

Evaluation of Distortion Product Otoacoustic Emissions (DPOAEs) among workers at an Industrial Company exposed to different industrial noise levels in 2014Sajad Zare¹, Parvin Nassiri², Mohammad Reza Monazzam², Akram Poubakht³, Kamal Azam⁴, Taghi Golmohammadi⁵

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Abstract

Background: Noise-induced hearing loss (NIHL) is usually one of the main problems in industrial settings. The aim of this study was to determine whether changes in the signal-to-noise ratio (SNR) in different DPOAE are caused by exposure to different levels of noise at different time intervals among workers exposed to noise.

Methods: This case-control study was conducted in the autumn of 2014 on 45 workers at Gol Gohar Mining and Industrial Company, which is located in Sirjan in southeast Iran. The workers were divided into three groups based on their noise exposure, i.e., 1) 15 office workers as a control group with exposure to low levels of noise, 2) 15 workers from manufacturing departments who were exposed to a medium level of noise, and 3) 15 workers from manufacturing departments who were exposed to high levels of noise. The SNRs at the frequencies of 1000, 2000, 3000, 4000, and 6000 Hz were measured in both ears at three different time intervals during the shift work. SNRs of 6 or greater were considered as inclusion criterion. Repeated measures, the Spearman rank-order correlation test, and paired t-test analyses were used with $\alpha = 0.05$ being the level of significance.

Results: For all frequencies in the right and left ears, the SNR values were more than 6, thus all SNR values were considered as acceptable responses. The effects of time and sound pressure level (SPL) on SNR were significant for the right and left ears ($p = 0.027$ and < 0.001 , respectively). There was a statistically significant correlation between the SNR values in the right and left ears for the time intervals 7:30–8:00 A.M. and 13:30–14:00 P.M., which implied that an increase in the duration of exposure led to reduced SNR values ($p = 0.024$, $r = 0.948$).

Conclusions: The comparison of the SNR values in the right and left ears (for all frequencies and the three different SPLs) indicated that the values decreased during the shift work.

Keywords: hearing loss, noise-induced, otoacoustic emissions, signal-to-noise ratio

1. Introduction

Noise is considered to be the most common occupational hazard in industries in developed and developing countries (1). More than 60 million people in the world are exposed to excessive noise levels (> 85 dBA) in their work environments (2). Harmful effects of noise have been identified (3), and when the noise level exceeds a certain

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threshold, it can have harmful effects on various aspects of the human body, such as hearing, circulation of the blood, the functioning of the mind, and work performance (4). The most important and certain effect of noise is hearing loss, and this is one of the most significant occupational hazards. Therefore, the damage to hearing that results from excessive noise has been reported to be one of top 10 harmful work-related factors (5, 6). Various studies have indicated that 7.4 to 10.2 million people in the U.S. and 30 to 50 million industrial workers in Europe have incurred hearing loss caused by excessive noise. According to the estimates of the World Health Organization (WHO), noise-induced hearing loss (NIHL) has imposed a financial burden of about four million U.S. Dollars (7, 8). Loss of hearing results from the damage caused to hair cells (HCs) by excessive noise. This damage generally causes hearing loss and sometimes causes other defects in hearing (9).

Several studies have been conducted that used industrial approaches and pure tone testing to determine the effects of noise on hearing loss and the likely mechanisms involved. However, since such tests have some significant limitations, including their non-objectivity, low sensitivity in the diagnosis of defects, and failure to provide detailed information about the changes that result from exposures to noise, there is a need for more accurate tests. The initial steps that cause early damage to the hearing system cannot be diagnosed by pure-tone audiometry; rather, this technique can measure damage only after the onset of irreparable damage to the hearing system (10). Otoacoustic emissions (OAEs) that result from DPOAE reflect the performance of the outer hair cells (OHCs), and they serve as a valid test and are useful in assessing changes in cochlea (11, 12).

Otoacoustic emissions are the result of the microscopic biomechanical activities of healthy OHCs. These activities produce mechanical movements in the cochlea that are transferred from the tympanum to the outer ear and are reflected in the auditory canal (13). The cochlea phenomena that create these emissions are called pre-neural phenomena (14), because they occur before a signal is transferred to the auditory nerve. Auditory emissions are very useful in exploring the OHCs of the cochlea (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 significant advantages over other otoacoustic tests because they are objective, do not require a special acoustic environment, have high precision, and can be performed quickly (16). In this study, the DPOAE test was used to check the otoacoustic performance of the cochlea. DPOAE is one of features of different types of OAEs. The method used to measure DPOAE is to record the emissions made and reinforced in the cochlea by certain frequencies, i.e., f_1 and f_2 (17). The DPOAE test is an objective and non-aggressive test that uses the properties of frequency sensitivity to determine otoacoustic damage (18). DPOAE is a valid test for detecting otoacoustic damage because it does not require the listener's cooperation, and, in addition to studying people in the workplace, it can be used to study animals, infants, and older people.

