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Gender differences in cognitive performance and psychophysiological responses during noise exposure and different workloads

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ABSTRACT

Background: Gender can affect the relationship between noise exposure and both cognitive function and comfort; however, evidence is still limited. This study aimed to examine the gender differences in cognitive performance and psychophysiological responses during exposure to noise under tasks with different workloads.
Methods: Thirty-two participants (16 females and 16 males) with normal hearing and good general health were recruited. They were asked to perform the N-Back test at three levels of workload during exposure to four low-frequency noise conditions: 55, 65, 70, and 75 dB(A). The participants were also asked to judge noise-induced annoyance and subjective fatigue using visual analog scales at the end of each noise condition. The heart rate variability was also recorded using Nexus-4 device before and during each trial and the ratio of low to high frequency (LF/HF) power was analyzed.
Results: The results revealed that the females rated significantly higher levels of annoyance and fatigue than the males. The mean accuracy of the women in the level of 55 dB(A) with a medium workload was higher than that of the men, while in higher noise levels the men showed better performance. The response time to the stimulus was also lower in females at different noise levels and workloads. Furthermore, the findings showed that, with increasing noise level and workload, the LF/HF of the women was higher than that of the men.
Conclusion: Females and males indicated significant and different responses in exposure to different noise levels and workloads. Therefore, this study suggests that gender criteria should be taken into account particularly in the job selection, work content, and design of workplaces.

1. Introduction

Noise has been found as a non-specific biological stressor which can cause negative effects beyond the ones that occur at the auditory system. Non-auditory effects of noise include speech interference [1], annoyance, sleep disturbance [2], cardiovascular problems [3], disorder in cognitive function and memory [4], and effects on behavior [5]. These effects can be observed at exposure to noise levels below those identified as causing hearing impairment and inflicted by occupational regulations [6]. The sound pressure level is the main factor related to the these adverse effects [7–9]. In addition, the type of noise and its characteristics [10], the duration of exposure [11], individual characteristics [12], and noise sensitivity determine the detrimental effects of noise [13]. Studies show that age, gender, genetics, underlying diseases, personality traits, and other individual features such as noise sensitivity are involved in noise-induced non-hearing effects [14].

Gender is the most important individual characteristics. The gender of the individual can be defined in different ways. Gender differences in humans can be of several types, including anthropometric, anatomical, physiological, biological, psychological, cognitive, and behavioral differences [15,16]. Gender differences in humans have been studied in a variety of fields such as physical

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and mental abilities and performance [17]. In general, men outperform women at a substantially higher level on most visuospatial tasks and mathematical abilities, while females show advantages in perceptual speed, accuracy, and fine motor skills [15]. Ahrenfeldt et al. have reported that females have better cognitive function than males, while males have higher grip strength measures. They also believe that gender differences decrease with age [18]. Moreover, Downing and Chan have expressed that women are more inclined to process details than men, which in turn is more inclined to use innovative tools to process information [19].

However, gender differences in performance may depend on task like workload and work environment conditions such as noise [20]. Shepherd et al. believe that gender is an effective variable in the relationship between personality and noise sensitivity [21]. Studies have suggested that women are more sensitive to noise than men, although evidence remains unclear [22]. Whilst some studies referred that females tend to tolerate more low-frequency noise than males, others denoted that females tend to report higher levels of noise-induced annoyance when exposed to low-frequency noise [23]. Previous studies also show that men tend to have higher accuracy in high noise and workload levels [24]. Furthermore, studies have reported that noise-induced sleep disturbance is higher in men than women [2]. In return, noise-induced cardiovascular problems are more prevalent among women [3]. Despite the several studies on gender differences [15,25–27], the role of gender in annoyance and other noise-induced health effects is still unclear. Therefore, in the study of occupational noise-induced health effects, gender should be taken into account as an important biological variable that affects many cognitive and physiological processes. Assessing and identifying the noise effects based on gender is one of the most important issues in occupational safety and health. That kind of information is crucial to the design of workplaces, determining the sound standards and criteria of the work environment, noise comfort, increasing productivity, and the implementation of different organizational measures. Moreover, determining the role of gender in the occurrence of noise-induced health effects can be effective in reducing fatigue and depression, preventing human errors, and other adverse consequences [28]. Finally, exploring gender differences in performance and psychophysiological parameters during noise exposure can help prevent noise effects, the suitable choice of people for the job, and optimization of the work environment. Since there are few studies on the noise-induced health effects in occupational environments involved in cognitive function considering gender, to predict favorable environmental conditions, this study wants to contribute with new inputs to this knowledge. Therefore, this study aimed to determine the gender differences in cognitive performance and psychophysiological responses during exposure to noise under tasks with different workloads.

