Hearing Loss with Exercise and Noise Exposure

D. Welch[1], A. Law[1], K. N. Dirks[1]

[1] School of Population Health, University of Auckland, New Zealand d.welch@auckland.ac.nz, alexlaw.nz@gmail.com, k.dirks@auckland.ac.nz

ABSTRACT

Many people use personal listening devices during exercise, and may adopt high listening levels to overcome background noise. Furthermore, during hard exercise, the autonomic nervous system reduces blood flow to the cochlea, potentially rendering it more susceptible to noise-induced damage as a result of reactive-oxygen species. Therefore, noise exposure while exercising may be especially dangerous. To investigate this, we first measured and recorded sound levels in a gym. Next, we set up a mock gym by putting an exercise-bike in a room with gym sounds playing at the natural level. We recruited 15 gym-goers who used personal listening devices. On three separate days, participants underwent a 30-minute session of either: listening to their music through headphones, exercising, or listening plus exercising. Participants set their devices to their own preferred listening level for the environment and used the same setting for all three conditions: levels measured at the ear-drum were on average 88 dBLAeq. There were small, non-significant, temporary threshold shifts (TTS) after exposure to exercise or music alone, but when exercise and music exposures were simultaneous, there was significant TTS. There was also a reduction in higher (4-8 kHz) frequency DPOAE after exposure to music and exercise, but not to either exposure alone. Combining noise and exercise exposures produces greater TTS and reduction in OAEs than does either exposure independently: this may reflect underlying oxygen deprivation associated with both exposures. People exercising to loud music may risk more hearing loss than conventional estimates predict.

INTRODUCTION

Noise-induced hearing loss results from excessive exposure to sound at high levels for prolonged periods. It causes injury to the hearing system. Short-term exposure to noise at damaging levels can induce a temporary reduction in a person's hearing ability, known as a temporary threshold shift (TTS); repeated noise exposure at these levels may lead to permanent thresholds shifts (PTS) (Katz et al, 2009).

Recreational noise exposure makes up a large percentage of an individual's daily noise exposure (Australian Hearing, 2010). Over the past decade, personal listening devices (PLDs), such as iPods and mobile phones, have increased in popularity and usage, and have the capacity to generate sound outputs above 100 dB(A) (Yales et al, 2011). Recently, research has been conducted focusing on the potential risks to hearing caused by PLD usage. It has been found there is an increased risk of noise-induced hearing loss when PLDs are used at high outputs for long listening durations (Berg et al, 2011, Peng et al, 2007, Williams, 2005, Torre, 2008).

It is common for people to listen to their PLD while exercising. There are many benefits of regular physical exercise, including improved fitness and general health and wellbeing. However, for many people, exercising is a noisy activity due to gym music and/or equipment noise as well as the use of PLDs at high volumes,

particularly when in the presence of background noise. Therefore, the time spent exercising may contribute substantially to a person's maximum recommended daily noise dose, increasing an individual's susceptibility to TTS, and thus increasing their risk of acquiring permanent noise-induced hearing loss.

The effect of noise on the hearing system has been well defined, inducing structural changes to the cochlea and altering cochlear homeostasis, damaging sensory cells and associated nerve fibres. One pathway involves eliciting a stress response that increases the production of reactive oxygen species, which can induce cell death via apoptosis (Talaska and Schach, 2007, Henderson et al, 2008). Prolonged noise exposure can lead to reduced cochlear blood flow as a result of a reduction in blood vessel diameter and red blood cell velocity in the stria vascularis. A repercussion of this is a reduction in the amount of oxygen reaching the hair cells, leading to an increase in reactive oxygen species in the cochlea by means of insufficient oxygen for mitochondrial respiration (Poirrier et al, 2010).

Noise can induce changes in cochlear blood flow through effects on the autonomic nervous system (Hildesheimer et al, 2002). It has been suggested that activation of the autonomic nervous system during exercise results in vasoconstriction of blood vessels and overall reduced blood flow in the cochlea, as well as a reduction in oxygen (Grant, 2007). There is evidence that suggests that when both the noise and exercise stress response is simultaneously activated, a person's susceptibility to TTS is increased (Engdahl, 1996).

