85 dBA: IS IT PROTECTIVE ENOUGH TO PREVENT HEARING LOSS IN SOUTH AFRICAN MINERS?

A Edwards
CSIR, Centre for Mining Innovation, Human Factors Research Group.

Abstract

Background: The Occupational Exposure Limit (OEL) for noise is legislated to be 85 dBA. However, owing to the energy of different frequencies the effect on the ear by sounds of different frequencies is known to vary. Also, there is recent evidence of the synergistic effect of chemicals and noise on the inner ear. Similarly, previous studies have shown that combined exposure to noise and exercise (workload) will cause greater cochlea stress than exposure to noise in isolation. A miner is not exposed only to noise in isolation. The environmental stressors that a miner may be exposed to simultaneously can include noise, heat and exercise, amongst others. The hypothesis is that the OEL which does not take into account complex exposure patterns may not provide adequate protection for miners' ears.
Method: A pilot study to evaluate the impact on the inner ear used otoacoustic emissions as a measure of stress to the cochlea was undertaken. Controlled exposure to noise, heat and exercise on a group of young healthy males and females was conducted using less than the prescribed OEL for noise. Pre-exposure and post-exposure otoacoustic measurements were compared to evaluate the impact of individual and combined exposures.
Results: Statistically significant differences were found between the pre-exposure and post-exposure otoacoustic measurements for noise as a stressor. Exposure to other health stressors did not appear to accentuate the effect on the cochlea.
Conclusion: The results appear to indicate that further investigation of the current OELs and the methods and aspects being measured is needed.

1. Background

Mining remains one of the most hazardous occupations in the world, both in terms of short-term injuries and fatalities and in terms of long-term impacts such as respiratory conditions and noise-induced hearing loss (NIHL), because dust and noise are inherently associated with rock breaking (Hermanus, 2007; Stephens and Ahern, 2001).

The effects of individual health stressors have been widely researched and in the current legislation the worker is protected by the Occupational Exposure Limits (OELs) set and adhered to by international standards (SAMOHP, 2002; DME, 1996). However, each OEL only takes into account the effect on a worker's health of the single health stressor to which it applies and gives neither theoretical nor practical recognition of the greater damage that can be caused when health stressors occur in combination in a workplace and how they impact on the person. The question of OEL validity is particularly relevant in the case of South African mineworkers, whose daily exposure to multiple stressors is often longer than the eight-hour period on which exposure limits are based.

In a working environment a miner is not exposed to only one health stressor at a time because the workplace is hot, dusty, and noisy and has poor ergonomic characteristics. There is progressively greater awareness in the research literature of the phenomenon of multiple occupational health (OH) stressor exposure and the impact of the synergistic effect of these stressors on a worker. As far back as 1976 Ashford is quoted as highlighting the fact that "hazards, whether chemical, physical, biological or stress, often combine in such a way that their effects are not merely additive but synergistic" (Eisler, 2003).

In the case of noise, a time weighted average (TWA_{8h}) of 85 dBA is the limit for safe exposure of the unprotected human ear (SANS 10083:2004; DME, 2002). However, noise exposure is a well-researched occupational stressor with regard to the impact of multiple stressors in synergy with noise. Noise and simultaneous chemical exposure, for example, have been found to increase the risk of developing hearing loss and balance problems (Fuente & McPherson, 2006). The reason appears to be that the hypoxia that occurs in the blood stream as a result of chemical exposure also affects the blood supply to the cochlea and thereby encourages the development of NIHL (Chen et al., 2007).

Temperature is believed to influence the biochemical properties of the outer hair cells (OHCs), and extreme cold or heat has been shown to reduce transient evoked otoacoustic emissions (TEOAEs) (Khvoles, et al., 1998). It has also been reported that body temperatures of above 38.4°C in humans significantly reduce the amplitude of TEOAEs (Ferber-Viart, et al., 1995).

Noise exposure in combination with physical work increases susceptibility to Temporary Threshold Shift (TTS) (Lindgren and Axelsson, 1988). TTS depends on the noise dose, and in a study by Chen et al.(2007) was found to be exacerbated by workload and heat stress. In addition, the development of TTS and potentially NIHL is accelerated by smoking, and hearing loss is accelerated by drugs for the treatment of tuberculosis (TB) and by HIV/AIDS (Khoza, 2007; Boggia et al., 2008).

