Research Article

An Investigative Study on Cognitive Decline among Textile Industry Workers with Occupational Noise-Induced Hearing Loss

Hamed Nadri[1], Ali Khavanin[1*], In-Ju Kim[2], Mehdi Akbari[3], Mohammad Gholami-Fesharaki[4]

[1] *Department of Occupational Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran*
[2] *Department of Industrial Engineering and Engineering Management, College of Engineering, University of Sharjah, Sharjah, United Arab Emirates*
[3] *Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran*
[4] *Department of Biostatistics, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran*

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Highlights

- Occupational noise exposure can lead to cognitive decline in textile workers
- Noise-induced hearing loss can be associated with cognitive decline

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*** Corresponding Author:**
Department of Occupational Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
khavanin@modares.ac.ir

ABSTRACT

Background and Aim: Occupational noise exposure is considered the second most common risk factor in the industry, which results in auditory and non-auditory health effects. The possibility of cognitive decline as one of the non-auditory health effects may be associated with noise-induced hearing loss (NIHL). This study aimed to investigate the cognitive decline among textile workers with NIHL.

Methods: A total of 30 male textile workers (mean age: 41.2±4.1 years and mean years of noise exposure: 18.9±5.4 years) with symmetrical NIHL (mean 49.3±4.5 dB at 4 kHz) and 30 healthy male textile office staff (aged-matched) with normal hearing and no history of noise exposure were included in this study. Exclusion criteria were included any deficit in ear function, neurological problems, and head trauma. Hearing thresholds were obtained by air and bone conduction audiometry. Workers' cognitive performance was investigated by two psychological tests: Corsi block and Stroop tests.

Results: The Corsi block indicators including block span (p=0.022) and visuospatial working memory (p=0.002) showed a significant difference between the two groups. Also, the Stroop test indicators including total test time (p<0.001) and response time (p<0.001) showed a significant difference between the two groups. Multiple linear regression analyses showed that workers with a higher hearing threshold at 3 kHz had a lower cognitive performance from both tests.

Conclusion: Our findings support the role of NIHL as a risk factor of developing cognitive decline in textile workers.

Keywords: Cognitive decline; noise-induced hearing loss; industrial worker; Corsi block test; Stroop test

Introduction

Occupational exposure into Occupational noise exposure is one of the most common risk factors in the industry, responsible for around 16% of hearing impairment in adults. It can also cause non-auditory health effects such as annoyance, cardiovascular disease, cognitive performance, and sleep disturbance [1, 2]. According to a World Health Organization (WHO) report, the prevalence of disabling hearing loss (>40 dB) was 6.12% (466 million people in the world) in 2018 and its number could increase to 8.27% (630 million) by 2030 and 9.6% (900 million) in 2050, respectively [3]. A recent WHO report estimated that the global costs of hearing loss (moderate or higher degrees) would be ranged from $750–790 billion annually. These costs include health care systems ($67–107 billion without hearing devices cost), loss of productivities ($105 billion: due to unemployment and premature retirement), and social expenses ($573 billion: due to social isolation, communication difficulties and stigma) [4]. The National Institute of Occupational Safety and Health (NIOSH) recommended a permissible exposure level (PEL) of 85 dB A (a time-weighted average of eight hours) for protection from hearing loss among workers (with an 8% risk of hearing loss after 40 years of exposure) [5].

The noise-induced hearing loss (NIHL) occurs due to excessive exposure to occupational complex noise (over 85 dB A) during the first 10 to 15 years of exposure with the maximal degree in a 3-4 kHz range. Pathological characteristics of NIHL include a bilateral loss of the sensory hair cells and degeneration of the neural auditory nerve. Because of the regenerative incapability of the human auditory system, NIHL is irreversible [6, 7]. NIHL has its peripheral substrate including outer hair cell (whose serves as a cochlear amplifier) and inner hair cell (whose transduce the mechanical vibrations into neural impulses) damage, auditory nerve fibres degeneration, and reduction of frequency-specific auditory nerve output to the central auditory system [8]. Also, auditory input to the central auditory system is important for normal maturation and brain connectivity [9].

On the other hand, noise can result in cognitive decline through increasing the oxidative stress and reduction of the antioxidant level in various regions of the brain, alteration of the neurotransmitter level and epigenetic modification [10]. In animal studies, Liu et al. showed a deficit in spatial learning/memory and a decrease in neurogenesis in the hippocampus due to NIHL [11, 12]. Also, in another study by Yu et al. reported that decreased spatial learning and memory and synapse degeneration in the hippocampus were shown by hearing loss [13]. Such a connection between peripheral hearing loss and cognitive function is attributed to strong anatomical and functional connections between the brain regions (hippocampus) and the auditory system.