Regulations have been implemented to prevent noise-induced hearing loss in workplace environments, where it is accepted in New Zealand that an individual should not exceed an average noise exposure of 85 dBA over an 8-hour period (NZ Government), ie: one work day. However, the regulations do not take into account recreational noise exposure, and are not designed to be applied to people operating under heavy exercise conditions.

This research reflects a desire to know whether people who use PLDs while exercising strenuously might potentially be injuring their auditory systems to a greater extent than would be expected given the noise dose to which they are exposed. TTS and changes in evoked OAE levels after exposure to exercise and 'natural' levels of PLD exposure were assessed in a group of regular gym-goers.

METHODS

There were two phases to the research: an initial phase of measurement of background noise levels in a gym, then the testing phase where people exercised on an exercycle while listening to their MP3 players in an environment where recorded gym sounds were played.

Phase 1: Background Noise Measurement and Recording

The "cardio room" was chosen for recording to ensure that the environmental noise experienced by the cycling participants would be as similar as possible to the noise they would be exposed to in reality. The recordings were made at The University of Auckland City Campus Gym and Recreation Centre. Two 45-minute sound recordings of the cardio room were made every day over a five-day period, using an

M-Audio Microtrack II sound recorder. The two recordings for each day were made at 10 am and 2 pm; times when the gym was highly occupied and scarcely occupied, respectively. During each of the sound recordings, the sound level was also recorded using a Solo SLM 01dB-Metravib sound level meter. The time-weighted average sound level recorded for the cardio room during the five-day period was 74.6 dBA. All sound recordings were recorded with a mono channel, at a 192 kbps bit rate, 24-bit audio sample size and an 8 kHz audio sample rate. The sound levels for the recordings were done with an A-weighted frequency response because the limits for occupational noise exposure are also set based on an A-weighting. During the five-day period of recording, the sound levels of the Kick Fit, Zumba and SPIN classes were also recorded. One representative of the cardio room recordings was selected for use as background noise of the simulated gym environment. The recording was edited in Adobe Sound Booth to remove any coherent voices present in the recording.

Phase 2: Exercise and hearing testing

Participants:

Fifteen participants, seven males and eight females aged between 20–32 years (mean 22.5, SD 3.1) participated in this study. The criteria for participation were: must do regular exercise at least once a week for a minimum duration of 30 minutes; listened to an mp3 player during exercise for a minimum of 30 minutes; have unobstructed external ear canals; have normal middle ear pressure (admittance peak between ± 100 daPa); and have normal (15 dB HL or less) auditory thresholds between 250–8000 Hz.

Exercise Room

A Monark 824E Ergomedic exercise bike was placed in the centre of an untreated room with an array of four AMAV ST50PB speakers placed on the four points of a square 1.5 m from the exercise bike. The recorded track of gym noise was played through the speakers via Windows Media Player.

A sound level meter (Bruel and Kjaer Type 2250) was set up on a tripod at approximately the same height and distance as a cyclist's head from the speaker array. The edited background noise recording was played through the speaker for a 40-minute duration, and the level was adjusted so that the SPL was as close as possible to the average SPL value observed at the gym (75.2 dBA over a 40-minute duration).

A fan was set up to the side of the bike to provide air flow to the participants. The fan was set at the same level for all participants, and preliminary checks indicated that it made no measureable difference to the sound levels. A laptop computer was set up in front of the participant and was available to play a movie or show of their choice with the sound muted.

An ER-7C Probe Microphone System was connected to a Bruel and Kjaer Type 2250 sound level meter and placed on a table in the room to measure a participant's real ear response during the sessions.

The exercise room itself had an ambient noise level of 38.6 dBA. When the exercise bike was in use and the fan was on, the noise level within the room was 56.4 dBA.

