Evaluation of Distortion Product Otoacoustic Emissions among workers exposed to different industrial noise levels

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Abstract: **Background**: Noise-induced hearing loss (NIHL) is usually one of the main problems in industrial settings. The use of otoacoustic emissions (OAEs) as a precise tool for investigating the properties of cochlea has been accepted**.** this study was aimed to evaluate changes in the signal to noise ratio (SNR) in different DPOAE's caused by exposure to different levels of noise at different time intervals among noise-exposed workers. **Materials and methods**: This case-control study was conducted on 45 workers in Gol Gohar mining and industrial company. The workers were divided into three groups. The signal to noise ratio (SNR) in the frequencies of 1000, 2000, 3000, 4000, 6000 Hz in both ears was measured in three different time intervals during the shift work. SNR of 6 dB or greater was considered as inclusion criterion. Repeated measurement, spearman correlation coefficient and paired t-test, analysis were used with $\alpha = 0.05$. **Results:** In all frequencies, in the right and left ear, the SNR values were more than 6 dB, thus 100% SNR values were considered as acceptable responses. The effects of SPL on SNR was significant for the right and left ears ($p= 0.027$, $p<0.001$). There was a statistically significant correlation between the SNR values in the right and left ears at the time intervals (7:30–8:00 am) and (13:30–14:00 pm), implying that an increase in the exposure duration will lead to declined SNR values ($p= 0.024$). **Conclusions**: The comparison of the SNR values revealed that in both the right and left ears (in all frequencies and the three different SPLs) the values decreased during the shift work.

[Orazanbox. **Evaluation of Distortion Product Otoacoustic Emissions among workers exposed to different industrial noise levels.** *Rep Opinion* 2017;9(5):93-98]. ISSN 1553-9873 (print); ISSN 2375-7205 (online). http://www.sciencepub.net/report. 9. doi:10.7537/marsroj090517.09.

Keywords: Hearing Loss, Noise-Induced, Otoacoustic Emissions, Signal-To-Noise Ratio.

Introduction

Noise is considered as the most common occupational hazard in industries in developed and developing countries (1). More than sixty million people in the world are exposed to excessive noise levels (>85 dBA) in their working environments (2). Harmful effects of noise have been identified (3). While noise level exceeds threshold level, it can have harmful effects on performance of various parts of body such as hearing, blood circulation, mind, and working performance (4). The most important and certain effect of noise is hearing loss Hearing loss resulted from noise is one of the most important occupational diseases. Therefore, damages resulted from noise have been reported as one of first ten harmful factors (5, 6). According to studies, only 7.4 to 10.2 million people in US and 30 to 50 million industrial workers in Europe are exposed to hearing loss caused by noise. According to the estimates of the World Health Organization (WHO), daily noise induced hearing loss (NIHL) imposes a financial burden of about 4 US Dollars (7, 8). Loss of neural sense of hearing is resulted from damages to hair cells (HCs). This damage generally causes hearing loss and sometimes defects of hearing (9). Several studies, applying industrial approaches and using pure tone testing, have been conducted to determine the effects of noise on hearing loss and probable mechanisms effective on its incidence, but such tests have some limitations for instance they are non-objective, have low sensitivity in diagnosis of defect, and do not offer more detailed information about the changes resulted from exposing to noise, there is need for more accurate tests. Early damages to hearing system in initial steps can not be diagnosed by pure-tone audiometry and this test is able to measure damages after the onset of irretrievable damages to hearing system (10). Otoacoustic emission (OAE) resulted from DPOAE reflects outer hair cells (OHCs) performance and acts as a valid test and is useful in order to test changes in cochlea (11, 12). Otoacoustic emissions are the results of biomechanics microscopic activities of healthy OHCs. This activity makes mechanical movement in cochlea that is transferred from tympanum to the outer ear and is reflected in auditory canal (13). By putting small microphone in outer auditory canal, we will be able to get and keep acoustic energy. The cochlea phenomena which make these emissions are called pre-neural phenomena (14), because they occur before a signal transfers to auditory nerve. Auditory emissions are very useful to explore cochlea OHCs (15). Auditory emissions include automotive auditory emissions and evoked otoacoustic emissions (transient otoacoustic, distortion product otoacoustic emission (DPOAE), and motive frequency otoacoustic emissions) (11). Medical tests of otoacoustic emissions have more advantages over other otoacoustic tests such as being objective, no need to acoustic environment, high precision, and high speed (16). In this study, DPOAE test was used to check otoacoustic cochlea performance. DPOAE is one of features of different types of OAEs. DPOAE measuring method is actually the recording of emissions made and reinforced in cochlea by certain frequencies of f_1 and f_2 (17). DPOAE test is an objective and non-aggressive test which uses the properties of frequency sensitivity to check otoacoustic damages (18). DPOAE is a valid test to detect otoacoustic damages that do not need listener's cooperation and is used for studies on animals, infants, and old people.