2. Material and methods

2.1. Participants

Thirty-two healthy students (16 females and 16 males) with an age range of 20–30 years were selected as the participant. Normal hearing, nonsmoking, non-alcohol, non-drugs, enough and good sleep, and no previous exposure to occupational noise were the eligibility criteria for the inclusion of the participants in to study. Therefore, at first, the subjects were screened for general health, hearing, and visual. The general health and noise sensitivity of subjects were measured using the General Health Questionnaire-28 (GHQ-28) [29] and the Weinstein Noise Sensitivity Scale (WNSS) [30], respectively. The visual health of the subjects was examined using the E chart. The hearing threshold level of them was also measured by an audiologist and using a calibrated audiometer (MEVOX ASB15) at the frequency range of 125–8000 Hz. Thus, the participants with at least 20dBA average hearing threshold levels were allowed to contribute to the study. The participants with a history of neurological diseases as well as the individuals taking drugs that influence the nervous system were excluded. All of the participants were asked to keep enough sleep (at least 7 h) the night before the experiments. They were also asked to refrain from consuming caffeine or any other stimulating substance 12 h before the test. All of the participants were paid to increase their motivation to participate in the study. Participation was voluntary and all of the participants signed an informed consent. This study was approved by the Ethics Committee of Kurdistan University of Medical Sciences.

2.2. Study design and experimental setup

An experimental study with four noise conditions was designed: 55 dB(A), 65 dB(A), 70 dB(A), 75 dB(A). Therefore, each of the subjects participated in four sessions. The sessions were held on four sequential days during the morning. The duration of each session was 1 h. To this end, an air-conditioned room with dimensions: 3.7 × 2.4 × 2.7 m, temperature: 22 ℃, relative humidity: 50%, and light intensity: 500 lx (supplied by two LED lights) was designed in the research laboratory of Hamadan University of Medical Sciences. The walls of the room were covered with polyurethane foam, and the floor was carpeted. Moreover, a desk, a chair, and a computer were placed to run the cognitive tests in the room. Two 10-watt speakers on either side of the monitor and an 8-watt subwoofer were used to expose all participants to similar noise levels. Fig. 1 shows the laboratory set and the interior of the room.

The office employees and operators' control room are mainly involved in cognitive tasks and exposed to noise levels in the range of 55–75 dBA. Therefore, to investigate gender differences, cognitive performance and psychophysiological responses of the subjects were examined during exposure to four low-frequency noise conditions include 55 dB(A) (background noise level), 65 dB(A), 70 dB(A), and 75 dB(A). The frequency spectrum of the noise levels (fan noise) in the one-octave band has been presented in Fig. 2.

2.3. Measurement of psychophysiological responses

At the end of each session, subjects were asked to evaluate noise-induced annoyance by using visual analog scale as recommended by ISO 15666:2003 [31] and noise-induced subjective fatigue using visual analog rating scales (VAS) [32]. The VAS consisted of a line 10 cm in length, labeled at each end as "0" at the left end, and "10" at the right. The subjects were asked to mark across the line the point that indicated the level of annoyance and fatigue that they were feeling. Moreover, heart rate variability (HRV) as a physiological variation during noise exposure was measured. HRV is a variation in the time interval between heartbeats. The variables of HRV are low frequency (LF), high frequency (HF), LF/HF ratio, and the standard deviation of NN intervals. In the current study, only values of the LF/HF ratio were examined during noise exposure. The data of the HRV were measured using Nexus 4 by Bio traces system (Mind Media Co.) that were recorded on a laptop via Bluetooth. The HRV was gathered from the raw data of electrocardiographs (ECG). ECG was measured through electrodes attached to the chest. In this way, the negative (Black) electrode on the right chest and ground (white) electrode was placed on the left chest below the collarbone and the Red positive electrode on the right of the sternum in the fourth intercostal space. The percentage changes of data were calculated to baseline values.

