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Occupational noise annoyance and sensitivity as potential contributors to oxidative stress in metal industry workers

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Noise is recognized as a psychological stressor that led to noise annoyance, and individual noise sensitivity could play a moderating role. This study aimed to investigate the association between noise annoyance, noise sensitivity, and oxidative stress responses among workers in metal manufacturing industries. A total of 161 workers participated in the study. Demographic data and noise sensitivity were assessed using the Weinstein Noise Sensitivity Scale, while noise annoyance was evaluated via the ISO/TS 15666:2003 questionnaire. Daily noise exposure was measured using a sound level meter. Serum levels of oxidative stress biomarkers, including Malondialdehyde (MDA), Total Antioxidant Capacity (TAC), and 8-hydroxy-2′-deoxyguanosine (8-OHdG), were determined using ZellBio diagnostic kits. Statistical analyses were performed in SPSS v.18, with a significance threshold of 0.05. The mean equivalent noise level was 80.11 ± 11.3 dBA. Among participants, 80.1% reported some degree of noise annoyance, and 74% reported noise sensitivity. No significant association was observed between demographic variables and oxidative stress markers, nor between noise sensitivity or annoyance and induction of oxidative stress. These findings suggest that, under current exposure conditions, subjective reactions to noise, such as annoyance and sensitivity, may not significantly influence oxidative stress, highlighting the need for further investigation into other modulating factors.

Keywords Noise annoyance, Noise sensitivity, Biomarkers, Oxidative stress, Workers, Metal parts

Abbreviations

8-OHdG	8-hydroxy-2′-deoxyguanosine
dB	Decibel
ISO	International organization for standardization
LEp,d-8 hr	Daily Personal Exposure Level for 8 h
Leq	Equivalent sound pressure level
MDA	Malondialdehyde
TAC	Total antioxidant capacity
WNSS	Weinstein noise sensitivity scale

Noise exposure is a common industrial problem, and it is one of the most potent risk factors for increasing the burden of diseases in 2019[1]. Noise causes auditory system disruption, and it is associated with some adverse

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health consequences, such as psychosocial well-being, annoyance, reduced work efficiency, and psychological problems[2]. On the other hand, mental problems, especially depression and anxiety, have had a significant growth rate in the Global Burden of Diseases report[3]. Many factors can affect human mental health. Noise annoyance is reported to be one of the crucial factors that could increase psychological problems in industrial societies[4].

Noise as a physical stressor can cause an increased rate of reactive oxygen species generation and induce oxidative stress[5]. The results of studies show that individual characteristics are effective in being influenced by noise[6]. Noise sensitivity is a psycho-physiological factor that determines the level of annoyance caused by it and the difference between people in response to a fixed level of noise[7]. The contribution of workers' noise sensitivity to the subsequent adverse effects was investigated in limited studies. These studies indicated the direct relationship between noise exposure and the onset of health problems in sensitive groups, which may even have effects independent of noise level[8]. Noise exposure in sensitive individuals probably causes a higher level of annoyance, but controversial findings in the different studies might be related to the effect of individual physiological characteristics responding to noise[9].

Annoyance is the most common and immediate response to noise, which is related to physiological stress in the body and can be considered a starter of serious health problems[10]. Noise annoyance is an internal psychological feeling, defined as an unpleasant factor interfering with the activity of an individual's nervous system[11]. The World Health Organization believes that annoyance affects the well-being of many people, but annoyance is not included in the International Classification of Diseases[12]. Noise annoyance may not be considered a direct health consequence, but it may induce irritability, distress, or other stress-related symptoms in individuals, leading to adverse health symptoms[13]. Researchers have reported that stimulation of the nervous system and activation of the endocrine glands caused by noise annoyance are possible causes of adverse health effects[14]. In many studies, the annoyance caused by environmental noise was reported as the source of stress, cardiovascular problems, exacerbation of arthritis, and migraine[15].

The effect of noise exposure and the induction of oxidative stress in the exposed population was reported by some authors. However, workers' characteristics and the noise's psychological consequences leading to higher oxidative stress are limited. In addition, most studies have reported the effect of psychoacoustic factors on the occurrence of health problems in exposure to environmental noise. But the impact of psychoacoustic factors such as noise annoyance and noise sensitivity in the workplace on health disorders has received less attention. Therefore, the present study investigated the impact of noise annoyance and noise sensitivity on the induction of oxidative stress in workers of metal parts manufacturers located in the Greater City of Tehran.

