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Job Stress among Workers Exposed to Extremely Low Frequency Electric and Magnetic Fields in a Combined Cycle Power Plant

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ABSTRACT

Introduction: Exposure to the low frequency electric and magnetic fields (ELF-EMF) is very common in workers occupied in the combined cycle power plant during work shifts The present study aimed to measure ELF-EMF flux density among shift and non-shift workers, determine job stress among workers and office workers, and identify major factors associated with job stress in the studied groups.

Materials and Methods: In this cross-sectional study, the exposed group was divided into 75 shift workers and 75 non-shift workers. Seventy-five office workers were selected as the reference group. The participants' exposure to ELF-EMF was measured by the EMF-828 device. In addition, Osipow Occupational Stress Questionnaire was used to assess the participants' stress levels.

Results: Maximum levels of ELF-EMF among shift workers, non-shift workers, and office workers were 28.67 µT, 23.43 µT, and 0.06 µT, respectively. Although the explosion rate to ELF-EMF was higher in the shift and non-shift workers than the office one's, this rate in both of them were lower than the recommended limit as suggested by the American Conference of Governmental Industrial Hygienists (ACGIH). The highest stress score was related to shift workers exposed to ELF-EMF, in which 42.7% of them experienced moderate to high levels of job stress. Multivariate linear regression analysis showed a significant association between shift work and exposure to ELF-EMF with increased stress.

Conclusion: The findings suggested that exposure to ELF-EMF, even at low intensities, is associated with increased stress. Moreover, Shift work is another risk factor for stress.

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Introduction

Nowadays, many electromagnetic waves are radiated from radar, communication equipment, cellphones, high-voltage lines, radio and television transmitters, power line columns, and electric equipment in houses and workplaces [1]. Given that job groups are exposed to these fields, one could point to power plant workers [2, 3]. Although

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electricity is one of the basic commodities of the world and benefits of the electrical power industry are consistently increasing, public concerns about ELF-EMF exposure caused by electricity distribution have been raised [4].

Wertheimer and Leeper reported that the number of cancer cases among children living near to electricity lines was significantly higher than the control group in Colorado that might be due to ELF-EMF explosion [5]. In addition, exposure to electromagnetic fields causes childhood leukemia, brain tumors, infertility, and cardiovascular diseases [3].

International Agency for Research on Cancer (IARC) classified ELF-EMF among probable human carcinogens (group 2B), but some studies observed a significant association between exposure to these fields and the prevalence of leukemia, breast, and brain cancer [4]. Headache, burnout, depression, anxiety, and fatigue caused by the effect of the fields on one's sleep were also reported among subjects exposed to the ELF-EMF[2].

The study of the effect of 12Hz electromagnetic fields on rats suggested that such fields could increase adrenaline and adrenocorticotropic hormone (ACTH) within 1-3 days after exposure, and these hormones could contribute to stress induction [6]. Asgari, et al.[7] confirmed the significant association between ELF-EMF and higher stress in workers of the electricity distribution company.

Stress is defined as changes in a person's physical and mental conditions in response to different conditions of the setting [8]. It is one of the most socio-psychological risks in the workplace that concerns employees, employers, and psychologists [9]. Job stress usually affects personal (behavioral, mental, and physical consequences) and organizational (reduced performance, job satisfaction, and organizational commitment) functions [10]. Most researchers agree that environmental factors contribute to job stress. These factors could be generally divided into physical and socio-psychological categories [11]. No one claim that people doing the same job experience the same stress level [12]. Job stress is considered as one of the important risk factors for cardiovascular diseases, metabolic syndrome, depression, cognitive disorders, and cancers [13].

In addition to ELF-EMF exposure, job stress can be increased because of shift work. Irregular work shifts (7 a.m. to 6 p.m.) [14] engage almost 20% of the workforce in the world [15]. Reduced consciousness and performance, especially during night shifts and daily sleeping difficulties, such as narcolepsy, are caused by work shifts. Sleep deprivation is associated with circadian rhythms disruption [16]. A change in the sleep-wake cycle may trigger such disorders as depression, anxiety, psychosis, attention deficit, different physical and mental problems, sleeping disorders, cardiovascular diseases, gastrointestinal symptoms, diabetes, and immune system disorders [14, 17, 18].