Fig. 1. Experiment setup and the interior design of the room.

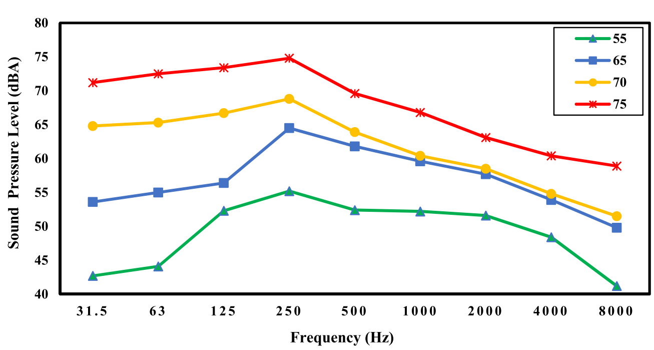

Fig. 2. The frequency spectrum of four noise conditions in a one-octave band.

2.4. Assessment of cognitive performance

To assess cognitive performance, the N-back test was implemented on a desktop computer during noise exposure. This test evaluates working memory. The N-back test (executive function measurement task) contains a random series of visual stimuli, where digits from 1 to 9 are presented repetitively. Three different levels of working memory were considered in this study: low workload (n = 1), medium workload (n = 2) and high workload (n = 3). The participants were asked to respond, pressing a key to all numbers presented. Each level of the N-Back tests consisted of 120 stimuli. Each stimulus (digits) was presented in the center of the screen for 1000 ms. At low workload, each stimulus (random digits from 1 to 9) was compared to the previous stimuli. At medium workload, each stimulus (random digits from 1 to 9) was compared to two previous stimuli. At high workload, each stimulus (random digits from 1 to 9) was compared to three previous stimuli. At each level of workload, the number of correct answers indicates accuracy in an average time. The response time to each stimulus was considered as the reaction time (millisecond) [33].

2.5. Study procedure

At first, a theory and practical session were held to familiarize the participants with the principles of conducted experiments. They were asked that they had had enough sleep and refrained from drinking caffeine or any other stimulus at the night before each session. At the commencing of each session, to adapt the participant to the chamber climate, the subjects were demanded to sit on the desktop for around 15 min. Then, the electrodes of ECG were attached to the subject's chest and baseline values were recorded for 5 min. Afterwards, they were exposed to noise, and the cognitive tests were run in three levels of the low, medium, and high workload at 5 min intervals. Each subject was asked to start the test about 5 min after the commencement of the noise exposure. The duration of each level of the test was also 5 min. The noise level was checked using an attached dosimeter to the subject's shoulder throughout noise exposure. The LF/HF ratio was recorded in each level of workload and during noise exposure. Noise exposure was stopped about 5 min after the ending of tests and once again the LF/HF ratio was recorded. At the end of each session, the subject was demanded to determine the noise-induced annoyance and subjective fatigue.

2.6. Data analysis

Data analysis was performed using the statistical software of SPSS. (IBM SPSS 24, Inc., Chicago, Ill). Mauchly's Test of Sphericity was used to assess the normal distribution of the data at different levels. The repeated measures analysis of variance (ANOVA) was used to analyze data. An ANOVA with repeated measures was often used to compare three or more group means where the participants are the same in each group. Additionally, to investigate the difference between the means, Tukey's Test for Post-Hoc analysis was conducted. The effect size (ES) was also reported. In this study, p-values<0.05 were considered statistically significant.

3. Results

3.1. Subjective parameters

The descriptive statistics of the 32 subjects' individual characteristics have been presented in Table1. As can be seen, noise sensitivity was the first major difference assessed between males and females participating in exposure to noise. There was a significant difference in noise sensitivity between men and women so that the average score of noise sensitivity of the women was higher than that of the men. Other individual characteristics were almost homogeneous.