Methods

Study sample

The participants in the present study were male workers in a metal parts manufacturing industry located in the west of Tehran, Iran. From 2019 to 2021, this study focused on 450 production line workers working 8 h a day and 5 days a week. The number of subjects was calculated according to a statistical formula reported by Daniel et al., and the statistical variables of the formula were chosen similarly to another study[16] with a probability of 70% and a precision of 7%. According to the calculated sample size, 161 persons were selected randomly with exclusion criteria of cardiovascular diseases, AIDS, hepatitis, diabetes, head injury or hearing impairment, smoking habits, and alcohol consumption, and use of medicinal supplements for 72 h before blood sampling and noise exposure.

Ethics approval for research

Ethical considerations in the present study were adapted to the provisions of the Declaration of Helsinki and the principles of trust, while keeping the confidentiality of people's information. Subjects were informed about the objectives of this study. All participants entered the study with full knowledge of their rights and after completing the informed consent form. Participants were also informed about the confounding and stress factors affecting the results of this study.

Consent for participation

This study was approved by the Ethics Committee of Iran University of Medical Sciences with the ethical approval code: [IR.IUMS.FMD.REC 94-04-27-26845].

Measuring the sound level equivalent to 8 h individually (LEP, d-8 h)

Due to the variability of participants' workplace during the working day, in the first step, the type and duration of workers' tasks were individually determined, and in the second step, the sound equivalent level was measured for each group of people with the same work nature using a calibrated noise level meter (Brüel & Kjær Co., Type 2339 Sound Level Meter, Denmark). The average level of noise exposure of each subject was estimated using the following formula:

$$LEP.d = 10\,log\,\left[\frac{1}{8}\sum t_i \times 10^{\frac{L_i}{10}} + \ldots + t_n \times 10^{\frac{L_i}{10}}\right]$$

Where LEP, d, t_i and L_i are, respectively, full shift equivalent sound pressure level (dBA), exposure time of t_i activity (hr), and equivalent sound pressure level (Leq) for the t_n activity (dBA). The impact of noise exposure on disruption in people's daily activities, including the quality of their work, being relaxed and focused, alertness, and conversing, was recorded in a questionnaire by asking the participants.

Evaluation of noise sensitivity and noise annoyance
In the present study, the Weinstein Noise Sensitivity Scale (WNSS) was used to measure individual noise sensitivity, investigated by Alimohammadi et al.[17], reported validity and reliability of 0.77 and 0.78, respectively. The WNSS questionnaire consists of 21 questions to determine a person's reactivity to noise, and each question is answered with the help of six qualitative expressions of emotion, which receive a score of 0 to 5. In the present study, scores ≤ 55, 56–72, and ≥ 73 were considered equivalent to low, medium, and high noise sensitivity, respectively. The demographic characteristics section of the WNSS questionnaire was used to record the age, education level, and work experience of each participant.

Noise annoyance in the participant was collected using the International Organization for Standardization ISO/TS 15666:2003 questionnaire[18]. The ISO-15,666 questionnaire consists of 20 questions. It is possible to answer each question of the ISO-15,666 questionnaire with 5 qualitative expressions that report the level of discomfort from the noise exposure as not at all, slightly, moderately, a lot, and very much. In the present study, qualitative expressions for noise annoyance were limited to three general responses: low (equivalent to not at all and partial), medium, and high (high and very high) noise annoyance levels.

The method of blood drawing from participants
Fasting blood samples were collected from the participants in sterile test tubes, and the serum was separated by centrifugation according to standardized procedures recommended by the Early Detection Research Network[19]. The serum was then transferred into 1 ml RNA-free and DNA-free microtubes and stored at – 80 °C until analysis.

Measurement of malondialdehyde (MDA)
MDA is routinely considered an oxidative stress biomarker that is generated by lipid peroxidation. The measurement of MDA concentration in the blood serum sample was performed using the ZellBio chemical colorimetric kit (MDA assay kit; ZellBio GmbH, Catalog No: ZB-MDA 96 A, V405, Ulm, Germany) and according to the manufacturer's protocol. The pink color produced by the reaction of MDA and thiobarbituric acid at a temperature of 90–100 °C, indicates the concentration of MDA, which was read at a wavelength of 535 nm using an Eliza reader device (Bio-Tek EL×800 Microplate Reader, USA).