Real ear measurement of the ear canal sound pressure level

The participant was placed in the sound field sitting at the spot that was used to calibrate the background noise. A probe tube was placed into the participant's ear canal at 31 mm for male and 28 mm for female participants. The participant's mp3-player headphones were then fitted into their external ear canal/concha bowl. All the participants used ear bud style headphones. The cardio room recording was played through the speakers and the SPL was measured and recorded. The participant was then instructed to turn on their mp3 player and set the volume at a level at which they could hear their songs coherently and at which the sound level would be comfortable to listen to for 30 minutes. Another SPL recording was then carried out. Each recording was for a duration of one minute. Participants kept the same level for both sessions which used the mp3 player.

Hearing testing

Hearing assessments were conducted in a sound-attenuating chamber. Otoscopy was done using a Welch Allyn TM otoscope. Pure tone audiometry used a Grason-Stadler GSI 61 Clinical Audiometer and Eartone 3A insert earphones. Speech audiometry was done using Millennium CVC word lists played through a Phillips mp3 player. Immittance testing was done with a Grason-Stadler GSI TympStar. DPOAEs were measured using a DP Echoport ILO292 attached to a laptop running ILOv6.

Procedure

Testing was divided into three sessions carried out on three separate days. Each exposure lasted 30 minutes. This duration was recommended by the gym staff for cardio-related exercise. Given time constraints and the recovery of TTS, only one ear was tested per participant.

All three sessions were run with each participant, and the order was counterbalanced:

1. Exercise with noise – the participant exercised and listened to their mp3 player while the recorded gym noise played in the background

2. Exercise only – the participant exercised with no mp3 player or background noise playing

3. Noise only – the participant listened to their mp3 player while sitting in a room while the recorded gym noise played in the background

For the sessions that involved noise exposure via background noise and the participant's mp3 player, a measurement of the SPL at the participant's ear drum was made before and after the mp3 player was turned on and adjusted to a level of the participant's choice.

For the conditions involving cycling, the participant was asked to warm up first by cycling on the bike with a 1.00-kg weight. The warm up time was not included as part of the 30-minute cycling duration. During the warm up, the participant was asked to cycle at a rate where the rpm (revolutions per minute) was above 50. Weights were added to the bike to the point where the participant felt they were exerting effort to keep cycling above 50 rpm but would be able to sustain the rpm for 30 minutes. This approach was taken to compensate for differences in physical fitness and strength, with the key outcome being that the participants be in a state of high oxygen consumption.

After completing the 30-minute condition, the participant's DPOAEs, growth functions and pure tone thresholds were retested immediately. DPOAEs were retested first as they were the measurement least affected by heavy breathing and other body noises (as determined during pilot testing).

At the start of each session, participants underwent pure tone audiometry at 2, 3, 4, 6 and 8 kHz in the better hearing ear. Thresholds were only obtained between 2-8 kHz as, during pilot testing, it was found that heavy breathing resulting from exercise interfered too much to reliably be able to test frequencies of 1 kHz and below, while evidence from previous studies investigating temporary threshold shifts suggest that the majority of observed noise-induced threshold shift occur at frequencies around 3-6 kHz. Thresholds were obtained using a modified Hughson-Westlake technique, descending in 2 dB steps and ascending in 1 dB steps. The threshold recorded corresponded to the level at which responses were obtained for two ascending runs.

DPOAEs were measured between 2-8 kHz at 8 points per octave, L1 = 65 dB, L2 = 55dB, F2/F1 = 1.22; parameters which produce a large 2f1-f2 response. Growth functions were measured at 4 kHz with a 2 dB step size between L1 and L2. The ILOV6 machine was configured to sweep from a L1/L2 level of 75/55 dB down to the minimum L1/L2 levels, which, for the machine, was 45/25 dB. Growth functions were measured to investigate any changes in DPOAE fine structure, as it has been found that low stimulus levels are more sensitive to cochlear impairment. A probe checkfit procedure was performed before every DPOAE recording for the purpose of in-the-ear calibration.

RESULTS

Levels recorded in the gym were reasonably high and would potentially cause NIHL after prolonged exposure (Table 1). The lowest levels were those measured in the Cardio Room, and these levels were chosen for the next phase of the research.

Table 1: Mean, maximum and minimum 1-minute Leq, and peak sound level measurements recorded at gym.

