigation extended to examining the relationship between hearing loss and MetS prevalence. The analysis revealed that 1.7% of participants exhibited low-frequency hearing loss, while a notably higher proportion (17.4%) demonstrated high-frequency hearing loss. Among individuals with low-frequency hearing loss, MetS was present in 12.5% of cases, while those with high-frequency hearing loss showed a slightly higher prevalence at 15.2%. These findings contrast with previous research by K. Kim et al., who reported substantially higher MetS prevalence rates of 22.3% and 22.4% in individuals with low-frequency and high-frequency hearing loss, respectively [32].

Our initial analysis revealed a significant bilateral association between MetS and elevated hearing thresholds at high frequencies, a finding that aligns with the existing literature [9, 16, 33]. However, after logistic regression analysis, this relationship was not significant. While the exact mechanistic relationship between MetS and hearing impairment remains to be fully elucidated, current evidence suggests that shared peripheral vascular pathology may underlie both conditions [16].

Further analysis of the relationship between individual MetS components and hearing impairment revealed significant associations between high-frequency hearing loss in both ears and several metabolic parameters: diastolic blood pressure, triglyceride levels, blood glucose concentration, and reduced HDL levels. However, logistic regression analysis revealed that the relationship between hearing loss and the components of MetS was insignificant. The association between hypertension and hearing loss, which has been documented in previous research, appears to exhibit a bidirectional relationship [13, 16, 33–35]. The initial stress response to noise exposure triggers elevated heart rate and blood pressure, and chronic exposure may lead to persistent hypertension [32]. Conversely, hypertension may contribute to sensorineural hearing loss through multiple pathophysiological mechanisms. These include inner ear hemorrhage, reduced capillary blood flow leading to oxygen deprivation, and atherosclerotic changes resulting in diminished vascular elasticity and narrowing of inner ear vessels [13]. However, due to the cross-sectional design of our study, we can only establish associations rather than causal relationships between hypertension and hearing loss; definitive determination of causality would require prospective investigations.

The association between elevated fasting blood glucose and hearing impairment has been consistently documented across multiple investigations [10, 16, 33, 35]. The pathophysiological mechanisms underlying this relationship appear to be multifaceted. Hyperglycemia may induce hearing loss through various pathways, primarily through diabetes-related complications affecting microvascular structures and sensory neurons. These pathological alterations potentially impact the inner ear capillaries and associated sensory neurons. Specifically, individuals with diabetes and elevated blood glucose levels demonstrate characteristic changes, including demyelination of the eighth cranial nerve and thickening of the stria vascularis capillaries. Additionally, elevated plasma glucose concentrations correlate with enhanced oxidative stress, a factor known to contribute to noise-induced hearing loss pathophysiology. Therefore, the augmented oxidative stress observed in hyperglycemic individuals may partially elucidate the mechanistic link between elevated blood glucose and auditory dysfunction [10].

Research examining the relationship between lipid disorders and auditory function has identified associations between high-frequency hearing loss in both the right and left ear and elevated triglyceride levels, as well as reduced HDL levels [9, 14, 34]. As previously established, noise exposure can induce alterations in lipid metabolism, potentially leading to hyperlipidemia. Experimental studies in animal models have demonstrated that dyslipidemia contributes to pathological changes in auditory structures, specifically cochlear edema and the stria vascularis degeneration. The mechanistic pathway appears to involve dyslipidemia-induced reduction in nitric oxide production coupled with increased reactive oxygen species generation. Notably, HDL's documented anti-inflammatory and antioxidant properties may serve a protective function against these dyslipidemia-induced pathogenic alterations [14]. However, establishing a causal relationship between lipid disorders and hearing loss necessitates future prospective studies.

Our investigation presents several notable methodological strengths. Primarily, the study was conducted within a homogeneous industrial population sharing comparable risk factors, enhancing internal validity. Furthermore, our analysis extended beyond conventional MetS variables (age, gender, marital status, and smoking status) to incorporate occupational factors including work experience, job demands, shift work patterns, and physical activity levels – a comprehensive approach infrequently adopted in previous research. Additionally, our study uniquely examined the specific effects of noise exposure within the 85–90 dB range, a discrete intensity level that had not been exclusively investigated in relation to MetS. Finally, while most existing literature has examined the relationship between MetS and hearing loss in general populations, our investigation specifically focused on occupationally noise-exposed individuals. The high prevalence of high-frequency hearing loss in our study strongly suggests that the observed auditory impairments were predominantly attributable to occupational noise exposure.

One limitation of this study is that a single measurement of fasting blood sugar and serum lipid levels was available. These values can fluctuate on different days [30]. Another limitation was the unavailability of air pollution data, which has been associated with MetS in various studies. Nevertheless, the individuals studied were likely exposed to a comparable level of air pollution, as most lived in the same suburban area. Additionally, data regarding other lifestyle-related factors, especially dietary habits, were not accessible. However, most factory workers belonged to lower and middle socioeconomic groups and did not have significant dietary variations. This may explain our research's low MetS prevalence. An additional limitation pertains to the cross-sectional structure of the investigation and potential recall bias regarding workers' medical histories and risk factors, which may have led to underestimation or overestimation of these risks.