Measurement of total antioxidant capacity (TCA)
TCA is an indicator for the measurement of the free radical's removal rate from biological samples. ZellBio colorimetric kit (TCA assay kit; ZellBio GmbH, Catalog No: ZB-TAC 96 A, V4527, Ulm, Germany) was used to measure TCA concentration in blood serum. The measurement of the blue color intensity caused by the reduction of Fe^{+3} to Fe^{+2} by antioxidant compounds at 490 nm wavelength by an ELISA reader (Bio-Tek, USA) was considered as an indicator of TCA concentration in the blood serum biological sample.

Measurement of 8-hydroxy-2′-deoxyguanosine (8-OHdG)
8-OHdG has been introduced as a useful index for the evaluation of oxidative damage to DNA, which causes carcinogenesis. 8-OHdG concentration was measured using a ZellBio Enzyme-Linked Immunosorbent Assay kit (8-OHdG assay kit; ZellBio GmbH, Catalog No: ZB-10187 S-M9648, Ulm, Germany) and according to the manufacturer's instructions. The concentration of 8-OHdG was measured by an ELISA reader (Bio-Tek, USA) at a wavelength of 450 nm and in ng/ml.

Statistical analysis
All statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS) version 18. Descriptive statistics, including means with standard deviations and percentages, were applied to summarize participants' demographic characteristics and noise exposure levels. To examine the relationship between noise exposure and outcomes, multiple linear regression analyses were performed. Specifically, these analyses assessed the association between noise exposure (as the independent variable) and two outcomes: noise sensitivity and noise annoyance. In a second set of regression models, noise sensitivity and noise annoyance were considered independent variables, and their relationship with oxidative stress biomarkers—namely MDA, TAC, and 8-OHdG—was explored, while adjusting for potential confounding demographic factors including age, education level, and work experience. Additionally, one-way ANOVA tests were employed to compare the levels of oxidative stress biomarkers across categorized levels (low, moderate, and high) of noise sensitivity and noise annoyance. A P-value of less than 0.05 was considered statistically significant in all two-tailed analyses.

Results
Demographic characteristics and noise exposure
The average age and work experience of participants were 36.99 ± 8.06 (range 22 to 62) and 7.78 ± 4.78 (range 0.3 to 20) years, respectively. 94.4% of the participants had non-academic education. The average daily individual exposure to the sound pressure level in the workplace was around 80.11 ± 11.3 dBA (minimum 50.1 and maximum 98.0 dBA). The most common complaints of the employees were the interference of noise exposure with relaxation (38.4%) and conversation (36%) (Fig. 1).

Distribution of noise sensitivity and annoyance
5.8%, 7.4%, 43.4%, 34.3%, and 9.1% of the participants reported their feelings about the loudness of the workplace as negligible, low, medium, high, and very high, respectively. 73.9% of the study population reported medium and high levels of noise sensitivity. 80.1% of participants in this study reported some degree of noise annoyance, of which 22.6% felt a high level of noise annoyance (Table 1).

