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RESEARCH ARTICLE

Investigating the effect of extended high-frequency hearing loss on duration pattern sequence test

Athareh Farahani[1], Saeid Farahani[1*], Nematollah Rouhbakhsh[1], Farzaneh Zamiri Abdollahi[1], Masoud Bolandi[2]

[1]- Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[2]- Department of Audiology, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran

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Abstract

Background and Aim: Temporal processing is affected in people exposed to occupational noise. The primary goal of this study was to evaluate the temporal processing of people exposed to occupational noise of more than 85 dB A but have not experienced clinically significant changes at hearing thresholds at conventional frequencies.

Methods: A comparison between groups were designed using individuals exposed to occupational noise (n = 15 as the case group) and non-exposed individuals (n = 16 as the control group). Two groups were age-matched ($p < 0.05$). The extended high-frequency audiometric thresholds and temporal processing system were evaluated through a duration pattern sequence test. Finally, the correlation between the extended high-frequency hearing thresholds and the duration pattern test scores was investigated.

Results: The case group had significantly higher hearing thresholds than the control group at 14, 15, and 16 kHz ($p < 0.05$). Although in other frequencies, the mean hearing thresholds in the case group was higher than the control group, the difference was not significant. Also, the case group had significantly lower duration pattern sequence scores than the control group in the right ($p = 0.02$) and the left ears ($p = 0.03$). There was no correlation between extended high-frequency hearing thresholds and duration pattern sequence test scores.

Conclusion: In people exposed to occupational noise, both extended high-frequency thresholds and temporal processing in lower frequency ranges (with normal hearing thresholds) are interrupted.

Keywords: Occupational noise; extended high-frequency hearing; duration pattern sequence test; temporal processing

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[*] **Corresponding author:** Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Piche-Shemiran, Enghelab Ave., Tehran, 1148965141, Iran. Tel: 009821-77530636, E-mail: s_farahani@tums.ac.ir

Introduction

Excessive noise is the most common risk factor in work environments that causes hearing impairment [1]. Noise-induced hearing loss (NIHL) is usually an irreversible disorder and is a common problem in industrial settings, especially where the noise level is harmful (more than 85 dB A) [2]. NIHL is the second most common form of acquired hearing loss after presbycusis, and it has long been known as a problem in professions that are too much associated with noise. Exposure to excessive noise can cause temporary threshold shift (TTS) or permanent threshold shift (PTS) [3]. However, NIHL can be a permanent and irreversible, but preventable disorder [4]. It has been suggested that frequencies higher than 8000 Hz may be more sensitive to noise, acoustic trauma, and ototoxic substances than lower frequencies. Therefore, hearing loss caused by noise at these frequencies can predict NIHL before it appears in lower frequencies, especially speech frequencies [5]. Türkkahraman et al. found that frequencies of 4000, 6000, 14000, and 16000 Hz were more exposed to noise. Therefore, they suggested that the extended high-frequency (EHF) hearing threshold with conventional audiometry should be used to identify and monitor people at risk of hearing loss [6].

The destructive effects of excessive noise are progressive and extensive, which are not fully detectable by conventional audiometric tests. Evidence suggests that in subjects with a history of noise exposure and normal auditory sensitivity, the temporal processing ability dramatically decreases [7]. Temporal auditory processing is one of the tasks of the central auditory nervous system that provides sound perception or sound changes in a given period. Also, temporal processing is an important aspect of auditory performance essential for a wide range of daily hearing activities, including speech and musical perception. Its defect can hinder the acquisition of speech, language, and reading [8]. According to the American Speech-Language-Hearing Association, evaluation of this aspect of auditory performance should be included in the auditory processing test batteries [9]. Therefore, temporal auditory processing is one of the critical abilities of the auditory processing system, which includes temporal resolution, temporal sequencing or ordering, temporal integration or summation, and temporal masking [10]. Duration pattern sequence test (DPST) is one of the auditory processing tests that evaluate skills such as temporal sequencing and duration discrimination [11]. The temporal sequencing of acoustic stimuli is one of the most basic and essential skills of the central nervous system, which allows a person to recognize the sounds based on the sequence of an auditory stimulus [11]. Also, correct judgment on the temporal ordering and sequencing in the presence of the minimum interval between different sounds is necessary for the accurate perception of speech [10]. Excessive noise can cause significant distortions in the processing of supra threshold temporal cues, which may add to difficulties in hearing in adverse listening conditions [7].