The effect of exposure to electromagnetic fields and work shift on job stress has so far been studied separately. No study has yet addressed the simultaneous effects of the two factors on job stress. Given workers in combined cycle power plants are exposed to both ELF-EMF and work in shifts, present study is the first in Iran to measure ELF-EMF flux density among shift and non-shift workers. This research was conducted to determine job stress among workers and office workers, identify the major factors associated with job stress in the studied groups, and measure the magnetic field flux density among shift and non-shift workers in order to address their effects on job stress.

Materials and Methods

The present comparative study was conducted to measure ELF-EMF flux density among shift and non-shift workers in a combined cycle power plant, determine job stress among all workers and office workers, and identify major factors associated with job stress in the studied groups. The inclusion criteria were at least one year work experience in the combined cycle power plant without any psychological background and mental disorders. Participants were divided into three groups (shift, non-shift, and office workers) with a population size of 75.

Measurement of electromagnetic fields

The magnetic field flux density was measured based on standard IEEE Std 644-1994 [19]. This study measured electromagnetic fields through Lutron Device (model: EMF-828; Taiwan) at a frequency range of 30-300Hz and 3d + %4 measurement accuracy at 20 μT, 3d + %5 at 200 μT, and 5d+%10 at 2000 μT. Given the device used in this study was three-directional, the root mean square (RMS) was calculated through the following equation:

$$B_{RMS} = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

Measurement was done at workers' waist height and 1m above the ground [19]. All measurements were done from 9 a.m. to 4 p.m. at temperatures ranging 25-40°C and 8% relative humidity. The frequency of electromagnetic fields in the whole power plant was 50Hz.

Measurement of job stress

Osipow Occupational Stress questionnaire was used for data collection. The validity and reliability of the questionnaire were evaluated by Sharifian et al. The reliability of the mentioned questionnaire was determined through a retest with Cronbach's alpha of 0.83 [20]. The first part of the questionnaire is concerned with demographic information. The second part is intended to evaluate a person's stress in terms of six sub-scales, including role overload, role insufficiency, role ambiguity, role boundary, responsibility, and physical environment. Role overload addresses the status of a person in relation to workplace demands. Role insufficiency is concerned with the fitness of a person's skill, education and training, and experience to workplace requirements. Role ambiguity measures a person's awareness of priorities, workplace expectations, and evaluation criteria. Role boundary considers the paradoxes a person perceives in terms of work ethics and the role that they are expected to play in the workplace. Responsibility measures a person's perceived responsibility to the efficiency and well-being of others in the workplace. Finally, physical environment addresses the unfavorable physical conditions of the workplace to which a person is exposed. Osipow Occupational Stress Questionnaire was scored based on a five-point Likert scale (never: 1; sometimes: 2; often:3; usually:4; and most of the times: 5) [7]. The scores ranged from 60 to 300. Higher scores showed higher job stress. Based on the obtained scores, the general stress level was categorized into four groups, including low (60-119), low to moderate (120-179), moderate to high (180-239), and high (240-300) [7].

Statistical analysis

Data analysis was conducted by SPSS Software (version 24). Many distributions were not normal, so non-parametric signed rank tests were run. The chi-square test and Fisher's exact test were used to assess the distribution of variables between the groups. To carried out a comparison between ELF-EMF flux density and job stress score in the three studied groups Kruskal-Wallis test was used to determine association between stress with shift work and exposure to ELF-EMF, linear regression analysis was used. For descriptive statistics, frequency and percentile frequency were used. A p-value of less than 0.05 was considered statistically significant.

Ethical Issues

This study was registered and confirmed in Shahid Sadoughi University of Medical Sciences (Ethical ID: IR.SSU.SPH.REC.1399.226).

Results

The demographic data of the studied groups, including age, work history; daily working hours, sex, marital status, smoking, and education are shown in Table 1. Most participants were in the age group of 33-43 years, with work history of 8 to 16 years, working about 7 to 10 hours per day, non- smoker, and mostly with bachelor's degrees. Table 1 show that there was no statistically significant difference between the three groups in terms of demographic variables.