Against the background provided above a pilot study was conducted to evaluate the protectiveness of the current OEL for noise for South African mineworkers, using the distortion product otoacoustic emission (DPOAE) measurement technique to evaluate OH stressors. Otoacoustic emission (OAE) testing has gained acceptance as a clinically practicable, sensitive and objective diagnostic measure of cochlear function (Hall, 2000; Kashiwamura, 1998). The procedure measures the echo or response from the inner ear's OHCs after a stimulus has been presented. The rationale for using OAEs as a measure in the study is the ease of testing and speed with which the OHC function can be evaluated (Hall, 2000). The objectivity and specificity with which the emissions can be measured is also a motivation for the use of this test (Sliwinska-Kowalska et al., 2006).

1.1 Research Question

The research question for this study was: Can significant differences be measured in OAE responses when participants are exposed to heat and humidity, physical exercise, and noise separately and are those differences greater when participants are exposed to the three health stressors in combinations?

1.1.1 Hypothesis

The research hypothesis was that the OH stressors of heat and humidity, noise and physical work would have measurable additive and cumulative effects on OAE responses.

2. Methodology

An experimental study under controlled and specified laboratory conditions was conducted, with the focus on each participant's responses to individual and combined stressors, as compared with his/her responses to baseline conditions.

2.1 Objectives

The objectives of the study were to compare:

1. Baseline values for DPOAE levels with responses to ***individual*** OH stressors, viz. heat and humidity, physical work, and noise;
2. Baseline values for DPOAE levels with responses to ***combinations*** of OH stressors (heat and humidity, physical work, and noise); and
3. The responses of male and female participants, considering DPOAE levels during exposure to individual and combined stressors (heat and humidity, physical work, and noise).

2.2 Participants

Eight male and three female volunteers between the ages of 18 and 30 were recruited to participate in the study. The climatic chamber available for controlled environmental conditions is only large enough to accommodate six participants at a time, and for this reason the experimental procedure was conducted in two sessions.

The sample size was not large enough for statistically valid deductions, but the study is regarded as the first stage in allowing researchers to determine the feasibility of using the measurement method in a real mining environment with larger sample sizes. It would also begin to quantify the individual and combined effects of health stressors. A small sample size was used because the experiment was part of a larger study that had as only one of its aims the evaluation of the synergistic impact of exposure to multiple health stressors, and because of the confined scope and financial limitations on time and costly equipment. Some of the limitations of the small sample size were counteracted by using each participant's baseline recordings as a control,.

Although the industry is predominantly male, females were included in the study because more information about the physiological responses of females to OH stressors is urgently required as legislation that leads to greater numbers of females in the mining workforce. The age of the participants was restricted to between 18 and 30 years, the age of most new recruits to the mining industry because researchers wanted to evaluate the effects of the selected health stressors on young, healthy, non-occupationally exposed people for comparison with miners' responses in subsequent research. The inclusion criteria listed below were, therefore, not aimed at having participants that were representative of the mining workforce with its high prevalence of conditions such as

HIV, TB, NIHL, and silicosis, but rather to provide information about a normal response to multiple health stressors.

2.4 Inclusion Criteria

The criteria for inclusion in the study were:

- Participants must have complied with the minimum acceptable standards of health used to determine fitness for work at an underground mine. This was confirmed by an occupational medical practitioner who had knowledge of these minimum standards.
- Participants must have had no middle ear pathology and have hearing within normal limits. An otoscopic examination, tympanometry and screening audiometry were used to ensure that these criteria were met.
- Participants must have had no recent occupational exposure to heat and humidity or noise.

If volunteers did not meet the inclusion requirements they were counselled and advised about whom to consult as necessary.

2.5 Data Collection

Data collection in the climatic chamber used the equipment listed and described below.

2.5.1 Otoacoustic Emissions (OAE)

Distortion product otoacoustic emissions (DPOAE) were measured using standard audiological equipment calibrated on a daily basis, with the precautions of controlling noise levels in the test area and ensuring satisfactory probe fit. Default settings for 8 stimulus frequencies ranging from 1kHz to 6kHz and intensities L1=65dBSPL and L2=55dBSPL were used as prescribed by the instrument manufacturer. OAEs were recorded using the instrument's computer software program and transferred to an Excel worksheet for analysis. A participant-numbering system was used to ensure confidentiality.

