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ORIGINAL ARTICLE

The effect of industrial noise exposure on attention, reaction time, and memory

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Abstract

Purpose Noise, a common physical hazard in many workplaces, may affect different aspects of human cognitive function. In this study, the effect of exposure to noise on some aspects of cognitive function was assessed in industrial workers.

Materials and methods This was a cross-sectional study on 84 individuals exposed to noise level higher than 85 dBA in a metal industry (noise group), comparing a group of workers from the same industry ($n = 80$) with exposure to noise level lower than 80 dBA (control group). The individuals in the noise group were classified as well according to noise intensity into: high exposure (90 dBA and higher) and low exposure (between 85 and 90 dBA). Selective attention score, divided attention score, selective response time, divided response time, and memory scale were measured before and after work shift. Data were analyzed by SPSS (Ver. 16) using Kolmogorov–Smirnov test, paired *t* test, Student's *t* test and Mann–Whitney *U* test were used to compare mean difference of the variables between two groups. $p < 0.05$ was considered as significant.

Results All measured cognitive functions were significantly changed after work shift in the noise group and the difference was statistically significant between noise and control group. Exposure to higher noise intensity caused more change in cognitive function.

Conclusion Exposure to noise higher than 85 dBA affects some aspects of cognitive function (reaction time, attention and memory).

Keywords Noise · Cognitive function · Attention · Memory · Reaction time

Introduction

Noise is an important physical hazard in many workplaces and is considered as an environmental pollution. It causes noise-induced hearing loss (NIHL), the second most common type of sensori-neural hearing loss after presbycusis. Besides NIHL, noise may have some other adverse effects on health, such as hypertension and sleep disturbances (Quis 1999; Chang et al. 2009). A review emphasized on the prevalent non-auditory health effects of noise by Basner et al. (2014). Recently, the idea of the effect of noise on human performance and cognitive function have been raised (Basner et al. 2014; Cui et al. 2009). Cognitive functions and mental performance are composed of a variety of domains such as rapidity of response or reaction time (RT), memory, intelligence, attention and concentration (Belojevic et al. 2003). Altered cognitive function may lead to human error and in some instances increase accidents (Girard et al. 2009) which eventually causes performance and productivity

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to decrease in the workplace. Estill et al. (2017) in recent review found that both noise exposure and hearing loss are attributed to occupational accidents.

Some studies have proposed this idea that noise can improve performance, especially in sleep-deprived workers (Humphreys and Revelle 1984) or in inattentive students (Söderlund et al. 2010) due to an increase in arousal. From another side, the idea of noise sensitivity is raised as a type of environmental intolerance, i.e., an unusual sensitivity to environmental noise even in doses lower than harmful or annoying levels which may affect cognition and attention (Palmquist et al. 2014). Deleterious effects of environmental or occupational exposure to noise on cognitive performance has been shown in a literature review (Szelma and Hancock 2011). Different cognitive functions may be affected by exposure to noise. This effect is dependent on the noise intensity, duration and frequency and also the task performed (IrgensHansen et al. 2015). It was shown that low-frequency noise especially in high-intensity may significantly affect cognitive performance (Gomes et al. 1990). Tzivian et al. (2015) in a review found that noise affects selective attention, and working and episodic memory. Pawlaczyk-Łuszczyńska et al. (2005) found that low frequency noise, which is commonly produced in different industries, may affect visual functions, concentration, and continuous and selective attention; although no effect of noise on cognitive function was found by Dudek et al. (1991).

Considering the differences in the results of the studies in this issue, and the importance of low attention, and concentration or increased reaction time in many occupational tasks, this study was designed to assess the effect of exposure to noise on some aspects of cognitive function in industrial workers exposed to high-level noise compared to those without this exposure.

