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Study of the Relationship Between Hearing Loss and Cognitive Performance at Chronic Exposure to Noise

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Abstract

Background: Noise is considered as one of the most significant and dangerous physical factors in work environments, and due to the advancement of industries, it has become a threat to physical and psychological health in the current era. In addition to its undesirable effects on the hearing system, noise can have harmful non-auditory effects that may cause physiological disorders and cognitive impairment.
Objectives: This study aimed to investigate the relationship between hearing loss and workers' cognitive performance in an industrial environment.
Methods: A total of 300 individuals were enrolled in this study after their informed consent was obtained, and their compliance with the inclusion and exclusion criteria was confirmed. Based on the sound intensity level, the individuals were classified into two groups of exposure to > 85 dB (n = 196) and ≤ 85 dB (n = 104). To measure the individuals' occupational exposure at an 8-hour equivalent level based on the ISO 9612: 2009 standard, the Testo device (Model CEL-815) was used with the precision of 0.5 dB. The most common weighting that is used in noise measurement is A-weighting. Like the human ear, this effectively cuts off the lower and higher frequencies that the average person cannot hear. The DANPLEX-AS54 device was also used to check audiometry. To investigate the workers' hearing performance, two psychological tests, namely Stroop and TOL, were used as well.
Results: Hearing loss was higher among workers exposed to a sound intensity level of > 85 dB than those exposed to a sound intensity level of ≤ 85 dB, and this difference was significant in all sound level frequencies (NIHL left ear: for ≤ 85 dB: 25.92 and for > 85 dB: 27.49) (NIHL right ear: for ≤ 85 dB: 27.62 and for > 85 dB: 29.50) (P value < 0.05). The results showed a significant positive relationship between cognitive indicators and hearing loss (P value < 0.05). Moreover, the study of cognitive indicators in the two groups revealed that the mean change of cognitive performance indicators was higher among subjects exposed to a higher sound intensity level (P value < 0.05).
Conclusions: The results of this study showed that noise-induced hearing loss in work environments had a significant positive relationship with cognitive indicators. In other words, an increase in the hearing loss level would result in changes in cognitive indicators such as number of errors and response time.

Keywords: Hearing Loss, Cognitive Science, Occupational Exposure, Noise, Industrial, Stroop Test

1. Background

Noise, as one of the most significant and dangerous physical factors in work environments, has become a threat to physical and psychological health in the current age due to the advancement of industries (1, 2). In addition to its negative effects on the hearing system, noise can have harmful non-auditory effects that may cause physiological disorders and cognitive impairment (3). It has been generally accepted that exposure to a sound intensity level of > 65 dB may be detrimental to health (4). Noise-induced hearing impairment is a direct consequence of the effects of sound energy in the inner ear, and exposure to a sound intensity level between 85 - 90 dB, especially during industrial life, will lead to progressive hearing loss, accompanied by an increase in the hearing sensitivity threshold. Sound may apply its effects directly through synaptic activities or indirectly through emotional, cognitive, and perceptual ones (i.e., exposure to sound may affect nerves and glands) (5). Noise-induced hearing loss (NIHL) is also a kind of permanent sensory hearing loss due to exposure to high levels of sound or acoustic shock (6). Work environment noise or occupational noise is considered as the most significant cause of NIHL (7), the extent of which depends on factors such as sound intensity level, duration of daily exposure to noise, and working experience in noisy environments. In the case of repeated exposure, hearing impairment may become permanent and lead to a permanent change in the hearing threshold (8). The effect of hearing loss is often observed as a defect in processing and speech comprehension (9). Although in some studies, the ability to understand speech was attributed to hearing loss (9), others considered it beyond changes in the hearing threshold (10). The effects of hearing loss on high-level cognitive functions such as attention and memory appear in processing and understanding of verbal information (11-13). Therefore, hearing loss affects the quality of life, and in most people, it has psychological, physical, and social consequences that gradually worsen with the progress of hearing loss (14). New medical research at the American Association for the Advancement of Science (AAAS) showed that hearing loss could cause dementia (15), accounting for about 36% of the cases (7). Moreover, people with hearing loss are 30% to 40% more likely to suffer from cognitive decline compared to those without hearing loss (7). Hearing loss not only makes it difficult to hear sound clearly, but also highly affects cognitive performance. In particular, it impairs the listener's accuracy of information processing and auditory comprehension (16). Evidence from various studies well indicates that noise-induced hearing loss in industrial environments is associated with significant changes in workers' cognitive and mental indices so that their attention, concentration, and memory change (3). Changes in the cognitive performance of individuals may lead to an increased risk of occupational and systematic errors in the long run, which can threaten the lives of individuals in such environments (4). In their study of the effects of sound exposure on cognitive performance, Jafari et al. (17) showed that visual/ auditory attention, as well as brain function, significantly decreased in people exposed to a sound intensity level of 95 dB. Further, Taljaard et al. (18) showed in their study that hearing impairment was significantly associated with people's mental functions. Similarly, Ali Mohammadi et al. (19) observed a significant relationship between hearing loss and mental health and functions. In work environments, workers are prone to systematic errors as a result of reduced cognitive performance in chronic exposure to noise and subsequent annoyances that can, directly and indirectly, affect their quality of life and organizational performance.