2.5.2 Climatic Chamber

The study was conducted in the CSIR Centre for Mining Innovation (CMI) climatic chamber to ensure precise control of temperature, humidity, and air velocity. Test conditions requiring physical work made use of graded stepping blocks chosen on the basis of each participant's body mass. The climatic chamber is equipped with loudspeakers to produce white noise for the noise exposure conditions. Noise levels were measured with a calibrated Class 1 (Precision Grade, IEC, 2002) sound level meter by the noise specialist member of the research team.

During rest periods, participants sat in a temperature-controlled room adjacent to the climatic chamber. A paramedic with all necessary resuscitation equipment was available during all exposure procedures. An occupational health practitioner was also on call.

2.6 Data Analysis

DPOAE results were entered into a spreadsheet. Descriptive statistics were calculated for the data set and used to evaluate the significance of differences between each individual's baseline results and results for the various test conditions.

2.7 Experimental Procedures

The researchers followed the experimental protocol summarised in Table 2.7.

Table 2.7 Summary of experimental procedures

Test day, stressor and duration of exposure	**Procedure**
Day 1	OAE testing
Baseline recordings: two hours	Sit quietly at room temperature (18,0°C wet-bulb/25,0°C dry-bulb) for baseline recordings
	OAE testing
Noise: two hours	Sit at room temperature (18,0°C wet-bulb/25,0°C dry-bulb), with 87 dBA white noise
	OAE testing
Day 2	OAE testing
Heat/humidity: two hours	Sit at 30°C wet-bulb/31.5°C dry-bulb
	OAE testing
	Rest at room temperature (18,0°C wet-bulb/25,0°C dry-bulb) for two hours. OAE testing
Physical work: two hours	Block-stepping at 12 steps per minute (35 watts) at room temperature (18,0°C wet-bulb/25,0°C dry-bulb) for ten-minute intervals, each followed by a 15-minute rest interval
	OAE testing
Day 3 Heat and physical work: two hours	OAE testing
	Block-stepping at 12 steps per minute (35 watts) at 30°C wet-bulb/31.5°C dry-bulb for ten-minute intervals, each followed by a 15-minute rest interval
	OAE testing
	Rest at room temperature (18,0° wet-bulb/25,0°C dry-bulb) for two hours. OAE testing
Heat and noise: two hours	Sit at 30°C wet-bulb/31,5°C dry-bulb, with 87 dBA of continuous white noise.
	OAE testing
Day 4	OAE testing
Physical work and noise: two hours	Block-stepping at 12 steps per minute (35 watts) at 18°C wet-bulb/25,0°C dry-bulb for ten-minute intervals, each followed by a 15-minute rest interval, with 87 dBA of continuous white noise
	OAE testing
	Rest at room temperature (18,0° wet-bulb/25,0°C dry-bulb) for two hours. OAE testing
Heat, physical work and noise: two hours	Block-stepping at 12 steps per minute (35 watts) at 30°C wet-bulb/31,5°C dry-bulb for ten-minute intervals, each followed by a 15-minute rest interval, with 87 dBA of continuous white noise
	OAE testing

A two-hour rest period was applied between test conditions, to eliminate the effects of the first exposure and avoid confounding the results, as well as to provide participants with an opportunity to rest and recover. Very little food was consumed by participants during the test day, as this would cause changes in metabolism and thermo-genesis, which could influence physiological responses. Small controlled snacks were given during the rest periods. Water was available in 250 ml quantities at 30-minute intervals during the course of each test day.

2.8 Ethical Considerations

Young participants were approached to participate in the study. A presentation was made to a group of prospective participants to explain the purpose of the research and the requirements for participation. Once prospective participants agreed to take part in the study, the informed consent form was given to each volunteer and the information was reviewed to ensure that all questions and concerns regarding the process were resolved. The volunteers were then required to sign their informed consent forms and arrangements for the induction session and the medical examination were made.

An occupational medical practitioner examined prospective participants to establish that they were in good health and to confirm the absence of any medical condition that would preclude exposure to the stressors that would be considered or the use of the physiological monitoring instruments.