To enhance our understanding of the complex interrelationship between occupational noise exposure, hearing loss, and MetS, future longitudinal cohort studies with expanded sample populations are warranted. Such investigations should incorporate a broader spectrum of variables, including lifestyle determinants and psychosocial factors, to provide more comprehensive insights into these associations. This approach would yield more robust evidence and potentially reveal additional pathways linking these health outcomes.

Conclusion

This study demonstrated significant associations between various metabolic parameters – specifically elevated triglycerides, increased waist circumference, and reduced HDL cholesterol levels – and occupational noise exposure. Notably, individuals diagnosed with MetS exhibited markedly higher median hearing thresholds at high frequencies in both ears compared to their counterparts without the condition. Furthermore, the initial analysis revealed associations between high-frequency hearing impairment in both ears and several metabolic parameters, including elevated blood glucose, increased diastolic blood pressure, high triglycerides, and decreased HDL levels. These findings underscore the importance of implementing comprehensive workplace health strategies that extend beyond conventional noise control measures. Such strategies should encompass personal measures for noise protection, regular monitoring of metabolic parameters, particularly blood glucose and lipid profiles, while emphasizing the optimization of lifestyle factors, including dietary habits and physical activity levels, in occupational settings with significant noise exposure.

Additional information

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Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Authors' contribution

K. Taheria, data collection and management, data analysis, text writing, approval of the final version of the manuscript; S. Mohammadi, the study concept and design, text writing, text editing, approval of the final version of the manuscript; M. Hosseininejad, statistical analysis, interpretation of the study results, text writing, text editing, approval of the final version of the manuscript. All the authors have read and approved the final version of the manuscript before submission, agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Ассоциация между воздействием производственного шума, тугоухостью и метаболическим синдромом у рабочих текстильной фабрики: исследование поперечного типа

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Обоснование. Результаты исследований, в которых изучали связь между неблагоприятным воздействием шума на орган слуха и метаболическим синдромом, противоречивы.

Цель – оценить ассоциацию между воздействием производственного шума, снижением слуха и параметрами метаболического синдрома.

Материал и методы. Данное исследование поперечного типа проведено в 2023 г. у 950 работников текстильной фабрики. Участников исследования распределили в две группы в зависимости от уровня шума – до 85 дБ и от 85 до 90 дБ. Снижение слуха определяли как средний слуховой порог более 25 дБ в одном или обоих ушах в пределах соответствующих частотных диапазонов. Диагноз метаболического синдрома ставили в соответствии с критериями экспертной группы по лечению взрослых III Национальной образовательной программы США по холестерину (NCEP – ATP III). Сбор демографических данных, оценку состояния здоровья и вредности условий труда производили во время периодических медицинских осмотров. Далее изучали связь между метаболическим синдромом и его компонентами с воздействием производственного шума.

Результаты. Медиана возраста участников исследования составила 33 года [28; 38], медиана стажа работы – 3 года [2; 9]. Подавляющее большинство были мужского пола (90,9%, n = 864), женаты (81,5%, n = 774), работали посменно (89,3%, n = 848). Диагноз метаболического синдрома был поставлен 10,8% (n = 103) обследованных; 72% (n = 684) подвергались воздействию производственного шума более 85 дБ. С воздействием производственного шума были значимо ассоциированы увеличение окружности талии (отношение шансов (ОШ) 1,61; 95% доверительный интервал (ДИ) 1,20–2,17, p = 0,002), гипертриглицеридемия (ОШ 2,03; 95% ДИ 1,36–3,02, p < 0,001) и снижение уровня липопротеинов высокой плотности (ЛВП) (ОШ 1,71; 95% ДИ 1,28–2,29, p < 0,001). Кроме того, выявлена значимая связь между компонентами метаболического синдрома и высокочастотными слуховыми порогами, а именно, двустороннее снижение слуха на высоких частотах находилось в ассоциации с гипергликемией натощак, повышенными показателями диастолического артериального давления и триглицеридов и низким уровнем ЛВП.

Заключение. Наше исследование выявило значимую ассоциацию между воздействием производственного шума и такими компонентами метаболического синдрома, как увеличенная окружность талии, высокие уровни триглицеридов и низкие – холестерина ЛВП. По данным первоначального анализа, обнаружена также значимая ассоциация между метаболическим синдромом и его компонентами, включая нарушения углеводного и липидного обмена, повышение диастолического артериального давления, с одной стороны, и медианой слухового порога на высоких частотах – с другой.

Ключевые слова: тугоухость, метаболический синдром, воздействие производственного шума, текстильная фабрика

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Участие авторов

К. Тахерия – сбор, обработка и анализ данных, написание текста, утверждение итоговой версии рукописи; С. Мохаммади – идея и дизайн исследования, написание и редактирование текста, утверждение итоговой версии рукописи; М. Хоссейнинеджад – статистический анализ, интерпретация результатов исследования, написание и редактирование текста, утверждение итоговой версии рукописи. Все авторы прочли и одобрили финальную версию рукописи перед публикацией, согласны нести ответственность за все аспекты работы, гарантируя, что ими надлежащим образом были рассмотрены и решены все вопросы, связанные с точностью и добросовестностью всех частей работы.

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