NOISE-INDUCED HEARING LOSS IN AEROBIC CLASS GOERS:

A LONGITUDINAL STUDY WITH PURE TONE AUDIOMETRY

AND DISTORTION PRODUCT OTOACOUSTIC EMISSIONS

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ABSTRACT

At-risk hearing conditions in various aerobic classes in different gymnasiums were identified and the hearing of aerobic class goers monitored to provide information for an improved understanding of noise-induced hearing loss. Hearing levels were monitored over time for four comparison groups, including regular attendees of aerobic classes with an average noise level above 85 dBA ("High-Risk" group), regular attendees of aerobic classes with an average noise level below 85 dBA ("Low-Risk" group), non-gym goers attending one "High-Risk" aerobic class with hearing protection ("Control with HP" group), and non-gym goers attending one "High-Risk" aerobic class without hearing protection ("Control without HP" group). Each comparison group consisted of three to five males and three to five females, aged between 18 to 50 years. Measurements of pure-tone audiometry (PTA) and distortion product otoacoustic emissions (DPOAEs) were obtained from before and immediately after participation in one class and 48 hours and 30 days after the initial test. Noise levels in many aerobic classes (77%) were found to be higher than 85 dBA and might have led to signs of hearing deterioration as shown mostly in the reduction of the activities of outer hair cells and sometimes in the shift of hearing threshold. The "High-Risk" group exhibited the largest reduction of DPOAEs amplitudes over time. The "Control without HP" group generally exhibited a larger degree of reduction in DPOAEs amplitudes immediately after exposure as compared with the "Control with HP" group. Measurement of DPOAEs levels appeared to be a more sensitive tool than PTA in detecting early signs of hearing deterioration related to noise exposure.

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Chapter 1. INTRODUCTION

This study concerns the assessment and prevention of noise-induced hearing loss (NIHL) in adults attending aerobic classes. This chapter includes a literature review and the research outline.

1.1 Literature Review

This section includes the background information, as well as a critical review of the literature, on the definition, cause, measurement, auditory pathophysiology, risk factors, and prevention of NIHL in relation to the noisy environment in aerobic classes and ways to monitor the acoustics of the gymnasium where aerobic classes take place to include establishing the acoustic characteristics of the gymnasium.

1.1.1 Noise-Induced Hearing Loss

Noise-induced hearing loss is an increasingly common disorder caused by exposure to high levels of noise, especially over a long period of time. It is a preventable hearing disorder that affects people of all ages and demographics (Henderson, Subramaniam, and Boettcher, 1993). According to a position statement released by the American Academy of Audiology in 2003, "the average, otherwise healthy, person will have essentially normal hearing at least up to age 60 if his or her ears are not exposed to high noise levels" (p. 1). Noise-induced hearing loss is referred to as a permanent damage caused by noise to the outer hair cells of the cochlea, resulting in the dysfunction of the cochlea.

Noise-induced hearing loss occurs slowly over time and the full effects

are usually not realised until after 10 to 15 years of chronic noise exposure (Miller, 1974).   According to Melnick (1991), there are three types of hearing changes that may occur following noise exposure, including acoustic trauma, noise-induced temporary threshold shift (TTS), and noise-induced permanent threshold shift (PTS).   Acoustic trauma refers to a sudden, permanent sensorineural hearing loss caused by a single exposure to an intense sound. The sound is normally an impulse sound with a sound pressure level (SPL) of 130dBA or higher (Henderson et al., 1993).   Noise-induced TTS refers to a "reduction in hearing sensitivity resulting from exposure to noise, provided that thresholds return to pre-exposure levels with time (minutes, hours, or days) after cessation of the noise" (Rintelmann et al., 1971, p. 1249).   Mild TTS can recover without causing permanent damage.   Moderate TTS recovers initially but noise-induced permanent threshold shift (PTS) may emerge when there is a lack of sufficient recovery due to repeated noise exposure.   Severe TTS may not recover completely after just a single exposure (Hellstrom et al., 1998).   In gradual NIHL, the outer hair cells are lost first, and damage to the inner hair cells and supporting cells begin when the loss of the outer hair cells have resulted in PTS (Henderson et al., 1993).