Materials and methods

This was a cross-sectional study on 84 individuals exposed to noise level higher than 85 dBA in a metal industry, producing metallic pins and screws (noise group), comparing a group of workers from the same industry ($n = 80$) with exposure to noise level lower than 80 dBA (control group). The noise group were selected from pressure forging, extrusion, machining and grinding units. All workers in the noise group were exposed to noise level higher than 85 dBA (8 h time-weighted average). Individuals in the control group were selected from packaging, ware-house and quality control units with exposure to noise level less than 80 dBA (8 h time-weighted average). Daily occupational tasks in two groups were not significantly different regarding physical demand of the job. The individuals in the noise group were classified as well according to noise intensity into: high exposure (90 dBA and higher) and low exposure (between 85 and 90 dBA). Audiometric data were used from the results of the last periodic occupational evaluations of the workers. Both data of noise measurement and audiometry were present in the medical files of the workers. Noise level measurements were performed via environmental noise monitoring using a sound level meter in the factory. Noise intensity and frequency spectrum were assessed as well. The noise in the workplace was a combination of continuous and impact noise containing a complex of low and high frequencies, but mostly rich in low frequencies. According to the information available in the medical files, pure tone audiometry (PTA) had been performed at least 16 h after work shift in an acoustic booth. We had no information about the device used for PTA.

Sample size was calculated considering the mean difference of 15 ms in response time between noise-exposed and non-noise exposed groups (IrgensHansen et al. 2015). Participants were selected by simple sampling method. The workers with at least 1-year work history entered the study. Exclusion criteria were: conductive hearing loss, moderate or severe hearing loss at speech frequencies, known psychiatric diseases, and employment in a second job.

At first, a questionnaire containing demographic data (age, work history, and educational status) was completed for each participant. Then cognitive tests were performed before the work shift begins (at 6 a.m.) and were repeated immediately after termination of the work shift (at 2 p.m.).

Some aspects of cognitive function were assessed and compared between groups. Cognitive function was assessed using a software containing cognitive function tests (Ravan Tajhiz Sina Co., Tehran, Iran) which was used in previous studies (Saremi et al. 2017). Visual attention test (Irgens-Hansen et al. 2015), and Wechsler memory test (Gomes et al. 1990) were used in this study.

The measurements were performed inside the factory in a quiet and undisturbed room. The subjects in each group where guided by an industrial hygienist to consecutively enter the room for cognitive function testing in a systematic pattern (i.e., one from noise group and the other from exposure group) before shift, and after the work shift they were tested in the same order. Each day, eight persons were tested (four from each group). The tests were performed by an occupational medicine resident after a brief explanation for each participant. He was blinded to the study groups and sampling method. The variables which were measured were as following: selective attention score, divided attention score, selective response time, divided response time, and memory scale. The variables were measured and saved in the laptop for each trial.

In visual attention test, the participants were instructed to fixate on the monitor and to press as fast as possible "space" button when the target stimulus appeared on the monitor. In the next test, they were instructed to press "?" button when the target stimulus appeared on the right side and to press "Z" button when the target stimulus appeared on the left side, or to press both buttons simultaneously when both target stimuli appeared at the same time. In Wechsler memory test, the participants were instructed to memorize the digits which were presented in the screen and enter them in the laptop in the order they appeared. Two errors would terminate the test.

Data were analyzed using SPSS (Ver. 16). Kolmogorov–Smirnov test was used to test the normality of variables. Paired *t* test was used for comparing the results before and after shift, and Student's *t* test and Mann–Whitney *U* test were used to compare mean difference of the variables between two groups. $p < 0.05$ was considered as significant.

Results

Totally 164 individuals entered the study (84 in noise and 80 in control group). All participants were males. Table 1 shows demographic data of both groups.

The mean (± SD) of noise exposure was 92.78 ± 5.9 dBA and 74.16 ± 6.2 dBA in the noise and control group, respectively. Table 2 shows hearing thresholds measuring by PTA in both groups.

The results showed that all measured aspects of cognitive functions were significantly decreased after work shift in noise group. Table 3 shows the descriptive information of the aspects of cognitive function in two groups.

The mean difference of the scores of all cognitive variables before and after work shift were significantly higher in the noise group (Table 4).