In areas of the cochlea where the hearing loss occurs, auditory processing of the signals is affected. This defect of auditory processing is associated with both hearing loss [12] and weaker supra threshold processing of the auditory system. However, processing defects may not be limited to frequencies where cochlear hearing loss is present. It may also extend to the surrounding area. The off-channel impact of cochlear lesions on signal processing has been indicated in both intensity and frequency coding [13,14]. It has recently been noted that in people with high-frequency hearing loss, temporal resolution decreases in lower-frequency areas with almost normal-hearing sensitivity [15]. Accordingly, the purpose of this study was to investigate the effect of extended high-frequencies hearing loss on the ability of temporal sequencing in people working in industrial environments but have normal hearing in the frequency range of conventional audiometry.

Methods

With the collaboration of Tehran University of Medical Sciences (TUMS) Deputy of Education and Iran Khodro Co., a group of 15 workers aged 18–40 years who were referred for periodic auditory evaluation and 16 participants for control group (with same age range), were selected. Sampling was based on available subjects. As temporal processing decreases after the fourth decade of life and this deterioration accelerates after the seventh decade of life [16], in the present study subjects under the age of 40 were selected to eliminate the effects of age on temporal processing. The study subjects had the following criteria: right-handedness, normal hearing at conventional audiometric frequencies (250–8000 Hz), lack of any otologic and neurologic disorder, not under any ototoxic medications, and no exposure to organic solvents. Subjects in the case group were working in the car body production line with exposure to the more than 85 dB A noise. They had more than 16 hours break from noise exposure before the test [5] to eliminate any TTS. Informed consent was obtained from all participants. The noise level was measured by the health care team at the factory, and it was recorded in workers' files. The following tests were conducted on the case (working in the car body production line) and control (working in the office without noise exposure) groups:

1) Examination of the head, neck, and external ear via otoscopy to be ensured of the healthy external ear, tympanic membrane and middle ear,

2) Immittance audiometry for ruling out any conductive deficit by Damplex Tymp87 (Denmark). Subjects with A type tympanogram were included.

3) Pure tone audiometry at octave frequencies from 250–8000 Hz by using Madsen ITERA (Denmark). Thresholds ≤ 25 dB were considered normal for the case and control groups [17].

4) Extended High Frequency Audiometry (EHFA) (10–16 kHz) was conducted by Beltone 2000 (USA) audiometer and Sennheiser HDA 200 headphones with the ascending-descending method. The lowest sound level at which workers could detect stimuli in 50% of times was considered the threshold.

5) DPST was performed by calibrated Dell Inspiron laptop, Beltone 2000 (USA) audiometer and Sennheiser HDA200 headphone. DPST was performed with the Musiek et al. [18] method. The 1000 Hz pure tone was presented with two different durations (short: 250 ms and long: 500 ms). We used patterns of three tones, with stimuli intervals of 250 ms and pattern intervals of 6 seconds. Finally, there were 6 final patterns (short-short-long, short-long-short, long-short-short, long-long-short, long-short-long, and short-long-long).

After instruction and trial items, 30 test items were presented for each ear, and the subjects' responses were scored. The participants had to repeat patterns verbally. The number of correct repetitions was multiplied by 3.33, and the percentages of correct responses were calculated for each ear.

Shapiro–Wilk test was used to test data distribution. The results showed that the data for 10 and 11 kHz in both ears and data for 12 kHz in the right ear were not normally distributed. But data for rest of frequencies had normal distribution. DPST data did not have a normal distribution. Therefore the independent t-test was used for comparing means of two groups for normally distributed data and Mann-Whitney U test for data without normal distribution. DPST scores lacked normal distribution in both ears, so the Spearman test was used for testing the correlation between EHF hearing threshold and DPST score. For comparing right and left ear, paired t-test was used for data with normal distribution and Wilcoxon test for data without normal distribution. The significance level for all the tests was < 0.05, and SPSS 23 was used for data analysis.