Alimohammadi et al. observed a significant relationship between the increase in the hearing thresholds and decrease in cognitive indicators of the Stroop test including the number of errors, number of non-response, and number of correct responses among industrial workers [14]. Further, Soylemez and Mujdeci showed in their study that workers with higher NIHL had a worse performance in doing dual tasks compared to the control group [15]. Similarly, a significant relationship between the increase in hearing impairment and cognitive performance decline has been shown in the meta-analysis study by Taljaard et al. [16]. Therefore, workers in the work environments may be prone to systematic errors because of reduced cognitive function due to NIHL. The relationship between cognitive declines and human errors doubles the importance of studying cognitive performance in workers with NIHL, especially in activities with high cognitive demands and high-risk work environments (especially risk factors for NIHL).

On the other hand, the lack of evidence shows that the relationship between the NIHL and cognitive functions among industrial workers in Iran is not well known and has been neglected. Therefore, the present study investigated the performance of two cognitive domains including visuospatial working memory (VSWM) and selective attention of textile workers with NIHL using the Corsi block and Stroop tests in comparison with control participants.

Methods

Study subjects

A total of 30 male textile workers (mean age: 41.2±4.1 years) with symmetrical NIHL and a minimum hearing threshold of 40 dB at 4 kHz (mean 49.3±4.5 dB) were participated in this study [17]. NIHL workers have historically (mean years of noise exposure: 18.9±5.4 years) been exposed to continuous steady-state daily noise levels (mean 92±2.9 dB A) for an 8-hour working day. In addition, all of these workers wore hearing aids such as earmuffs or earplugs.

The occupational noise exposure of workers in the NIHL group was determined based on the ISO 9612: 2009 standard [18]. The measurements were carried out according to the task-based measurement strategy on the

A-weighted network, in slow mode and at the height of the workers head (1.50 m above the floor) using the TES-1358C sound analyzer (TES company, Taiwan). The calibration of the measuring device was carried out using the TES-1356 sound level calibrator. The Frequency analysis (mean±2SD) of daily noise exposure was also measured for each worker in 1/1 octave band center frequencies (Figure 1). As can be seen, the highest sound pressure level is at a frequency of 4 kHz.

Another thirty healthy male textile office staff (mean age 40±3.9 years and mean experience: 17.4±4.9 years) with normal hearing (mean 18.8±2.2 dB at 4 kHz) and no history of noise exposure were recruited and tested in the same paradigm as a control group. In addition, to eliminate the positive effect of education on cognitive performance, the literacy level (years of education) of participants in the control group (mean education: 13±3.4 years) were matched with the NIHL group (mean education: 13.1±3.4 years) [19].

As inclusion criteria, the diagnostic criteria of NIHL were based on the guidance of the American College of Medicine and the Environment [7]. Participants with tympanic membrane perforation, middle ear deficit, history of ear surgery, mixed-type hearing loss, neurological problems, taking a tranquillizer, sedative and vestibular suppressant drugs, and head trauma were excluded from the study. Other exclusion criteria were included those aged more than 50 years (to eliminate the effect of presbycusis), and occupational concurrent exposures to ototoxic chemical substances such as carbon disulphide. The workers for both groups were selected voluntarily from the available population (425 workers in the production line and 110 office staff) according to inclusion and exclusion criteria. On the other hand, all the participants were able to work with computers and perform computer based cognitive tests. All the subjects who participated in the study signed with informed and voluntary consent and were free to leave the study at any stage of the experiments.

Audiometric examinations

Audiometric examinations were performed by using a SIEMENS audiometer (model SD270), which is a very compact audiometer and has the flexibility to be used for both clinic and portable applications in a standard audiometric booth. Pure tone air conduction (AC) and bone conduction (BC) hearing thresholds in each ear of all the participants were obtained from frequency ranges of 0.25 to 8 kHz and 0.25 to 4 kHz, respectively. In addition to the diagnostic criteria described by the American College of Occupational and Environmental Medicine [7], NIHL was defined as a bilateral hearing loss ≥ 40 dB (at 4 kHz) in this study. To avoid the temporary threshold shift, audiometry was performed at least 14 hours after the last occupational noise exposure.

Cognitive assessment

To perform computer-based versions of cognitive assessment tests, participants in both groups were seated on a height-adjustable office chair in the front of the display screen (with 15-in size) in a quiet (with 35 dB background noise) and with a standard illuminance (about 350 lux at worksurface height). It is important to note that both cognitive performance tests were carried out at the beginning of the working day (from 8 am to 11 am).

Corsi block test

The Corsi block test (CBT), which was developed by Philip Corsi [20], is widely used for the assessment of VSWM in clinical practice and neuropsychological examinations. The current study used the Persian version of the computerized standard CBT, which consists of nine cubical blocks positioned on a board. The psychometric properties such as scoring procedure and stimuli presentation of the Persian version were the same as the English version [21]. Contrary to the three-dimensional standard CBT, this computerized version was two dimensional one and displayed on a laptop screen (display screen: 225 mm×205 mm and blocks: 30 mm×30 mm). The administration procedure of the computerized version of the CBT was equal to that of the standard one.

