Original Article

Journal of Iranian Medical Council, Volume 8, Issue no. 3
http://dx.doi.org/10.18502/jimc.v8i3.18796

Investigating the Central Auditory Processing Damage Caused by Industrial Noise

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Received: 6 Jul 2024
Accepted: 12 Oct 2024

Citation to this article
Emami SF, Shariatpanahi E, Shahtaheri SMM. Investigating the Central Auditory Processing Damage Caused by Industrial Noise. *J Iran Med Counc*. 2025;8(3):518-26.

Abstract

Background: The Word-In-Noise Perception test (WINP) is a new assessment that assesses the auditory brain function by recognizing speech consonants. The Dichotic Digits Test (DDT) measures the directional superiority of the temporal cortex and brainstem function based on the ability to recognize the tonality of words. So far, the performance of the central auditory processing of industrial personnel has not been investigated by referring to the WINP test. The aim was investigating Central Auditory Processing Damage (CAPD) caused by industrial noise.

Methods: This case-control study was conducted in a cross-sectional-comparative way on 69 industrial personnel aged 25-40. The case (n=39) and the control (n=30) groups were evaluated by audiological tests, WINP and DDT.

Results: The participants were divided into three groups based on their hearing status: 60 normal ears in the control group, 37 normal ears and 41 abnormal ears in the case group. Mean scores of WINP and DDT in three groups were significantly different from each other (right ear: p'WINP=0.01, p'DDT=0.02 and left ear: p'WINP=0.01, p'DDT=0.01). The mean scores of WINP and DDT in the abnormal ears of the case group were significant compared to the normal ears of the control group (right ear: p'WINP <0.001, p'DDT <0.001 and left ear: p'WINP =0.02, p'DDT=0.02).

Conclusion: In industrial personnel with a history of continuous exposure to noise pollution, there is a possibility of damage to the brainstem and auditory brain functions.

Keywords: Auditory brain, Brainstem, Noise, Perception

Introduction

A normal baby at birth has 12,000 outer hair cells and 4,000 inner hair cells in the cochlea. If these cells are destroyed by pathogens or loud noises, they are unable to reproduce and permanent acquired hearing loss occurs, which may develop from the fetal period (1). Individual susceptibility plays a significant role in the incidence of Noise-Induced Hearing Loss (NIHL) and is caused by several factors. For example, blue-eyed individuals tend to be more vulnerable to NIHL than black and brown-eyes, or white people are more vulnerable than blacks (2). Men are also more likely to suffer from NIHL than women. Also, increasing age and the occurrence of senility reduces a person's resistance to noise pollution (3). There are other predisposing factors: cardiovascular disorders and high blood pressure, nervous tension (2), abnormal increase in blood fat and urea, alcohol consumption and pollution with chemicals, lack of oxygen and presence in closed and polluted or hot and humid spaces that cause dilatation of surface vessels and decrease in blood flow (4).

Long-term use of cigarettes, which causes a decrease in blood oxygen levels (5) and an increase in carbon monoxide (2), can aggravate the damage to hearing ciliated cells and hearing loss in high frequencies (1). But, at the same time, since it causes the blood vessels of the inner ear to contract, it reduces the vulnerability caused by sound (6).

Children, whose classroom is near the street or close to the airport and industrial places have weaker reading ability than the children who study in quiet places. In fact, the noise of the environment causes children to not hear the teacher's voice well in the classroom (1). If a child with mild hearing loss is present in this type of class, he/she will suffer academic loss due to cognitive disorders and may even have a delay of one to two years in learning language and speech skills (2,7). However, proximity in noisy environments also has advantages, sine it causes plasticity and changes the shape of the auditory system and makes it resistant to noise-induced hearing loss. If the auditory system is exposed to loud sounds for a while, it will be prepared for the sound and the amount of damage will be reduced (7).