2. Objectives

However, given the lack of evidence on the relationship between hearing loss and cognitive functions of workers in chronic exposure to noise, this study aimed to investigate the relationship between hearing loss and cognitive functions in chronic exposure to noise in an automotive manufacturing plant.

3. Methods

The presents descriptive-analytical study was conducted on people working in the automotive industry in Tehran in 2018. After obtaining their informed consent, workers meeting the inclusion criteria, including chronic exposure to noise and being over 18 years of age, entered the study. The exclusion criteria were as follows: a history of systemic diseases such as diabetes and thyroid disorder, a history of taking ototoxic drugs, a history of severe or recurrent ear infections, a history of noise exposure in the second or previous job, exposure to organic solvents, a history of severe head injury, and having less than one year of work experience. The final sample size was calculated to be about 300 using the sample size determination formula for comparing the means in the two independent populations by considering $\alpha = 0.05$, $\beta = 0.2$, and 10% loss.

$$n = \frac{\left(Z_{1-\alpha/2} + Z_{1-\beta}\right)^2 \times \left(\sigma_1^2 + \sigma_2^2\right)}{\left(\bar{X}_1 - \bar{X}_2\right)^2} \tag{1}$$

The selected participants were divided into two groups based on exposure to noise: the first group included individuals exposed to a noise level of ≤ 85 dB (n = 196) and the second group included those exposed to a noise level of > 85 dB (n = 104). The hearing loss rate and cognitive performance in each group were assessed separately. Moreover, all the experiments were conducted according to the Ethics Committee of Iran University of Medical Sciences (ethics code: IR.IUMS.REC1395.9411139003).

Measuring the sound pressure level in the work environment indicated that the workers' exposure level was 80 dB to 89 dB. To measure the individuals' exposure at an 8-hour equivalent level (Equation 2) based on the ISO 9612: 2009 standard, the Testo device (Model CEL-815) with a precision of 0.5 dB and measurement in Network A was used. The most common weighting that is used in noise measurement is A-Weighting. Like the human ear, this effectively cuts off the lower and higher frequencies that the average person cannot hear. The sound pressure level was obtained through the following procedure: sound pressure levels in the workplace were measured in all the work stations within three working days, and the mean sound pressure at each station was calculated for the three days. At the beginning of the study, the informed consent of all the subjects was obtained, and those willing to continue the study were subjected to psychological tests. The hearing level of individuals willing to participate in the study was measured using a DANPLEX-AS54 audiometry device (previously calibrated).

$$L_{Epd}\,(dB) = 10\,log\lfloor \frac{1}{8}\sum_{1}^{n} t_i 10^{SPL/10} \rfloor \quad (2)$$

Before entering the workplace and starting the work shift, the subjects were tested for eight standard frequencies ranging from 250 to 8000 in an acoustic room. The tonal test (air-conduction) was used to perform auditory measurements. In this study, data derived from the audiogram curves for both the left and right ears in both groups at all the frequencies as well as the mean hearing threshold at low frequency (HTL-L) and high frequency (HTL-H) were calculated and recorded, and all the information from this stage was recorded in a questionnaire designed to conduct the study. Moreover, to measure hearing loss in the left ear, right ear, and both ears, the two following equations were used (Equations 3 To examine the cognitive performance, the Stroop and Tower of London (TOL) tests were applied. The criteria for choosing these tests were their suitable validity and reliability, provision of appropriate results in terms of accuracy, attention, and intellectual flexibility compared to other software, and frequent use in previous related studies.

$$NIHL = \frac{(TL_{500\ Hz+}\,TL_{1000\ Hz+}\,TL_{2000\ Hz+}\,TL_{4000\ Hz})}{4} \quad (3)$$

$$NIHL_t = \frac{(NIHL_b \times 5) + (NIHL_w)}{6} \quad (4)$$

b, better; w, weak.