This test is performed in two stages: a) forward and b) backward. Before starting each stage of this test, participants must go through a warm-up stage (or training stage) to become familiar with the test procedure. The score of this stage does not affect the result. In the forward stage, a sequence of blocks flashed on the laptop screen (starting from two blocks per sequence to nine blocks), which must be reproduced in the same order as presented by participants. However, in the backward stage, participants must reproduce a sequence of blocks flashed in reverse order. The CBT was terminated if participants made a mistake twice in the reproduction of one sequence. Blocks flashing time and inter-block interval were set to 0.5 and 1.0 second, respectively. Finally, block span (length of the last correctly repeated sequence) and product score (block span×the number of correctly repeated trials) for both forward and backward stages were computed. In addition, the VSWM score was calculated by adding the forward and backward stage product score. The test-retest reliability of the Persian version of the computerized CBT was randomly carried out with the same experimenter over a period of four weeks in 20% of the total participants (six participants in each group). The results revealed that there was excellent test-retest reliability for CBT (mean block span: r=0.86; VSWM: r=0.91). In addition, the Cronbach's alpha coefficient for all parameters was 0.68, which indicates a good reliability of the CBT.

Stroop test

This test was first designed and introduced by Ridley Stroop in 1935 to assess the ability to inhibit cognitive interference [22]. However, this test has been used to measure other cognitive functions such as selective attention, processing speed, and flexibility [23]. The current study used the Persian version of the computerized Stroop Color and Word Test (SCWT). The psychometric properties such as scoring procedure and stimuli presentation of the Persian version were the same as the English version [24]. This test was also carried out in two stages. In the first stage or warm-up stage (or training stage), participants must specify the colors of the words displayed on the screen (blue, red, green and yellow) by pressing the corresponding colored circles on the keyboard. The score of this stage does not affect the result.

The second stage of this test is the main one, which presents 48 congruent color words that have the same ink color and meaning and 48 incongruent color words that do not have the same ink color and meaning on the computer screen. Therefore, participants should pay attention to the ink color of presented words regardless of their meaning and press the corresponding-colored circles on the keyboard as fast as possible. A total of 96 congruent and incongruent stimuli were presented randomly. The presentation time of stimulus and the inter-stimulus interval was set to 2 seconds and 0.8 seconds, respectively. Test performance was evaluated by taking into account parameters including test times, number of errors, number of non-response, number of correct responses, response time in congruent, and incongruent conditions. Interference score (a difference between the number of correct answers in both incongruent and congruent conditions) and interference time (a difference between the response time in both incongruent and congruent conditions) are two other parameters that are calculated in this test. To simplify the results, a mean value of all the parameters in both congruent and incongruent conditions was calculated for further analyses.

The test-retest reliability of the Persian version of the computerized Stroop test was randomly carried out with the same experimenter over a period of four weeks in 20% of the total participants (six participants in each group). The results revealed that there was good test-retest reliability for Stroop test (test time: r=0.94; number of errors: r=0.70; number of non-response: r=0.63; number of correct responses r=0.64; response time: r=0.96; interference score: r=0.61; interference time: r=0.67). In addition, the Cronbach's alpha coefficient for all parameters was 0.73, which indicates a good reliability of the Stroop test.

Statistical analysis

IBM SPSS 17 program was used for statistical analysis. Kolmogorov-Smirnov test was used to determine the normality of the data. To compare hearing thresholds, cognitive indicators and demographic information of two groups, the Mann Whitney test and independent-sample T-test were used. The relationship between hearing thresholds and cognitive indicators was tested using Spearman and Pearson correlation coefficients. Multiple linear regression analyses were conducted to investigate the dependence of cognitive indicators on hearing thresholds. A p-value less than 0.05 was considered statistically significant.

Results

Figure 2, shows the air conduction-hearing thresholds (mean±2SD) of two groups from 250 to 8,000 Hz. There were no significant differences between the right and left ears in the mean hearing threshold with all frequencies ($p>0.05$), thus the hearing thresholds of the two ears in each frequency were pooled together in both groups.

As shown in Figure 2, however, there is a significant difference in frequencies of 3, 4, 6, and 8 kHz between the two groups. In addition, the hearing threshold of 4 kHz showed the worst hearing threshold compared to other frequencies. It represents the 4 kHz audiometric notch. Audiometric notch as a principal characteristic of occupational NIHL can help us to exclude the possibility of presbycusis, which involves bilateral high-frequency hearing loss associated with difficulty in speech discrimination and central auditory processing of information.