Exposure to loud sounds can also cause Central Auditory Processing Disorder (CAPD). In a number of patients with CAPD, hearing thresholds are normal, and in some there is some degree of hearing loss (1,2), which is accompanied by other symptoms as follows; impaired speech-in-noise perception, poor listening skills, impaired orientation of sounds, poor learning of foreign languages and specialized terms (8), constant request to repeat content, difficulty in processing fast speech, delay in answering questions (7), inability in understanding speech reverberation, quick distraction by external stimuli, weakness in executing verbal commands and poor ability to perceive music (9). Since CAPD is not detected by magnetic resonance imaging and computed tomography scan, some experts do not accept it as a specific lesion (8). In general, the diagnosis of this lesion, which has nothing to do with the IQ, is possible through audiological tests (10). There is no definitive treatment for CAPD after the age of 15, but by creating a series of communication facilitating factors, the issues associated with affected patients can be reduced (9,10), which include the use of simple words by the talker, speaking in quiet environments (1), face-to-face conversation with the affected person, using hearing aids, lip reading, speech therapy and neurofeed BAck to improve pronunciation, writing problems and strengthen the affected person's memory (7,9).

Concomitant stress and noise pollution can increase the risk of CAPD (10). Those who listen to sad songs are affected by the stress caused by the semantic content of the song, which exacerbates the development of CAPD in them (8). Consumption of antioxidants plays a significant role in preventing NIHL and CAPD (2). Thus, the aim was to investigate CAPD caused by industrial noise.

Materials and Methods

Setting

This case-control study was conducted in a cross-sectional-comparative way. Its location was one of the industrial units of Hamadan, Iran.

The inclusion criteria were being monolingual (Persian), no self-reported speech, voice, language, and swallowing disorders, no history of underlying diseases, not using drugs that modulate the immune system, corticosteroids, anticonvulsants and sedatives.

The exclusion criteria were reluctance to continue cooperation in the project, suffering from ear infection, history of ototoxic drugs, ear surgery, suffering from ear diseases, rheumatological, vasculitis, acoustic neuroma and known neurological disorders, smoking and drug addiction.

The participants included 69 industrial personnel. The case group (n=39) included young men 25 to 40 years (33.07±5.89) and had a history of noise exposure of 6 months or more. The selection of this age group was to eliminate the hearing loss caused by aging (presbycusis), which is usually more likely to occur after the age of 40 (3). The control group (n=30) was matched with the case group in terms of age, sex, and level of education. It comprised the personnel of the administrative department of the same industrial unit who had no history of exposure to loud noises. The work shift of both groups was 8 *hr* a day, with two rest periods. Also, insert ear plugs were prepared for all industrial personnel by the managers of that industrial unit and distributed among them.

Ethical considerations

In this research, the privacy and security of the participants was a priority and their evaluations were completely free.

Practical work

The practical work place was one of the rooms of the office unit, where the noise level of the industrial unit was equal to 33 *dBA*, based on the evaluation of the occupational health expert. Before starting the practical work, the background noise level of the chosen industrial unit was also determined by occupational health expert who reported that the background noise level in all sections is between 90 and 97 *dBA*; considering that prolonged exposure to loud noises (75 *dBA*) over eight hours a day for years can lead to hearing loss (1).

After explaining the research process and obtaining written consent from all the participants, they were subjected to otoscopic examination to observe the tympanic membrane and external auditory canal. Then, they were evaluated by general audiological tests, which were pure tone audiometry (using SA78 model screening, made by PEJVAK AVA company, Iran), also WINP and Dichotic Digits Test (DDT).

WINP

WINP was performed with 25-word lists available in the audiology department of Hamadan University of Medical Sciences (Appendix 1) It was conducted at the comfortable listening level of the participants and using recorded woman's voice, which was provided through a high-quality headphone connected to the computer. Each ear was examined separately. The participants were asked to respond quickly. The presentation interval between two words was 2000 *ms*. If there was no response, the next trial was automatically initiated 2000 *ms* after the last word was played. The intertrial interval of each list was 1000 *ms*. In other words, after presenting the last word in each 25-word list, there was a pause of 1000 *ms*, and the first word from the second 25-word list was presented after 3000 *ms*. To calculate the WINP score, the number of words that the participants repeated correctly was multiplied by 4 and the score was calculated out of 100.

