h604 Edwards

Early identification of noise-induced hearing loss:

a pilot study on the use of distortion product otoacoustic emissions as an adjunct to screening audiometry in the mining industry

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ABSTRACT

This study investigated the feasibility of using Distortion Product Otoacoustic Emission (DPOAE) testing as an adjunct to pure-tone screening audiometry in the annual medical surveillance environment commonly found in the South African platinum mining industry. Signal-to-noise (S/N) ratios of the DPOAE test results conducted at two venues by a trained technician, the degree of hearing loss in platinum employees, the correlation between screening audiometry hearing threshold levels (HTLs) and DPOAE levels, and the ability of the DPOAE test to identify early NIHL in these employees were evaluated.

Most S/N ratios were within the acceptable levels of greater than 10 dBSPL, hearing levels were within the range of hearing that provide valid DPOAE levels, significant correlations were found between the HTLs from the screening audiometry and DPOAE testing, and in 73% of the 100 ears tested early NIHL could be identified before the pure-tone audiogram indicated evidence of hearing loss. This indicates that DPOAEs would be a feasible and useful an adjunct to pure-tone audiometry in this setting.

Key words: Distortion Product Otoacoustic Emission, DPOAE, early noise-induced hearing loss

INTRODUCTION

The screening audiogram is routinely used in the mining industry at the annual medical surveillance to measure the extent of employee's hearing loss. However, the cooperation of the employee being tested is required and the reliability of the audiogram is sometimes questioned when an employee exaggerates their hearing loss or when the results are negatively influenced by the language and cultural differences between tester and testee.[1] The ideal solution to these challenges is a reliable, sensitive and objective test of auditory function that provides valid results without a need for the person being tested to understand instructions or respond to test stimuli. Auditory Brainstem Response (ABR) and Auditory Steady State Response (ASSR) are objective measures for obtaining estimated hearing threshold levels but due to the high levels of expertise required by the tester and the need for sleep or even sedation in some cases during testing, these diagnostic methods are more suited to individual worker testing and would not easily become a routine part of screening testing in large workforces.[1]

Distortion-product otoacoustic emission (DPOAE) testing may be a solution, as it is a clinically feasible and sensitive tool for assessing the part of the ear that is damaged by noise exposure, namely the outer hair cells in the cochlea and has been shown to be a feasible method of evaluating the effectiveness of hearing protection devices (HPDs).[2-6] The value of the DPOAE test in an occupational audiology environment is its objectivity, because no active response is required from the subject, only passive cooperation,[2,3] its ability to reliably identify early cochlear damage due to noise, as well as the effects of temporary threshold shift (TTS),[7-10] its speed and cost-effectiveness,[3,9,11] and that the testing environment does not require a sound-proof booth but only a relatively quiet test room. However, these findings are for a diagnostic audiology or clinical environment where the tester is skilled in audiological testing.[1] There is a need to show the same reliability and validity of the test results when tests are conducted in a non-clinical environment, such as an annual medical surveillance environment, where the ambient noise levels in the testing area are not as easily controlled due to large numbers of people needing to be accommodated for testing. Furthermore, the same reliability and validity of test results has not been shown when tests are conducted by a less skilled tester such as an audiometrist or technician. Another aspect for investigation is whether the use of the DPOAE test in a population with pre-existing hearing loss, such as is found in the mining population, can provide reliable and valid test results. This is because DPOAEs disappear when the hearing loss exceeds a moderate range and if too many of the measurements were in this category the use of the test as an adjunct to audiometry would not be feasible. Finally, as NIHL is permanent and irreversible it is very important to identify early NIHL in order to facilitate effective prevention strategies. Although DPOAEs have been shown to identify early cochlear damage in military environments this has not been clearly shown in an industrial environment such as in the mining industry.

This pilot study evaluated the feasibility of using DPOAE testing as an adjunct to audiometry in annual medical surveillance in the mining environment. The objectives of the study were to evaluate the:

- S/N ratio of the DPOAE test results when the tests were conducted by a technician in different venues in an Occupational Health Centre where ambient noise levels are not easily controlled;
- the viability of DPOAE testing in a population that has been exposed to noise and therefore may have existing hearing loss;
- the correlation between screening audiometry HTLs and DPOAE levels; and
- the ability of DPOAE test results to identify early NIHL in the mining industry.

Methodology

Design

A cross-sectional descriptive and comparative study on noise-exposed platinum mine employees was conducted between January and April of 2008.