Area	dBA Leq	Max dBA Leq	Min dBA Leq	dBC Peak
Cardio room	74.6	86.6	70.7	105.9
Weights room	77.5	97.0	62.9	122.3
Pump class	84.3	95.1	56.9	118.5
Zumba class	85.3	94.7	63.8	123.6
Kick Fit class	85.4	95.4	50.8	120.5
Spin class	86.8	95.9	63.5	122.2

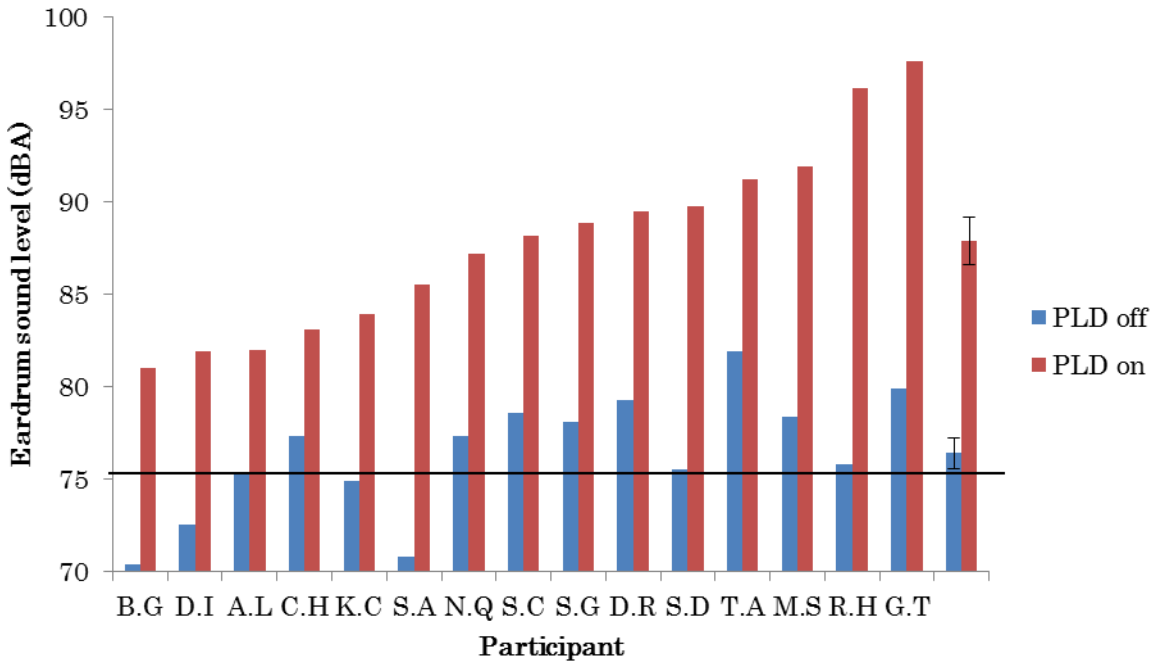

Figure 1: Sound pressure level measured at the tympanic membrane with a 75.2 dBA noise playing in the sound field (blue, PLD off) and with the participant listening to their PLD in the 75.2 dBA soundfield (red, PLD on). The horizontal black line represents a noise intensity value of 75.2 dBA. The bars on the far right represent the mean of the sample, and the error bar represents the standard error of the mean.

There was a marginal change in mean pure tone threshold of all of the tested frequencies from the mean threshold measured before each session, $F(3,39)=2.53$, $p=0.095$; Figure 2. The exercise-in-noise session produced the largest change in threshold, with the average threshold worsening after the session by 1.08 dBA.