1.1.2   Relationship between Noise Exposure and NIHL

Gradually developing NIHL, which progresses slowly over years, results from recurring exposures to sounds at a SPL lower than that producing acoustic trauma.   The effect of NIHL depends on the intensity of the sound and the duration and the number of times a person is exposed to the sound (LePage & Murray, 1998).

1.1.2.1 Noise Exposure

Noise exposure is the combination of sound pressure level and duration (Royster, Royster, and Killion, 1991). As the sound pressure level increases, the duration required to cause harmful exposure decreases (Attias & Bresloff, 1996). In order to compare occupational noise exposures with different daily duration, an eight-hour equivalent continuous dBA SPL is normally calculated based on a standard schedule using a conventional eight-hour workday and an industrial limit for 5 days per week (i.e. 40 hours working week). For example, the New Zealand Occupational Safety and Health Service (2003) has set a level of no more than 85 dBA (i.e., decibels measured on the A scale of a sound level meter) over an 8 hours period as the safety level for noise exposure that "represents the total sound energy experience over a given period of time as if the sound was unvarying" (Lipscomb, 1994, p. 16). However, the noise that induces hearing loss can be occupational (industrial) or non-occupational (e.g., recreational noise). It is evident from the literature (Royster, Royster, and Killion, 1991; Rintelmann et al., 1971; Yaremchuck & Kaczor, 1999; Williams, 2005) that acquiring NIHL is highly likely with individuals exposed to noise above 85 dBA for more than 40 hours a week regardless of the noise type.

Along with the permissible exposure limit for eight hours, an exchange rate can be used to define the allowed continuous levels for exposure durations other than eight hours. The exchange rate is determined by the relationship between the sound pressure level of the exposure and the length of exposure time (Behar, Chasin, and Cheesman, 2000). Based on the "equal energy principle", two exposures containing equal amount of acoustic energy

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are considered equally hazardous regardless of the temporal pattern of the noise (Henderson, Subramaniam, and Boettcher, 1993). The recommended noise level for a given exposure period is known as the damage-risk criterion (Lipscomb, 1994). A damage-risk criterion of 85 dBA with a 3 dB exchange rate means that there is an identical risk if the sound pressure level is increased by 3 dB with only half the amount of time exposure (Behar et al., 2000).

A list of recommended maximum noise levels for given exposure periods for noisy industrial environments was adopted by the Occupational Safety and Health Administration (OSHA) in the United States in 1971. These recommendations have also been accepted by Workers' Compensation Boards in Canada. The US regulation uses a 5 dB exchange rate and sets the maximum permissible exposure limit (PEL) at 90 dBA, which is measured as a time-weighted average exposure level (TWA). These levels are approximately five decibels above those recommended by the American Otological Association (Lipscomb, 1994).

1.1.2.2 The Effects of Noise on Hearing Sensitivity

Following excessive noise exposure, changes in hearing may include distortion of the perceived quality and clarity of auditory stimuli and reduced ability to detect sound (Hetu & Fortin, 1995). The classic sign of NIHL is decreased hearing sensitivity in the 3 to 6 kHz frequency region, with the greatest loss typically occurring at 4 kHz. Various theories have been developed to explain the loss of sensitivity in this frequency range (Rodriguez and Gerhardt, 1991). One theory is that vascular insufficiency in the part of cochlea responsible for the frequencies of interest may increase the

susceptibility of hair cells around that area to the damage caused by intense noise exposure (Crowe, Guild, and Polvogt, 1934).   Another theory is that the site along the cochlear partition that codes these frequencies may be the area of the basilar membrane that often receives excess mechanical stimulation leading to greater hair cells injury during acoustic processing (Hilding, 1953; Schuknecht, 1974).