Figure 3 shows the comparison of the CBT and Stroop test results (mean±2SD) between the two groups. The CBT results showed significant differences between the two groups in the scores of block span and VSWM ($p<0.001$). In addition, the Stroop test disclosed a sig-

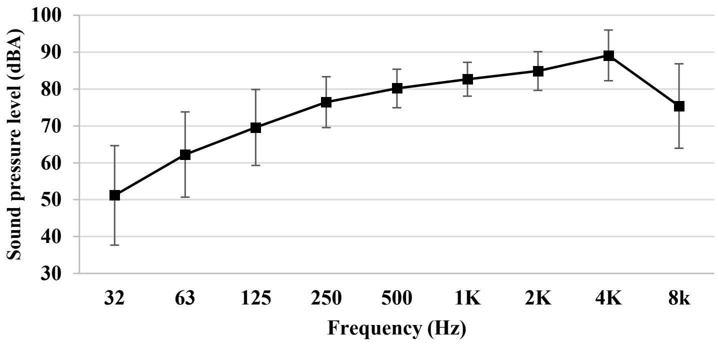

Figure 1. Frequency analysis (mean±2SD) of the daily noise exposure level of 30 workers with noise-induced hearing loss

nificant difference between the two groups in parameters including the total test time and response time (p<0.001). Other parameters of the Stroop test including the number of errors response, number of non-response, and number of the correct response, interference score, and interference time showed no significant differences between the two groups (p<0.001).

The correlation between the block span and the VSWM values with literacy level (years of education) and experience (years of work experience) is shown in Figure 4. There was a significant interaction between the effect of education on the block span (p<0.001) and VSWM scores (p=0.001). In addition, there was a significant interaction between the effects of experience on the block span (p<0.003) and VSWM scores (p=0.001). There is no significant interaction between the effects of education and experience on the indicators of the Stroop test.

Table 1 summarizes the relationship between the cognitive indicators with hearing thresholds of 3, 4, 6 and 8 kHz. Based on the results, the block span and VSWM indicators of the CBT had a significant relationship with the hearing thresholds of 3 and 4 kHz, but not with the hearing thresholds of 6 and 8 kHz. In addition, the total test time and response time indicators of the Stroop test had a significant relationship with the hearing thresholds of 3, 4, 6 and 8 kHz.

The significant relationship shown among the hearing thresholds and CBT cognitive indicators as well as the Stroop test (Table 1) was investigated using multiple linear regression analysis. Based on the results (Table 2), only the hearing threshold at 3 kHz in the regression model of the CBT cognitive indicators including block span (p=0.007) and VSWM (p=0.001) remained significant. In addition, only the hearing threshold at 3 kHz in the regression model of the cognitive indicators of the Stroop test including total test time (p<0.001) and response time (p<0.001) remained significant.

Discussion

This study provides evidence of performance declines in two cognitive domains including VSWM and selective attention among textile industry workers working under occupational NIHL≥40 dB (at 4 kHz). The re-

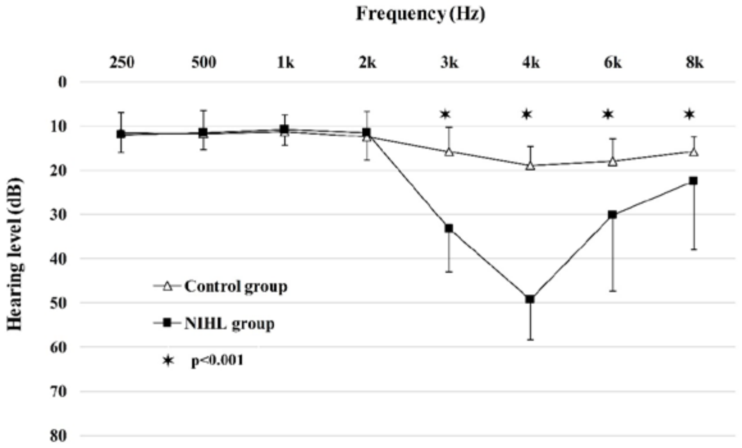

Figure 2. Air conduction-hearing thresholds (mean±2SD) of 30 workers noise-induced hearing loss versus 30 control participants. NIHL; noise-induced hearing loss