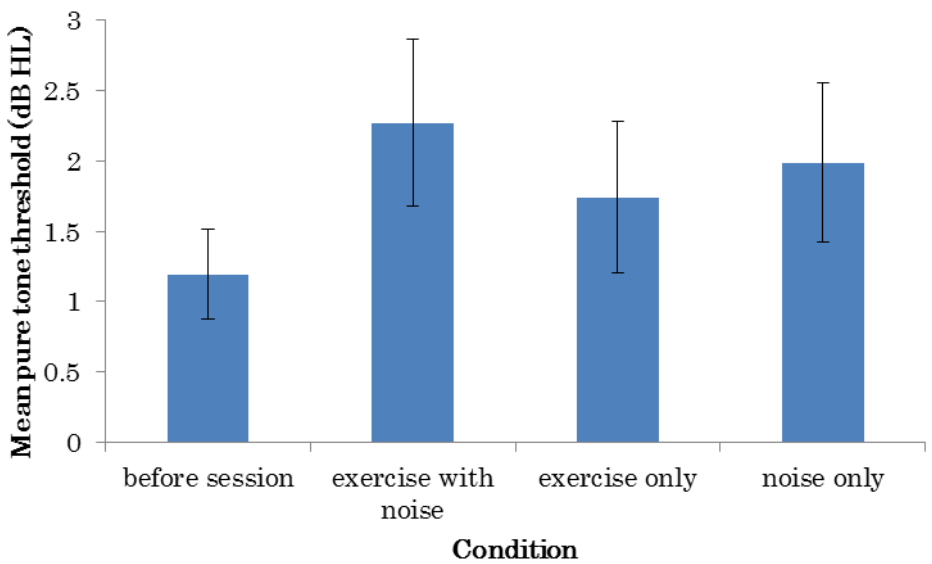

Figure 2: Mean pure tone audiometric results across the five tested frequencies for the three testing conditions (n = 15, except for exercise with noise where n = 14). Error bars reflect one standard error of the mean.

The effects of the conditions and frequency were investigated by conducting a repeated measures ANOVA. A significant difference was observed across the different frequencies, $F(4,52)=12.78$, $p<0.001$, suggesting an overall poorer performance in the higher frequencies. There was also a marginal interaction between frequency and condition $F(12,156)=1.44$, $p=0.160$. Tests of the simple effects within this interaction using one-way repeated-measures ANOVAs showed a significant difference between the points at 4 kHz ($F(3,39)=3.142$, $p=0.036$) but not at the other frequencies tested (all $p>0.05$). This would reflect the apparent non-parallel nature of the four lines in Figure 3, and suggests that the 4-kHz threshold had increased after exercising in noise.