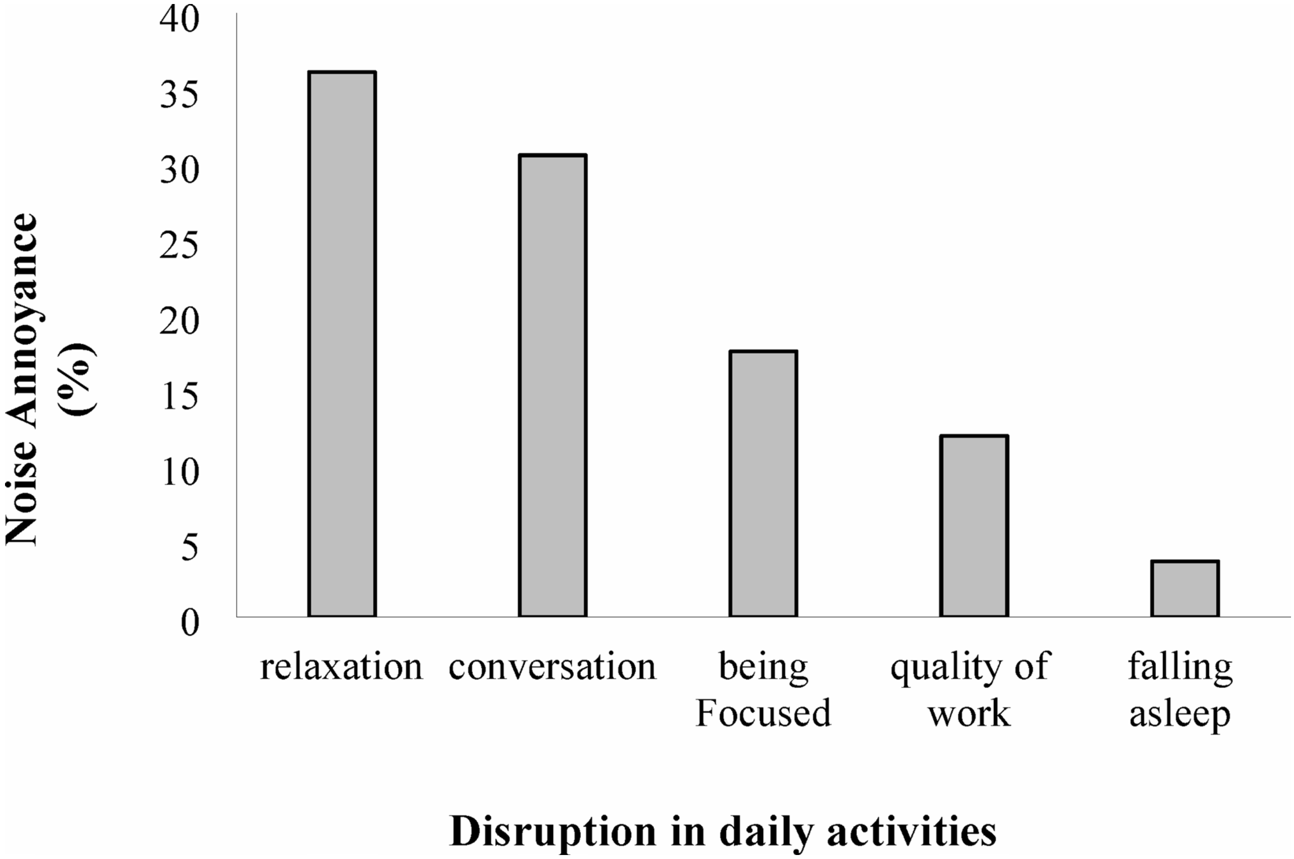

Fig. 1. The effect of noise exposure on disruption in daily activities.

Association between noise exposure and subjective responses

The results of the regression analysis showed that there was a significant relationship between noise sensitivity ($\beta = 0.06$, P-value < 0.001) and age ($\beta = -0.08$, P-value = 0.001) with the level of noise annoyance, but the effect of education level ($\beta = 1.41$, P-value = 0.083) and work experience ($\beta = -0.06$, P-value = 0.124) was not significant statistical effect on the noise annoyance level. The results of the linear regression analysis showed that the equivalent sound pressure level affected noise sensitivity (P-value < 0.001, $\beta = 0.29$) and noise annoyance (P-value < 0.001, $\beta = 0.56$). For each dB increase in daily noise exposure level, noise sensitivity and noise annoyance increased by 0.29 and 0.56, respectively.

Effect of noise sensitivity and annoyance on oxidative stress biomarkers

The associations between noise sensitivity, noise annoyance, and oxidative stress biomarkers are presented in Fig. 2. One-way ANOVA results showed no statistically significant differences in the serum levels of MDA (P-value = 0.360, F = 1.029), TAC (P-value = 0.935, F = 0.067), or 8-OHdG (P-value = 0.461, F = 0.778) across different levels of noise annoyance. Similarly, no significant differences were found for MDA (P-value = 0.408, F = 0.902), TAC (P-value = 0.061, F = 3.130), or 8-OHdG (P-value = 0.078, F = 2.580) across noise sensitivity levels.

Linear regression analysis indicated that demographic variables, including age, education level, and work experience, were not independently associated with oxidative stress biomarkers. Furthermore, after adjusting for these variables, no significant associations were found between equivalent noise pressure level, noise sensitivity, or noise annoyance and the oxidative stress markers. These findings suggest that neither demographic characteristics nor subjective noise responses significantly influenced oxidative stress under the studied exposure conditions (Table 2).

Discussion

As industrialization progresses, the number of individuals exposed to noise pollution continues to rises, especially among workers in industrial sectors. Noise acts as a significant physical stressor, which can induce various physiological and psychological disturbances, often modulated by individual differences in noise sensitivity and annoyance[20,21].