A qualified and registered paramedic was present during each day of testing to safeguard participants' health and safety. The pilot study simulated exposure to OH stressors found in an underground mining environment, and for this reason researchers needed to ensure strict adherence to the relevant OEL to prevent any risk of harm or injury to participants.

In the case of noise, as a time weighted average (TWA_{8h}) of 85 dBA is the limit for safe exposure of the unprotected human ear, participants exposed to 85 dBA for eight hours without hearing protection will not be affected. In accordance with local and international standards for measuring noise levels (ISO 1990; SANS 10083:2004), researchers used a calibrated sound level meter and applied a 3 dB exchange or energy doubling rate. The 3 dB exchange rate dictates that, for each 3 dB increase above the 85 dBA OEL, the permissible time for safe exposure will be halved. This means that participants without hearing protection can be safely exposed to 88 dBA for four hours without risk of damage. To provide a margin of safety for participants' hearing, the study limited the noise level to 87 dBA for a period of two hours, after which a two-hour rest and recovery period was applied.

Separate ablution and changing facilities for female and male participants were provided to ensure dignity and privacy.

Confidentiality of participants' results was of utmost concern. No names or identity numbers were recorded on any of the data sheets or electronically. Participants were given access to their results and records if they so wished and a participant's results and records would be removed from the study if he or she chose to withdraw from the study.

Participation was strictly voluntary and each subject was given the right to withdraw at any stage if he or she wished to.

Informed consent was given by means of a signed form by those individuals who agreed to participate, after an induction and information-sharing meeting at which prospective participants' questions and concerns were addressed.

The study was presented to the Human Ethics Research Committee of the University of the Witwatersrand Health Sciences Department and approved as conforming to ethically acceptable standards.

3. Results

One of the presentation methods for DPOAE results is the use of a DP-gram, which uses the x-axis to represent the stimulus frequencies and the y-axis to represent the intensity of the emission. The DP-gram also indicates the 'noise floor'(NF) levels which represent the levels of ambient noise in the testing environment. The difference between the NF and the emission level is used clinically to evaluate the reliability of the emission measured since the testing environment should be as quiet as possible so as not to interfere with the extremely small emissions that emanate from the ear. The difference between the DPOAE level and the NF should be as large as possible but at least 3 to 6dBSPL (Hall, 2000). A clinically significant deterioration in cochlea function is regarded as a change of greater than 3 dBSPL (Khoza, 2007). The results of this study are depicted using DP-grams in Figures 3.1 to 3.4, which indicate averaged noise floor and averaged emission levels for all 11 participants at the respective test frequencies. Previous research has shown that females have slightly larger DPOAE levels than males (Dunckley & Dreisbach, 2004) but in the context of this pilot study, that included only three female participants, the differences were not regarded as significant enough to influence the findings and the results for all 11 participants were averaged.

Figure 3.1 shows that only at 2 375 Hz was there a clinically significant deterioration in cochlea function after two hours of noise exposure at 87 dBA. When physical exercise was combined with noise (Figure 3.2), there appeared to be a synergistic impact, since six of the eight frequencies tested had lower DPOAE levels after two hours of noise plus physical exercise. On the other hand, noise combined with heat (Figure 3.3) resulted in a less of an impact since clinically significant deterioration of emission levels occurred at only three of the test frequencies. When participants were exposed to all three stressors simultaneously (Figure 3.4), DPOAE levels deteriorated at five of the frequencies tested. When investigating the amount of deterioration that occurred, it can be seen that the emission levels deteriorated by between 1 and 4 dBSPL. The largest degree of deterioration in cochlea function, approximately 4 dBSPL, occurred when physical work was combined with noise.