Fig. 3 illustrates the results of the noise-induced annoyance and subjective fatigue in males and females studied. As shown, the females rated higher levels of annoyance and fatigue than males. These differences were statistically significant in all four acoustic conditions. Significant levels of noise annoyance were 0.041, 0.033, 0.024, and 0.001, in four noise conditions respectively ($p < 0.05$ for all noise conditions). Also, the *p*-values for noise-induced fatigue were 0.047, 0.005, 0.001, and 0.039 respectively ($p < 0.05$ for all noise conditions).

3.2. Cognitive performance

Mean ± SD of accuracy and response time of males and females in the three levels of workload and in the four noise conditions have been described in Table 2. The results showed that the effect of noise level on the average accuracy for the women was lower than that for the men in a low workload; in other words, the mean accuracy of the women was higher than that of the men. The results also showed that the mean accuracy of the women in the sound pressure level of 55 dB(A) with a medium workload was higher than that of the men. On the contrary, with increasing noise levels and workloads, the average accuracy for the men was higher than that for the women, i.e., men showed better performance. It was also found that the mean response time to the stimulus for the women was lower than for the men at different noise levels and workloads. In other words, the speed of response to the stimulus in women was higher than that in men.

Table 3 shows the effect of gender on the means of accuracy and response time to the stimuli. The effect of gender on the mean accuracy at low and high workloads and at different noise levels was significant ($p < 0.05$). Furthermore, the effect of gender at low and high workload levels was 17.8 and 14.6%, respectively, and the noise effect at these two levels, regardless of gender, was 53.1 and 37.2%, respectively. Also, the effect of gender on the mean response time at low workload levels was significant ($p < 0.05$). Moreover, the effect of gender was 23.6% and for different noise levels was 5.6%.

Table 1
Descriptive statistics of males and females' characteristics participating in the study.

Variables	Male (n = 16)		Female (n = 16)	
	Mean	SD	Mean	SD
Age	23.81	3.8	22.62	1.02
Body Mass Index	23.27	2.70	23.14	3.67
General Health score	15.77	4.83	14.79	5.92
Hearing Threshold Level	21.70	2.2	20.42	2.3
Noise sensitivity	57.16	11.08	77.56	16.19

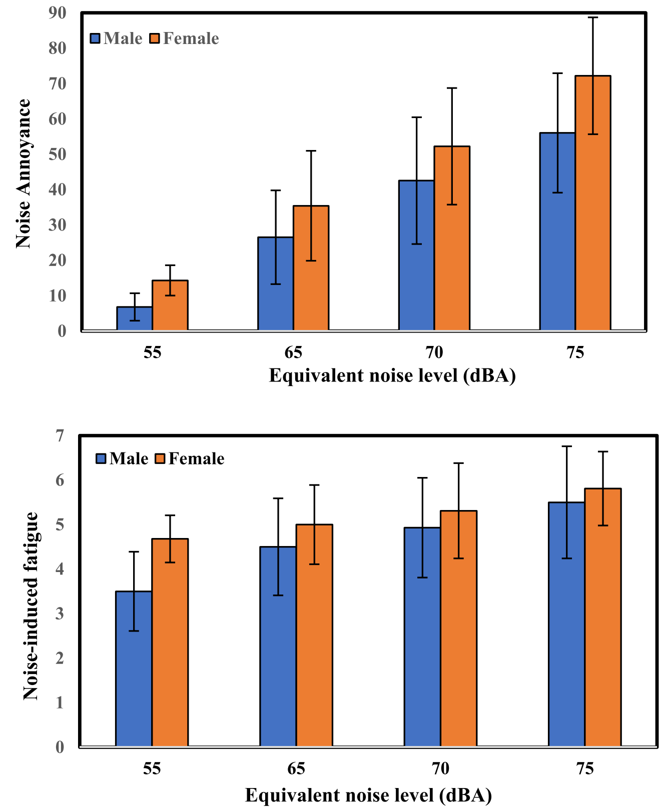

Fig. 3. The mean rate of noise-induced annoyance and fatigue in males and females.

3.3. Physiological responses

Fig. 4 illustrates the values of the LF/HF ratio of the men and women during one-hour in exposure to four noise conditions. As can be seen, the LF/HF ratios for the females were higher than those for the males. Moreover, the results showed that the LF/HF ratio has been increased as the noise level increased.