The present study confirmed that exposure to industrial noise increases psychological reactions related to sound perception, such as noise sensitivity and annoyance, with higher sensitivity intensifying the feeling of annoyance. Several studies have similarly suggested that individuals with elevated noise sensitivity tend to report greater annoyance, even when exposed to the same sound levels[22]. Some studies reported that workers with increased sensitivity, irritability, and concurrent exposure to noise are more vulnerable to developing health

	Frequency (*N*)	Percentage (%)
Age (year)		
(20–29)	23	14.3
(30–39)	85	52.8
(40–49)	39	24.2
(≥ 50)	14	8.7
Educational level		
Illiterate	4	2.5
Under diploma	80	49.7
Diploma	68	42.2
Academic degree	9	5.6
Work experience (year)		
< 1	18	11.2
2–5	45	28
6–9	34	21.1
10–14	49	30.4
15–19	14	8.7
> 20	1	0.6
Noise sensitivity		
Low (Score ≤ 55)	42	26.1
Medium (Score 56–72)	78	48.4
High (Score ≥ 73)	41	25.5
Noise annoyance		
Low	77	47.8
Medium	48	29.8
High	36	22.3

Table 1. Frequency and percentage of demographic variables, noise sensitivity and noise annoyance in the study sample.

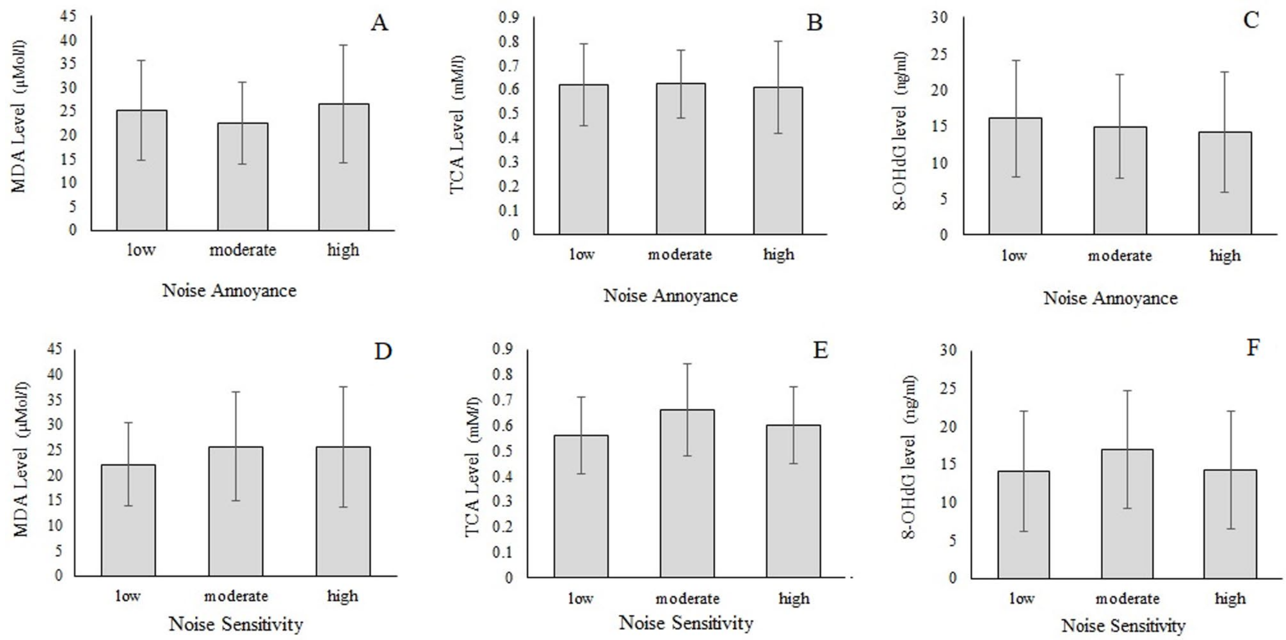

Fig. 2. The effect of noise sensitivity and noise annoyance on oxidative stress biomarkers generation.

	MDA Level		TAC Level		8-OHdG Level	
Demographic characterization	*P*-value	β	*P*-value	β	*P*-value	β
Age (year)	0.70	0.03	0.43	0.06	0.17	0.11
Educational level	0.49	0.06	0.76	0.02	0.84	0.02
Work experience (year)	0.06	0.15	0.91	0.01	0.06	0.16

Table 2. Association between demographic variables and oxidative stress induction in the sample study.

problems[23]. Generally, individuals with higher levels of sensitivity often pay more attention to noise and report it as an annoyance factor[24]. Some studies also reported that noise sensitivity is an effective factor in increasing noise annoyance[25]; however, some authors emphasized that noise annoyance is not solely determined by acoustic intensity, but also by individual attitudes and cognitive-emotional responses[26].