In addition, in the noise group, 64 individuals (58.7%) were exposed to noise lower than 90 dBA and the remainders were exposed to 90 dBA or higher intensities of noise. Intensity of the noise also affected the loss in all measured aspects of cognitive function except for selective attention. Table 5 compares the mean difference of the scores of cognitive variables before and after work shift in these two groups.

Spearman correlation test showed that in the high exposure group, selective reaction time ($r = -0.36$, $p = 0.001$) and divided reaction time ($r = 0.22$, $p = 0.047$) were the only measures of cognitive function which were significantly correlated with noise intensity. Figure 1 shows the correlation between sound intensity and divided and selective reaction time.

Table 1 Demographic data (mean ± SD) of the individuals in both groups

Variable	Study groups		*p* value
	Noise ($n = 84$)	Control ($n = 80$)	
Age (year)	33.92 ± 7.95	37.62 ± 8.13	0.004
Work history (year)	7.16 ± 6.34	8.37 ± 6.74	0.52

Table 2 Hearing thresholds (dB) at different frequencies in each group

Audiometric frequency (Hz)	Ear	Mean (SD)		*p* value
		Noise	Control	
500	Right	10.14 (1.87)	9.87 (2.4)	NS
	Left	10.02 (0.88)	9.62 (1.37)	
1000	Right	10.49 (2.36)	9.73 (2.78)	NS
	Left	10.46 (2.29)	9.98 (2.99)	
2000	Right	10.80 (4.06)	9.73 (1.69)	NS
	Left	11.08 (4.21)	9.99 (1.87)	
3000	Right	13.02 (6.27)	9.12 (2.69)	S
	Left	13.46 (6.81)	9.23 (2.79)	
4000	Right	16.68 (7.17)	10.29 (3.29)	S
	Left	17.37 (10.62)	10.08 (3.18)	
6000	Right	20.27 (10.03)	11.89 (3.28)	S
	Left	21.12 (10.66)	12.01 (4.12)	
8000	Right	17.45 (6.22)	11.37 (4.23)	S
	Left	17.93 (6.01)	11.23 (4.07)	

Discussion

Many workers in the industrial plants are exposed to high levels of noise which may affect their cognitive function. This study showed that selective and divided RT of industrial workers exposed to noise higher than 85 dBA increased during a work shift significantly more than the workers with exposure to noise intensity lower than 80 dBA. In the same manner, selective and divided attention scores and memory scale were significantly decreased in the noise group after work shift and this decrease was significantly higher than the control group. These changes in cognitive variables were more prominent in those exposed to noise level higher than 90 dBA.

It has been known from many years ago that environmental stimulants affect human cognition (Broadbent 1958). The idea of the effect of noise on cognitive function was first observed in some animal studies, in which noise caused neuronal dendrite alteration (Manikandan et al. 2006), decreased neurogenesis in the hippocampus (Kim et al. 2006), and peroxidation of some regions in the lemniscal ascending auditory pathway, hyperphosphorylation of the hippocampus (Cheng et al. 2011), and impaired neurogenesis in hippocampus (Liu et al. 2016). Liu et al. (2016) found that noise and NIHL independent of oxidative stress impaired spatial memory and spatial learning in mice. Another mechanism of the effect of noise

Table 3 Descriptive statistics of the aspects of cognitive function in two groups before and after exposure

Variable	Time	Study groups			
		Noise		Control	
		Mean ± SD	*p* value	Mean ± SD	*p* value
Selective attention score (%)	BS	95.77 ± 3.97	< 0.001	95.57 ± 3.63	1.00
	AS	91.38 ± 10.11		95.57 ± 4.01	
Divided attention score (%)	BS	75.33 ± 6.26	< 0.001	78.3 ± 6.44	0.56
	AS	72.25 ± 6.15		78.7 ± 6.17	
Selective reaction time (ms)	BS	423.44 ± 42.82	< 0.001	431.04 ± 40.56	0.14
	AS	448.64 ± 49.84		429.26 ± 45.27	
Divided reaction time (ms)	BS	468.60 ± 43.12	< 0.001	456.48 ± 34.57	0.28
	AS	493.77 ± 48.69		459.00 ± 37.16	
Memory scale	BS	5.79 ± 1.47	< 0.001	5.91 ± 1.49	0.38
	AS	4.92 ± 1.42		6.03 ± 1.53	