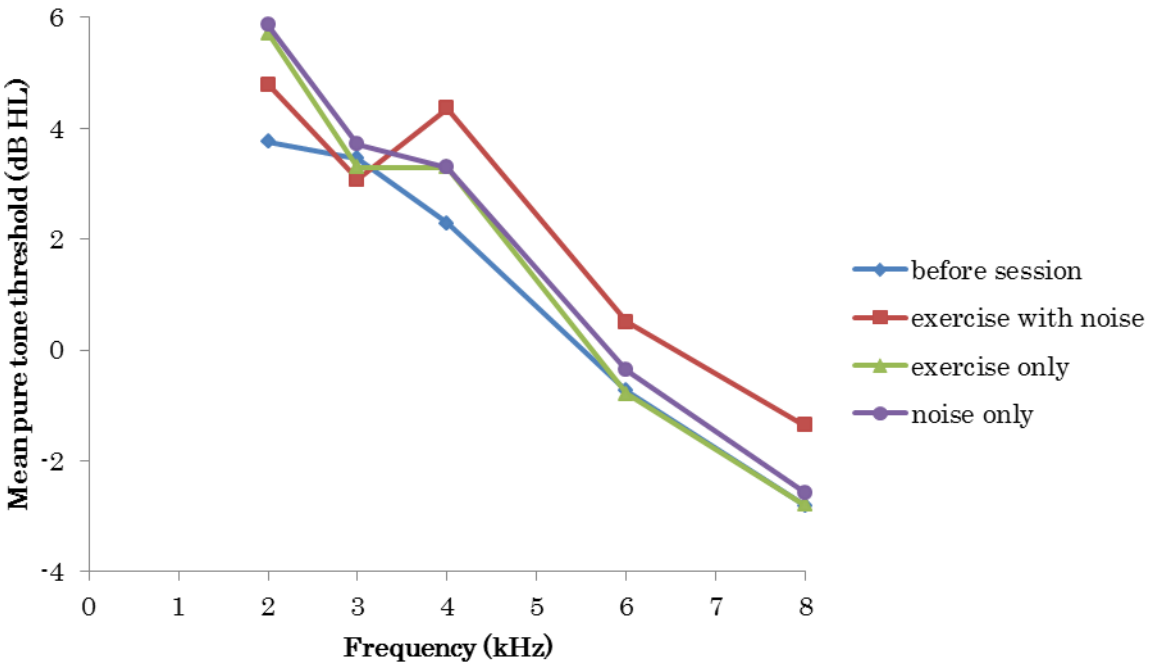

Figure 3: Average pure tone thresholds at 2, 3, 4, 6 and 8 kHz before the sessions and after the three different sessions (n = 14 before session, exercise with noise; n = 15 exercise only, noise only). Error bars were not included because they obscured the graph.

Repeated measures ANOVA showed a marginal effect for the difference in the average distortion product between the different conditions ($F(3,39)=2.97$, $p=0.066$; Figure 4). The exercise-with-noise session had the largest decrease in level, having a change of 1.22 dB SPL after the session.

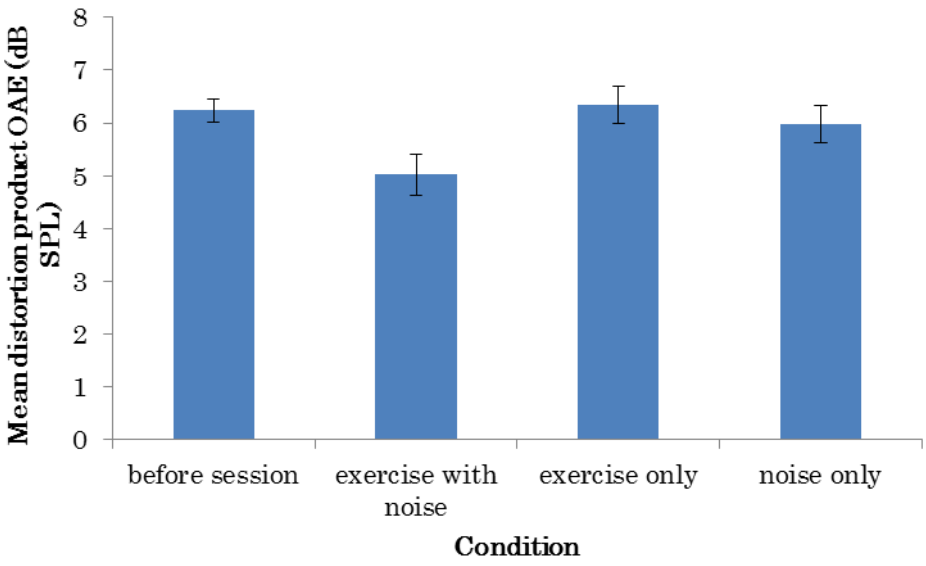

Figure 4: Mean DPOAEs for each session (n = 14). The error bars represent one standard error of the mean

Presentation by frequencies reveals that DPOAE were most influenced in the higher frequencies tested (Figure 5). Repeated measures ANOVA revealed a significant change in the before and after average DPOAEs for the exercise-with-noise session, $F(1,13)=7.50$, $p=0.017$. Therefore, a more in-depth analysis was conducted to determine at what frequency the greatest change in DPOAEs occurred.