3.1. Stroop Test

The computerized Stroop test was first designed by Ridley Stroop in 1935 to evaluate selective attention and cognitive flexibility (20). The test consists of two stages, the first of which asks the subject to press a button corresponding to the color of a circle on the screen (the circle is shown in four colors: red, blue, yellow, and green). The aim of this stage is to do the mock test, and it will not affect the final result. In the second stage, which is the implementation of the test, 48 congruent colored words as well as 48 incongruent ones which are red, blue, yellow, and green, are shown to the subject sequentially and randomly (Figure 1). The congruent words refer to the uniformity of the colors of a word and its meaning, and the incongruent words are those with different colors for each word and its meaning. The subjects are asked to determine only the apparent color of each word regardless of its meaning. This test measures mental flexibility and response inhibition. Various studies have reported the validity of 0.83% for this test (21).

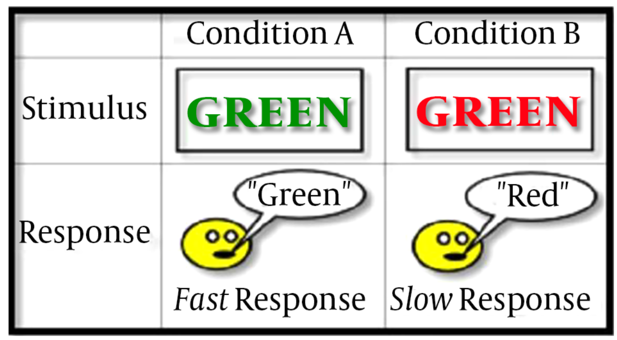

Figure 1. The computerized Stroop test

3.2. Tower of London Test

This test was first designed by Shallice in 1982, and is one of the key tools for measuring brain function, planning, and organizing. Since it is a computer-based test, it has many advantages, including accurate implementation, accurate measurement of results including number of right and wrong answers, and accurate timing of the stages. The aim of this test is to investigate whether the subject uses their maximum ability and quickly achieves the best result. The examiner explained to the subjects that it was a problem-solving test, in which the subjects needed to move colored balls (green, blue, and red) and put them in the right place, with minimum necessary movements. A board with three pillars of different sizes and three colored balls was provided to each subject (Figure 2). The initial and final shapes to be made were verbally presented to each subject with visual description. It was explained that only one ball could be moved in each movement and no ball could be removed from the board. All the participants successfully completed three experimental puzzles before doing the real experimental test. They were then given twelve Questions, as in the example, and they had to make shapes with minimum necessary movements. The reliability of this test was reported by 0.79% (21).

In this study, descriptive-analytical methods (central tendencies such as mean and standard deviation) were used to analyze the data. The normalization of the data was confirmed through the use of the Kolmogorov-Smirnov

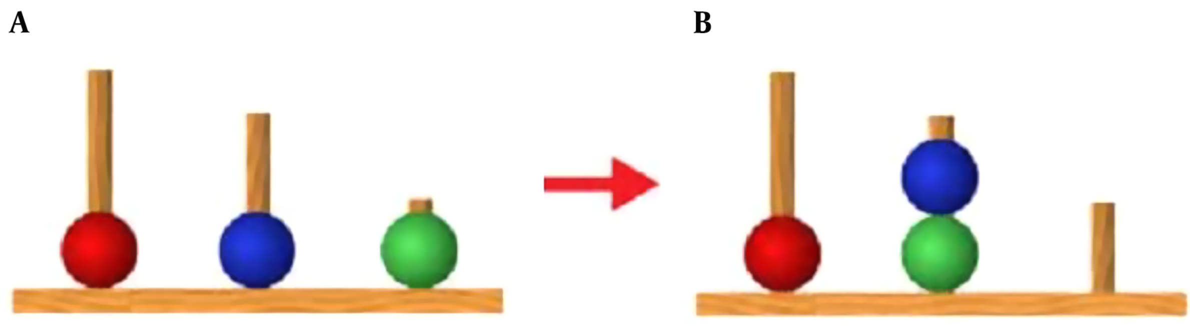

Figure 2. The Tower of London test

test. Given the data normalization, the Pearson correlation coefficient and the independent *t*-test were used. The data were analyzed using the SPSS software (version 22), and all the tests were carried out at 95% confidence level.

