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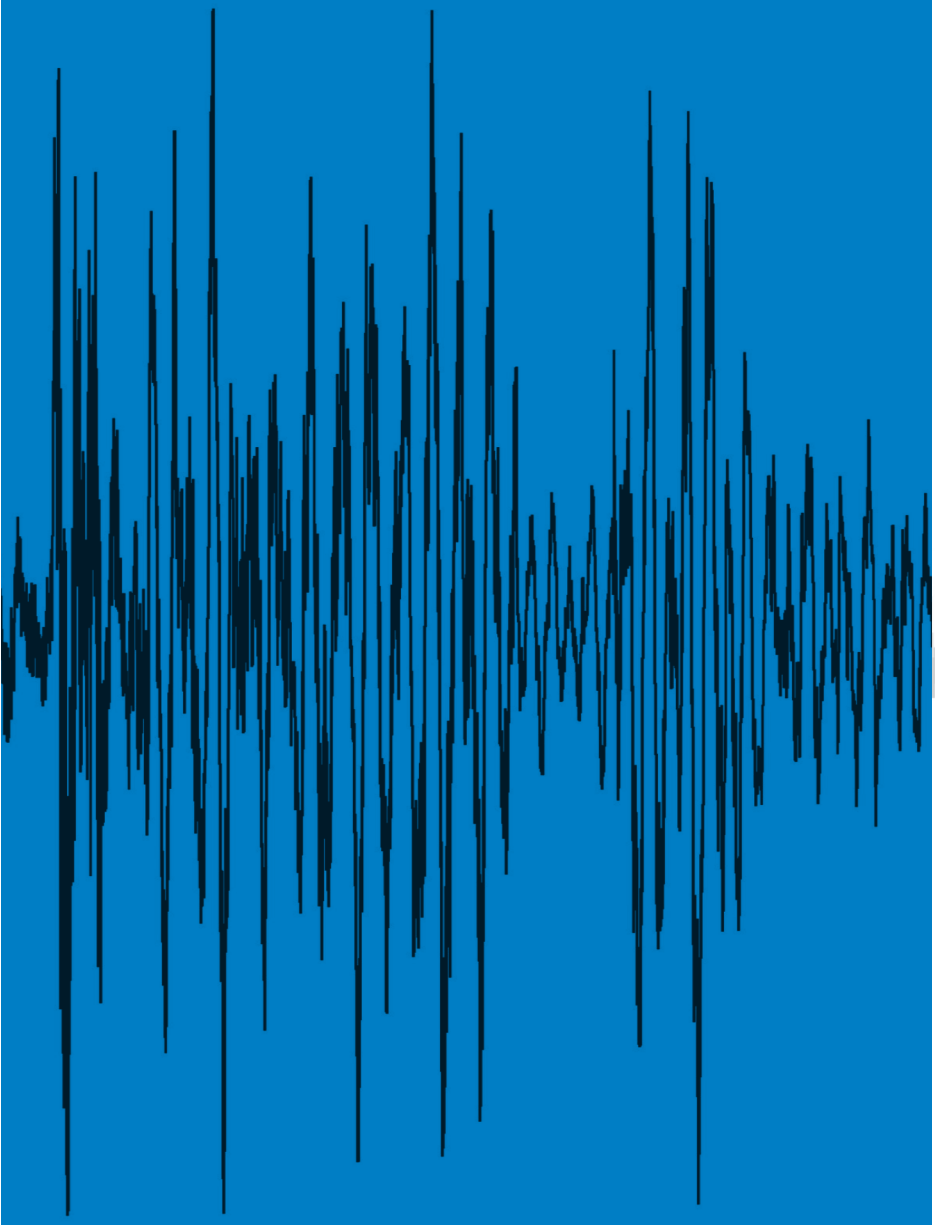

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High-frequency audiometry: A means for early diagnosis of noise-induced hearing loss