The mean of differences of LF/HF ratios in different noise levels at three workload levels have also been presented in Table 4. As shown, there was a significant difference between the means of LF/HF males and females at different levels of noise and in low ($n = 1$) and medium ($n = 2$) workloads ($p < 0.05$). In this regard, the results showed that with increasing levels of noise and workload, the mean LF/HF ratios for the women were higher than those for the men. However, the mean LF/HF of males and females was not significant in different noise levels at the high workload.

The effect of gender on the mean LF/HF ratios of the males and females in noise levels and different workloads have been analyzed in Table 5. The effect of gender (17.5%) on the mean LF/HF of the participants in the medium workload was significant (Table 5). However, the effect of noise was about 10.8%. The effect of gender on low and high workloads was not significant during exposure to different noise levels ($p > 0.05$).

Table 2
Mean ± SD of accuracy and response time of males and females in three levels of workloads and four noise levels.

Parameter	Gender	55dBA		65dBA		70dBA		75dBA		P-value	ES
		Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Accuracy (%)											
Low	Male	84.58	7.40	82.18	10.84	81.54	11.00	78.65	8.38	<0.000	0.531
	Female	92.72	5.49	87.18	12.24	84.87	9.39	82.81	9.13		
Medium	Male	83.85	6.35	76.43	9.61	72.62	14.22	70.06	8.95	<0.000	0.460
	Female	87.99	5.67	70.16	7.83	68.56	5.52	66.87	7.52		
High	Male	82.24	2.77	70.87	10.15	69.12	18.89	62.50	16.50	<0.000	0.372
	Female	80.94	5.56	64.62	8.35	63.12	13.14	55.77	17.00		
Response time (ms)											
Low	Male	467.18	95.22	507.19	52.46	521.12	95.41	556.86	92.14	>0.160	0.056
	Female	460.69	127.82	465.50	58.77	470.23	77.59	480.19	60.87		
Medium	Male	523.01	124.57	501.88	110.80	480.94	118.89	454.94	82.10	>0.060	0.078
	Female	505.38	162.57	460.56	72.37	434.56	86.22	427.44	96.87		
High	Male	548.06	142.37	763.12	10.02	703.88	31.75	380.56	48.83	>0.055	0.111
	Female	515.69	154.06	467.06	88.07	413.31	127.66	285.62	40.82		

Accuracy: the percentage of correct answers; **Response Time:** average response rate to the stimulus, ES: the effect size index.

Table 3
Effect of gender on the mean accuracy and response time of males and females during exposure to noise levels and three levels of workload.

Workload	Parameters	Source	Type111 sum of squares	df	Mean square	f	P-value	ES
Low	Accuracy (%)	Gender	852.226	1	852.226	6.476	<0.016	0.178
	Response time (ms)	Gender	62216.281	1	62216.281	9.282	<0.005	0.236
Medium	Accuracy (%)	Gender	207.647	1	207.647	2.656	>0.114	0.081
	Response time (ms)	Gender	35278.320	1	35278.320	3.205	>0.084	0.097
High	Accuracy (%)	Gender	854.239	1	854.239	5.129	<0.031	0.146
	Response time (ms)	Gender	317405.281	1	317405.281	2.504	>0.124	0.077

ES: the effect size index.