BS before shift, *AS* after shift

Table 4 Comparison of mean difference of the scores of cognitive variables before and after shift between two groups

Variable	Study groups				*p* value
	Noise		Control		
	Mean ± SD	Mean ranks	Mean ± SD	Mean ranks	
Selective attention	− 4.39 ± 10.15	67.98	0.00 ± 3.53	97.75	< 0.001
Divided attention	− 3.08 ± 2.31	53.90	0.40 ± 2.38	112.53	< 0.001
Selective reaction time	25.20 ± 26.40	104.80	− 1.7 ± 27.39	59.08	< 0.001
Divided reaction time	25.15 ± 19.71	106.95	2.51 ± 21.24	56.83	< 0.001
Memory scale	− 0.86 ± 1.20	65.40	0.12 ± 1.29	100.45	< 0.001

Table 5 Comparison of mean difference of the scores of cognitive variables before and after shift between two exposure groups

Variable	Study groups				*p* value
	Low exposure ($n = 64$)		High exposure ($n = 20$)		
	Mean ± SD	Mean ranks	Mean ± SD	Mean ranks	
Selective attention	− 2.29 ± 7.92	55.93	− 5.02 ± 10.89	53.68	0.71
Divided attention	− 1.42 ± 2.48	66.52	− 3.78 ± 2.32	38.62	0.0003
Selective reaction time	15.37 ± 23.42	48.03	30.28 ± 30.15	64.91	0.006
Divided reaction time	14.62 ± 20.60	47.72	27.66 ± 22.62	65.36	0.004
Memory scale	− 0.39 ± 1.20	61.68	− 1.02 ± 1.31	45.50	0.006

on cognitive function can be attributed to generalized hypervigillance or multiple chemical sensitivity in which affected individuals are more sensitive to the deleterious effects of noise on cognition (Alessandrini et al. 2016; Hollins et al. 2009; Viziano et al. 2017). Viziano et al. (2017) in a study found that sensitivity to noise can be a new aspect of multiple chemical sensitivity syndrome, although Dudek et al. (1991) in their study did not find a relationship between noise sensitivity and cognitive function.

Studies on the effect of noise on cognitive function, especially in industrial settings are few.

Some human studies have proposed deleterious effects of noise on cognitive function and performance (Pawlaczyk-Łuszczyńska et al. 2005; Saeki et al. 2004); although such mental functions as attention or concentration are subject to changes due to many factors, which may lead to controversial results.

Some studies showed a beneficial effect of exposure to noise on cognitive function, although most of such studies