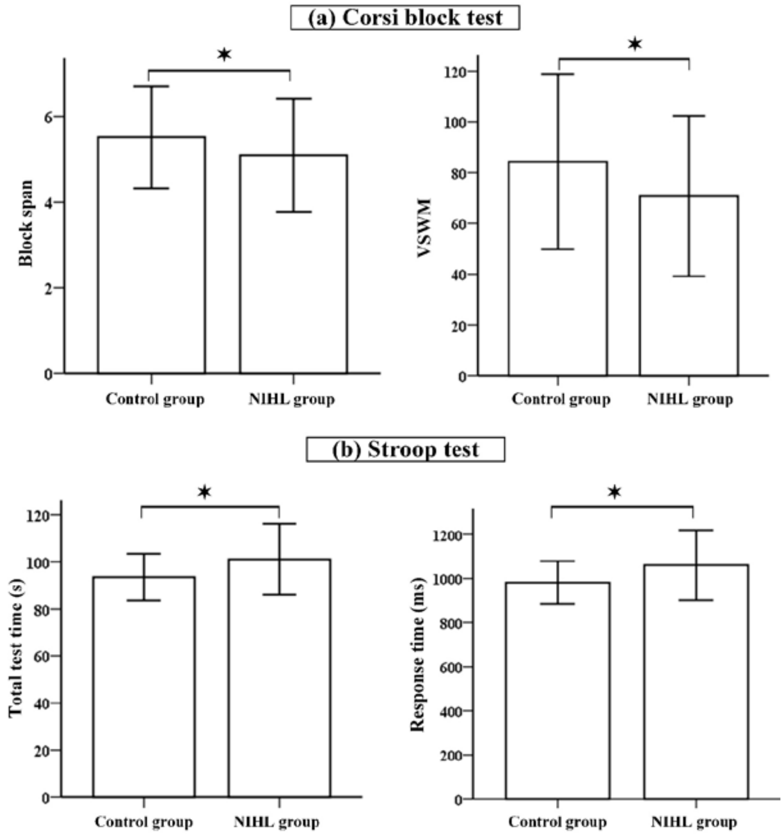

Figure 3. Block span and visuospatial working memory scores (mean±2SD) for Corsi block test (a) and total test time and response time (mean±2SD) for Stroop test (b). NIHL; noise-induced hearing loss

* p<0.001

sults of the CBT indicators including block span and VSWM showed significantly lower values in the workers with NIHL compared to the control group participants. In addition, multiple linear regression analysis showed a significant contribution of the 3 kHz hearing thresholds in the regression model for block span and VSWM indicators. This means that NIHL at the 3 kHz hearing threshold is negatively correlated with block span and VSWM values, so the textile workers with a higher threshold at this frequency exhibit lower cognitive performance in the CBT.

Recently Soylemez and Mujdeci showed that workers with higher NIHL (pure-tone average >40 dB) had a worse performance in doing dual tasks (using the time up and go and the digit span tests) compared to the control group [15]. In addition, a meta-analysis study by

Table 1. Relationship between the cognitive indicators of Corsi block and Stroop tests with hearing thresholds

Cognitive indicators		Hearing thresholds							
		3 kHz		4 kHz		6 kHz		8 kHz	
		p	r	p	r	p	r	p	r
Corsi block test	Block span	0.004	–0.362	0.009	–0.337	0.369	–0.118	0.445	–0.100
	VSWM	0.001	–0.404	0.001	–0.416	0.133	–0.196	0.200	–0.168
Stroop test	Total test time (s)	<0.001	0.583	<0.001	0.521	<0.001	0.476	<0.001	0.502
	Response time (ms)	<0.001	0.597	<0.001	0.529	<0.001	0.484	<0.001	0.460