Table 1: Comparison of demographic and job variables in the studied groups

Variable	Levels	Office workers N	Office workers %	Shift workers N	Shift workers %	Non-shift workers N	Non-shift workers %	P-value
Age (year)	23-33	14	18.7	8	10.7	7	9.3	
	33-43	44	58.7	46	61.3	50	66.7	0.43*
	43-53	17	22.6	21	28	18	24	
Work experience (year)	1-8	33	44	35	46.7	38	50.7	
	8-16	31	41.3	30	40	23	30.7	0.652*
	16-24	11	14.7	10	13.3	14	18.6	
Daily working hours	4-7	13	17.3	13	17.3	6	8	
	7-10	59	78.7	57	76	69	92	0.057**
	More than 10	3	4	5	6.7	0	0	
Sex	Male	57	76	65	86.7	67	89.3	0.062*
	Female	18	24	10	13.3	8	10.7	
Marital status	Single	9	12	5	6.7	3	4	0.168*
	Married	66	88	70	93.3	72	96	
Smoking status	Smoker	3	4	3	4	6	8	0.453*
	Non-smoker	72	96	72	96	69	92	
Education	High-school Diploma	7	9.3	4	5.3	5	6.6	
	Associate degree	3	4	14	18.7	8	10.7	0.176*
	Bachelor's degree	37	49.4	33	44	38	50.7	
	Master's degree and higher	28	37.3	24	32	24	32	

*Chi-squared test **Fisher's exact test

Table 2 shows the median of ELF-EMF flux density for the studied groups. Based on this table, there was a statistically significant difference between the three groups in terms of exposure to ELF-EMF, so that the differences between shift workers and office workers (p = 0.001) as well as between non-shift workers and office workers (p = 0.048) were statistically significant.

Table 2: Comparison of ELF-EMF flux density (µT) in the studied groups

Studied group	Min. intensity	Max. intensity	Median	IQR	p*
Office workers	0	0.06	0.01	0.014	< 0.001
Shift workers	0	28.67	0.54[a]	2.46	
Non-shift workers	0	23.43	0.49[b]	1.41	

*Kruskal-Wallis test
[a] p = 0.001 vs. the office workers
[b] p = 0.048 vs. the office workers

Table 3 shows the results obtained from job stress scores and its six sub-scales among the studied groups. The total job stress score for shift workers, non-shift workers, and office workers was 176, 171, and 161, respectively. The observed differences between shift and non-shift workers (p = 0.022), shift workers and office workers (p < 0.001), and non-shift workers and office workers (p = 0.044) were statistically significant.

The job stress scores revealed that the highest and lowest scores for job stress were found among shift workers and office workers in terms of the role boundary and physical environment, respectively. In addition, the difference between two groups was statistically significant (p = 0.048 for the role boundary and p = 0.001 for the physical environment). In addition, the job stress caused by physical environment among non-shift workers was significantly higher than office workers (p = 0.03).

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Given the work overload, the highest and lowest stress scores were found among shift workers and non-shift workers, respectively. Meanwhile, the observed difference was statistically significant (p = 0.033). Also, the observed difference in work overload between non-shift and office workers was statistically significant (p = 0.041).

The results of the general classification of job stress among the studied groups are shown in Table 4. Generally, the distribution of total job stress score was different among the groups (p = 0.002). In addition, the maximum and minimum levels of stress were observed among shift workers (42.7%) and office workers (16%), respectively. In low to moderate levels of stress, office workers and shift workers had maximum and minimum of stress, respectively (82.7% and 57.3%,).

Table 3: Comparison of job stress score in the studied groups

Variable	Shift workers		Non-shift workers		Office workers		p*
	Median	IQR	Median	IQR	Median	IQR	
Work overload	28[c]	9	24[b]	7	27	8	0.001
Role ambiguity	25	6	22	5	24	6	0.075
Role insufficiency	32	9	32	7	33	8	0.371
Role boundary	32[a]	6	28	6	27	5	0.002
Responsibility	27	10	25	10	28	9	0.174
Physical environment	29[a]	8	27[b]	9	16	13	< 0.001
Total job stress score	176[c,a]	25	171[b]	31	161	28	0.038

*Kruskal-Wallis test
[a] p < 0.05 vs. office workers (p = 0.048 for role boundary, p = 0.001 for the physical environment, and p = 0.001 for total job stress score).
[b] p < 0.05 vs. office workers (p = 0.041 for work overload, p = 0.03 for the physical environment, and p = 0.044 for total job stress score).
[c]p < 0.05 vs. non-shift workers (p = 0.033 for work overload and = 0.022 for total job stress score).