The distinction between the measured OAE emission and the background noise level can be shown by the signal to noise ratio (SNR); hence, when it is positive then it can indicate a measurable response over the background noise (19, 20).

So far, however, there has been little discussion about the effects of exposure to various noise pressure levels based on signal to noise ratio. The present study was designed to; (1) determine SNRs in 1000, 2000, 3000, 4000, 6000 Hz frequencies in the right and left ears of the workers exposed to different levels of noise at three time intervals, (2) determine the effects of various noise levels on SNR values in the right and left ears, and (3) determine the effects of the duration of exposure to noise on SNRs in the right and left ears.

Materials and methods

Participants

This cross - sectional study was performed on 45 workers of Gol Gohar mining and industrial company, Sirjan situated in south east of Iran during autumn 2014. Prior to conducting the study, subjects' hearing status was tested. Their general health conditions in terms of cardiovascular and mental conditions were also checked through reviewing their medical records which ultimately lead to the selection of the healthiest individuals. To control the potential confounding effects of shift work, only day shift workers were enrolled in the study.

Industry selection

Gol Gohar mining and industrial company was selected as an industrial setting for the present investigation. Workers in this industry are exposed to industrial noise. The workers are not exposed to thermal stress and vibration in their industrial workplace.

Study design

Prior to commencing the experiment, subjects were informed about the aim of the study. A written informed consent form was obtained indicating workers' willingness to participate in the study. The participants also completed a form which collected demographic data and their body mass index (BMI) was computed. The workers were divided into three groups on the basis of noise exposure; (1) 15 office workers as a control group with exposure to low level of noise, (2) 15 workers from manufacturing departments as a case group exposed to medium noise level, and (3) 15 workers from manufacturing departments as a case group exposed to high noise level. The Selected workers from the exposed groups (cases) did not use any hearing protection devices and normally performed light work (based on ISO 8996) (21). The SPLs intensities, as the environmental variables, were measured at different places of the company. For all the subjects in the control and both case groups, the DPOAE test was conducted at three different time intervals by an experienced audiologist; at the beginning of the shift and before exposure to noise (7:30-8:00 am) and during exposure to noise (10:30–11:00 am) and (13:30-14:00 pm) at frequencies of 1000, 2000, 3000, 4000, 6000 Hz.

Prior to the DPOAE test, the following requirements were evaluated; (1) Ear canals were kept free from blockage, (2) The ear-probe was fitted to the ear canal, (3) The probe was correctly placed in the ear canal, (4) Middle ear disorder was considered, (5) The subjects were calm, and (6) Noise-free environment was provided. (There would be no need for performing the test in a sound- proof room) (22).

Measurement

Noise

Ambient noise measurements were performed (ISO 9612) for each workstation using a sound level meter (CEL-440). Using CEL-282 calibrator, the sound level meter was calibrated right before the measurements (23).