While these theories may explain the loss of hearing sensitivity at 4 kHz in NIHL, they do not address the variability in the pattern of NIHL often shown in industrial workers.   After years of similar noise exposure, some individuals may suffer the greatest hearing loss at 3 kHz, while others exhibit maximum NIHL at 4 kHz or 6 kHz.   Individual differences were not only found in the frequency maximally affected by a particular noise exposure but also the magnitude of the hearing loss.   One of the factors that have been shown to have an impact on the pattern and magnitude of NIHL is outer ear resonance properties.   Based on a study 31 normal hearing individuals who were exposed to a 30-minute broadband noise at 95 dBA, Rodriguez and Gerhardt (1991) found that the external ear played a significant role in determining which frequencies were affected by noise exposure.   In Rodriguez and Gerhardt's (1991) study, the outer ear resonance frequencies were measured utilising a probe-microphone system and Bekesy (self-recording) audiometry of pulsed pure tone signals ranging from 1 to 8 kHz were measured prior to, immediately following, and 24 hours after the broadband noise exposure. The results of Rodriguez and Gerhardt's (1991) study revealed that individuals with larger ear canal volume or length had a greater likelihood of exhibiting TTS at 3 kHz.   These findings necessitate further investigation on the frequency selectivity in NIHL, suggesting that the frequency range tested and

the sensitivity of the test used to gauge the effect of noise on hearing need to be considered.

1.1.3 Measurement of NIHL

Major advances in diagnostic audiology in recent years have enabled audiologists these days not only to perform diagnostic procedures that rely on behavioural tests such as pure tone audiometry (PTA) and speech audiometry but also perform physiological measurements such as middle ear measures and otoacoustic emissions (Katz, 2002). This section reviews the effectiveness of traditional diagnostic audiological tests and other behavioural or physiological tests in detecting NIHL.

1.1.3.1 Pure Tone Audiometry

According to the Occupational Noise Management Regulations as outlined in the Australian/New Zealand Standard (AS/NZS 1269.1, 1998), when monitoring pure tone audiometry is carried out, a temporary threshold shift is indicated if the monitoring audiogram differs from the reference audiogram in one of the following five ways:

1. A shift in mean threshold at 3, 4 and 6 kHz greater than or equal to 5 dB,

2. A shift in mean threshold at 3 and 4 kHz greater than or equal to 10 dB,

3. A threshold shift at 6 kHz greater than or equal to 15 dB,

4. A threshold shift at 0.5, 1, 1.5, or 2 kHz greater than or equal to 15 dB,

5. A threshold shift at 8 kHz greater than or equal to 20 dB.

These criteria were adopted by the Occupational Safety and Health Service of the New Zealand Department of Labour. The typical method of

assessing these criteria is to measure the subject's threshold before and at a specific time after a noise exposure. If hearing recovers to its pre-exposure level, the threshold shift is considered temporary. Any hearing loss four weeks or more after an exposure is considered to be permanent (Quaranta et al., 1998; Miller, 1974). However, it is noteworthy that there is no agreement among researchers about the recovery time and whether recurrent TTS may bear a risk of PTS (Serra et al., 2005).

Noise-induced hearing loss after long-term exposure to broadband noise has a characteristic audiometric pattern with a notch in the 3 to 6 kHz region, which has been related to the primary resonant frequency of the external auditory canal (Rodrigues & Gerhardt, 1991). However, limitations in the specificity and sensitivity of such a notch in the audiometric configuration in detecting NIHL have been reported (Schmuziger, Fostiropoulos, and Probst, 2006). In particular, it has been suggested that conventional audiometry (from 0.25 to 8 kHz) presents serious limitations in test specificity and sensitivity due to the complex nature of cochlear structure and function (Fausti, Ericson, Frey, Rappaport, and Probst, 1981).