Results

The mean and standard deviation of age in the case group (36.38 ± 3.84 years) and the control group (36.33 ± 4.03 years) were obtained. Statistical analysis showed no significant difference between case and control groups in age ($p > 0.05$). Also, DPST and EHFA test showed no significant difference between the left and right ear in both groups of cases and controls ($p > 0.05$).

Extended high-frequency audiometry

Table 1 presents descriptive and analytic data obtained from the right and left ear of both case and control groups. The results indicate that in both groups the hearing thresholds increase with increasing test frequency, so that in both groups, with EHFA, the highest hearing threshold was observed at a frequency of 16000 Hz (105.66

Table 1. Descriptive and analytic data of extended high-frequency audiometry test in case (n = 15) and control (n = 16) groups

		Mean (SD)		
Frequency (kHz)	**Ear**	**Case**	**Control**	**p**
10	**Right**	29.00 (6.03)	28.75 (7.18)	0.861**
	Left	32.00 (7.02)	30.63 (10.14)	0.446**
11	**Right**	43.00 (9.41)	37.19 (7.73)	0.093**
	Left	44.67 (16.41)	36.25 (10.08)	0.066**
12	**Right**	49.67 (12.60)	43.44 (9.43)	0.202**
	Left	55.67 (14.50)	44.06 (10.68)	0.016*
13	**Right**	56.00 (15.83)	50.94 (11.43)	0.314*
	Left	66.67 (17.49)	51.88 (14.24)	0.015*
14	**Right**	75.00 (17.32)	59.69 (18.75)	0.025*
	Left	81.00 (19.65)	61.87 (19.90)	0.012*
15	**Right**	94.00 (15.02)	69.06 (18.09)	< 0.001*
	Left	95.33 (17.16)	70.00 (20.81)	0.001*
16	**Right**	106.00 (1284)	81.65 (13.13)	< 0.001*
	Left	105.33 (14.69)	81.88 (17.21)	< 0.001*

* Independent t-test
** Mann-Whitney test

dB in the case group and 81.71 dB in the control group) (Fig. 1). The statistical analysis showed that at 3 frequencies of 14, 15, and 16 kHz, the case group significantly had worse hearing thresholds than the control group (Table 1). Although in other frequencies, the mean hearing thresholds of the case group were worse than the control group, this difference was not statistically significant.

Duration pattern sequence tests

In both groups, DPST scores did not have a normal distribution. In both ears, the case group had significantly lower DPST scores than the control group (p = 0.019 for the right ear) and p = 0.03 for the left ear).

Correlation between EHF hearing threshold and DPST scores

Considering that in the case group, the hearing thresholds of 14, 15, 16 kHz and DPST scores were significantly different with the control group, the correlation between the hearing thresholds of EHF hearing threshold test and the DPST scores were examined in both ears (Table 2). The results indicated no linear correlation in all analyzed variables.

Discussion

Noise-induced hearing loss is one of the most common occupational and reversible disorders which happens in industrial environments. In the present study, ear effects were studied in