Signal to noise ratio

The DPOAE test device (Vivosonic 2.5.2; Vivosonic, Toronto, Canada) was employed to measure SNRs at frequencies 1000, 2000, 3000, 4000, and 6000 Hz. The main reason for selecting the DPOAE test was its frequency selective nature. During the test, all the subjects were in sedentary positions. The f_2/f_1 was set as 1.22 and the levels of the signals were L_1=65 dB, L_2=55 dB SPL, respectively. Using small probes, the outer ear channel audio frequencies were sent to the tympanic membrane and it received the reflected sounds which were slightly delayed by a microphone embedded in the probe. Test procedures and recordings were performed in a silent room. In this study, the SNR in $2f_1$-f_2 was considered and evaluated as a response to DPOAEs at 1000, 2000, 3000, 4000, and 6000 Hz in the subjects' right and left ears separately. This range of frequencies was selected due to the susceptibility of the ears to hearing loss within this range. DP-NF was also used to calculate SNRs for the other three groups. The SNR of 6 dB or greater was considered as the inclusion criterion (24, 25).

Statistical analysis

SPSS18 software was used to analyze the collected data using statistical tests such as paired t-test, Spearman's rho, and repeated measurements analysis of variance. The results were considered as significant at p-value<0.05.

Results

Results of analysis of demographic characteristics

Table 1. Presents the mean age and body mass index of the three studied groups.

Results of Noise measurement

Table 1. Demographic characteristics of the subjects

Variables	Control group exposed to low noise level	Case group exposed to medium noise level	Case group exposed to high noise level
	Mean± SD	Mean± SD	Mean± SD
Age (years)	28.8±2.05	30.1±2.37	29.4±2.63
BMI (kg/m^2)	25.1±2.28	25.5±3.25	25.5±2.97

Table 2. Means and standard deviations of the SNRs at different frequencies in the right ear

SPL (dB)	Time (h)		Frequency (Hz)				
			1000	2000	3000	4000	6000
72 (Control group)	7:30-8 am	Mean	18.45	22.45	20.80	20.95	16.15
		SD	1.343	3.88	1.69	5.02	8.27
	10:30-11 am	Mean	16.80	21.00	19.10	17.90	16.10
		SD	1.97	2.40	1.97	5.79	7.91
	13:30-14 pm	Mean	14.90	19.05	16.80	14.70	14.75
		SD	5.51	1.767	4.66	8.76	4.31
(Case group) 88	7:30-8 am	Mean	23.53	20.60	21.80	20.76	18.93
		SD	1.42	.264	2.56	2.79	6.72
	10:30-11 am	Mean	20.70	19.50	19.73	21.06	18.26
		SD	0.86	0.96	0.90	1.62	6.05
	13:30-14 pm	Mean	19.23	18.70	17.66	20.16	17.33
		SD	0.30	1.56	2.34	1.50	4.29
103(Case group)	7:30-8 am	Mean	20.10	21.90	22.35	20.5	25
		SD	0.21	0.49	0.35	0.84	1.97
	10:30-11 am	Mean	19.50	20.40	21.15	19.15	20.4
		SD	0.42	0.56	2.33	0.49	0.49
	13:30-14 pm	Mean	18.40	19.25	19.85	19.10	21
		SD	4.66	0.07	1.34	0.84	1.41