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Abstract

Noise-induced hearing loss (NIHL), an irreversible disorder, is a common problem in industrial settings. Early diagnosis of NIHL can help prevent the progression of hearing loss, especially in speech frequencies. For early diagnosis of NIHL, audiometry is performed routinely in conventional frequencies. We designed this study to compare the effect of noise on high-frequency audiometry (HFA) and conventional audiometry. In a historical cohort study, we compared hearing threshold and prevalence of hearing loss in conventional and high frequencies of audiometry among textile workers divided into two groups: With and without exposure to noise more than 85 dB. The highest hearing threshold was observed at 4000 Hz, 6000 Hz and 16000 Hz in conventional right ear audiometry, conventional left ear audiometry and HFA in each ear, respectively. The hearing threshold was significantly higher at 16000 Hz compared to 4000. Hearing loss was more common in HFA than conventional audiometry. HFA is more sensitive to detect NIHL than conventional audiometry. It can be useful for early diagnosis of hearing sensitivity to noise, and thus preventing hearing loss in lower frequencies especially speech frequencies.

Keywords: Audiometry, high-frequency audiometry, noise-induced hearing loss, noise

Introduction

Noise is the most pervasive hazardous agent in the workplace. Noise-induced hearing loss (NIHL), an irreversible disorder, is a common problem in industrial settings, especially where hazardous noise level (more than 85 dBA) is present.[1]

Occupational Safety and Health Association (OSHA) has set 90 dBA as the time-weighted average (TWA) for an 8-hour work day exposure to noise.[2] This limit according to National Institute of Occupational Safety and Health (NIOSH) is 85 dBA.[3]

Noise has deleterious effects on health and performance including NIHL.[1] NIHL is the second most common form of acquired hearing loss, after presbycusis[4] and has long been recognized as a problem in occupations associated with prominent noise.[1]

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NIHL is currently one of the most common occupational diseases and the second most frequently self-reported occupational injury.[4] Although NIHL is permanent, irreversible, and prevalent, it is preventable.[4] The OSHA hearing conservation amendment mandates audiometric surveillance of workers who are exposed to noise levels equal to or exceeding 85 dBA on an 8-hour time-weighted average.[5]

This routine audiometric testing is performed periodically among workers exposed to noise higher than 85 dBA. OSHA regulations require testing at the frequencies of 500, 1000, 2000, 3000, 4000 and 6000 Hz.[4] Routine audiometry is still restricted to 125-8000 Hz frequencies. NIHL mostly affects high frequencies (i.e., 4000 and 6000 Hz). Early diagnosis of NIHL can help us prevent the progression of hearing loss and its extension to speech frequencies (i.e., 500, 1000, 2000 and 3000 Hz).

Some other methods have been proposed for early diagnosis of NIHL, i.e., otoacoustic emissions (OAEs) and high-frequency audiometry (HFA). OAEs include low-intensity signals which are spontaneously produced by external hair cells in response to an acoustic stimulus and can be recorded in external ear canal. Presence of OAEs shows that cochlea is healthy.[6] OAEs are now used for diagnosis of functional hearing loss and malingering. Some studies have shown a higher sensitivity of OAEs than PTA for diagnosis of individuals with a high sensitivity to noise.[7,8]

HFA was introduced into clinical practice in the beginning of the 1960s.[9] Many studies have been performed in order to standardize and validate this test.[10-12] Recently it has been proposed that frequencies higher than 8000 Hz may be more sensitive than lower frequencies to noise, acoustic trauma or ototoxic substances, thus hearing loss in these frequencies after exposure to noise may predict NIHL in lower and especially speech frequencies; although there is still controversy about this issue.

There are some studies which have shown higher sensitivity to noise in the frequency range 10000 to 20000 Hz,[13-21] although some studies have not shown this sensitivity.[9,22,23] Some other studies have assessed the importance of HFA in evaluating the auditory effects of ototoxic substances or acoustic trauma.[24,25]

Ahmed *et al*. found a significant difference between conventional and high frequencies after exposure to noise and the most sensitive frequencies were 14000 and 16000 Hz.[17]

Porto *et al*. showed that extended high frequencies may be affected by noise sooner than conventional audiometry and 16000 Hz was the most sensitive frequency.[18]

Another study in Turkey showed the most affected frequencies being 4000, 6000, 14000, and 16000 Hz suggested that HFA should be used together with standard audiometry in the detection and follow-up of individuals who are at potential risks for hearing losses.[26] Kuronen found a significant temporary threshold shift in conventional and HFA after exposure to noise.[27]

Thus, considering the high incidence and irreversibility of NIHL, early diagnosis of it, before involvement of speech frequencies, is really invaluable. So in this study we compared the hearing threshold and frequency of hearing loss in conventional and HFA among workers exposed to noise.