4. Results

In the present study, the mean age of subjects was 35.92 years ($\pm$ 3.81) in the group exposed to a > 85 dB sound intensity level and 36.23 years ($\pm$ 3.78) in the group exposed to an $\leq$ 85 dB sound intensity level. There was no statistically significant difference between the mean ages of the two groups (P value = 0.505). The mean work experiences in the two groups were 15.08 ($\pm$ 1.98) and 14.79 ($\pm$ 2.09) years, respectively, which had no statistically significant difference and did not have any effects on the results (P value = 0.242). Most of the subjects had a high school diploma [n = 217 (72.3%)], and there was a significant relationship between the two groups in terms of educational levels. In other words, education was a factor affecting the study results, especially in the cognitive testing stage (P value < 0.001). Based on the statistical methods, marital status also influenced the study results (P value < 0.05). Table 1 shows the demographic data of the subjects in terms of exposure to noise.

As shown in Table 2, the results of the independent t-test carried out to investigate the relationship between hearing loss in the two groups (85 < and 85 $\geq$) indicated that hearing loss was more severe in people exposed to a > 85 dB sound intensity level than in the other group (P value < 0.05). The results also revealed a significant relationship between the right and left ears in terms of NIHL and total NIHL (P value < 0.05) (Table 2).

The Pearson coefficient showed a significant relationship between the total noise-induced hearing loss (NIHL T) and the cognitive performance indicators in the TOL test in terms of the following indicators: test time (time needed for the study), test delay (time wasted during problem-solving), total time (sum of test time and test delay), and mean number of errors (number of problems with incorrect solutions) (P value < 0.001). The Stroop test showed a significant relationship between the groups in terms of mean number of errors, mean non-response, and mean number of correct responses. In the Stroop test, no significant difference was observed between the mean interference score (the difference between correct responses at the congruent/incongruent stage) and interference time (reaction time difference between the congruent/incongruent stage) (P value = 0.418 and P value = 0.130) (Table 3). Figure 1 shows the relationship between the two groups in terms of NIHL T (85 < and 85 $\geq$) (Figure 3).

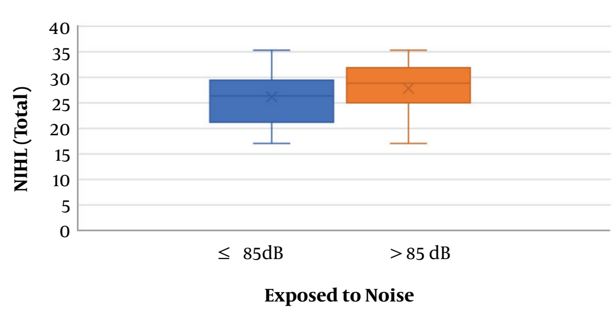

Figure 3. Comparison between the two exposed groups in terms of total hearing loss

According to the independent *t*-test, there was a significant difference between both groups in terms of all cognitive indicators except for the test score (TOL final score based on the number of errors) and the mean interference score in the TOL and Stroop tests (85 < and 85 $\geq$) (P value < 0.001) (Table 4).

Table 1. The Demographic Information of the Workers Based on Exposure to Noise[a]

	L_{epd}		Total	t	χ^2	P Value
	≤ 85	> 85				
Age, y	36.23 ± 3.78	35.92 ± 3.81	36.03 ± 3.79	0.668		0.505
Experience, y	14.79 ± 2.09	15.08 ± 1.98	14.98 ± 2.02	1.17		0.242
Education					17.08	< 0.001
Diploma	60 (20)	157 (52.3)	217 (72.3)			
Associate degree	32 (10.7)	29 (9.7)	61 (20.3)			
Bachelor's degree and more	12 (4)	10 (3.3)	22 (7.3)			
Marital status					11.81	0.001
Single	14 (4.7)	6 (2)	20 (6.7)			
Married	90 (30)	190 (63.3)	280 (93.3)			

[a]Values are expressed as No. (%) or mean ± SD.