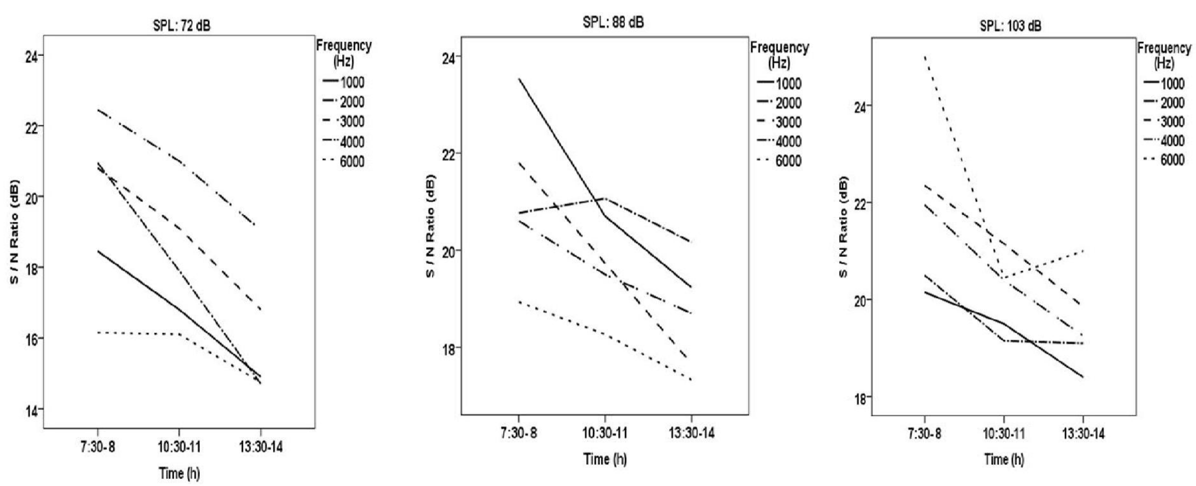

Figure 1: Means of the SNR values at different frequencies in the right ear

Having measured the SPLs in identified locations, the control group was exposed to a maximum level of 72 dBA SPL. Cases, in the two distinct groups, were exposed to noise levels of 88 and 103 dBA SPL.

Result of the alterations in the SNRs at studied frequencies in the right and left ears

In this study SNR≥6 was considered as inclusion criterion. After the evaluation of SNRs, it was found that at all the frequencies, SNR values were more than 6, hence all SNR values were considered as acceptable responses.

Table 2 demonstrates the means and standard deviations of the SNRs at the frequencies 1000, 2000, 3000, 4000, and 6000 Hz in the right ear at different SPLs and time intervals.

Figure 1 shows the means of the SNRs at 1000, 2000, 3000, 4000, and 6000 Hz frequencies in the right ear at different SPLs and time intervals. It is evident that as time moved towards the end of the shift work, the SNR values from the right ear declined. Such a decline happened at all frequencies and all SPLs.

Table 3 shows the means of the SNRs of the left ear at 100, 2000, 3000, 4000, and 6000 Hz frequencies at different SPLs and time intervals.

Table 3. Means and standard deviations of the SNRs at different frequencies in the left ear

SPL (dB)	Time (h)		Frequency (Hz)				
			1000	2000	3000	4000	6000
72 (Control group)	7:30-8 am	Mean	17.65	22.35	21.05	21.10	22.05
		SD	4.17	1.767	0.77	1.55	.21
	10:30-11 am	Mean	16.95	19.65	19.55	19.60	19.55
		SD	4.87	0.91	0.07	0.28	0.35
	13:30-14 Pm	Mean	13	18.60	19.10	19.25	16.40
		SD	6.61	0.42	0.28	0.21	0.42
88 (Case group)	7:30-8 am	Mean	24.86	21.5	21.2	23.40	18.56
		SD	3.63	0.60	2.77	1.55	5.65
	10:30-11 am	Mean	21.70	20	19.76	20.86	17.06
		SD	2.48	0.79	1.91	1.05	5.37
	13:30-14 pm	Mean	20.93	20.13	18.50	19.73	11.83
		SD	2.08	0.30	1.04	0.73	3.55
103 (Case group)	7:30-8 am	Mean	22.65	20.50	21.45	23.20	23.55
		SD	1.48	0.70	2.33	2.54	3.464
	10:30-11 am	Mean	20.10	19.05	20.15	21	21.55
		SD	0.56	0.07	0.77	1.13	2.33
	13:30-14 pm	Mean	19.80	18.20	17.65	19.45	19.75
		SD	0.56	1.41	2.33	0.35	0.77

Figure 2 illustrates the means of the SNRs at 1000, 2000, 3000, 4000, and 6000 Hz frequencies in the left ear at different SPLs and time intervals. It was observed that as the duration of exposure to noise increased, the SNR values decreased.