DDT

In the next step, the two groups were evaluated by DDT and at the comfortable listening level, which was done binaurally (auditory stimulation was presented to both ears simultaneously). The stimuli were monosyllabic numbers (1-3,5-9) that were recorded with the voice of a female speaker and were installed as a speaker on a laptop computer as in the WINP. Each stimulus consisted of 4 numbers (2 numbers simultaneously to the right ear and 2 numbers to the left ear). The participants were asked to repeat the numbers heard in one ear (test-ear) and not pay attention to the opposite ear (non-test).

Data analysis

The analysis software was SPSS17. Kolmogorov-Smirnov and Shapiro-Wilk descriptive testes were used to check the normal distribution of variables. Kruskal-Wallis test was utilized to compare two or more independent samples with similar or different sample sizes. Chi-square test was used to examine the relationship between two categorical variables. Independent t-test was also used to compare the mean of two samples from unrelated groups. All statistical analyses were performed at a significance level of 0.05.

Appendix 1. Lists of phonetically balanced monosyllabic words of Iranian Persian language with the arrangement of homotonic-monosyllabic words for word-in-noise perception test, based on the Iranian Persian international transliteration alphabet [1]

n	Vowel / e /	Vowel / o /	Vowel / i: /	Vowel / ɒ: /	Vowel / æ /	Vowel / u: /
	Σen	Σol	Si:b	Kɒ:r	Sær	gu:ʃ
	Sen	Pol	Σi:b	Bɒ:r	Dær	Mu:ʃ
	Dʒen	gol	Dʒi:b	Mɒ:r	Kær	Du:ʃ
	gel	Kol	Si:r	Qɒ:r	Σær	Nu:ʃ
	Del	Khol	Pi:r	Zɒ:r	Pær	Hu:ʃ
	Hel	Qom	Di:r	Jɒ:r	Sær	Dʒu:ʃ
	Sel	gom	Σi:r	Hɒ:r	Xær	Tʃu:b
	Vel	Xom	Qi:r	Dɒ:r	Nær	Mu:r
	Ʒel	Dom	Zi:r	Nɒ:r	Tær	Σu:r
	Beh	Som	Dʒi:r	Sɒ:r	gær	Su:r
	Meh	Σok	Mi:r	Xɒ:l	Sæm	Du:r
	Deh	Nok	Ti:r	Sɒ:l	Næm	Zu:r
	Leh	Σod	Mi:ʃ	Mɒ:l	Xæm	Ku:r
	Deq	Xod	Ni:ʃ	Bɒ:l	Gæm	Dʒu:r
	Neq	Por	Pi:ʃ	Zɒ:l	Dæm	Nu:r
	Nej	Sor	Ki:ʃ	Kɒ:l	Bæm	Bu:r
	Dej	Σor	Bi:ʃ	Σɒ:l	Kæm	Tu:r
	Keʃ	Lor	Fi:l	Tʃɒ:l	Qæm	Du:d
	Σeʃ	Lop	Mi:l	Nɒ:m	Jæx	Su:d
	Fer	Boz	Bi:l	Σɒ:m	Σæb	Ru:d
	Qer	Hoz	Si:x	Dɒ:m	Tæb	Ku:d
	Kez	Moz	Mi:x	Dʒɒ:m	Læb	Bu:d
	Vez	Motʃ	Ni:m	Kɒ:m	Σæk	Zu:d
	Mes	Xoʃ	Bi:m	Vɒ:m	Tæk	Bu:q
	Hes	Σoʃ	Si:m	Rɒ:m	Sæg	Du:q

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Results

None of the participants were abnormal in the otoscopy examination and all of them met the conditions for entering the study. The difference in the mean mental health (GHQ28) and level of education between the two groups of case and control was not significant (Tables 1 and 2).