Table 2. Comparison of the Workers' Hearing Loss Based on Exposure to Noise Using the Independent *t*-test[a]

	Sound Frequency	L_{Epd}		P Value	t
		≤ 85	> 85		
Left ear	250	16.49 ± 2.49	18.19 ± 4.59	0.004	2.90
	500	15.77 ± 4.68	17.38 ± 4.49	0.007	2.74
	1000	25.42 ± 0.75	26.96 ± 4.56	0.007	2.70
	2000	31.04 ± 4.42	32.89 ± 4.99	0.002	3.06
	3000	36.94 ± 7.71	38.87 ± 5.13	0.002	3.11
	4000	31.47 ± 4.79	32.77 ± 3.45	0.002	3.06
	6000	27.47 ± 3.83	28.77 ± 3.45	0.003	3.07
	8000	23.32 ± 3.76	24.68 ± 3.67	0.003	2.97
	NIHL	25.92 ± 4.30	27.49 ± 4.20	0.003	3.03
Right ear	250	17.70 ± 6.21	19.75 ± 5.52	0.004	2.92
	500	17.21 ± 6.06	19.20 ± 5.58	0.005	2.78
	1000	28.05 ± 4.74	29.56 ± 4.61	0.009	2.65
	2000	35.45 ± 6.31	37.44 ± 5.60	0.005	2.80
	3000	40.79 ± 7.95	43.28 ± 7.28	0.009	2.65
	4000	29.78 ± 5.98	31.81 ± 5.65	0.005	2.85
	6000	28.21 ± 3.83	29.48 ± 3.65	0.006	2.77
	8000	22.84 ± 3.76	24.04 ± 3.45	0.007	2.71
	NIHL	27.62 ± 5.72	29.50 ± 5.32	0.006	2.77
Total	NIHL[b]	26.15 ± 4.61	27.79 ± 4.44	0.003	2.96

[a]Values are expressed as mean ± SD.
[b]Noise-induced hearing loss.

5. Discussion

The results of this study clearly showed the positive and significant effect of hearing loss on the cognitive performance of individuals exposed to chronic noise.

Other similar studies clearly showed that increased exposure to noise was associated with increased speed and action of mental functions, as the results of the TOL and Stroop tests also showed in the present study. Moreover,

Table 3. The Relationship Between Cognitive Indicators and Total Hearing Loss Using the Pearson Coefficient[a]

	Cognitive Performance Indicators	Values	Pearson Correlation	P Value
TOL	Test time, s	200.55 ± 100.70	0.205[b]	< 0.001
	Test delay, s	77.42 ± 35.13	0.123[c]	0.034
	Total time, s	277.98 ± 118.12	0.211[b]	< 0.001
	Mean number of errors	6.11 ± 3.55	0.203[b]	< 0.001
	Test score	26.85 ± 3.30	0.036	0.538
STROOP congruent	Test time, s	57.03 ± 7.88	0.036	0.280
	Mean number of errors	5.44 ± 2.41	0.191[b]	0.001
	Mean non-response	3.15 ± 1.28	0.132[c]	0.022
	Mean number of correct responses	39.42 ± 3.55	-0.177[b]	0.002
	Response time, ms	1244.57 ± 73.07	0.105	0.07
STROOP incongruent	Test time, s	66.82 ± 5.41	-0.071	0.218
	Mean number of errors	6.44 ± 2.41	0.191[b]	0.001
	Median non-response	4.15 ± 1.28	0.132[c]	0.022
	Mean number of correct responses	37.42 ± 3.55	-0.177[b]	0.002
	Response time, ms	1420.46 ± 70.59	0.018	0.761
	Mean interference score	3.69 ± 2.17	-0.047	0.418
	Interference time, s	178.26 ± 92.77	-0.088	0.130

[a]Values are expressed as mean ± SD.
[b]Correlation is significant at the 0.01 level.
[c]Correlation is significant at the 0.05 level.

there was a strong dose-response relationship between exposure to noise and increased hearing loss and mental dysfunction, which could interact with other factors and individual characteristics in the long run to increase work errors. In addition, the role of high- and low-frequency sounds and increased chronic exposure to noise in increasing hearing sensitivity and mental activity has been well demonstrated. This can lead to physiological changes such as high blood pressure and psychiatric problems such as aggression (22, 23). The results of this study also indicated an increase in the speed of brain activities of workers exposed to noise, which was caused by hearing loss. This is consistent with the results of other related studies (24-27).

In their study, Taljaard et al. (18) clearly identified that damage to the auditory system resulting from exposure to noise that caused hearing loss could increase the risk of cognitive diseases such as dementia. This confirms the results of the present study in terms of the impact of chronic exposure to noise in work environments on increased hearing loss and changes in cognitive performance. On the other hand, hearing loss can affect other brain activities, as shown by Peelle et al. (21) and Choi et al. (28) in their studies. They suggested that hearing loss affected the neuro-brain system, which is related to speech. Moreover, a study by Alimohammadi et al. (29) on the effects of noise annoyance on cognitive function showed a significant relationship between noise annoyance and cognitive function of workers chronically exposed to noise. The researchers also indicated that noise annoyance was associated with reduced mental performance of the workers, resulting in an increased risk of job errors.