Methods

In a historical cohort study in 2009, we compared the effect of noise on HFA and conventional audiometry.

Subjects

Two groups of subjects entered the study. The first group (case) consisted of 120 textile workers (108 males and 12 females) from two factories. These subjects were working in the spinning, weaving, and finishing sections with exposure to continuous noise more than 85 dBA (according to the results of noise monitoring). They would not have regularly used hearing protection devices. The second group (control) consisted of 120 workers from the same factories (106 males and 14 females) who were working in warehouse, guarding, and office sections without exposure to hazardous noise (according to the results of noise monitoring). The subjects were selected randomly.

Those older than 50 years or with the history of acoustic trauma, conductive hearing loss, exposure to ototoxic substances or ototoxic drug consumption were excluded from the study. After 16 hours removal from noise exposure, conventional audiometry was performed for the participants in both groups (using clinical audiometer: AC40, Interacoustic, Denmark, headphone: TDH39) and then HFA was perfomed for each participant, as well (same audiometer, headphone: Koss, R/80).

Audiometry was performed by an expert audiologist (blinded to the study) in an acoustic chamber, meeting standards ANSI 2004.[28] We considered hearing loss as hearing threshold more than 20 dBA in each frequency.[29] We defined hearing threshold in all frequencies and compared them.

The results of both tests were compared using SPSS (Ver. 17). Paired '*t*' test was used for comparison. A *P-value* of less than 0.05 was taken as the level of significance. An informed consent was filled for each participant.

Results

Table 1 shows the descriptive data of the subjects in both groups. There was not any significant difference between two groups in age and duration of employment.

Among the subjects of case group the highest hearing threshold in conventional audiometry was observed at 4000 Hz in left ear (22.87 dB), and at 6000 Hz in right ear (23.56 dB). In HFA the highest hearing threshold was observed at 16000 Hz (39.69 dB and 39.19 dB, in right and left ears, respectively). Table 2 shows mean hearing thresholds at different frequencies. Figures 1 and 2 show hearing threshold at all frequencies studied among the participants of both groups.

There was not any statistically significant difference between right and left ears in both groups. Hearing loss was more common in males than females, but the difference was not statistically significant (P=0.28, and P=0.18 for conventional audiometry and HFA, respectively).

Since in conventional audiometry, 3000, 4000 and 6000 Hz frequencies are three most sensitive frequencies to noise, we

Table 1: Descriptive data of the subjects of both groups

Variable	Mean	SD*	SE**	Significance
Age				
Case	33.64	5.22	0.48	0.3
Control	32.79	5.92	0.69	
Employment duration				
Case	10.72	5.01	.047	0.1
Control	9.59	4.88	.056	
Noise				
Case	89.07	2.38	.031	<0.001
Control	75.60	1.81	.022	