The distinction between the measured OAE emission and the background noise level can be shown by the SNR; hence, when SNR is positive, it can indicate a measurable response over the background noise (19, 20). However, to date there has been little discussion about the effects of exposure to various sound pressure levels based on SNR. The specific objectives of the study were:

- 1) To determine SNRs at three time intervals for frequencies of 1000, 2000, 3000, 4000, and 6000 Hz in the right and left ears of the workers exposed to different levels of noise.
- 2) To assess the effects of various noise levels on the values of the SNR in the right and left ears.
- 3) To assess the effects of the duration of exposure to noise on values of the SNR in the right and left ears.

2. Material and Methods

2.1. Participants

This case-control study was performed in the autumn of 2014 on 45 workers at Gol Gohar Mining and Industrial Company in Sirjan, which is situated in southeast Iran. The hearing status of each of the subjects was tested prior to conducting the study. Their general health conditions in terms of cardiovascular and mental conditions also were determined by reviewing their medical records, which ultimately led 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.

2.2. Industry selection

Gol Gohar Mining and Industrial Company was selected as an industrial setting for this investigation. The workers are not exposed to thermal stress and vibration in the workplace.

2.3. Sampling method

This case-control study included a control group and two case groups; hence, the participants were selected so that the same number of participants could be placed in each of the three groups. Based on previous studies, with a power of 80% and first-type error of 0.05 ($\alpha = 0.05$), the appropriate number of participants was determined to be 45. The formula used to estimate the number of participants was based on the differences between the studied groups; as a result, the number of participants in each group was determined to be 15.

2.4. Study design

Prior to beginning the experiment, the participants were informed about the aim of the study. A written informed consent form was obtained from each participant indicating her or his willingness to participate in the study. The participants also completed a form that was used to collect demographic data, and their body mass indexes (BMIs) were calculated. A total of 45 workers were enrolled in the study on the basis of noise exposure, 15 office workers as a control group with exposure to low levels of noise, 15 workers from manufacturing departments as a case group exposed to a medium noise level (88 dBA), and 15 workers from manufacturing departments as a case group exposed to high levels of noise (103 dBA). The workers selected for the exposed groups (cases) did not use any hearing protection devices and normally performed light work (based on ISO 8996) (21). The intensities of the SPLs, as the environmental variables, were measured at different locations in the industrial facility. An experienced audiologist conducted the DPOAE test for all of the participants in the control group and in both case groups at three different time intervals, i.e., at the beginning of the shift before any exposure to noise (7:30-8:00 A.M.), during exposure to noise at frequencies of 1000, 2000, 3000, 4000, and 6000 Hz at 10:30-11:00 A.M. and 13:30-14:00 P.M.

Prior to the DPOAE tests, the following requirements were evaluated: 1) Ear canals were free of any blockage, 2) The ear-probe was fitted to the ear canal, 3) The probe was placed correctly in the ear canal, 4) Middle ear disorder was considered, 5) The subjects were calm, and 6) A noise-free environment was provided. (There was no need to perform the test in a sound-proof room) (22).

2.5. Measurement

2.5.1. Noise

Ambient noise was measured (ISO 9612) at each workstation using a sound-level meter (CEL-440) that was calibrated immediately before the measurements were taken using a CEL-282 calibrator (23).

2.5.2. SNR

The DPOAE test device (Vivosonic 2.5.2: Vivosonic, Toronto, Canada) was used to measure SNRs at frequencies of 1000, 2000, 3000, 4000, and 6000 Hz. The main reason for selecting the DPOAE test was its frequency-selective nature. During the test, all of 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 and $L_2 = 55$ dB. Using small probes, the outer ear channel audio frequencies were sent to the tympanic membrane, and it received the reflected sounds, which were delayed slightly by a microphone that was embedded in the probe.

The test procedures and recordings were performed in a silent room. In this study, the $2f_1 - f_2$ SNR was considered and evaluated separately in the subjects' right and left ears as a response to DPOAEs at 1000, 2000, 3000, 4000, and 6000 Hz. This range of frequencies was selected due to the susceptibility of the ears to hearing loss within this range. DP-NF also was used to calculate SNRs in studied groups. The SNR of 6 or greater was considered as the inclusion criterion (24, 25).