Reed (22) studied cognitive effects of hearing loss in adults and stated that hearing loss caused mental and cognitive changes and altered the quality of life and communications. All these factors decreased social activities, which is in line with the results of the present study on the effect of noise-induced hearing loss on the workers' cognitive performance. In other words, increased exposure to noise in the work environment would lead to increased hearing loss, followed by an acceleration of mental functions and brain activities. Hence, accelerated brain activities, along with other interacting factors such as a history of smoking, would increase the risk of errors in the workplace (30).

Zheng et al. (31) carried out a study on mental consequences of hearing loss and suggested that hearing loss could increase the risk of cognitive diseases, which is con-

Table 4. Comparison of Cognitive Indicators in the Two Groups of Exposure to Noise[a]

	Cognitive Performance Indicators	L_{Epd}		P Value	t
		≤ 85	> 85		
TOL	Test time, s	100.28 ± 50.96	253.77 ± 77.26	< 0.001	18.25
	Test delay, s	55.95 ± 20.69	88.81 ± 35.91	< 0.001	8.6
	Total time, s	156.23 ± 50.56	342.58 ± 89.11	< 0.001	19.69
	Mean number of errors	2.42 ± 1.30	8.07 ± 2.71	< 0.001	20.05
	Test score	27.08 ± 3.47	26.42 ± 2.85	0.082	1.74
STROOP Congruent	Test time, s	55.11 ± 9.46	58.05 ± 6.71	0.002	3.12
	Mean number of errors	2.95 ± 0.85	6.76 ± 1.86	< 0.001	19.69
	Mean non-response	2.14 ± 1.2	3.68 ± 0.837	< 0.001	12.02
	Mean number of correct responses	42.9 ± 2.18	37.57 ± 2.62	< 0.001	18.77
	Response time, ms[b]	1208.40 ± 88.85	1263.76 ± 55.9	< 0.001	6.68
STROOP Incongruent	Test, s	67.93 ± 5.73	66.23 ± 5.14	0.012	2.52
	Mean number of errors	3.95 ± 0.85	7.76 ± 1.86	0.012	19.69
	Median non-response	3.14 ± 1.36	4.68 ± 0.837	< 0.001	12.06
	Mean number of correct responses	40.90 ± 2.18	35.57 ± 2.62	< 0.001	18.77
	Response time, ms	1436.01 ± 61.26	1412.21 ± 77.8	0.005	2.81
	Mean interference score	3.59 ± 1.86	3.74 ± 2.32	0.552	0.599
	Interference time, s	227.61 ± 96.72	152.08 ± 79.16	< 0.001	7.26

[a]Values are expressed as mean ± SD.
[b]Millisecond.

sistent with the results of the current study on the increased hearing loss on mental performance of the workers with hearing loss. Similarly, Lin et al. (13) suggested that there was an inverse relationship between hearing loss and mental functions so that the increase in hearing loss led to a significant decrease in individuals' mental performance. This is inconsistent with the results of the present study, which might be due to the lower age of the workers in this study that significantly reduced the confounding effects of age. Yuan (30), demonstrated in his study that age was a risk factor for increased hearing loss that was associated with increased damage to mental functions and an increased risk of mental disorders. In the present study, there was no difference between the two groups in terms of the mean age. Therefore, the results clearly showed the effects of hearing loss on the cognitive performance of the workers, regardless of age effects.

One limitation of the current study was the lack of examination of the relationship between hearing loss and cognitive performance among men and women. Given the nature of the work spaces in this study, it was not feasible to access females, and it needs to be addressed later.

The results of this study showed that hearing loss was significantly higher in subjects exposed to a > 85 dB sound intensity level than in those exposed to ≤ 85 dB sound intensity level. It was also found out that noise-induced hearing loss in the work environment had a significant positive relationship with the subjects' cognitive indicators. Moreover, cognitive indicators had a significant difference with respect to the sound intensity level groups (> 85 dB and ≤ 85 dB), showing that noise affected the workers' mental performance both directly and indirectly.

Footnotes

Authors' Contribution: Study concept and design: FAK and IA. Analysis and interpretation of data: KR and JA. Drafting of the manuscript: SHV. Critical revision of the manuscript for important intellectual content: FAK, MHC, and IA. Statistical analysis: JA.

Conflict of Interests: All the authors have no potential conflicts of interest in this submission clinical trial registration.

Ethical Approval: The ethical approval code was IR.IUMS.REC 1395.9411139003.

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