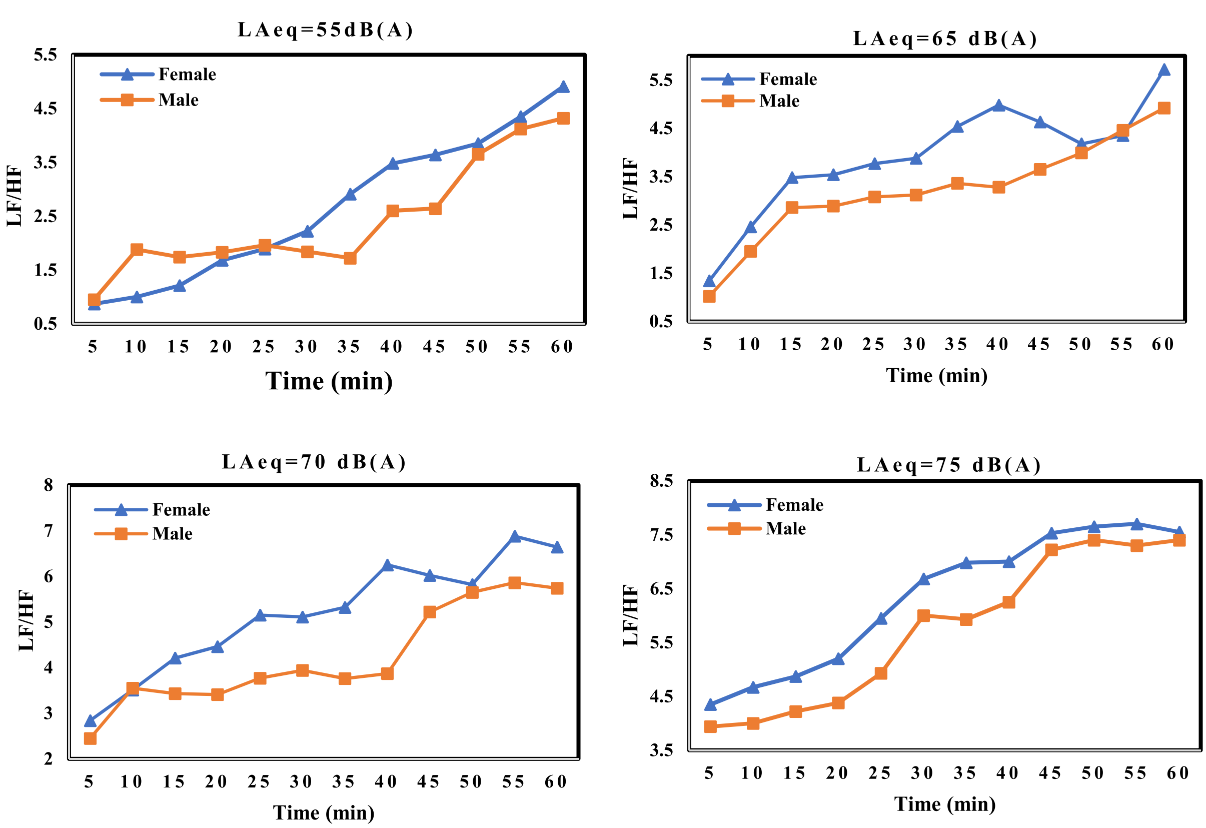

Fig. 4. The LF/HF ratio of males and females in exposure to four noise conditions.

Table 4
MD ± SE of LF/HF ratio of males and females in three levels of workload and four noise levels.

Workload	Gender	55dBA		65dBA		70dBA		75dBA		P-value	ES
		Mean	SE	Mean	SE	Mean	SE	Mean	SE		
Low	Male	1.83	8.97	2.62	2.88	3.32	3.56	4.34	3.86	<0.05	0.097
	Female	1.09	1.72	3.21	2.53	4.32	1.82	4.8	1.56		
Medium	Male	1.88	8.83	3.11	2.28	3.60	2.95	5.22	3.25	<0.033	0.108
	Female	3.48	2.82	4.88	2.79	5.59	2.78	6.95	1.65		
High	Male	3.66	9.20	4.86	2.94	5.57	3.20	6.02	4.32	>0.151	0.058
	Female	4.91	3.73	5.70	3.10	6.06	2.16	7.47	2.89		

LF/HF: The rate of change ratio of the LF over the HF relative to baseline, MD: mean of difference, ES: the effect size index.

4. Discussion

In the present study, the cognitive performance of the males and females, perceived annoyance and fatigue, and LF/HF ratio were evaluated during the exposure to different noise levels, considering task workload. In general, the present study elucidates some of the gender differences in the noise-induced non-auditory effects.

The results of this study indicated that the rate of annoyance and fatigue was significantly more prevalent in females than in males in high noise levels conditions. Furthermore, the findings indicated that the average score of noise sensitivity in women was significantly higher than that in men. These results are consistent with the results of previous studies. In an experimental study, Beheshti et al. reported a higher rate of noise-induced annoyance among females than that among the males in exposure to low-frequency noise [23]. In the study on the relationship between noise sensitivity and diminished health, Hill and et al. noted that gender plays an important role and that women are more sensitive to sound [34].