2.6. Statistical analysis

SPSS version 18 (SPSS, Inc., Chicago, Illinois, United States of America) was used to analyze the collected data using statistical tests, such as the paired t-test, Spearman rank-order correlation test, and repeated measures analysis of variance. The results were considered as significant at $p < 0.05$.

2.7. Ethical Considerations

Ethical approval was obtained from the Ethics Committee of Tehran University of Medical Sciences (ID: 1394.51). Informed consent was obtained before beginning the study. The data were reported on a confidential basis.

3. Results

3.1. Analysis of demographic characteristics

Table 1 presents the mean age and body mass index of the participants in the three groups that were studied.

3.2. Noise measurement

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

3.3. Changes in the SNRs in the right and left ears at the frequencies that were studied

In this study, $SNR \geq 6$ was considered as the inclusion criterion. After the evaluation of SNRs, it was found that the SNR values were > 6 at all of the frequencies, so all of the SNR values were considered as acceptable responses. Table 2 provides the means and standard deviations of the SNRs at the frequencies of 1000, 2000, 3000, 4000, and 6000 Hz in the right ear at different SPLs and time intervals.

Table 1. Demographic characteristics of the participants

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 A.M.	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 A.M.	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 P.M.	Mean	14.90	19.05	16.80	14.70	14.75
		SD	5.51	1.767	4.66	8.76	4.31
88 (Case group)	7:30-8 A.M.	Mean	23.53	20.60	21.80	20.76	18.93
		SD	1.42	.264	2.56	2.79	6.72
	10:30-11 A.M.	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 P.M.	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 A.M.	Mean	20.10	21.90	22.35	20.5	25
		SD	0.21	0.49	0.35	0.84	1.97
	10:30-11 A.M.	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 P.M.	Mean	18.40	19.25	19.85	19.10	21
		SD	4.66	0.07	1.34	0.84	1.41

Figure 1 shows the means of the SNRs at frequencies of 1000, 2000, 3000, 4000, and 6000 Hz in the right ear at different SPLs and time intervals. It is evident that time progressed towards the end of the shift work, the SNR values for the right ear decreased. Decreases occurred at all frequencies and all SPLs. Table 3 shows the means of the SNRs of the left ear at frequencies of -1000, 2000, 3000, 4000, and 6000 Hz at different SPLs and time intervals. Figure 2 shows the means of the SNRs at frequencies of 1000, 2000, 3000, 4000, and 6000 Hz in the left ear at different SPLs and time intervals. It was observed that the SNR values decreased as the duration of exposure to the noise increased.

3.4. The effects of different factors on the SNR

The statistical method of 'repeated measures' was used to study the effect of various factors on the SNR. The results showed that the effects of age and BMI on the SNR were not statistically significant ($p > 0.05$). The effect of the duration of the measurements on the SNR was statistically significant in both the right and left ear ($p = 0.027$ and $p < 0.001$, respectively). The SPL also had a significant effect on the SNR in both the right and left ears ($p = 0.023$

and $p = 0.041$, respectively). Further analysis indicated that the SNR values of the right ear at the time intervals of 7:30-8:00 A.M. and 13:30-14:00 P.M. were statistically different ($p = 0.024$). Nevertheless, such differences between the time intervals 7:30-8:00 A.M. and 10:30-11:00 P.M. and the time intervals 10:30-11:00 A.M. and 13:30-14:00 P.M. were not statistically significant ($p > 0.05$). Also, the SNR values of the left ear obtained at the time intervals of 7:30-8:00 A.M. and 13:30-14:00 P.M. 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 observed 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 of 1000 and 2000 Hz. The results of Spearman rank-order correlation test in control group members exposed to 72 dBA SPL showed that there was a significant correlation between the duration of exposure and SNR values in the left ear at 2000, 3000, and 6000 Hz, and the SNR values decreased as the duration of exposure increased at these frequencies. 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. At 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.