*Standard deviation. **Standard error of mean

Table 2: Mean hearing threshold in different frequencies in both groups

Audiometric frequency	Mean (±SD*)		Significance (95%CI)
	Case	Control	
250			
RE	9.57 (±2.52)	9.24 (±2.74)	0.3 (−0.44-1.10)
LE	10.17 (±3.56)	9.03 (±2.74)	0.2 (0.17-2.11)
500			
RE	10.13 (±3.19)	9.09 (±2.69)	0.02 (0.14-1.92)
LE	10.65 (±4.21)	8.82 (±2.72)	0.001 (0.73-2.93)
1000			
RE	11.29 (±5.44)	7.84 (±2.49)	<0.001 (2.09-4.79)
LE	11.08 (±4.99)	8.19 (±2.72)	<0.001 (1.62-4.16)
2000			
RE	13.31 (±9.02)	7.50 (±3.25)	<0.001 (3.63-7.99)
LE	12.52 (±8.03)	7.64 (±3.14)	<0.001 (2.92-6.84)
3000			
RE	16.55 (±12.00)	8.54 (±3.50)	<0.001 (5.14-10.87)
LE	18.30 (±11.75)	8.68 (±3.84)	<0.001 6.79-12.45)
4000			
RE	19.48 (±13.53)	9.31 (±3.96)	<0.001 (6.94-13.41)
LE	22.87 (±14.26)	9.65 (±4.84)	<0.001 (9.77-16.65)
6000			
RE	23.56 (±15.35)	10.97 (±5.01)	<0.001 (8.90-16.28)
LE	21.36 (±14.28)	11.11 (±5.45)	<0.001 (6.77-13.62)
8000			
RE	18.91 (±15.43)	10.76 (±5.61)	<0.001 (4.41-11.88)
LE	19.91 (±15.77)	9.93 (± 3.89)	<0.001 (6.24-13.72)
10000			
RE	10.10 (±13.79)	5.55 (±4.86)	0.08 (1.19-7.89)
LE	9.59 (±11.94)	4.72 (±3.74)	0.001 (1.99-7.75)
12000			
RE	12.92 (±16.88)	5.62 (± 7.26)	0.001 (3.11-11.49)
LE	11.41 (±15.45)	5.55 (±7.39)	0.003 (1.97-9.74)
14000			
RE	18.13 (±18.37)	7.22 (±8.47)	<0.001 (6.31-15.50)
LE	16.76 (±18.64)	6.45 (±8.02)	<0.001 (5.68-17.93)
16000			
RE	39.69 (±17.68)	10.48 (±12.31)	<0.001 (24.42-33.99)
LE	39.19 (±16.41)	9.79 (±10.39)	<0.001 (25.05-33.74)

*Standard deviation

compared hearing threshold at 16000 Hz with these three frequencies. In case group, hearing threshold was higher at 16000 Hz in both ears, and the difference was statistically significant for all frequencies (P<0.001 for each frequency in each ear); but this comparison did not show any significant difference in control group (P=0.18, 0.41, 0.72 for right ear 3000, 4000, and 6000 Hz; and P=0.39, 0.91, 0.28 for left ear 3000, 4000, 6000 Hz, respectively).

In all, 54.2% of cases had hearing loss at least in one ear and at one frequency in conventional audiometry. This measure was 87.6% at high frequencies. In control group subjects had hearing loss in conventional and HFA in 5.1% and 12.3%, respectively.

Prevalence of hearing loss in each frequency (higher than 2000 Hz) is shown in Table 3.