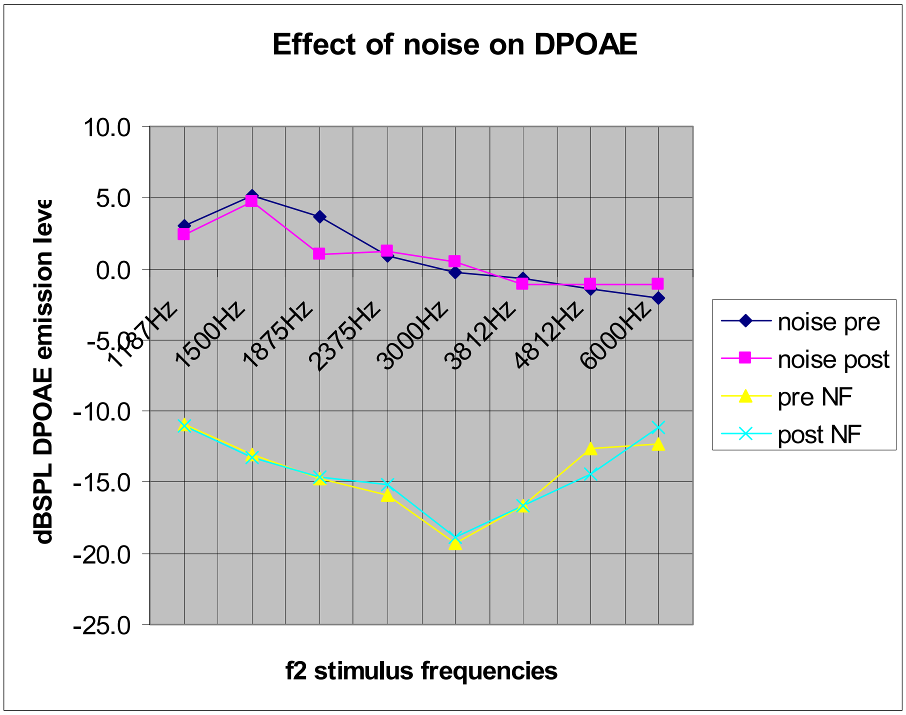

Figure 3.1 DPOAE comparisons of pre-noise exposure and post-noise exposure measurements

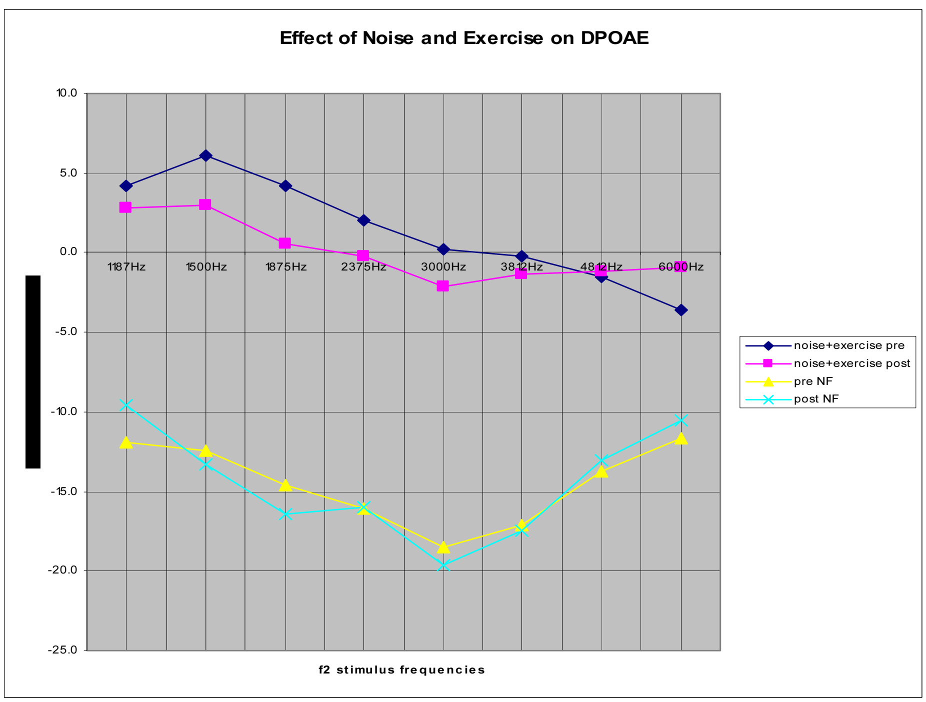

Figure 3.2 DPOAE comparisons of pre- and post-noise plus exercise exposure measurements