Based on the results of the pure tone audiometry test (hearing status), the case group was divided into two groups: normal ears (n=37) and abnormal ears (n=41). The control group consisted of the participants with ears with normal hearing thresholds (n=60). In 39 participants from the case group (left ear=39 and right ear=39), 16 had bilateral (left ear=16 and right ear=16) and 9 unilateral (left ear=0 and right ear= 9) mild sensorineural hearing loss (25 to 40 *dBHL*)

Table 1. Demographic information of the case (n=39) and the control (n=30) groups, according to ear (L= Left, R= Right)

Variable	Normal ears (case group)			Abnormal ears (case group)			Normal ears (control group)			
	n	Median	IQR	n	Median	IQR	n	Median	IQR	p *
Age L	23	29.48	10.67	16	36.92	9.11	30	34.17	10.23	0.653 *
Age R	14	28.59	9.81	25	38.09	8.99	30	33.93	9.80	-
GHQ28 score L	23	13.84	11.48	16	14.32	12.58	30	10.00	12.92	0.290 *
GHQ28 score R	14	12.93	12.80	25	13.90	11.60	30	11.03	11.49	-
History of working L	23	9.23	14.88	16	11.49	14.37	-	-	-	0.476 *
History of working R	14	10.18	15.21	25	12.02	13.75	-	-	-	-

* Kruskal Wallis Test.

Table 2. Level of education of all the participants (n=69)

Variable	Normal ears (case group)		Abnormal ears (case group)		Normal ears (control group)		Total		
	n	%	n	%	n	%	n	%	*p'
Diploma	15	65.20	8	50.00	5	33.30	28	51.1	0.005
Advanced diploma	3	13.00	3	18.80	0	6.70	6	11.1	-
Bachelor	3	13.00	4	25.00	1	0.00	8	14.8	-
Master	2	2.00	1	6.30	9	60.00	12	22.2	-
Total	23	100.00	16	100.00	15	100.00	54	100.00	-

*Fisher's Exact Test.

in the frequency range of 1500 to 8000 *Hz* and were normal in the frequencies of 250 to 1000 *Hz*. Also, 14 participants had bilateral normal hearing thresholds (left ear=14 and right ear=14) and 9 were unilateral (left ear=9 and right ear=0) (Table 3).

WINP scores in the left ear ($_{WINPL}$)

According to the Shapiro-Wilk test, the WINP scores had no normal distribution, thus the mean of the three groups were compared by the analysis of variance test, which was a significant difference between the three groups (p'_{WINPL}=0.011). The significant difference was observed in the comparison of the mean WINP scores of the normal ears of the control group with the abnormal ears of the case group based on the independent samples t- test (p'_{WINPL} =0.024), (Table 4). However, the difference in the mean WINP scores of the normal ears of the case group and the control group was not significant (p'_{WINPL} = 0.287).

WINP scores in the right ear ($_{WINPR}$)

According to the Shapiro-Wilk test, the WINP scores had a normal distribution, and the analysis of variance test showed that there is a significant difference between the mean of the three groups (p'_{WINPR}=0.013). Independent samples t-test was used to compare the mean WINP scores of the normal ears of the control group compared to the abnormal ears of the cases. The significant difference was observed between them (p'_{WINPR} <0.001) (Table 4). Also, the mean scores of WINP in normal ears of case and control groups were compared and no significant difference was observed between them (p'_{WINPR} =0.172).

DDT scores in the left ear ($_{DDTL}$)

Shapiro-Wilk test did not confirm the normal distribution of DDT scores, Kruskal-Wallis test was used to compare the mean DDT scores in three groups, and there was a significant difference (x2 = 1.39, df=

Table 3. Mean and standard deviations (S.D) of hearing thresholds (dBHL) in the case and control groups