Population and sampling strategy

The population was noise-exposed mine employees undergoing annual screening audiometry at the Occupational Health Centres (OHCs) of Anglo Platinum's Mogalakwena Mine and at the Platinum Health Clinic in Makopane. The two venues had similar ambient noise levels since both had easy access to a relatively quiet room near the audiometry testing department. Throughout the year, up to 15 employees underwent annual medical surveillance each day at each of these OHCs. The HPD technician worked at both OHCs daily and saw employees after their audiometry testing in order to check their HPD. After explaining the purpose of the study, the technician approached employees to participate in the study, all of whom agreed. A sampling period of four months was considered sufficient length of time to provide a representative sample of the types of employees that would be tested at the two test venues and would allow an evaluation of the feasibility of DPOAE testing as part of annual medical surveillance.

A convenience sample of 56 employees was used. Each ear of each participant was treated as a separate record, yielding 122 records. The inclusion criterion to select records suitable for the study were normal middle ear function. Records were excluded if participants reported current medical treatment for ear problems or if tympanometry results indicated possible middle ear dysfunction. When applied, 100 of the original 122 records were included in the analysis.

Participants' ages ranged from 20 to over 60 years, with most within 25-30 years (22 participants) and 30-35 years (24 participants). Length of service was generally low, as 37 had worked for less than one year and the majority for three years or less. Only males were included as the time and costs related to being able to compare males and females was outside the scope of this study.

Procedures

Audiometric testing

Audiometric data were obtained from annual medical surveillance screening testing. No changes were made to the usual procedures to prevent disruptions to the routine and enable an assessment of the feasibility of incorporating standard DPOAE testing into current procedures. Registered audiometrists conducted the tests, using a calibrated automated Interacoustics AS216 audiometer and recording the results with the Everest Audio program version 2.04 at the mine and a calibrated Tremetrics RA650 automatic audiometer that was automatically recorded with the African Management Software Program at the town clinic. The researcher entered the hearing threshold levels of the eight frequencies from the printed audiogram into a Microsoft Excel® spreadsheet, and categorised the degree of hearing loss according to Table 1.

DPOAE recordings

DPOAE data were collected by the HPD technician immediately after the audiogram. The technician had received approximately two days of training on testing protocols from the equipment suppliers.

The otoscopic examination conducted during the annual medical surveillance process was repeated by the technician, who then conducted tympanometry to ensure that no middle ear condition existed that could effect the validity of the of the DPOAE measures. The tympanogram for both ears was printed using a GSI 33 Tympanometer.

DPOAE testing was performed with a GSI Audera instrument. The DPOAEs were elicited by the two primary frequencies f_1 and f_2 and the DPOAE-gram paradigm was used. Eleven f_2-stimulus frequencies were used and intensity levels of L1=65 dBSPL and L2=55 dBSPL were applied. Because extraction of the DPOAE data from the Audera machine proved to be a complex task, the DPOAE levels for the 11 frequencies and the signal-to-noise (S/N) ratio as calculated by the Audera were manually transferred to the same Microsoft Excel® spreadsheet as were the audiometric results. Table 1 also outlines the testing protocol and categories assigned to the results.

Ethical considerations

The accepted ethical considerations necessary for human research were adhered to throughout the study. Confidentiality was maintained by means of coded research records, informed consent was obtained and participants were assured of their right to withdraw without repercussions. The study protocol was approved by the Human Research Ethics Committee at the University of the Witwatersrand (Clearance Certificate Protocol No. M080906).

Data analysis

Statistical analysis was conducted using the SPSS package version 15 by a professional statistician. The One-Sample Kolmogorov-Smirnov Test was used to establish the distribution of data, which indicated that the Spearman's Rho Rank correlation test was the appropriate procedure to determine correlation. Correlations between the eight audiometric thresholds and the 11 DPOAE levels were calculated, as was the two-tailed significance of the correlations. Comparisons of the Spearman's Rho Rank correlations for all the variables, and the two-tailed significance of the correlations at the two test venues were then calculated.

Results

The results are presented according to the objectives of the study.

Signal-to-noise ratio of the DPOAE test results conducted in different venues in an OHC by a technician.