The effects of different factors on the SNR

Repeated measurement was used as a statistical method to study the effect of factors on the SNR. The results showed that the effects of age and BMI on the SNR was not statistically significant (P >0.05). The effect of the duration of measurement on the SNR was statistically significant in both right and left ear (p= 0.027, p<0.001). The SPL also showed a significant effect on the SNR in both right and left ears (p= 0.023, p= 0.041). Further analysis indicated that the SNR values of the right ear at the time intervals (7:30-8:00 am) and (13:30-14:00 pm) were statistically different (p= 0.024). Nevertheless, such differences between the time intervals (7:30-8:00 am) and (10:30-11 pm) and time intervals (10: 30-11:00 am) and (13:30-14:00 pm) were not statistically significant (P>0.05). Also the SNR values of the left ear obtained at the time intervals (7:30-8:00 am) and (13:30-14:00 pm) were significantly different (P<0.001). Also, there was a significant difference between the two means of the SNR values of the right and left ears at 3000 Hz for the SPL of 88 dBA. No significant difference was seen in the other frequencies (P>0.05). In the SPL of 103 dBA, there was a significant difference between the means at 3000 and 4000 Hz but there was no significant difference at the frequencies 1000 and 2000 Hz. Spearman's rank correlation coefficient showed that at 72 dBA SPL (control group) there was a significant correlation between the duration of exposure and SNR values in the left ear at 2000, 3000 and 6000 Hz, respectively and as the duration of exposure increased at these frequencies, the SNR values decreased.

Also, in the 88 dBA SPL, there was a significant correlation between the duration of exposure and SNR values at 1000, 2000 and 3000 Hz in the right ear. A similar relationship was found for the left ear at frequencies of 2000, 3000, and 4000 Hz. In 103 dBA, there was a statistically significant correlation between the duration of exposure and SNR values at 2000 Hz in the right ear and at 3000, 4000, and 1000 Hz in the left ear, respectively.

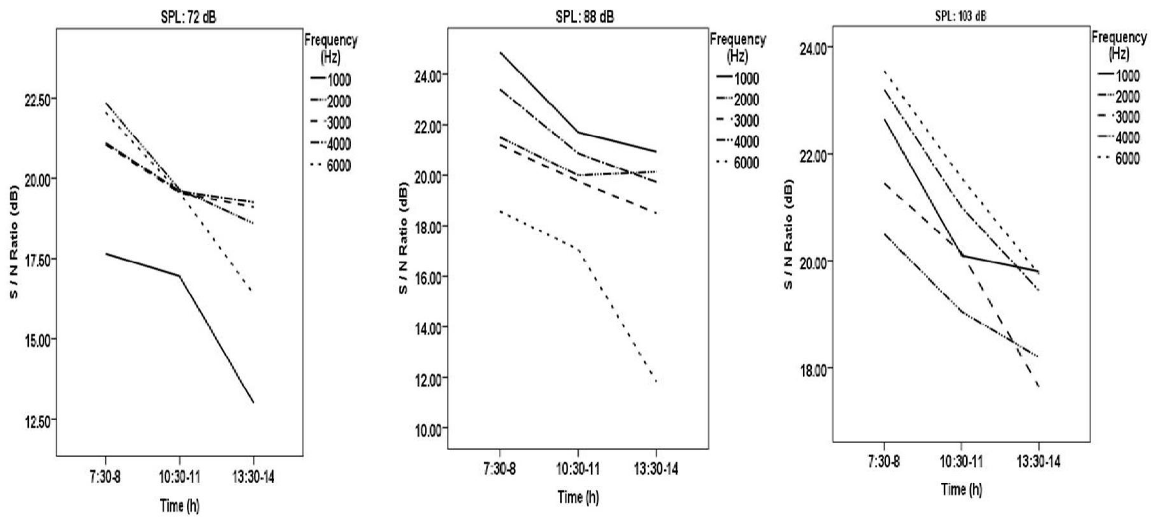

Figure 2: Means of the SNR values at different frequencies in the left ear

Discussion

In this study we evaluated the changes in the signal to noise ratio (SNR) using the DPOAE test. All subjects were in sedentary positions during the test. Researchers believed that inappropriate body postures would affect the results of DPOAE test. The change in body posture, changes the pressure inside the skull, and such a change in pressure in turn will affect the inner ear via spiral channel (26). Thus, to eliminate the confounding effects of possible uncomfortable postures on test results, all subjects were placed in a sitting position throughout the test.