While numerous studies have implicated noise exposure above permissible limits in activating stress response systems—particularly the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic nervous system (SNS)—and subsequently inducing oxidative stress[27], the current findings did not show significant increases in oxidative stress biomarkers (MDA, TAC, 8-OHdG) with noise exposure levels below industrial permissible thresholds. Some researchers suggest that noise annoyance, independent of actual sound intensity, may itself activate stress-related physiological pathways, including stimulation of the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic nervous system. This activation leads to systemic inflammation through macrophage recruitment and the release of pro-inflammatory cytokines—such as TNFα and IL-6/1β—which in turn contribute to neuroinflammation and oxidative stress[28]. However, the lack of association observed in our study may be explained by the relatively low noise levels to which participants were exposed, as exposure exceeding 90 dB is frequently cited as the threshold above which oxidative stress responses become significantly pronounced. This mechanism, which involves changes in activity within the medial prefrontal cortex, could potentially blunt both subjective and physiological stress responses to chronic noise exposure at lower intensities[29].

The observed reduction in noise complaints with increasing age and work experience in our cohort, with statistical significance for age only, may also support this adaptive interpretation. While some previous findings have reported increasing annoyance with longer exposure durations[30], the apparent reduction in sensitivity and annoyance among older participants in our study could reflect the development of habituation or desensitization over time, rather than the absence of underlying stress responses. Additionally, differences in individual cognitive and emotional coping mechanisms, education levels, and awareness of environmental risks[31–33] might further contribute to the variability in responses observed.

Nevertheless, several studies have indicated that exposure to sound levels below the permissible threshold may not be associated with notable adverse health effects[34]. For instance, Mirmohammadi et al.[35] demonstrated that co-exposure to noise and dust elevated MDA levels, with significantly greater increases observed among individuals exposed to noise levels exceeding the permissible limit compared to those exposed to lower levels. Similarly, in a prospective cohort study, Stansfeld et al.[36] examined the impact of road traffic noise on the incidence of cardiovascular and mental health conditions. Their findings suggested that neither sound pressure level nor psychological responses such as noise sensitivity and annoyance were significantly associated with the occurrence of ischemic heart disease. However, they pointed out that psychological traits like noise sensitivity and annoyance could, to some degree, heighten the risk of mental health issues, potentially due to an underlying heightened reactivity to broader environmental stressors.

The sensitivity to noise is directly related to sensitivity to other environmental stimuli, which may indicate the interfering role of the other environmental parameters on the occurrence of stress responses in the body[37]. However, few studies reported, increased rates of noise sensitivity could be the reason for the decreased rates of mortality[38]. Some studies in support of the former conclusion stated that noise sensitivity was reported to increase the level of health-protective behaviors against noise and other environmental stimuli[39].

The observed reduction in noise complaints with increasing age and work experience in our cohort, with statistical significance for age only, may also support this adaptive interpretation. While some previous findings have reported increasing annoyance with longer exposure durations[30], the apparent reduction in sensitivity and annoyance among older participants in our study could reflect the development of habituation or desensitization over time, rather than the absence of underlying stress responses[31]. Additionally, differences in individual cognitive and emotional coping mechanisms, education levels, and awareness of environmental risks[33,40] might further contribute to the variability in responses observed. Paunović et al.[32] reported that having a high level of knowledge about the health risks associated with environmental stressors can lead to concern and efforts to prevent exposure to these parameters. Therefore, people with higher education are more aware of the dangers of physical stressors, and as a result, they are more annoyed by noise.

To clarify the complex relationships among noise exposure, psychological factors, and oxidative stress, future investigations should consider larger sample sizes and compare acute versus chronic noise exposures at varying intensity levels, incorporating comprehensive assessments of individual susceptibility traits, including more heterogeneous sociodemographic characteristics such as education level. Such studies may help distinguish between immediate physiological reactions and long-term adaptation processes in response to environmental noise.

Data availability

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

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Author contributions
Raziyeh Asadi conducted the study. Iraj Alimohammadi supervised the study and developed the main idea. Athena Rafieepour contributed to the study design and manuscript writing. Azadeh Ashtarinezhad provided consultation on the study implementation. Agha Fatemeh Hosseini performed the statistical analysis. Hosein Tabatabaei and Hossein Jafari collaborated in conducting the study.

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Declarations

Competing interests
The authors declare no competing interests.

Additional information
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