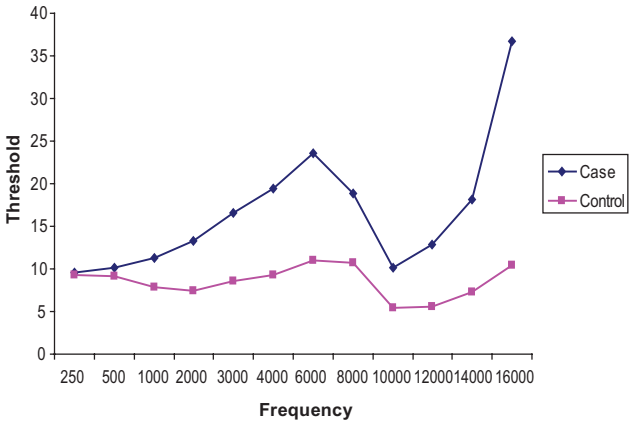

Figure 1: Hearing threshold in different frequencies in right ear

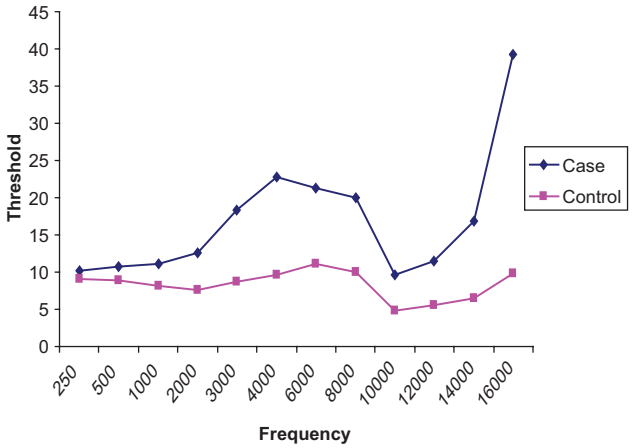

Figure 2: Hearing threshold in different frequencies in left ear

Discussion

Occupational hearing loss may be induced by noise, toxic substances or acoustic trauma. Occupational hearing loss due to noise is one of the most common occupational diseases. Audiometric evaluation of the subjects exposed to noise is a simple and inexpensive method for diagnosis of NIHL. Recently, HFA has been introduced as a better predictor of occupational hearing loss, especially NIHL in workers.

In this study we compared the effect of noise on conventional and HFA. Hearing threshold in HFA was significantly higher than conventional frequencies (250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz) which was consistent with some other studies.[18-21,26] In most studies 16000, 18000, and 20000 Hz were the most sensitive frequencies to noise.

Balatsouras *et al*. assessed HFA in persons exposed to impulse noise and their study did not find any statistically significant threshold difference between conventional and HFA.[23]

We found a higher incidence of hearing loss at 4000, 6000, and 16000 Hz, with 16000 Hz being the most sensitive frequency,

Table 3: Frequency of hearing loss in different frequencies in both groups

Audiometric frequency	Hearing loss (%)		Significance
	Case	Control	
3000			
RE	24 (20)	0 (0)	<0.001
LE	31 (25.8)	2 (1.7)	<0.001
4000			
RE	35 (29.2)	0 (0)	<0.001
LE	53 (44.2)	3 (2.5)	<0.001
6000			
RE	49 (40.8)	2 (1.7)	<0.001
LE	39 (32.5)	5 (4.2)	<0.001
8000			
RE	34 (28.3)	3 (2.5)	<0.001
LE	33 (27.5)	2 (1.7)	<0.001
10000			
RE	11 (9.1)	2 (1.7)	0.02
LE	12 (1)	0 (0)	0.002
12000			
RE	28 (23.3)	3 (2.5)	0.002
LE	22 (18.3)	3 (2.5)	0.002
14000			
RE	44 (36.7)	5 (4.2)	<0.001
LE	35 (29.2)	5 (4.2)	<0.001
16000			
RE	103 (85.8)	15 (12.5)	<0.001
LE	98 (81.6)	10 (8.3)	<0.001

which was consistent with some other studies.[18,21,26] In Türkkahraman's study hearing loss at 14 KHz was also common,[26] which was inconsistent with our study; in our study hearing loss at 14 KHz was clearly lower than 4, 6, and 16 KHz. Wang *et al*. found hearing loss in all high frequencies (10-16 KHz), but in our study hearing threshold at 10, 12, and 14 KHz frequencies was almost normal and lower than 4 and 6 KHz.[16]

Kuronen could not find a significant difference between conventional and HFA among pilots;[27] although he only assessed temporary threshold shift.

There was not any statistically significant difference between right and left ears in both groups in our study which was consistent with Balatsouras study. We could not find any statistically significant gender difference in conventional and HFA which was consistent with another study,[11] although our female subjects were much lower than male subjects.

Tanga *et al*. assessed HFA among workers exposed to ototoxic substances and found a greater sensitivity to these substances in high frequencies.[25]

Although many studies have shown the effectiveness of HFA in predicting NIHL, there is still controversy in this issue, but most recent studies were consistent with our study in this issue that performing HFA can help in the early diagnosis of NIHL.

So according to the results of this study, for early diagnosis of NIHL we can perform HFA during periodic or surveillance examinations of the workers who are exposed to hazardous noise. This may predict later hearing loss due to noise in conventional and speech frequencies. Studies with a follow-up period after pre-employment examinations can more precisely show the effectiveness of HFA for early diagnosis of NIHL.

Our study had some limitations. We could not assess 18000 and 20000 Hz frequencies because of our equipment limitations. The number of female subjects was much lower than male subjects.

Conclusions

HFA is more sensitive to detect NIHL than conventional audiometry. It can be useful for early diagnosis of hearing sensitivity to noise, and thus preventing hearing loss in lower frequencies especially speech frequencies.

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