Variable		Normal ears (case group)					Abnormal ears (case group)					Normal ears (control group)				
Frequency (Hz)	Ear	n	Mini	Max	Mean	S.D	n	Mini	Max	Mean	S.D	n	Mini	Max	Mean	S.D
250, 500, 1000																
	L	2w3	0.00	15.00	12.83	9.15	16	10.00	20.00	22.50	10.33	30	0.00	15.00	17.007	11.31
	R	14	5.00	20.00	12.50	10.14	25	15.00	20.00	23.60	17.66	30	-5.00	15.00	12.007	12.79
1500, 2000, 3000																
	L	23	0.00	20.00	7.61	4.74	16	20.00	35.00	30.31	7.41	30	-5.00	20.00	13.337	12.78
	R	14	5.00	20.00	12.86	4.26	25	25.00	50.00	32.20	10.38	30	0.00	15.00	19.337	13.10
4000, 6000, 8000																
	L	23	0.00	20.00	15.52	8.32	16	25.00	50.00	35.00	11.25	30	10.00	15.00	14.67	11.25
	R	14	10.00	20.00	14.36	8.65	25	20.00	55.00	37.40	13.00	30	10.00	15.00	18.33	12.05

Table 4. The mean and standard deviations (S.D) of word-in-noise perception (WINP) and the dichotic digit test (DDT) scores of case and control groups

Variable		Normal ears (case group)					Abnormal ears (case group)					Normal ears (control group)				
	Ear	n	Mini	Max	Mean	S.D	n	Mini	Max	Mean	S.D	n	Mini	Max	Mean	S.D
	L	23	66.00	88.00	74.52	14.69	16	30.00	72.00	56.62	17.51	30	67.50	100.00	80.83	10.07
WINP	R	14	66.00	96.00	76.00	10.61	25	30.00	74.00	52.24	11.83	30	72.00	96.00	77.06	14.05
	L	14	80.0	100.0	93.57	6.40	25	60.0	100.0	62.10	10.65	30	52.0	80.0	97.20	8.97
DDT	R	14	56.0	96.0	90.00	10.61	25	40.0	84.0	62.24	11.84	30	52.0	96.0	96.07	14.06

2, p'_{DDTL}=0.011). To compare the mean DDT scores in the normal ears of the case group compared to the abnormal ears, due to the non-establishment of its normal distribution, the Mann-Whitney test was used, and there was a significant difference (U=147.50, Z= -1.067, p'_{DDTL} =0.023) (Table 4), but the difference between the mean scores of the normal ears of the case group and the control group was not significant (U=168.12, Z =0.009, p'_{DDTL}= 0.324).

DDT scores in the right ear ($_{DDTR}$)

The DDT scores had no normal distribution (Shapiro-Wilk test) and there was a significant difference between the mean DDT scores in the three groups (Kruskal-Wallis, x2=0.93, df=2, p'_{DDTR} =0.019). According to the Mann-Whitney test, the comparison of the mean DDT scores of the normal ears of the controls compared to the abnormal ears of the cases was significant (U=175.00, Z=00, p'_{DDTR} <0.001) (Table 4). However, the difference between the mean scores of the normal ears of the case group and the control group was not significant (U=97.50, Z= -0.03, p'_{DDTR} = 0.858).

Discussion

In this research, it was observed that industrial personnel who had a history of exposure to noise pollution for over 6 months had a lesion in the peripheral part of the auditory system in the form of sensorineural hearing loss of middle to high frequencies in the range of 25 to 40 *dBHL*. The findings showed that this group was damaged in some of the functions of the central auditory system to some degree, which was confirmed by referring to

WINP and DDT.

Since the WINP assesses the ability to discover spoken consonants by the auditory brain (2,8), and the DDT evaluates the ability to distinguish numbers by discovering spoken vowels by the brainstem (11). It can be concluded that in addition to the damage to the peripheral part of the auditory system, there are some degrees of disorders in the brainstem and auditory brain. In other words, the destructive effects of noise have affected their entire peripheral and central auditory system. Similar findings have been reported by others as follows:

Groschel *et al* reported that exposure to loud noise can cause NIHL and damage to the cochlea and neural structures of the auditory system from the level of the nerve to the auditory brain. In the early stages of NIHL, when the hearing thresholds are temporarily reduced, the peripheral auditory centers are damaged. When NIHL becomes permanent, the central auditory centers are also affected (12). Therefore, their findings confirmed the damage of the entire peripheral and central auditory system due to noise pollution and were consistent with findings of the current study.