The use of pure tone audiometry to assess the potentially harmful effects of noise on people's hearing has failed to show any marked effect in numerous studies (Carter, Murray, Khan and Waugh, 1984; Meyer-Bisch, 1996; Williams, 2005). For example, Meyer-Bisch (1996) investigated the hearing damage related to strongly amplified music in 1,364 participants. As part of his research, he examined 211 participants (103 females and 108 males) who never or only occasionally went to rock concerts or discotheques. The results showed no audiometric damage shown on the audiogram post exposure. The frequencies tested (for participants under 30 years of age)

were 0.5 to 16 kHz.   One of the conclusions of the research was that the risk of developing NIHL as a result of attending discotheques was limited to those who attend discotheques regularly.   However, another possible interpretation of the results was that the sensitivity of PTA tests was low in the detection of latent cochlear damage caused by exposure to loud noise.

The clinical value of extended high frequency audiometry for the detection of noise-induced hearing loss has not been established conclusively due to conflicting findings reported in studies using extended high frequency testing to detect NIHL (Schmuziger, Patscheke, Probst, 2007;   Fausti, Erickson, Frey, Rappaport, and Schechter, 1981).   Several studies have shown evidence in support of using the extended high frequency range as a possible addition or alternative to the conventional PTA.   For example, Fausti et al. (1981) tested a group of 36 military veterans with history of impulsive and steady-state noise exposure.   Thresholds were obtained using the modified Hughson-Westlake technique with 2 dB increments.   Frequencies tested were 0.25 kHz to 20 kHz.   It was found that conventional audiometry results from 0.25 kHz to 8 kHz failed to detect NIHL while measurements of auditory sensitivity from 8 kHz through 20 kHz reliably detected noise-induced TTS.

On the other hand, a research conducted by Schmuziger et al. (2007) showed that thresholds measurements in the extended high frequency (9kHz to14 kHz) failed to detect noise-induced TTS.   The researchers measured PTA thresholds (0.25 kHz to 14 kHz) of 16 non-professional musicians aged 27-49 before and after a 90-minute rehearsal session.   All subjects had experienced repeated exposure to loud music during at least five years of their musical careers.   The results post-exposure were found to be

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significantly poorer for frequencies from 0.5 kHz to 8 kHz but were unchanged in the extended high-frequency range from 9 kHz to 14 kHz.   Since there was no reference to the SPL of the noise subjects were exposed to in the study, the reason for the failure of the extended high frequency audiometry in detecting NIHL was unclear.

1.1.3.2   Distortion Product Otoacoustic Emissions

As the primary reason people suffer from a permanent NIHL is a significant decline in the numbers (or functionality) of outer hair cells (OHC) resulting in reduced internal amplification (LePage, 1998), testing for the presence of otoacoustic emission (OAE), a sound generated by the activity of the OHC, has been identified as a sensitive measure of the outer hair cells function (Kemp, 1978).   With or without an evoking stimulus, the presence of OAE is indicative of the intactness of the inner ear health (Hall, 2000). Otoacoustic emissions can be measured in the ear canal with a microphone and, with modern technology, separated from sounds entering the ear. Middle ear disorders may affect OAEs but are easily distinguishable from sensorineural hearing loss (Kemp, 1978).

Clinically, the greater sensitivity of OAEs to cochlear dysfunction has been shown by reports of abnormal or absent OAEs among patients with normal audiograms.   It is assumed that the presence of OAEs implies hearing thresholds better than about 30 dB hearing level (HL).   In contrast, the absence of OAEs suggests some degree of hearing loss, provided that the middle ear is functioning normally.   The absence of OAEs may also reflect an early stage of noise-induced auditory dysfunction when outer hair cells are deteriorating but the damage is still incomplete (Hall, 2000).   Animal

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research conducted by Bohne & Clark in 1982 has confirmed that scattered OHC damage, perhaps less than 20 percent of the total OHC population, is not always evident in pure tone threshold measurements. As the proportion of OHC damaged exceeds some critical level (e.g., 25 to 30 percent), permanent threshold shift can be documented.