An acceptable S/N ratio is 10 dBSPL, meaning that the emission level and noise floor differ by 10 dBSPL.[2] The lower the S/N ratio the less reliable the results, and the greater the margin of error in recording results. The S/N ratio is directly related to the control of the ambient noise in the test venue, since the quieter the environment the easier it is for the recording equipment to distinguish between an emission from the cochlea and background noise. The results (Table 2) show that the ambient noise levels in the venues were sufficiently controlled to obtain results with an S/N ratio greater than 10 dBSPL at most frequencies. The lowest and highest frequencies did not reach an S/N ratio of 10 dBSPL, but the levels of 7.5 and 9.2 are still greater than 6 dBSPL, a level regarded as acceptable in clinical practice.[2,10]

Viability of DPOAE testing in a population that may have existing hearing loss

Screening audiograms were classified into three categories (see Table 1) to evaluate the viability of DPOAE testing in the mining industry, where many employees have existing hearing loss that varies, depending on length of service, noise exposure levels and their individual susceptibility to NIHL. The hearing levels in this sample were on average within normal limits, although 20% of participants presented with mild-to-moderate HTLs at certain test frequencies (Figure 1).

Figures 2 and 3 indicate the averaged DPOAE levels for the participants from both OHCs for all eleven of the f_2 –frequencies. The emission levels were found to be similar to those found in diagnostic DPOAE testing in a similar population.[1]

Correlations between screening audiometry HTLs and DPOAE results

Correlations were highest for the mid frequencies but, in general, were lower for screening audiometry (-0.01 to -0.57) than for diagnostic audiology (-0.20 to -0.73).[1] However, the correlations were statistically significant at most frequencies (see yellow areas in Table 3), particularly the higher frequencies. This finding is important since the high frequencies are those most affected by noise exposure and strong correlations in these frequencies would therefore make this test a valid measure in this population.

A comparison of results from the two test venues indicated that correlations between audiometric screening and DPOAE results were greater and more statistically significant for tests conducted at the clinic than for those conducted at the mine.

Ability of DPOAE test results to identify early NIHL in the mining industry

The DPOAE levels of participants with normal hearing on the audiogram but who had DPOAE levels that were out of the normal range described by the Vanderbijlt norms on the GSI machine were regarded as an early indication of cochlear damage.

Table 4 indicates that in 53 of the 73 participants (73%) who had normal hearing, DPOAE levels were below the expected Vanderbijlt range. This indicates that cochlear damage had already occurred, despite the lack of evidence on the screening audiogram.

Similarly, in the group of 26 participants who already had early hearing loss, in particular at the high frequencies, 11 (42%) had DPOAE levels that were lower than expected and therefore also indicated more cochlear damage than was shown by the audiogram. The remaining 15 (58%) participants in the early hearing loss group had DPOAE levels that were in line with what was expected for their degree of hearing loss, which confirms the validity of the test.

Discussion

The comparison of the S/N ratio between the two test venues revealed that both provided adequate S/N ratios, with the possible exception of the high frequencies tested at the mine.[1] However, the results for the high frequencies still comply with acceptable S/N ratios[2] and do not contraindicate the usefulness of this test in a mining occupational health environment. This suggests that if DPOAE testing is performed by a technician with some training in a screening environment similar to those of the current study, the results are reliable and valid and may provide a valuable adjunct to the current use of the audiogram.

The hearing levels of noise-exposed platinum miners were within the range of hearing that provide valid DPOAE levels, indicating that the use of this test as part of the annual medical surveillance is a feasible option. The correlations between DPOAE and audiometric testing were closer and more statistically significant at the clinic than at the mine, possibly because ambient noise levels were lower and more easily controlled at the former. At irregular intervals, large trucks passed by the mine venue causing higher ambient noise levels. This highlights the need to choose the DPOAE test venue carefully to ensure that ambient noise levels are as low as possible.[2]

The study results also support the use of DPOAE testing as an early indicator of NIHL in the mining industry and confirm the potential for using the test results as a counselling tool and a monitor for hearing conservation programme (HCP) efficiency, to help in the prevention of NIHL.[4,5] The potential of a reduction in the development of NIHL in 73% of the workforce would be sufficient to warrant the use of DPOAE testing for early identification of developing NIHL. If the DPOAE was then also employed to measure TTS and an indicator of the effectiveness of the HPD being used the impact on the HCP could be even greater.[3,4,6,9,10,12]

The fact that the correlations between DPOAE and screening audiometry results are not as close as those for diagnostic audiometry[1] may be due to the less stringent controls applied during screening, such as less soundproof booths and the presence of more ambient noise when large groups of people are being tested at the same time. Improved quality control of these factors for audiometric screening could provide closer correlations and, make it possible to use DPOAE testing in place of audiometry. However, further research with larger samples, more venues and more technicians would be necessary to properly evaluate the feasibility of such changes in annual medical surveillance procedures.