Dewey *et al* suggested that exposure to loud noise can cause damage to the brainstem and auditory brain in conditions where the hearing thresholds are within the normal range and cause increased activity of the upper centers of the auditory system, tinnitus and CAPD (13). Findings of the present study were not consistent with theirs, and it was observed that the difference in mean scores of WINP and DDT were significant only in ears with abnormal hearing thresholds compared to normal ears of case and control groups. In fact, CAPD and damage to the central parts of the auditory system were created along with the damage to the peripheral areas.

Arjunan and Rajan reported that noise causes disturbances in cognitive behaviors, fluctuations in the level of neurotransmitters and changes in mechanisms and molecular structures. The greater the exposure to louder sounds than 70 decibels, the greater the susceptibility to age-related hearing loss. Also, people who live in a quiet environment and away from urban and industrial noise are immune to many diseases, one of which is NIHL (14). Wieczerzak *et al* demonstrated that noise disrupts the communication and functional interactions of the temporal and prefrontal cortex. It has destructive effects on learning, memory and higher cognitive activities (15). Similarly, they have confirmed hearing threshold damages and CAPD from exposure to harmful noises.

Liu *et al* also described that in people who have a history of long-term exposure to noise, cognitive disorders, reduced learning and memory damage are observed. Moreover, living in areas with high crime and social delinquency reduces the mean life expectancy of a person by 10-12 years and increases the vulnerability to NIHL and CAPD (16). In this study, it was also observed that the scores of WINP and DDT tests, which evaluate cognitive functions, were impaired in ears with abnormal hearing thresholds, but the effect of noise pollution on people's life expectancy was not investigated, and it is an interesting idea for subsequent research.

Pienkowski concluded that people who are exposed to loud and annoying noise, despite having normal hearing thresholds, may have hidden hearing loss, which occurs in the range of frequencies higher than 8000 *Hz* or lower than 250 *Hz*. It causes disturbances in attention, speech perception in noise, memory, learning, functional defects of the auditory cortex and brain areas related to speech and language processing (17). In this study, hearing thresholds at frequencies lower than 250 and higher than 8000 *Hz* were not evaluated, but the abnormal ears of the participants had hearing loss and CAPD at frequencies higher than 1500 *Hz*. Therefore, considering that there was no evidence of CAPD in the normal ears studied, it can be concluded that even if this group had hidden hearing loss in the frequency range below 250 *Hz* and above 8000 *Hz*, the symptoms of CAPD were not detected in them based on WINP and DDT scores.

Vermiglio stated that children whose classes are close to streets, airports, and industrial places have poorer reading ability than those who study in quiet places. In fact, the background noise causes the speaker's voice to be unheard, and these conditions are similar to hearing injury. Children who have slight or mild hearing loss will experience academic decline and cognitive impairment. They may be one to two years late in learning language and speech skills compared to their peers (18). Fuente and Mcpherson conducted a comparative cross-sectional study to investigate the harmful effects of industrial noise pollution. The case group included 50 workers at risk of loud noise and controls involved 50 individuals who were not in a noisy environment and matched with the case group based on age, gender and education level. Their findings showed that industrial workers, even with normal hearing thresholds, suffer from varying degrees of damage to the central auditory system. They suggested that assessment of pure tone audiometry is not sufficient and it is definitely necessary to include central auditory tests in hearing protection programs for industrial workers (19). However, in this study, the possibility of CAPD in ears with abnormal hearing thresholds was observed. Since the susceptibility of people to the occurrence of central lesions is different, which is also affected by lifestyle and psychological factors, they can be the causes of the difference between our results and those of these researchers.

Conclusion

In industrial personnel who have a history of continuous exposure to noise pollution, there is a possibility of damage to the brainstem and auditory brain functions.

Acknowledgement

The financial sponsor of this research was Hamadan University of Medical Sciences (registered number: 140111049605 and ethics code: IR.UMSHA.REC.1401.728). The authors thank and appreciate the esteemed participants who cooperated in this research.

Conflict of Interest

The authors declare that they have no competing interests.

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