The two most commonly used OAEs recording techniques are distortion product otoacoustic emissions (DPOAEs) and transient evoked (or click) otoacoustic emissions (TEOAEs), which were originally proposed for clinical applications by David Kemp and his research team in 1986 (Hall, 2001). Distortion product otoacoustic emissions are inter-modulation distortion tones that the cochlea generates in response to a close pair of stimulus tones. Transient evoked otoacoustic emissions response consists of a complex sound waveform obtained in response to repeated clicks, which can be subsequently analysed to chart OAEs strength as a function of frequency (Robinette & Glattke, 2007). A study conducted by Attias & Bresloff (1996) examined temporary cochlear alterations following a 10-minute noise exposure of white noise at 90 dB SL (sensation level) in 20 young male subjects with normal audiometric thresholds. Standard PTA, as well as and DPOAEs and TEOAEs were measured before and after the noise exposure. The researchers observed a strong correlation between the TEOAEs results and the audiometric TTS. However, in a number of cases, the cochlear alterations were not shown in the PTA measurements. In contrast, temporary emission shifts (TES) were found to be statistically significant at 1, 2, 3, and 4 kHz. It was then concluded that OAEs accurately reflected noise-induced changes to the cochlea among those who were exposed to noise but have normal auditory thresholds.

According to Hall (2000), tests of OAEs are already an integral part of the audiological test battery because they play an important role in early identification and diagnosis of auditory dysfunction in varied paediatric and adult population.   It is important to note that OAEs is considered to be complementary (rather than supplementary) to PTA.   Interpretation of PTA results should be used in conjunction with OAEs results because the two test results can more fully capture the patient's auditory function (Hall, 2000).   In other words, cases of individuals with a long history of noise exposure may show normal audiometric thresholds with absent OAEs.

1.1.3.2.1   Clinical Application of DPOAEs in Adults

Testing of otoacoustic emissions is a powerful new addition to the audiology test battery.   The clinical advantage of OAEs in the pediatric population is its site specificity to auditory dysfunction and the high degree of sensitivity to cochlear impairment.   These advantages are equally important for adult patients (Hall, 2000).   Clinically, OAEs testing is also used (in conjunction with other audiological assessments) for diagnostic assessment of various retrocochlear lesions and ear pathologies like Meniere's disease (Royster et al., 1991).

Basic research in small animals models, such as chinchilla, guinea pig, gerbil, rabbit, cat, and chicken, has confirmed the unique sensitivity to noise-damaged cochlea of OAEs, especially distortion product otoacoustic emissions (Schmiedt, 1986;   Franklin et al., 1991;   Smurzynski, 1992;   Canlon et al., 1993;   Subramaniam et al., 1994;   Hamernik et al., 1996;   Trautwein et al., 1996;   Hamernik et al., 1998;   Iwasaki et al., 1998,   White et al., 1998).   During the DPOAEs measurement process, the frequency of

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the stimulus pair is stepped across the hearing range of interest. The intensity of one selected distortion product emission (usually of DP1: that is the level difference between 2f1 and f2) is recorded as a function of frequency forming a DP-gram (Kemp, 1978). The main advantage of DPOAEs is that DPOAEs can capture OAEs at frequencies much higher than those captured by TEOAEs. Both DPOAEs and TEOAEs suffer from low frequency noise interference mostly from the background noise in the testing room, with TEOAEs being slightly more effective in low frequencies (Robinette & Glattke, 2007). According to Hall (2000), DPOAEs have assumed an important role as an electrophysiological index of the cochlea's status. However, the correlation among OAEs, audiometric threshold changes, and cochlear damage as indicated by outer hair cell populations is inexact.

1.1.3.2.2 Monitoring Noise Damage with OAEs

The use of OAEs encompasses various advantages such as sensitivity, site-specificity, objectivity and speed when monitoring for NIHL. According to Hall (2000), DPOAEs are especially well suited as a monitoring tool because of their larger frequency range (0.5 kHz to 8 kHz and sometimes higher) in comparison to other OAEs techniques. Distortion products otoacoustic emissions extend up to the region affected by overexposure to noise, particularly the 3 kHz to 6 kHz region. Thus, conventional PTA testing in conjunction with DPOAEs testing is a strong assessment tool for individuals at risk of NIHL.

Attias et al. (1998) investigated the clinical effectiveness of DPOAEs as a tool for screening for NIHL in 76 military personnel and found that the amplitude of the DPOAEs among the participants was significantly reduced.