Table 4: Classification of total stress levels among the studied groups

Studied groups	Stress Levels: Low		Low to Moderate		Moderate to High		High	
	N	%	N	%	N	%	N	%
Office workers	1	1.3	62	82.7	12	16	0	0
Shift workers	0	0	43	57.3	32	42.7	0	0
Non-shift workers	0	0	53	70.7	22	29.3	0	0

Table 5 shows the linear regression analysis of the relationship between groups and exposure to ELF-EMF with the stress score. The results showed that there was significantly higher stress in shift workers (B = 14.04, 95% CI 13.71–14.37, p < 0.001) and non-shift workers (B = 8.66, 95% CI 8.33–8.99, p < 0.001) than in office workers. An increase of one unit in ELF-EMF flux density resulted in a 0.32 unit increase in stress score.

Table 5: Association between stress and ELF-EMF exposure and shift work in the studied groups

Parameters	Beta	SE	95% confidence interval	P-value
Exposure to ELF-EMF	0.32	0.015	0.29-0.35	< 0.001
Shift Workers	14.04	0.17	13.71-14.37	< 0.001
Non-shift Workers	8.66	0.17	8.33-8.99	< 0.001
Office Workers	-	-	-	-

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Discussion

This study measured ELF-EMF flux density among shift and non-shift workers, determined job stress among workers and office workers, and identified major factors associated with job stress in the studied groups. The three groups were similar in terms of demographic characteristics and different in median scores for job stress that were probably due to their working conditions.

In the present study, although the explosion level of shift and non-shift workers to ELF-EMF were significantly higher than the office workers, ELF-EMF levels for both worker groups were lower than 1000 and 500μT suggested by the American Conference of Governmental Industrial Hygienists (ACGIH) and the Institute of Standards and Industrial Research of Iran (ISIRI), respectively. This finding is consistent with studies conducted by Baqeri et al. [21] and Asgari et al. [7] who reported ELF-EMF flux densities of 29.18 ± 27.58 μT and 12.09 ± 7.12 μT in the power plant workers, respectively.

The median total job stress score among shift and non-shift workers and office workers was 176, 171, and 168, respectively. The highest stress score was observed among shift workers who had the highest exposure to electromagnetic fields, so that 42.7% had moderate to high stress levels.

Similar to the results of this study, Baqeri et al. [21]. Found a significant difference in sleep quality score between workers exposed to electromagnetic fields and the control group. Technicians with the highest exposure to electromagnetic fields (58.74 ± 44.91) experienced lower sleep quality, higher anxiety, stress, and depression than other workers.

In 2019, Asgari et al. [7] reported the mean total stress score of 171.60 ± 17.5 in the Electricity Distribution Company workers through Osipow Occupational Stress Questionnaire (i.e., moderate to high levels). The authors also reported a significant association between exposure to electromagnetic fields (12.09 ± 7.12 μT) and higher stress.

Ghotbi et al. [22] reported the mean ELF-EMF field flux density of 2.50 ± 0.78 mT in Mes Sarcheshmeh Refinery. Meanwhile, 48.9% of workers had a social anxiety disorder, 28.9% had anxiety and sleep disturbance, as well as 5.6% showed depression symptoms. Also, anxiety, depression, and sleep disorder among exposed workers were significantly higher than the non-exposed group. In 2014, Davanipour et al. [23] in a study on 3050 older-than 65 Mexican-Americans, reported that exposure to ELF-EMF could increase the risk of cognitive dysfunction.