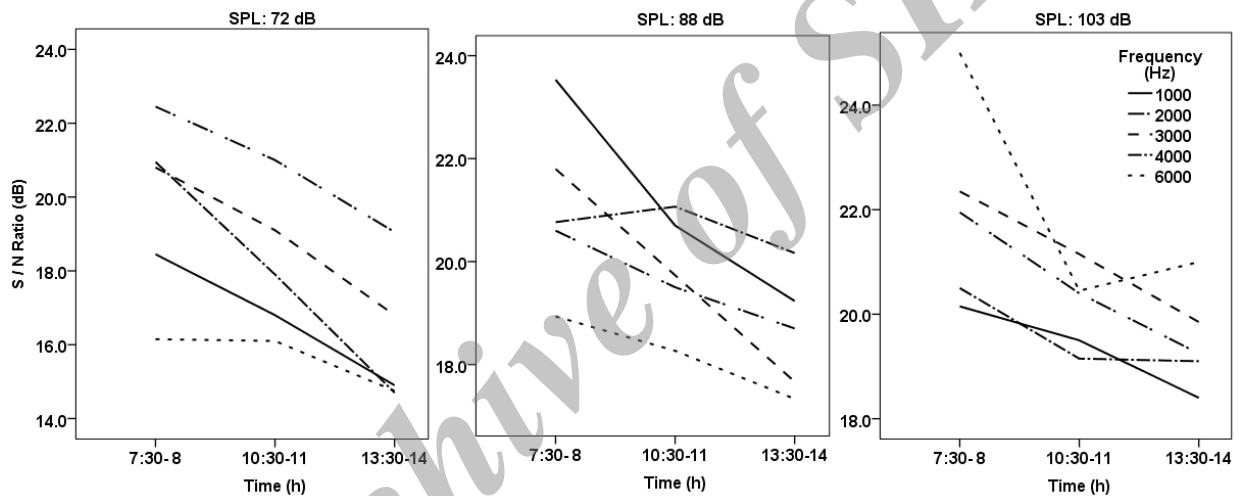


Figure 1. Means of the SNR values at different frequencies in the right ear

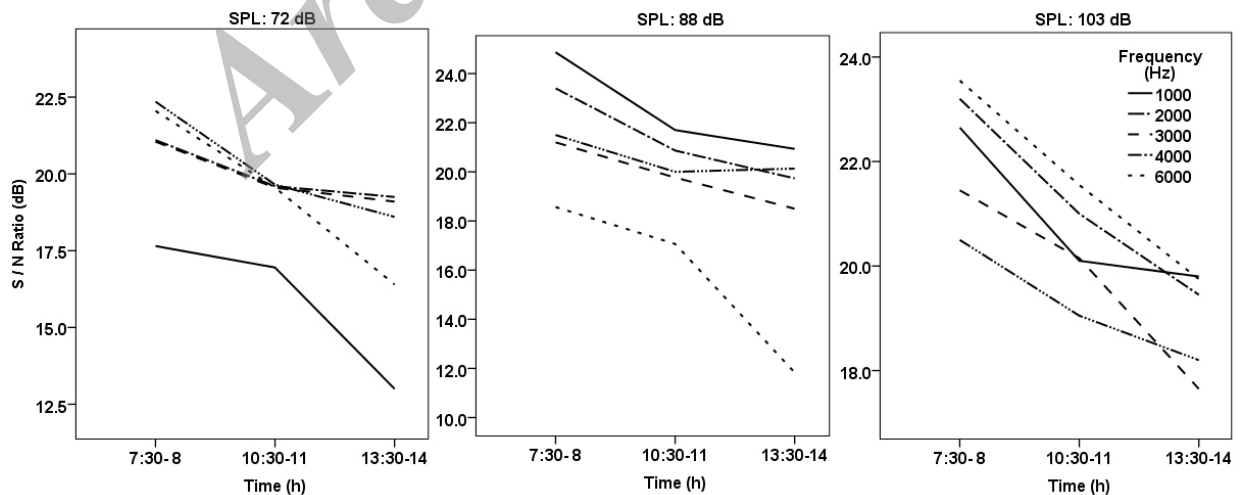


Figure 2. Means of the SNR values at different frequencies in the left ear

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 A.M.	Mean	17.65	22.35	21.05	21.10	22.05
		SD	4.17	1.767	0.77	1.55	0.21
	10:30-11 A.M.	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 P.M.	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 A.M.	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 A.M.	Mean	21.70	20	19.76	20.86	17.06
		SD	2.48	0.79	1.91	1.05	5.37
	13:30-14 P.M.	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 A.M.	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 A.M.	Mean	20.10	19.05	20.15	21	21.55
		SD	0.56	0.07	0.77	1.13	2.33
	13:30-14 P.M.	Mean	19.80	18.20	17.65	19.45	19.75
		SD	0.56	1.41	2.33	0.35	0.77

4. Discussion

In this study, we evaluated the changes in the SNR using the DPOAE test. All subjects were in sedentary positions during the test. The researchers believed that inappropriate body postures would affect the results of the DPOAE test. The change in body posture changes the pressure inside the skull, and such a change in pressure could, in turn, affect the inner ear via the 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 tests.