Conclusion and recommendations

The results of the pilot study provide the scientific evidence that DPOAE testing is feasible for use in a screening audiometry setting by a reasonably trained person. It appears that DPOAE testing would provide more information about the actual damage that is occurring in the cochlea if this test format became a regular part of annual medical surveillance testing. This in turn would provide evidence for counsellors of noise-exposed miners that will motivate them to protect their hearing and prevent NIHL and improve the success of hearing HCPs.

Acknowledgement

The authors would like to thank Leone van Coller for her assistance with the DPOAE testing for this study.

Lessons Learned

1. DPOAE is a feasible test to use in an occupational health centre environment.
2. Ambient noise control may improve correlations between screening audiometry and DPOAE results.
3. A trained technician can obtain reliable DPOAE results in an occupational health centre.
4. DPOAE testing appears to be a feasible tool for early indication of NIHL in the mining industry.

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Pull quotes

1 "The ideal solution . . . is a reliable, sensitive and objective test of auditory function that provides valid results . . ."

2 "The value of the DPOAE test in an occupational audiology environment is its objectivity, because no active response is required from the subject . . ."

3 "There is a need to show the same reliability and validity of the test results when tests are conducted in . . . an annual medical surveillance environment . . ."

4 "The S/N ratio is directly related to the control of the ambient noise in the test venue . . ."

5 "The comparison of the S/N ratio between the two test venues revealed that both provided adequate S/N ratios . . ."

6 "The correlations between DPOAE and audiometric testing were closer and more statistically significant at the clinic than at the mine . . ."

7 "The . . . results . . . support the use of DPOAE testing as an early indicator of NIHL in the mining industry . . ."

Table 1. Testing protocol and category criteria

Test	Test protocol	Category criteria
Audiogram	250Hz,500Hz,1000Hz, 2000Hz,3000Hz,4000Hz, 6000Hz, 8000Hz	Normal = thresholds at all eight frequencies less than 25 dBHL. Early NIHL = thresholds for any of the frequencies above 2000 Hz of between 20 and 35 dBHL. NIHL = thresholds at the frequencies above 2000 Hz greater than 35 dBHL.
DPOAE	633 Hz, 797 Hz, 996 Hz, 1266 Hz, 1605 Hz, 2027 Hz, 2555 Hz, 3234 Hz, 4055 Hz, 5133 Hz and 6434 Hz	Early identification = audiogram thresholds are categorised as normal but emission levels are lower than the normal Vanderbijlt norms as indicated on the GSI Audera Identified = audiogram thresholds are categorised as early NIHL but the emission levels are worse than would be expected for the degree of hearing loss. Consistent with normal hearing=audiogram thresholds are normal and DPOAE are within the Vanderbijlt norms.

Table 2. Comparison of signal-to-noise ratio between emission levels and noise floor at the two testing venues

f_2 Frequency	633 Hz	797 Hz	996 Hz	1266 Hz	1605 Hz	2027 Hz	2555 Hz	3234 Hz	4055 Hz	5133 Hz	6434 Hz
Clinic	8.9	11.3	13.3	14.6	15.6	14.6	12.6	13.7	19.9	15.2	7.9
Mine	10.0	12.8	13.4	15.9	15.2	14.9	12.5	14.2	20.3	17.1	6.4

S/N ratio is expressed as decibel sound pressure level (dBSPL)