VSWM; visuospatial working memory

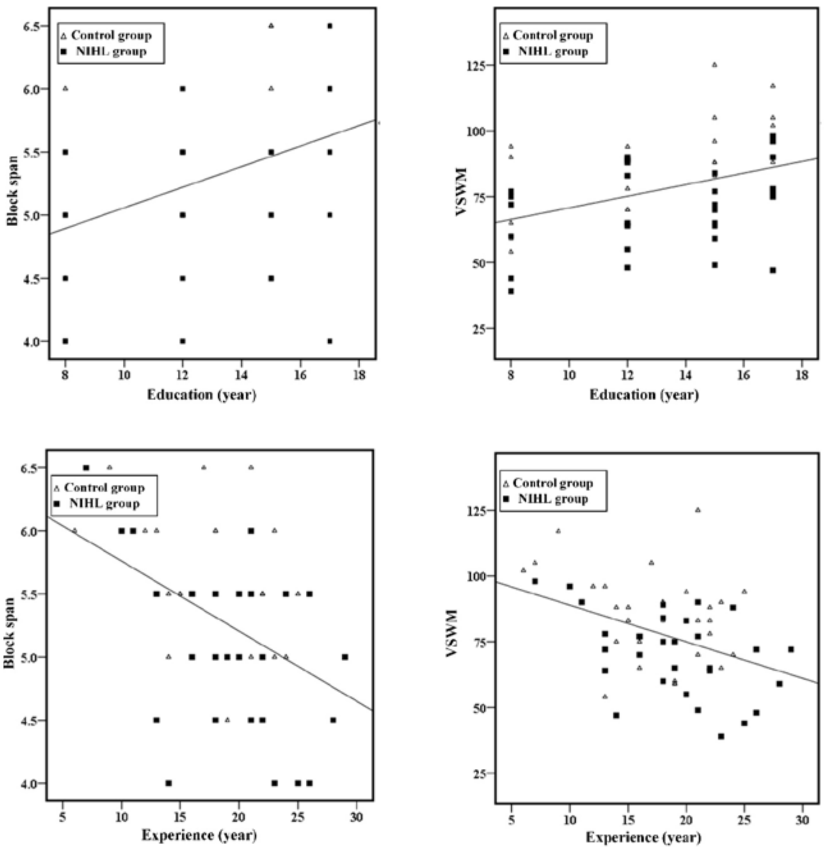

Figure 4. Correlation between Block span and visuospatial working memory scores with education (years of academic education) and experience (years of work experience). NIHL; noise-induced hearing loss

Taljaard et al. showed that better hearing is associated with better performance in working memory. Studies included in this meta-analysis examined working memory using various cognitive tests [16]. The association between noise exposure and NIHL with VSWM has been explained in a number of studies as follows. In an animal study, Shukla et al. have shown that noise exposure not only damages the peripheral auditory system but also result in a reduction of hippocampal neurogenesis as an important area in the brain and responsible for learning/memory [25]. In addition, spatial learning/memory impairment due to NIHL (independent of its oxidative effect) has been shown in several animal studies [11, 12, 26]. These studies evidently showed that in addition to

Table 2. Multiple linear regression model for the cognitive indicators of Corsi block and Stroop tests

Dependent variable	Predictors	B	SE	Standardized coefficients (β)	p
Block span	Constant	5.89	0.22		0.007
	Hearing threshold (3 kHz)	–0.02	0.01	–0.35	
VSWM	Constant	96.55	5.80		0.001
	Hearing threshold (3 kHz)	–0.78	0.22	–0.42	
Stroop total test time (s)	Constant	86.32	2.16		<0.001
	Hearing threshold (3 kHz)	0.45	0.08	0.58	
Stroop response time (ms)	Constant	906.96	22.25		<0.001
	Hearing threshold (3 kHz)	4.65	0.85	0.59	

B; unstandardized coefficient, SE; standard error, VSWM; visuospatial working memory reducing cell proliferation, NIHL could reduce the promoting effect of the learning activity on later stages of hippocampus neurogenesis. Other studies in the literature also showed that NIHL might lead to cortical changes affecting the cognitive functions of these damaged areas of the brain [27-30]. Findings of the present study are consistent with the results of earlier studies and confirm a reduction in VSWM due to NIHL. The VSWM as an essential function for visually dependent organisms plays an important role in storage and processing visual and spatial information such as shapes and colors (object's identity) as well as their spatial layout/location [31, 32]. The importance of VSWM decline is understood when performing tasks cognitively requires this domain. Thus, this study suggests that NIHL may be a potential risk factor for the occurrence of VSWM decline among textile workers.

The results of the Stroop test indicators including the total test time and response time showed significantly lower values in the workers with NIHL compared to the control group ones. In addition, multiple linear regression analysis showed a significant contribution of the 3 kHz hearing threshold in the regression model for total test time and response time indicators. Therefore, the hearing threshold at 3 kHz shows a positive association with the total test time and response time values, meaning that workers with a higher threshold at 3 kHz exhibit lower performance in the Stroop test. Recently, Alimohammadi et al. showed a significant relationship between the increase in the hearing thresholds and decrease in cognitive indicators of the Stroop test including the number of errors and response time among industrial workers [14]. In a meta-analysis study, Taljaard et al. reported a significant association between the hearing impairment degree and lower cognitive performance in attention/ processing speed. They also emphasized that hearing impairment can affect all cognitive domains [16].

In other literature reviews, auditory nerve fibres degeneration, reduction of frequency-specific auditory nerve output to the central auditory system, increasing the oxidative stress and reduction of the antioxidant level in the brain, alteration of the neurotransmitter level and epigenetic modification due to noise exposure have been proposed as an explanation of the occurrence of cognitive decline due to NIHL [8-10]. The outcomes of the present study are consistent with the results of earlier studies and confirm cognitive performance decline in selective attention because of NIHL. On other hand, selective attention is one of the main functions of attention, by which needs to pay attention to some stimuli and ignore others [33]. However, the importance of this cognitive domain will be significant for tasks that require attention. Therefore, this study suggests that the NIHL may be a potential risk factor for the occurrence of selective attention decline which was examined by the Stroop test among textile workers.

The current study conducted two non-auditory tests to investigate the performance of two cognitive domains including VSWM and selective attention with the CBT and Stroop tests, respectively. However, auditory cognitive tests are available that can be used in future studies. Although the current experimental designs were limited to male workers as participants due to difficulty of recruitment during the COVID-19 pandemic situation, overall findings from this study showed evidence on cognitive decline among textile industry workers with occupational NIHL. This result can be further applied to other industry workers to identify this issue in the future.