It was also found that DPOAEs were generally absent among participants with a history of noise exposure even though they have shown normal audiogram results.   The results indicated that at least 25% of the auditory normal hearing ears which were exposed to noise had an absence of DPOAEs in certain frequencies.   The researchers concluded that reduced DPOAEs levels may be the first indication of hearing loss after noise exposure.

A possible reason for the relative shortage of published studies on the use of OAEs in hearing conservation is the ease and (in most cases), accuracy with which adults can be tested using the basic PTA technique.   However, as NIHL results from cochlear damage, or more specifically, outer hair cells damage, adding OAEs to the traditional PTA method would seem to be of value especially when testing individuals who were exposed to either occupational or recreational noise.   Although some attempts to employ OAEs as an objective measure of hearing sensitivity and hearing loss are unsuccessful, there is ample evidence from hundreds of studies that OAEs can be successfully applied as a technique for screening auditory function (Hall, 2000).   An example of a research that was only partially successful in showing the unique sensitivity of OAEs to latent cochlear damage was a research published in 2008 by Torre III & Howell but this was possibly due to the fact that here was only one experimental group and no comparison control groups and thus the internal validity was weakened.

It appears that OAEs, with increasing popularity in its usage and recognition in recent years as a screening tool, will play a key role in the early identification of NIHL in various settings and as an objective "cross-check" to the traditional PTA (Hall, 2000).

1.1.3.2.3 Early Detection of NIHL

The primary site of auditory injury from excessive exposure to noise is the organ or Corti (Yoshii in 1909; Miller, 1974). The early stages of hearing loss have been considered to be difficult to monitor because the early destruction of the hair cells in the cochlea may not be reflected on the audiogram results (Jokitulppo, Bjork, and Akaan-Penttila, 1997). Many studies have shown the effectiveness of using OAEs to detect early signs of NIHL (Engdahl, 1996; LePage and Murray, 1998; Emmerich et al., 2000; Torre III and Howell, 2008).

Experiments conducted on animals as well as humans have shown that DPOAEs (as well as TEOAEs) are altered by noise exposure.   This was proven as early as 1983 by a study conducted by Kemp and Brown. Further research conducted during the 1980s and the 1990s on animals and human have shown that moderate noise exposure gives rise to temporary threshold shift which alters the amplitude of DPOAEs.   Schmiedt (1986) showed that the temporary level shift of an acoustic emission measured in the ear canal of gerbils and cats reflected the change occurred to their cochlea as a result of acute noise injury.   Martin et al. (1987) have demonstrated reduced DPOAEs amplitude in rabbit ear canal due to noise exposure.   Furthermore, a research conducted by Subramanian, Henderson, and Spongr (1994) found a relationship among DPOAEs, evoked potential thresholds, and outer hair cells following interrupted noise exposure.   Further research in that field conducted by Sutton et al. (1994) showed the sensitivity of DPOAEs in humans to tonal over-exposure over the time course of recovery.   The studies outlined above have all shown that OAEs could detect decline in

cochlear function long before there was any clinically detecTable hearing loss. These findings suggested that testing of OAEs could potentially provide early warning of noise-induced hearing loss.

LePage and Murray (1998), in a study of the impact of the use of personal stereo system (PS) on hearing, investigated the possibility that the transient evoked otoacoustic emissions (TEOAEs) technique, as compared with PTA, may be a more sensitive tool for early detection of ear damage resulting from inappropriate use of sound amplification. The researchers tested for TEOAEs in 2,500 participants aged between 10 to 59 years. Among all participants, only 39 participants have reported any hearing difficulties. Usable TEOAEs records were obtained from 1,724 participants (including 1,066 males and 658 females). A strong trend was found for the strength of otoacoustic emissions to decline with protracted use of PS headset. The extent of this decline was found to be proportional to the amount of PS exposure. As previous studies have failed to observe, with PTA testing alone, any signs of hearing loss among PS users, the uniqueness of LePage and Murray's (1998) study is the inclusion of TEOAEs. It was concluded that the preclinical phase of hearing loss was latent and TEOAEs offered early warning for hearing loss.