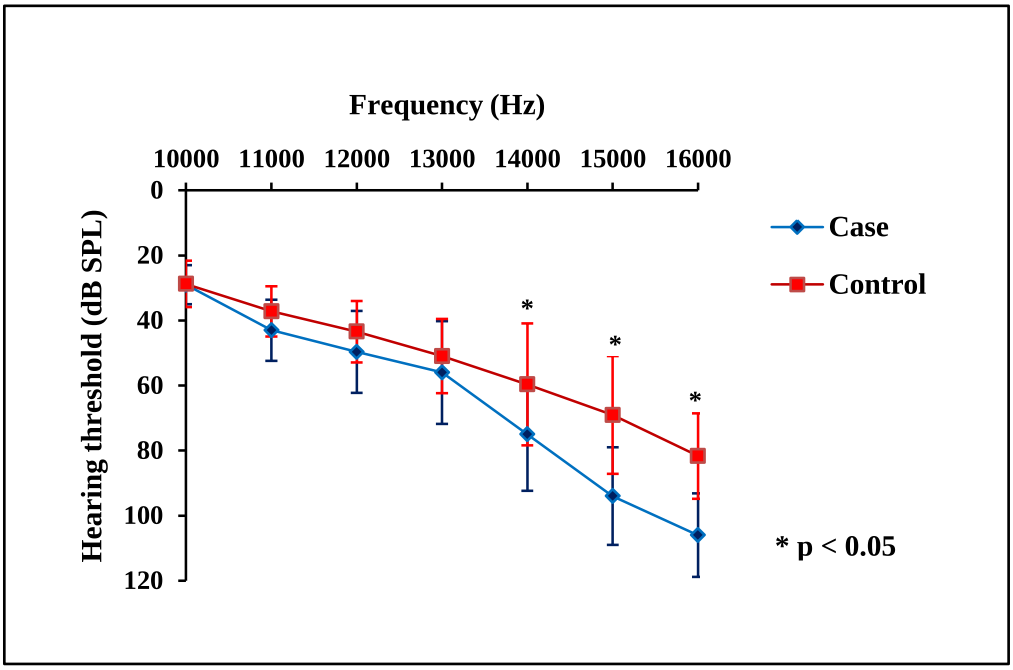

Fig. 1. Extended high-frequency hearing thresholds (10 to 16 kHz) in case (n = 15) and control (n = 16) groups.

DPST and EHFA, and there was not any significant difference between two ears. This finding was in line with Mehrparvar et al. [5] and Balatsouras et al. [19] results. The lack of ear difference shows that two ears are affected by the same extent in industrial environments [20]. Tajik et al. studied temporal processing differences between normal and dyslexic children. The results showed no significant difference between the two ears [8]. Mustek et al. studied DPST in subjects with cortical lesions and reported impaired results for both ears without any significant inter-ear difference. They believed that none of the hemispheres alone were capable of temporal pattern processing, and low scores was usually observed bilaterally [21]. There was no significant age difference between case and control groups in the present study because based on Somma et al. [22] findings, age has greater effects on extended high frequencies (9–18 kHz) than lower frequencies (less than 8 kHz). The results of the present study showed that auditory thresholds increase with test frequency, and the worst threshold was found at 16 kHz. This finding is in agreement with Türkkahraman et al. [6] finding. Some studies have shown that EHF hearing thresholds are considerably higher than conventional audiometric frequencies [6,23-25]. According to Mehrparvar et al. [5], most studies maintain that 16, 18, and 20 kHz frequencies are the most vulnerable frequencies to noise. Porto et al. studied conventional and extended high frequencies, and reported that the worst thresholds belonged to 6 and 14 kHz [25], but in the present study and da Rocha et al. study [26], only subjects with a normal hearing level at conventional frequencies were included. In general, it is demonstrated that noise exposure can affect EHF hearing threshold without any impact on conventional frequencies. This finding is in agreement with Wang et al. [27] results. They reported that the effects of the noise exposure on extended high frequencies (10–20 kHz) could be seen much earlier than lower frequencies (0.5–6 kHz). Therefore, EHF hearing threshold can be beneficial in the early detection of NIHL. Recently some studies have conducted on the noise effects on central auditory processing despite normal hearing thresholds [7,28]. However,

Table 2. Correlation between scores of duration pattern sequence test and extended high-frequency hearing thresholds

	Ear	Correlation coefficient (p)	
		Case	**Control**
10 kHz EHF hearing threshold/ DPST score			
	Right	0.24 (0.37)	0.05 (0.82)
	Left	-0.13 (0.62)	0.01 (0.95)
11 kHz EHF hearing threshold/ DPST score			
	Right	0.24 (0.38)	0.24 (0.35)
	Left	-0.33 (0.21)	-0.28 (0.27)
12 kHz EHF hearing threshold/ DPST score			
	Right	0.22 (0.41)	0.19 (0.47)
	Left	-0.18 (0.50)	-0.26 (0.31)
13 kHz EHF hearing threshold/ DPST score			
	Right	0.36 (0.17)	-0.01 (0.95)
	Left	-0.003 (0.99)	-0.40 (0.11)
14 kHz EHF hearing threshold/ DPST score			
	Right	0.23 (0.39)	-0.13 (0.62)
	Left	0.05 (0.85)	-0.31 (0.23)
15 kHz EHF hearing threshold/ DPST score			
	Right	0.05 (0.85)	-0.21 (0.41)
	Left	-0.03 (0.90)	-0.36 (0.15)
16 kHz EHF hearing threshold/ DPST score			
	Right	0.25 (0.36)	-0.24 (0.36)
	Left	0.27 (0.32)	-0.30 (0.25)