Table 3. Correlations between screening audiogram thresholds and DPOAE levels

DPOAE f_2 frequency	633 Hz	797 Hz	996 Hz	1266 Hz	1605 Hz	2027 Hz	2555 Hz	3234 Hz	4055 Hz	5133 Hz	6434 Hz
	Correlation coefficient										
Audiogram frequency	Test venue : Clinic										
500 Hz	-0.3	-0.26	-0.32	-0.18	-0.15	-0.14	-0.28	-0.18	-0.22	-0.06	-0.24
1000 Hz	-0.13	-0.13	-0.2	-0.14	-0.03	0.02	-0.09	-0.12	-0.18	-0.13	-0.27
2000 Hz	-0.11	-0.11	-0.2	-0.24	-0.37	-0.47	-0.54	-0.6	-0.48	-0.59	-0.48
3000 Hz	-0.2	-0.18	-0.19	-0.25	-0.3	-0.4	-0.53	-0.71	-0.69	-0.67	-0.58
4000 Hz	-0.09	-0.08	-0.14	-0.1	-0.25	-0.3	-0.35	-0.58	-0.6	-0.66	-0.5
6000 Hz	-0.19	-0.2	-0.2	-0.3	-0.35	-0.43	-0.36	-0.5	-0.5	-0.58	-0.59
	Test venue: Mine										
500 Hz	-0.37	-0.28	-0.04	-0.06	0.00	-0.02	-0.11	-0.25	0.19	-0.02	-0.37
1000 Hz	-0.29	-0.15	-0.23	-0.25	-0.28	-0.41	-0.41	-0.43	-0.18	-0.33	-0.36
2000 Hz	-0.15	-0.09	-0.05	-0.11	-0.06	-0.25	-0.2	-0.41	-0.13	-0.27	-0.4
3000 Hz	-0.07	-0.08	0.11	0.13	0.14	0.08	-0.06	-0.38	-0.24	-0.28	-0.11
4000 Hz	-0.13	-0.05	0.1	0.11	0.1	0.06	0.05	-0.29	-0.49	-0.24	-0.08
6000 Hz	-0.37	-0.31	-0.1	-0.08	-0.03	-0.06	-0.17	-0.22	0.24	-0.03	-0.24

Yellow = Correlation coefficient is significant (2-tailed) $p<0.05$

Table 4. Indication of cochlea damage by DPOAE results

Degree of HL according to screening audiometry	DPOAE results						Total	
	Early identification		Identified		Consistent with normal hearing			
	n	%	n	%	n	%	N	%
Normal hearing	53	73	4	5	16	22	73	100
Early NIHL	11	42	15	58	0	0	26	100
NIHL	0	0	1	100	0	0	1	100
Total	64	64	20	20	16	16	100	100

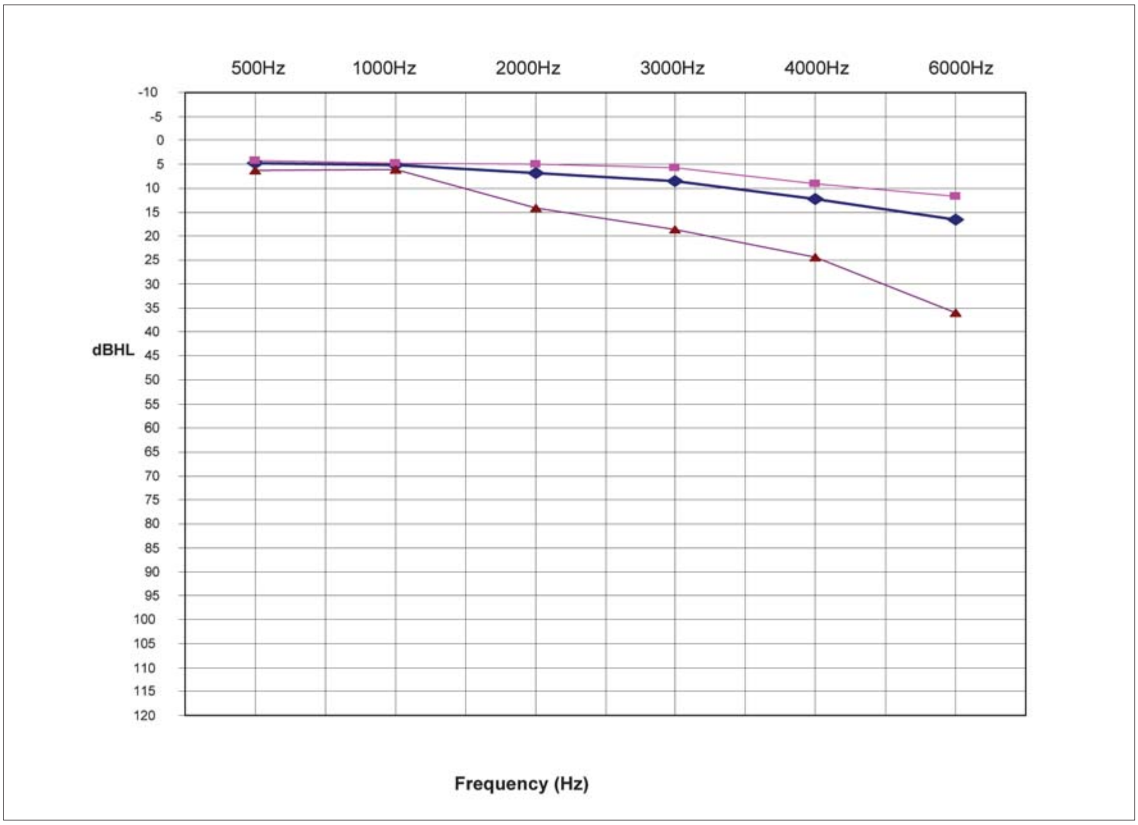


Figure 1. Average screening hearing threshold levels in a group of platinum miners