In order to record DPOAE ($2f_1$-f_2) two signals of f_1 and f_2 (f_2>f_1) were used. The f_2/f_1 ratio was kept at 1.22 and the levels of these signals were L_1=65 dB and L_2=55 dB. The test was performed at 1000, 2000, 3000, 4000, and 6000 Hz frequencies with an SNR≥6. In the DPOAE test, SNR is commonly measured at 2000, 3000, and 4000 Hz and the SNR≥6 was also used for inclusion (24, 27, 28). Having evaluated the SNR values, it was found that in all the frequencies, in the right and left ear, the SNR values were more than 6dB, thus all SNR values were considered as acceptable responses.

Beattie et al. (2003) performed the DPOAE test on 50 individuals. They also made use of f_2 / f_1 ratio 1.19 for 550 Hz, 1.21 for 1, 2 and 4 kHz and stimulus level of 65 dB SPL along with SNR values of 3, 6 or 12 dB for inclusion. According to their results, acceptable measurements ranged from 42% to 66% at 0.55 kHz, from 92% to 98% at 1 kHz, from 86% to 96% at 2 kHz, and from 90% to 96% at 4 kHz (29).

Dreisbach et al. (2006) evaluated a group of distinctive parameters with f_2 varying between 16 to 2 kHz using either 25 or 24 points per octave. They made use of various stimulus level conditions for L_1/L_2 (60/45, 60/50, 70/55, and 70/60). They also reported the SNR of 6dB or greater for inclusion. Using 60/50% acceptable tests at 9 kHz, 11 kHz, 13 kHz and 15 kHz, the reported levels were 92%, 96%, 84% and 76% respectively (30).

In Wagner et al. (2008) study, they conducted the DPOAE test on 40 subjects. They used a range of primary tones which included 60, 50, 40, 35, 30, 25 and 20 dB SPL and a range of frequencies from 1 to 6 kHz. SNR of 6dB or greater was also used for inclusion which resulted in the exclusion of 4 subjects because of not meeting the SNR of 6dB (27).

In 2000 Beattie and Bleech, set a DPOAE test with 55 participants and used a protocol of L_1=L_2 and primary tone levels of 35, 45 and 55 dB; they had four pairs of frequencies with geometric means of 531, 1000, 2000, and 4000 Hz (ratio 1.21). Different sample sizes with 12, 25, 50, 100, 200, and 400 participants were tested. SNR> 3 dB was used for the selection. The greatest proportion of acceptable tests was seen with a stimulus level of 55 dB SPL, frequencies over 1 kHz (31).

Poole et al. (2010) used the DPOAE test for 33 subjects and made use of the protocol f_2/f_1 1.22. L_1=65 and L_2=55 dB SPL, 3 points per octave. They included the SNRs above zero in their analysis. Their proportion measurable tests ranged between 99% and 82% with the lowest proportion at 4 kHz (32)

Uchida Y et al showed that with increasing age, DPOAE amplitudes reduced (33). This study evaluated the effects of age and BMI on the SNR; the results showed that age and BMI did not have significant effects on the SNR. Therefore, after adjusting the effects of age and BMI, we investigated the effects of sound pressure levels and duration of exposure on the signal to noise ratio. The effects of time and SPL on signal to noise ratio in the right ear and left ear were significant; the ratio decreased in the left and right ears in a working shift, gradually from the beginning to the end of the shift. There was a statistically significant relationship between SNR values in the right and left ears at the two specific times of (7:30-8:00 am) (13:30-14:00 pm), and with an increase in duration of exposure, the signal to noise ratio reduced. The effect of time duration on signal to noise ratio was more significant in the left ear. This study showed that the frequency of 3000 was more affected. The findings of the current study are consistent with other studies. In accords with other researches, DPOAE was more sensitive to noise at high frequencies (3000, 4000, and 6000 Hz) (34, 35). Edward in 2008 and Balatsouras in 2005 showed that DPOAE was mainly affected at the frequency of 3 kHz (36, 37). However, the findings of the current study differ from Buchler et al. (2012) who found that DPOAE was most severely affected at 6000 Hz (38).

These results are consistent with those of other studies. Costa et al (2009) performed DPOAE test on 50 newborns. Results showed that 90% of them had acceptable responses to DPOAE test. The 3 kHz frequency band was also more affected and had better repeatability (39).

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