EHF; Extended high-frequency, DPST; duration pattern sequence test

these studies have focused only on conventional frequencies (250–8000 Hz). Temporal processing disorder and speech perception difficulty in noise in subjects with noise exposure might be secondary to extended high-frequency hearing loss. Therefore, Feng et al. studied temporal resolution and speech understanding in the frequency region with normal hearing in adults with sloping high frequency sensory neural hearing loss (at 4–8 kHz). [15]. Temporal resolution was evaluated by amplitude modulation detection and gap detection tasks. Speech perception was evaluated via hearing in noise tests. The patients with high-tone loss showed poor performance in both tests. Test stimuli were limited to the frequencies in which patients had a normal hearing threshold, so they suggested that the abnormality can be attributed to the extended high-frequency hearing loss. Therefore evaluation of the effects of EHF hearing thresholds on the central auditory processing in subjects with normal conventional audiometry can be helpful.

The present discussion aimed at reviewing the ways temporal processing can be affected in subjects with exposure to the occupational noise without any hearing loss at conventional frequencies. By comparing the results of the case and control groups, it turned out that EHF hearing thresholds can affect temporal processing. This finding is in agreement with Kumar et al. [7] results. They reported that poor DPST performance in normal-hearing subjects with noise exposure might be due to alterations in the central auditory system secondary to the prolonged exposure to noise. Based on Kujawa and Liberman reports, long duration of noise exposure can result in a fast and irreversible degeneration in spiral ganglion cells and a TTS so that neuron destructions may even persist in spite of hair cell and hearing sensitivity recovery. This reduction in neuronal population might affect temporal processing [29]. Time, duration, and frequency information of the stimuli are encoded at lower levels of the auditory system. It seems that neurons responsible for transmission and coding of these characteristics are located at the level of the inferior colliculus (IC). There are neurons at IC that are tuned to signal duration [30].

Willott and LU studied IC in rats with noise exposure and found that excessive noise exposure would cause unpredictable changes in the temporal pattern of the action potentials. Consequently, NIHL would make some changes in neural functions and temporal coding [31]. In addition, the adverse effect of brain damages on auditory pattern sequence recognition is a proven fact [21,32]. For that matter, DPST can be a suitable temporal processing test. Gold et al. tried to evaluate working memory in diabetic patients [33] and showed that grey matter in areas related to working memory (such as the hippocampus) had lower density. Seraji et al. studied the correlation between diabetes type I and DPST scores [34] and showed that these patients have lower DPST scores than the control group. So DPST is related to working memory function. Salame and Baddeley [35] reported that noise exposure could interfere with short-term working memory and auditory attention. As these two functions are vital for proper performance in DPST [7], noise exposure might lead to poor performance in DPST.

The present study failed to show any linear correlation between DPST and EHFA. This might be attributable to this fact that behavioral pure tone audiometry is simply a response of only a few inner and outer hair cells (IHCs and OHCs) and their related fibers [36]. Therefore normal hearing sensitivity in patients with noise exposure is not necessarily indicative of normal cochlear function. Animal studies show that it is possible to have a normal hearing sensitivity accompanied by cochlear dysfunction [29]. Otoacoustic emission (OAE) amplitude is the result of the cumulative activity of many OHCs, so OAE response is sensitive to cochlear defects and show changes accordingly; however, these changes might not be measurable by the audiometry [36]. Studying the correlation between OAE and DPST might address this issue, and it is highly recommended.

Conclusion

Noise exposure affects EHF hearing thresholds and temporal processing in spite of normal audiometric thresholds at the conventional frequencies. Therefore noise can distort supra threshold temporal cues considerably.

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Conflict of interest

The authors declared no conflicts of interest.

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