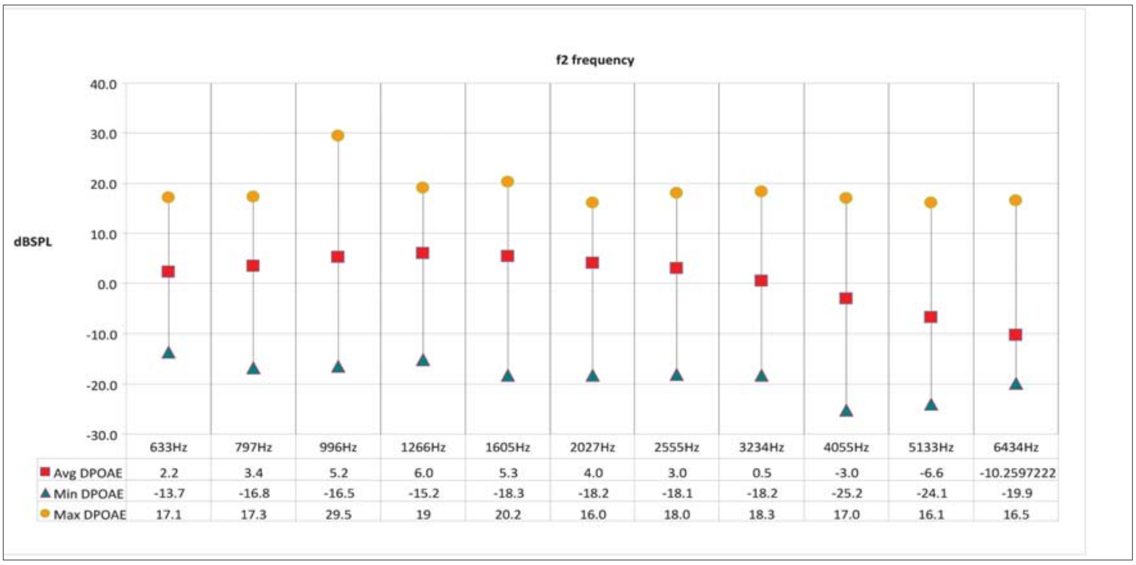
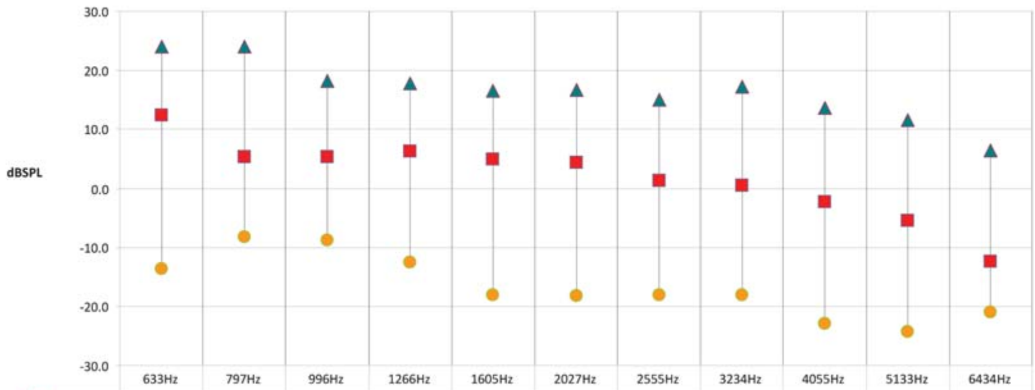


Figure 2. Average DPOAE levels of participants tested at the clinic



	633Hz	797Hz	996Hz	1266Hz	1605Hz	2027Hz	2555Hz	3234Hz	4055Hz	5133Hz	6434Hz
Avg DPOAE	12.4	5.4	5.4	6.3	5.0	4.3	1.3	0.5	-2.2	-5.5	-12.4
Max DPOAE	24.02	24.0	18.2	17.8	16.6	16.7	15.1	17.2	13.6	11.6	6.4
Min DPOAE	-13.7	-8.3	-8.8	-12.6	-18.1	-18.2	-18.1	-18.1	-22.9	-24.3	-21

f2 frequencies

Figure 3. Average DPOAE levels of participants tested at the mine

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