In order to record DPOAE ($2f_1-f_2$), two signals, i.e., f_1 and f_2 (with $f_2 > f_1$) 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 frequencies of 1000, 2000, 3000, 4000, and 6000 Hz with an $SNR \geq 6$. In the DPOAE test, SNR is commonly measured at frequencies of 2000, 3000, and 4000 Hz, and the $SNR \geq 6$ also was considered as the inclusion criterion (24, 27, 28). The evaluation of the SNR values indicated that the SNR values were greater than 6 - in the right and left ear for all of the frequencies, so all of the SNR values were considered as acceptable responses.

Some researchers have performed the DPOAE test on 50 individuals. Four frequencies in the range of 550 to 4000 Hz were used in the study. The f_2/f_1 ratio of 1.19 for the frequency of 550 Hz and the f_2/f_1 ratio of 1.21 for the frequencies of 1000, 2000, and 4000 Hz were used with the primary-tone level of 65 dB SPL. The results of study showed that the acceptable measurements for the frequency of 550 Hz were in the range of 42 to 66%. The acceptable measurements for the corresponding frequencies of 1000, 2000, and 4000 Hz were in the range of 92 to 98%, 86 to 96%, and 90 to 96%, respectively (29). Other researchers have used DPOAEs at different f_2 frequencies, ranging from 2 to 16 kHz. 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 an SNR value of 6 - or greater for inclusion. The reported acceptable test of 60/50% for the frequency of 9 kHz was 92%. The acceptable tests for frequencies of 11, 13, and 15 kHz were 96, 84, and 76%, respectively (30).

In a prior study, the DPOAE test was conducted on 40 subjects. They used primary-tone levels that ranged from 20 to 60 dB SPL and frequencies that ranged from 1 to 6 kHz. An SNR of 6 - or greater also was used for inclusion, which resulted in the exclusion of four subjects the SNR of 6 - was not met (27). In 2000, Beattie and Bleech conducted the DPOAE test with 55 participants and used a protocol of $L_1 = L_2$. The 35, 45 and 55 dB of primary-tone levels at geometric means of the frequencies of 531, 1000, 2000, and 4000 Hz with the ratio of 1.21 were used in the study. Sample sizes of 12, 25, 50, 100, 200, and 400 participants were determined for the study. $SNR > 3$ - was used for the selection. The frequencies over 1 kHz provided a high proportion of acceptable tests at the 55 dB SPL stimulus level (31).

In another study, researchers used the DPOAE test with 33 participants. They used the ratio of 1.22 for f_2/f_1 . The levels of L_1 and L_2 were 65 and 55 dB SPL with three points per octave. They included the SNRs above zero in their analysis. The proportion of acceptable tests was obtained in the range of 99% and 82%. The frequency of 4 kHz had the lowest proportion (32). Uchida et al. showed that, with increasing age, DPOAE amplitudes were decreased (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 SNR. The effects of time and SPL on SNR in the right ear and left ear were significant; the ratio decreased gradually in the left and right ears from the beginning to the end of the work shift. There was a statistically significant relationship between SNR values in the right and left ears at the two specific time periods of 7:30-8:00 A.M. and 13:30-14:00 P.M., and the SNR decreased as the duration of exposure increased. The effect of time duration on SNR was more significant in the left ear. This study showed that the frequency of 3000 Hz was affected the most. The findings of the current study are consistent with other studies. In accord with the findings of other researchers, DPOAE was more sensitive to noise at high frequencies, i.e., 3000, 4000, and 6000 Hz (34, 35). In 2005 and 2008, Balatsouras and Edward, respectively, showed that DPOAE was affected mainly at the frequency of -3000 Hz (36, 37). However, the findings of the current study differed from the results obtained by another researcher, who found that DPOAE was most severely affected at 6000 Hz (38). These results are consistent with findings of other studies. In a prior study, the DPOAE test was performed on 50 newborns, and the results showed that 90% of them had acceptable responses to the test. The 3 kHz frequency band also was more affected and had better repeatability (39). Therefore it was concluded that SNR values indicated that the values decreased during shift work in both the right and left ears for all frequencies and the three different SPLs. The limitation of this study was the small number of DPOAE devices that were prepared by the researchers with much effort.

5. Conclusions

This study showed that SNR values in both the right and left ears (in all frequencies and the three different SPLs) decreased during shift work. Since noise is the most common physical stress at workplaces and a high prevalence of hearing loss has been reported among Iran's industrial workers, further studies should be conducted to prove the importance of the issue for health policy makers.

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Conflict of Interest:

There is no conflict of interest to be declared.

Authors' contributions:

All authors contributed to this project and article equally. All authors read and approved the final manuscript.

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