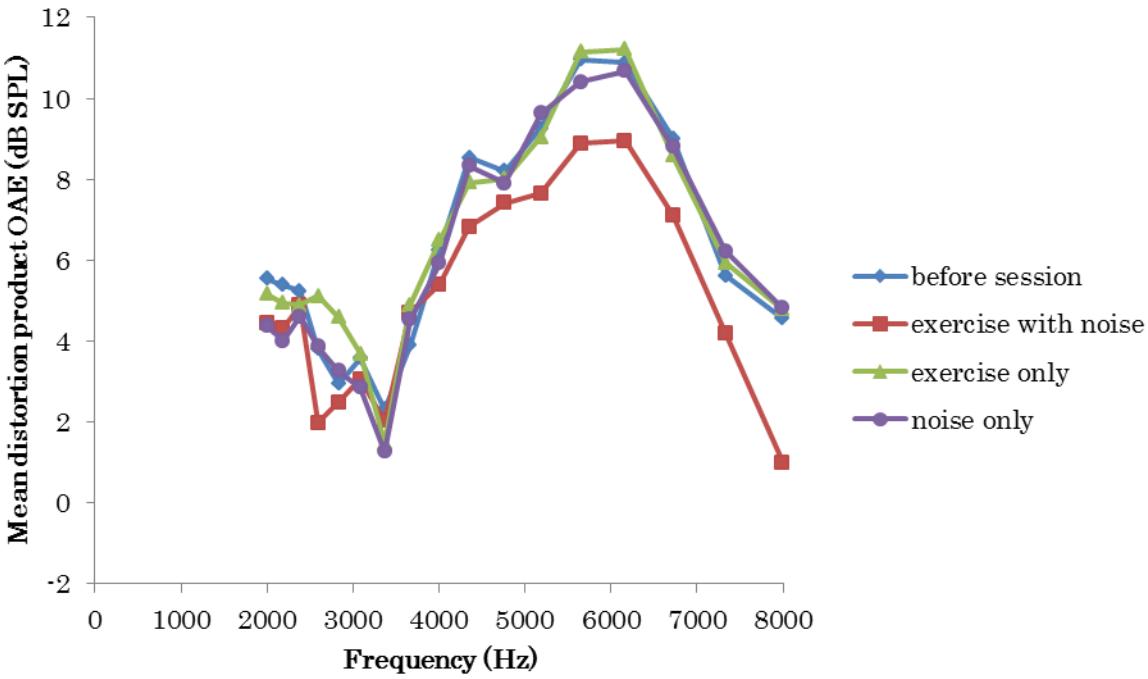

Figure 5: Mean DPOAE levels recorded between 2002 – 7996 Hz for each session

No differences were observed between conditions in terms of DPOAE growth functions.

DISCUSSION

Noise levels in the gymnasium were high, and participants' listening levels with their mp3 players were sufficiently high that some would have exceeded their recommended noise dose due to this exposure alone. For others, the exposure due to their mp3 players would have contributed to their overall noise exposure.

Both exercise and noise activate a stress response that results in changes to cochlear blood flow. Homeostasis of the cochlea is disrupted, leading to an increase in ROS production and subsequent breakdown of the cells via apoptosis. As such, it was hypothesised that a participant's hearing would worsen after either exercise or noise exposure; that is, an increase in pure tone thresholds and a reduction in DPOAEs. It was hypothesised that the greatest change in hearing would be observed in the exercise-with-noise session due to the combined stress response of both exercise and noise.

There was an increase in pure tone threshold and a decrease in DPOAEs in all three conditions, with the only significant change being in the exercise-with-noise condition. For both pure tone and DPAOEs, the smallest change was observed in the exercise-only condition. The results agree with the results found by Engdahl (1996). Noise has been found to induce structural changes to the Organ of Corti and neuronal damage to the nerve fibres projecting from the cochlea. Conversely, exercise is mainly believed to influence cochlear blood flow and oxygen concentration by activation of the Sympathetic division of the Autonomic Nervous System. Unlike noise, which directly affects the structures in the cochlea, exercise creates an indirect effect; blood flow is reduced to other parts of the body to help supply the demand for oxygen and nutrients of the skeletal muscles. The combined stress effect of both noise and exercise caused a significant TTS, found with both pure tone audiometry and DPOAE measures. The two factors may have interacted by reducing cochlear blood flow and subsequently reducing the amount of oxygen and nutrients in the cochlea, disrupting cochlear homeostasis. Under increased cochlear activity by means of noise exposure, the hair cells are unable to meet the demand for signal processing and TTSs occur.