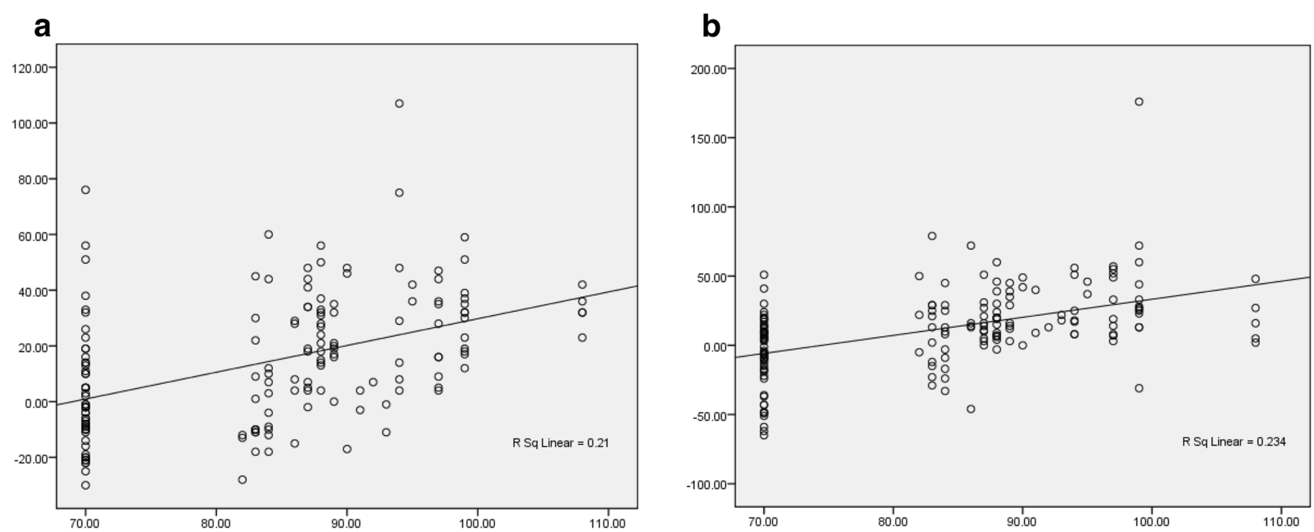

Fig. 1 Correlation between sound intensity (*X* axis) and divided reaction time (**a**), and selective reaction time (**b**) (*Y* axis) among all participants

assessed low-intensity noise. Alimohammadi et al. (2013) found that low frequency noise (intensity 50–70 dBA) increased arousal level of university students, hence increased the accuracy. This effect was observed in another study among inattentive students with opposite effect among attentive students (Söderlund et al. 2010). These results were not consistent with the results of the present study; this inconsistency can be explained by different intensities and durations of noise exposure. Both studies have assessed the effect of noise below 80 dBA with a short duration, but we used noise exposure (more than 85 dBA during an 8-h work shift) in a real occupational setting.

Gomes et al. (1990), consistent with our results, found that high-intensity noise (more than 90 dBA) affected some aspects of cognitive function, i.e., memory and number of errors in employees of aeronautical industry. They used a control group without exposure to this level of noise similar to our study. Similar results were also observed in Irgens-Hansen study among navy personnel. They found that exposure to noise higher than 85 dBA significantly increased the response time compared to those exposed to noise intensity lower than 72 dBA which was completely in agreement with the results of the current study (IrgensHansen et al. 2015).

The method of assessing cognitive function and the cognitive variables which have been assessed in studies are different which may explain the controversial results. Szelma et al. (2011) found that noise affects accuracy, but not speed, which was inconsistent with the results of the current study and the study conducted by Irgens-Hansen et al. (2015), in which both response time and attention were influenced by exposure to noise.

Some studies have proposed the effect of personal characteristics in the effect of noise on performance. Belojevic et al. (2003) found a difference in the effect of noise on cognitive function between extroverted and introverted subjects. In this study we did not collect information about personal characteristics, so we could not assess this effect, and it may be a confounding factor in the current study.

This study showed that the higher the intensity of the noise, the higher loss in cognitive function. This association was specifically observed in reaction time which showed a significant correlation with noise intensity. The higher scores of reaction time in comparison to attention and memory may explain this effect. In addition, the number of subjects in the high exposure group was low ($n = 20$), so increasing the number of the subjects may show the differences better than this study.

This study had some advantages: this was one of the few studies on the effect of noise on cognitive function in industrial settings; in this study we assessed the acute effect of noise on cognitive function across a work shift, and we had a control group as well.

This study had some limitations: It was a cross-sectional study with its inherent limitations; all participants were males; and we could not assess some confounding factors such as personal characteristics; Noise levels which were used in this study were the results of environmental noise monitoring, so data on personal noise exposure were not available.

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Compliance with ethical standards

Ethical statement This study was an occupational medicine residency thesis in Shahid Sadoughi university of medical sciences. We did not have any source of funding. The study has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The study was approved by the ethics committee of the university. An informed consent was obtained from all participants.

Conflict of interest The authors declare that they have no conflict of interest (financial or non-financial).

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