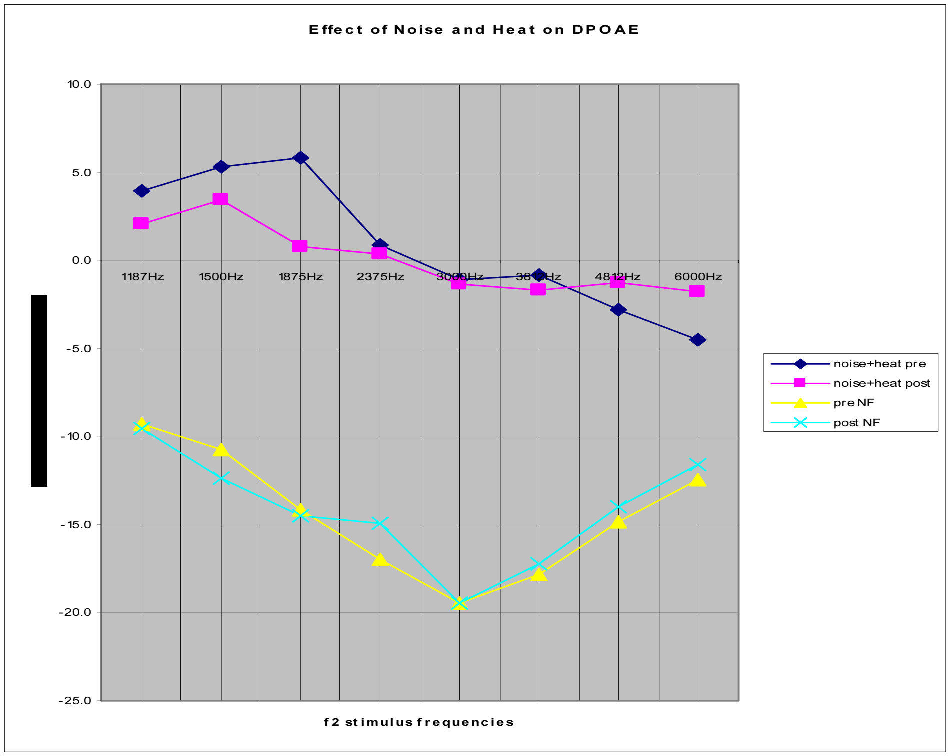

Figure 3.3 DPOAE comparisons of pre- and post-noise plus heat exposure measurements

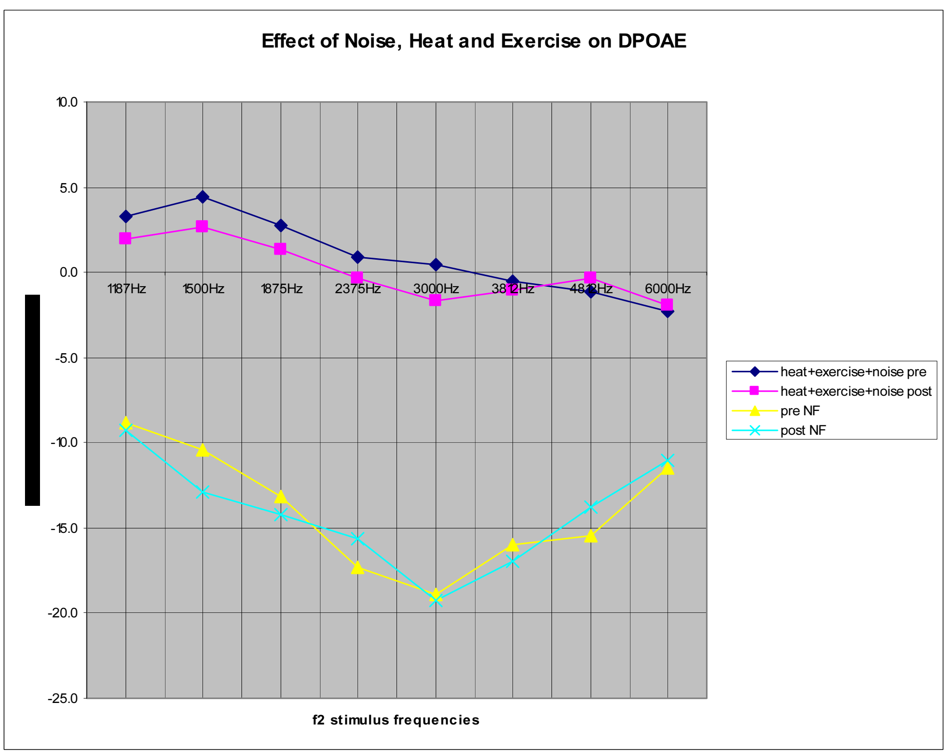

Figure 3.4 DPOAE comparisons of pre- and post-exposure to heat, noise and exercise measurements