Conclusion

The present study provides evidence of lower cognitive performance in visuospatial working memory and selective attention among textile industry workers with occupational noise induced hearing loss (NIHL) (≥40 dB at 4 kHz). As well, the multiple linear regression analysis attributed a significant contribution of this cognitive performance decline to the hearing thresholds at 3 kHz. This means that workers with higher hearing thresholds exhibit lower cognitive performance. Thus, this study suggests that NIHL may be a great potential risk factor for the occurrence of cognitive decline. The importance of cognitive decline in performing tasks with high cognitive demands becomes more apparent because it can negatively affect safety behaviour and increase human errors. Therefore, the NIHL affirms increased concerns and efforts to take steps to improve the textile worker's environment. In this regard, the implementation of noise control strategies and hearing protection programs to prevent hearing loss in the textile industry can be helpful. However, conclusions from the present study needs to be treated with caution. Further research requires confirmation of whether there is a strong association between the incidence of cognitive decline and NIHL from other types of industrial sectors.

Ethical Considerations

Compliance with ethical guidelines

All the experiments were conducted according to the Ethics Committee approval (Ethics Code No:

IR.MODARES.REC.1399.037) of Tarbiat Modares University, Tehran, Iran.

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Authors' contributions

HN: Study design, acquisition of data, interpretation of the results, and drafting the manuscript; AK: Study design and supervision, interpretation of the results and critical revision of the manuscript; IJK: Study design and supervision, interpretation of the results, and critical revision of the manuscript; MA: Study design and supervision, and Interpretation of the results; MGF: Statistical analysis.

Conflict of interest

The authors declare that there is no conflict of interest.

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References

[1] Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, et al. Auditory and non-auditory effects of noise on health. Lancet. 2014;383(9925):1325-32. [DOI:10.1016/S0140-6736(13)61613-X]

[2] Themann CL, Masterson EA. Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden. J Acoust Soc Am. 2019;146(5):3879. [DOI:10.1121/1.5134465]

[3] World Health Organization. Addressing the rising prevalence of hearing loss. Geneva: World Health Organization. 2018. Available from https://apps.who.int/iris/handle/10665/260336. Accessed November 09, 2021.

[4] World Health Organization (WHO). Global costs of unaddressed hearing loss and cost-effectiveness of interventions. Geneva World Health Organization. 2017. Available from https://apps.who.int/iris/handle/10665/254659. Accessed November 09, 2021.

[5] National Institute for Occupational Safety and Health (NIOSH). Occupational noise exposure, Revised Criteria 1998. Publication No. 98-126. 1998. Available from: https://www.cdc.gov/niosh/docs/98-126/default.html. Accessed November 09, 2021.

[6] May JJ. Occupational hearing loss. Am. J. Ind. Med.. 2000;37(1):112-20. [DOI:10.1002/(SICI)1097-0274(200001)37:13.0.CO;2-#]

[7] Mirza R, Kirchner DB, Dobie RA, Crawford J, ACOEM Task Force on Occupational Hearing Loss. J Occup Environ Med. 2018;60(9):e498-501. [DOI:10.1097/JOM.0000000000001423]

[8] Eggermont JJ. Noise and the Brain: Experience Dependent Developmental and Adult Plasticity. 1st ed. London: Academic Press; 2014.

[9] Wingfield A, Peelle JE. How does hearing loss affect the brain? Aging health. 2012;8(2):107-9. [DOI:10.2217/ahe.12.5]

[10] Arjunan A, Rajan R. Noise and brain. Physiol Behav. 2020;227:113136. [DOI:10.1016/j.physbeh.2020.113136]

[11] Liu L, Shen P, He T, Chang Y, Shi L, Tao S, et al. Noise induced hearing loss impairs spatial learning/memory and hippocampal neurogenesis in mice. Sci Rep. 2016;6:20374. [DOI:10.1038/srep20374]

[12] Liu L, Xuan C, Shen P, He T, Chang Y, Shi L, et al. Hippocampal mechanisms underlying impairment in spatial learning long after establishment of noise-induced hearing loss in CBA mice. Front Syst Neurosci. 2018;12:35. [DOI:10.3389/fnsys.2018.00035]

[13] Yu Y-F, Zhai F, Dai C-F, Hu J-J. The relationship between age-related hearing loss and synaptic changes in the hippocampus of C57BL/6J mice. Exp Gerontol. 2011;46(9):716-22. [DOI:10.1016/j.exger.2011.04.007]

[14] Alimohammadi I, Ahmadi Kanrash F, Vosoughi S, Abolaghasemi J, Chalak MH, Rahmani K. Study of the Relationship Between Hearing Loss and Cognitive Performance at Chronic Exposure to Noise. Iran Red Crescent Med J. 2020;22(7):e102092. [DOI:10.5812/ircmj.102092]