Despite the importance of cognitive function during noise exposure, cognitive gender differences are still reported. However, in the current study, the working memory (rate of accuracy and reaction time) of the females and males were examined during exposure to four noise conditions considering mental workload. Generally, the observations showed that the females tend to outperform the males at noise levels lower than 65dBA as well as the workload of low and medium, while the males outperformed at the high workload and the noise levels higher than 65 dBA. Moreover, the response time to the stimulus in women was shorter than that in men; it may be because of the fact that women have a lower tolerance threshold in exposure to noise. In this regard, although no particular study has been found, the evidence illustrates that males perform better in high workloads [18,35]. Upadhayay and Guragain believe that males have poorer performance than females in attention, working memory, and color reading at normal [36].

In the current study, the HRVs of the females and males were also recorded during noise exposure considering workloads. The HRV indices reflect acute changes in self-regulation and emotional states that are best explained as defense reactions (physiological regulation) of the body to stimulus (noise) [37]. The ratio of low frequency (LF) to high frequency (HF) reflects the ratio between the sympathetic nervous system and parasympathetic nervous system activity under controlled conditions [32]. Therefore, the LF/HF index was analyzed among males and females as a stress indicator. The results showed that with increasing the noise level and the workload, the LF/HF ratio accordingly increased. However, the findings of this study illustrated that the ratio of this index was higher in women. This suggests that the stress on women is higher than on men in those conditions. Furthermore, in the medium workload, the effect of gender (17.5) on the LF/HF ratio was evaluated more than the noise (10.8). Several studies have proved that the HRV is strongly affected by noise level [38,39]. However, no study has analyzed the effect of noise on the HRV considering gender. In this regard, Voss et al. reported that the HRV indices are influenced by gender. Thus, the different hormonal situations led to higher sympathetic activity and a lower parasympathetic tone in men and vice versus in women [38]. Moreover, in a cohort study, Lim et al. have concluded that the risk of overall and nonfatal MI incidence was 30% higher in women exposed to ≥56 dB road traffic noise levels [40].

However, it should be noted that the results were limited to the conditions of this experiment, and therefore subjects' responses may be different in other conditions. In the current study, only four low-frequency noise conditions (55, 60, 65, and 75 dB(A)) were examined. Therefore, future studies are required to focus on the examination of gender differences in cognitive performance during exposure to middle and high-frequency noise or irrelevant speech. Future investigation can also examine gender differences in motor skills during noise exposure. Moreover, it should be noted that in real work environments, there are other harmful factors such as heat and vibration that affecting gender differences in noise exposure.

5. Conclusion

In general, females and males indicated responses of significant and different during noise exposure. The women are more sensitive to noise; thus, they experience more noise-induced annoyance and fatigue. The females had a better cognitive performance at levels of ≤65 dBA with a low and medium mental workload, while the males had a better cognitive performance at levels ≥65 dB and high workload. It seems that the noise-induced stress effect in women was more than in men because the LF/HF ratio increased significantly in noise exposure among female participants. Hence,

Table 5
Effect of gender on the mean LF/HF of males and females during exposure to noise and three levels of workload.

Workload	Source	Type111 sum of squares	df	Mean square	f	P-value	ES
Low	Gender	3.785	1	3.785	0.330	>0.570	0.011
Medium	Gender	92.378	1	92.378	6.343	<0.017	0.175
High	Gender	37.455	1	37.455	1.728	>0.199	0.054

ES: the effect size index.

the results of this study suggest that gender criteria should be especially taken into account in selecting jobs, workplace design, and work content. This study was a first approach to examine gender differences in performance and other responses during noise exposure. Therefore, more research needs to be done on gender differences in noise exposure to be used in the workplace.

CRediT authorship contribution statement

Ali Mohammad Abbasi: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration. **Ebrahim Darvishi:** Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Matilde A. Rodrigues:** Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Kourosh Sayehmiri:** Conceptualization, Data curation, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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