A paired t-test was applied to the OAE measurements at each of the eight test frequencies before and after experimental condition (physical work; heat; heat+physical work; heat+physical work+noise; heat+noise; noise; noise+physical work). The assumption of normality of the differences between the paired samples was tested and found to be not satisfied. A non-parametric alternative test was performed (Wilcoxon signed ranks test), which indicated that the difference between the measurements before and after exposure was only marginally significant for heat+noise ($p<0.06$) and for heat+physical work+noise ($p<0.005$). To evaluate the differences between the conditions, a three-way analysis of variance (ANOVA) was performed, with gender as a fixed factor and frequency and experimental condition as random factors. No significant differences between the experimental conditions were found.

Table 3.1 Statistics of DPOAE averages for occupational health stressors

Experimental condition	**Z**	**Post–exposure minus pre-exposure** Asymp. Sig. (2-tailed)
Physical work	-0,621	0,534
Heat/humidity	-1,158	0,247
Heat+physical work	-1,802	0,072
Heat+physical work+noise	-3,489	0,000
Heat+noise	-1,933	0,053
Noise	-0,617	0,537
Noise+physical work	-0,656	0,512

The results of the preliminary investigation using DPOAE measurement appears to indicate that DPOAEs can give an indication of cochlear stress as a result of exposure to multiple health stressors and that emission level and noise floor differences are large enough to make this a practicable tool for use in a non-clinical environment. Finally, despite the lack of statistically significant results, DPOAE testing can be used to compare cochlear function on a pre- and post-exposure basis, since the use of pre-exposure results as a comparative index has been shown to be feasible in demonstrating changes in cochlear function.

4. Conclusions

The small sample size and the ethical restraint of exposing participants to safe levels of health stressors meant that the results of the experiment were not conclusive. However, there was evidence that the DPOAE can show the effects of exposure to occupational health stressors and that exposure to three stressors has a greater impact than exposure to one health stressor. DPOAEs appear to be affected by noise and heat exposure combined and by the impact of all three health stressors. The low frequencies were the most affected by the exposure to the health stressors.

This experiment is a first stage in allowing researchers to determine the feasibility of using the DPOAE method in a real mining environment with larger sample sizes and in beginning to quantify the individual and combined effects of health stressors.

The OEL as currently set, 85 dBA, is determined for an environment where noise is the only stressor. If other stressors are present, people may suffer hearing damage, even at the 'safe' level of 85 dBA. The findings of this experiment are encouraging in showing the effect of other stressors on noise induced hearing loss and warrant further investigation into whether the OEL for noise is protective in the South African mining environment.

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5. References

Boggia, B., Farinaro, E., Grieco, L., Lucariello, A., Carbone, U. 2008. Burden of Smoking and Occupational Exposure on Etiology of Chronic Obstructive Pulmonary Disease in Workers of Southern Italy. Journal of Occupational & Environmental Medicine, 50(3):366-370.

Campbell, K.C., Meech, R.P., Klemens, J.J., Gerberi, M.T., Dysstad, S.S., Larsen, D.L., Mitchell, D.L., El-Azizi, M., Verhulst, S.J. & Huges, L.F. 2007. Prevention of noise- and drug-induced hearing loss with D-methionine. Hearing Research, 226, 1-2: 92-103.

Chen, C., Dai, Y., Sun, Y., Lin, Y. & Juang, Y. 2007. Evaluation of auditory fatigue in combined noise, heat and workload exposure. Industrial Health, 45: 527-534.

Chen, G., & Zhao, H. 2007. Effects of intense noise exposure on the outer hair cell plasma membrane fluidity. Hearing Research, 226, 1: 14-21.

DME. 1996. Mine Health and Safety Act, Act 29 of 1996. Pretoria: Republic of South Africa, Department of Minerals and Energy.