[15] Soylemez E, Mujdeci B. Dual-task performance and vestibular functions in individuals with noise induced hearing loss. Am J Otolaryngol. 2020;41(6):102665. [DOI:10.1016/j.amjoto.2020.102665]

[16] Taljaard DS, Olaithe M, Brennan-Jones CG, Eikelboom RH, Bucks RS. The relationship between hearing impairment and cognitive function: a meta-analysis in adults. Clin Otolaryngol. 2016;41(6):718-729. [DOI:10.1111/coa.12607]

[17] Yilmaz N, Ila K, Soylemez E, Ozdek A. Evaluation of vestibular system with vHIT in industrial workers with noise-induced hearing loss. Eur Arch Otorhinolaryngol. 2018;275(11):2659-2665. [DOI:10.1007/s00405-018-5125-y]

[18] International organization for standardization (ISO). ISO 9612. Acoustics: Determination of occupational noise exposure, engineering method. 2009. Available from: https://www.iso.org/standard/41718.html

[19] Bento-Torres NVO, Bento-Torres J, Tomás AM, Costa VO, Corrêa PGR, Costa CNM, et al. Influence of schooling and age on cognitive performance in healthy older adults. Braz J Med Biol Res. 2017;50(4):e5892. [DOI:10.1590/1414-431x20165892]

[20] Corsi PM. Human memory and the medial temporal region of the brain. Montreal, Canada: McGill University; 1972.

[21] Khodadadi M, Amani H. Corsi Spatial-Visual Working Memory Test. Institute for Behavioral & Cogntive Sciences. Tehran, Islamic Republic of Iran. 2018: Available at: https://www.sinapsycho.com/Shop/Product/1319.

[22] Stroop JR. Studies of interference in serial verbal reactions. J Exp Psychol Gen. 1935;18(6):643-62. [DOI:10.1037/h0054651]

[23] Scarpina F, Tagini S. The stroop color and word test. Front Psychol. 2017;8:557. [DOI:10.3389/fpsyg.2017.00557]

[24] Khodadadi M, Mashhadi A, Amani H. Simple Stroop Software. Institute for Behavioral & Cogntive Sciences. Tehran, Islamic Republic of Iran. 2014: Available at: https://www.sinapsycho.com/Shop/Product/1328.

[25] Shukla M, Roy K, Kaur C, Nayak D, Mani K, Shukla S, et al. Attenuation of adverse effects of noise induced hearing loss on adult neurogenesis and memory in rats by intervention with Adenosine A2A receptor agonist. Brain Res Bull. 2019;147:47-57. [DOI:10.1016/j.brainresbull.2019.02.006]

[26] Tao S, Liu L, Shi L, Li X, Shen P, Xun Q, et al. Spatial learning and memory deficits in young adult mice exposed to a brief intense noise at postnatal age. J Otol. 2015;10(1):21-8. [DOI:10.1016/j.joto.2015.07.001]

[27] Dietrich V, Nieschalk M, Stoll W, Rajan R, Pantev C. Cortical reorganization in patients with high frequency cochlear hearing loss. Hear Res. 2001;158(1-2):95-101. [DOI:10.1016/S0378-5955(01)00282-9]

[28] Pienkowski M, Eggermont JJ. Cortical tonotopic map plasticity and behavior. Neurosci Biobehav Rev. 2011;35(10):2117-28. [DOI:10.1016/j.neubiorev.2011.02.002]

[29] Wang H, Brozoski TJ, Ling L, Hughes LF, Caspary DM. Impact of sound exposure and aging on brain-derived neurotrophic factor and tyrosine kinase B receptors levels in dorsal cochlear nucleus 80 days following sound exposure. Neuroscience. 2011;172:453-9. [DOI:10.1016/j.neuroscience.2010.10.056]

[30] Zhuang H, Yang J, Huang Z, Liu H, Li X, Zhang H, et al. Accelerated age-related decline in hippocampal neurogenesis in mice with noise-induced hearing loss is associated with hippocampal microglial degeneration. Aging (Albany NY). 2020;12(19):19493. [DOI:10.18632/aging.103898]

[31] Baddeley A. Working memory: theories, models, and controversies. Annu Rev Psychol. 2012;63:1-29. [DOI:10.1146/annurev-psych-120710-100422]

[32] McAfoose J, Baune B. Exploring visual-spatial working memory: a critical review of concepts and models. Neuropsychol Rev. 2009;19(1):130-42. [DOI:10.1007/s11065-008-9063-0]

[33] Krauzlis RJ, Bogadhi AR, Herman JP, Bollimunta A. Cortex. 2018;102:161-175. [DOI:10.1016/j.cortex.2017.08.026]