Yousefi et al. [24] observed an increase in the prevalence of certain symptoms, such as depression, anxiety, hostility, inter-personal sensitivity, and obsessive-compulsive disorder among workers of high-voltage substations compared to the control group. In addition, the authors reported a significant statistical association between exposure to fields and psychological symptoms. Zamanian et al. [25] also reported a higher frequency of mental disorders due to 0.087-30 μT explosion in power station workers.

In determining mechanisms of ELF-EMF induced stress, Szemerszky et al. [26] reported that exposure of rats to electromagnetic fields for 4 to 6 weeks affected the hypothalamic-pituitaryadrenal (HPA) system function, leading to increased secretion of corticotropin- releasing hormone (CRH) from hypothalamus, increased secretion of ACTH from the pituitary gland, and induced stress.

Mahdavi et al. [6] in a study on rats at 12Hz frequency and 0.1mT flux densities suggested that levels of adrenaline and ACTH as the two stress-causing hormones increased significantly in 1 and 3 days after exposure of rats to 12Hz electromagnetic waves.

Kitaoka et al. [27] approved that exposure of rats to ELF-EMF with 3 mT flux density for 200h leads to increased secretion of corticosterone, depression, and anxiety-caused behaviors.

Oxidative stress by increasing nitric oxide (NO) is another mechanism of the effect of electromagnetic fields on stress. NO is a two-atom free radical and one of the most significant intracellular signaling molecules regulating many cellular processes, such as blood pressure, immune response, transferring neurotransmitters, and oxidation-sensitive mechanisms. It plays a significant role in learning, memory, and the development of anxiety and depression. Under oxidative stress conditions, overproduction of NO in brain might change the functioning of the hypothalamic pituitary adrenal (HPA) axis and contribute to depression and anxiety [21].

In addition, electromagnetic fields affect sleep quality through melatonin, a hormone secreted by the pineal gland. Melatonin suppression is accompanied by physiological disorders, such as sleep disorders, depression, stress, breast cancer, melanoma, colon cancer, lung cancer, and leukemia. Since melatonin is an antioxidant and a scavenger of free radicals, the level of this hormone declines due to exposure to electromagnetic fields, which might reduce sleep quality [21].

In addition, ELF-EMF-induced oxidative stress contributes to mitochondrial dysfunction. Since mitochondria plays a role in ATP generation, their dysfunction could cause energy deficit in the body and burnout syndrome [2].

Not only exposure to electromagnetic fields is a risk factor of stress and cognitive problems, but also other occupational factors, such as working shifts of combined cycle power plant workers are associated with stress.

In this study, the total job stress score of shift workers was significantly higher than non-shift workers. This finding is supported by some studies [28-31]. For instance, Lin et al. [28] found out nurses on rotating shifts experience higher job stress. Also, in 2014, Lin et al. [29] in a study on 266 nurses in Taiwan, reported that nurses experience mild stress and there was a significant inverse association between sleep quality and job stress.

In 2010, Srivastava et al. [30]. in a study on 200 dairy factory workers, reported significant increases in all variables related to job pressure and mental health of shift workers. A study on Swiss police officers also indicated that work shifts are associated with stress, low-quality sleep, and dissatisfaction [31].

Ahmad et al. [32] conducted a study on 22 shift workers and 22 people from the general public. The authors indicated that the disruption of circadian rhythms might affect one’s mood and cognitive function. Sartang et al. [33] in a study on 100 police members in two groups (50 shift members and 50 non-shift members), reported that job burnout, depression, anxiety, and stress levels were significantly higher in the shift members than in the non-shift members. Chachi et al. [34] showed that shift work plays a significant role in job stress.

It seems possible that different physiological disorders, such as sleep disorders, depression, and stress in shift workers are due to a decrease of nightly melatonin secretion [21, 35].

The results are further supported by the multivariate linear regression analysis. When the studied groups and exposure to ELF-EMF were included in the model, significant associations were found between shift and non-shift work and exposure to ELF-EMF with the increase in the stress.

Conclusion

The finding of present study confirmed association between occupational exposure, ; even with low levels of ELF-EMF; with stress. Shift work is another risk factor for stress. Further studies with larger sample sizes and longer exposure duration are recommended to confirm the findings.

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Conflict of interest

The authors declare that there is no conflict of interest.

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