DME. 2002. Guideline for the compilation of a mandatory code of practice for an occupational health programme (Occupational Hygiene and Medical Surveillance) on Thermal Stress, DME Reference Number 16/3/2/4-A2. Pretoria: Republic of South Africa, Department of Minerals and Energy.

Dunckley, K. T., & Dreisbach, L. E. (2004). Gender effects on high frequency distortion product otoacoustic emissions in humans. Ear and Hearing, 25(6), 554-564.

Eisler, R. 2003. Health risks of goldminers: A synoptic review. Environmental Geochemistry and Health, 25: 325–345.

Ferber-Viart, C., Savourey, G., Garcia, C., Duclaux, R., Bittel, J. & Collet, J. 1995. Influence of hyperthermia on cochlear micromechanical properties in humans. Hearing Research, 91, 1-2: 202-207.

Fuente, A. & McPherson, B. 2006. Organic solvents and hearing loss: The challenge for audiology. International Journal of Audiology, 45, 7: 367.

Hall, J.W. 2000. Handbook of Otoacoustic Emissions. San Diego: Singular Publishing.

Hermanus, M. 2007. Occupational health and safety in mining-status, new developments, and concerns. The Journal of the South African Institute of Mining and Metallurgy, 107(August): 531-538.

IEC. 2002. IEC 61672-1:2002 Ed. 1.0, Electroacoustics – Sound level meters – Part 1: Specifications. Geneva: International Electrotechnical Commission.

ISO. 1990. ISO 1999:1990, Acoustics – Determination of occupational noise exposure and estimation of noise-induced hearing impairment. Geneva: International Organization for Standardization.

Khoza, K. (2007). An investigation and monitoring of the auditory status in a group of adults with AIDS receiving anti-retroviral and other therapies attending a provincial hospital HIV/AIDS clinic in Johannesburg, South Africa. Electronic Theses. The University of the Witwatersrand. Johannesburg South Africa. www.wits.ac.za Retrieved Feb 2009.

Khvoles, R., Freeman, S. & Sohmer, H. 1998. Development of transient evoked otoacoustic emissions in the neonatal rat. Audiology & Neuro-Otology, 3, 1: 40-53.

SANS 10083:2004. The measurement and assessment of occupational noise for hearing conservation purposes. Pretoria: South African Bureau of Standards.

Sliwinska-Kowalska, M., Dudarewicz, A., Kotylo, P., Zamyslowska-Szmytke, E., Pawlaczyk-Luszczynska, M., & Gajda-Szadkowska, A. (2006). Individual susceptibility to noise-induced hearing loss: Choosing an optimal method of retrospective classification of workers into noise-susceptible and noise-resistant groups. International Journal of Occupational Medicine and Environmental Health, 19(4), 235-245.

Stephens, C. & Ahern, M. 2001. Worker and community health impacts related to mining operations internationally: A rapid review of the literature. London: International Institute for Environment and Development, Mining, Minerals and Sustainable Development, Project 25.

South African Mines Occupational Hygiene Programme Code Book (SAMOHP). 2002. Pretoria, Republic of South Africa: Department of Minerals and Energy, Mine Health and Safety Inspectorate.

Lindgren, F. & Axelsson, A. 1988. The influence of physical exercise on susceptibility to noise-induced temporary threshold shift. Scandinavian Audiology, 17,1: 11-17.

Kashiwamura, M. 1998. Studies of the evaluation of cochlea function with distortion product otoacoustic emissions. Hokkaido Journal of Medical Science, 73, 6: 641-662.

The Author

Anita Edwards, *Researcher*, CSIR Centre for Mining Innovation

- Audiologist with special interest in Noise Induced Hearing Loss prevention.
- Qualified as a Speech and Hearing Therapist at Wits University. Obtained Masters in Audiology from Pretoria University. Currently working towards PhD.
- Experience in private Speech therapy and Audiology practice for most of professional career.
- Number of years of experience in the gold mining environment as an Audiologist.
- Lectured Audiology at Wits Universities.
- Currently employed as a researcher at the CSIR working in the field of Human Factors and Noise Induced Hearing Loss and Distortion Product Otoacoustic Emissions, which is the topic of today's presentation.