In all three conditions, there was a significant change in the 4 kHz pure tone threshold, with the largest increase in threshold occurring in the exercise-with-noise condition (an increase in threshold of 2.07 dB HL). It was hypothesised that the largest change in threshold and DPOAEs would be around 4 kHz, as previous research has shown that NIHL first develops in the 4 kHz region (Katz et al, 2009). In the exercise-with-noise session, the high frequencies were most affected, with a significant reduction in DPOAEs at the 11 frequencies tested from 4358-7996 Hz. For the noise-only session, DPOAE levels at 2002, 2185 and 3369 Hz were reduced, whereas no effects of exercise alone were observed. The observed change is similar to what has been reported by Torre and Howell (2008), who found a significant 0.3-1.4 dB change in the 6 kHz DPOAE in people attending aerobics classes with a mean sound level of 87.1 dBA (the current study had participants exposed to a mean sound level of 87.9 dBA). They only measured DPOAEs between 1200-6000 Hz. The observed reduction in DPOAEs below 6 kHz in the current study may be attributed to differences in the ambient noise levels of the testing rooms (the previous work tested on site at a gym whereas the present study used a sound-attenuating chamber). In the gym, sound from other classes may filter into the testing room, reducing the signal-to-noise ratio and masking any small changes in DPOAEs.

The combined effect of exercise and typical noise from a gym and PLD produced a greater temporary threshold shift than either exercise or noise alone. Exposure to exercise and noise together was able to cause a greater reduction in the 4 kHz pure tone threshold and distortion product otoacoustic emissions between 4358-7996 Hz. Our findings suggest that noise exposure during exercise may be a significant proportion of a person's recreational noise exposure, and raises the possibility that noise exposure while exercising may be more damaging than would be expected given the sound level and duration.

REFERENCES

Australian Hearing. Binge Listening. Is exposure to leisure noise causing hearing loss on young Australians? 2010.

Berg AL, Serpanos YC. High frequency hearing sensitivity in adolescent females of a lower socioeconomic status over a period of 24 years (1985-2008). Journal of Adolescent Health. 2011;48(2):203-8.

Engdahl B. Effects of noise and exercise on distortion product otoacoustic emissions. Hear Res. 1996 Apr;93(1-2):72-82.

Grant RJ. Can physical exercise worsen the hearing loss caused by hazardous levels of music or noise? Texas: The University of Texas Medical Branch Graduate School of Biomedical Science; 2007.

Henderson D, Hu B, Bielefeld E. Patterns and Mechanisms of Noise-Induced Cochlear Pathology. In: Schacht J, Popper AN, Fay RR, editors. Auditory Trauma, Protection, and Repair: Springer US; 2008. p. 195-217.

Hildesheimer M, Henkin Y, Pye A, Heled S, Sahartov E, Shabtai EL, et al. Bilateral superior cervical sympathectomy and noise-induced, permanent threshold shift in guinea pigs. Hear Res. 2002 Jan;163(1-2):46-52.

Katz J, Medwetsky L, Burkard R, Hood L. Handbook of Clinical Audiology. 6 ed. Philadelphia: Lippincott Williams & Wilkins; 2009.

New Zealand Government, Department of Labour, Approved Code of Practise for the Management of Noise in the Workplace, (2002).

Peng JH, Tao ZZ, Huang ZW. Risk of damage to hearing from personal listening devices in young adults. J Otolaryngol. 2007 Jun;36(3):181-5.

Poirrier AL, Pincemail J, Van Den Ackerveken P, Lefebvre PP, Malgrange B. Oxidative stress in the cochlea: an update. Curr Med Chem. 2010;17(30):3591-604.

Talaska AE, Schacht J. Mechanisms of noise damage to the cochlea. Audiological Medicine. 2007;5(1):3-9.

Torre III P. Young adults' use and output level settings of personal music systems. Ear and hearing. 2008;29(5):791.

Torre III P, Howell JC. Noise levels during aerobics and the potential effects on distortion product otoacoustic emissions. Journal of communication disorders. 2008;41(6):501-11.

Williams W. Noise exposure levels from personal stereo use. International journal of audiology. 2005;44(4):231-6.

Yates C, Ray L, Yang J, editors. An investigation into iPod Touch generation 2011: ACM.