Further studies have shown that the use of DPOAEs was useful for providing early warning for hearing loss. For example, Torre III and Howell (2008) examined the effects of noise during aerobic classes on the hearing of participants in aerobic classes. Fifty participants (48 females and 2 males) underwent a hearing protocol including otoscopy, screening tympanometry, and a pre and post-aerobic class DPOAEs testing. Statistically significant change in DPOAEs strength after aerobic class was found at 6 kHz, with a

mean absolute decrease of 1.4 dB SPL in DPOAEs amplitude.   However, there was only one experimental group and no comparison control groups in Torre III and Howell's (2008) study and thus the internal validity was weakened. In addition, since only a short observation period (i.e., only one-shot before and after observations) was used to monitor the change of DPOAEs, the short-term and long-term effect of the noise exposure on the DPOAES can not be assessed.

Engdahl (1996) examined the effects of noise and exercise on the human cochlear function using both audiometry and measures of the amplitude of DPOAEs.   Hearing of the 8 subjects participated in the research was tested on 3 separate occasions: before and after 10 minutes of noise exposure, before and after a 10-minute exercise at 60 percent maximal oxygen uptake, and before and after a combination of noise exposure and exercise for 10 minutes.   Engdahl (1996) found that physical exercise significantly increased the noise-induced TTS and the effect of noise exposure on DPOAEs amplitude.   Although the research design is robust, the validity of the results should be interpreted with caution in light of the small sample size and the lack of control group.

Emmerich et al. (2000) conducted a longitudinal experiment in awake guinea pigs to assess the effects of industrial noise exposure on DPOAEs and hair cell loss of the cochlea.   As part of their research, 12 awake guinea pigs were exposed to industrial noise at a level of 105 dB SPL for 2 hours duration. The researchers obtained measures of DPOAEs from the guinea pigs before and immediately after exposure at 5 minutes intervals for a total period of 2 hours.   The recording was repeated daily during the first 3 days after noise exposure and then at regular intervals of 2 days until DPOAEs amplitude has

stabilised.   Four month after noise exposure, the experimental protocol was terminated.   Three different patterns of recovery were identified: partial recovery of DPOAEs (in about 70 percent of the ears investigated), complete recovery of DPOAEs within 9 days after noise exposure (in about 16 percent of the ears investigated), and no recovery of DPOAEs (in 14 percent of the ears investigated).   No relationship was found between number of lost outer hair cells (OHC) and percentage decline in DPOAEs.   In some cases, an increase in DPOAEs amplitude after noise exposure was observed.   It was speculated that tinnitus could be related to the increased DPOAEs caused by a changed efferent cochlear innervation after acoustic trauma.   The researchers concluded that continuous industrial noise produced resulted in a reduction in the level of DPOAEs due to severe damage to the OHC.   Despite the small sample size used, Emmerich et al.'s (2000) study has demonstrated the negative short-term and long-term effects of noise on the amplitude of DPOAEs in the animal model.

As evidence demonstrating the effectiveness of DPOAEs in detecting early signs of NIHL is in existence but constrained due to the limitations of the studies in sample size, experimental control, and subject selection, the potential of using DPOAEs in monitoring the development of NIHL in humans needs further investigation.

1.1.4   Auditory Pathophysiology

Animal research confirms that scattered OHC damage, perhaps less than 20 percent of the total OHC population, is not always evident in pure tone threshold measurements (Bohne & Clark, 1982, In Hall, 2000).   As the proportion of damaged OHC exceeds some critical level (for instance, 25-30

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percent), permanent hearing threshold shift can be observed (Hall, 2000). The discrepancy between results from behavioural and physiological measures may be related to the physiology of hair cells and their protection mechanism.

1.1.4.1 Physiology of Hair Cells

The cochlea of mammals contains two sets of hair cells: IHCs and OHC. The IHCs are passive, sensory cells which directly stimulate the auditory nerve, while the OHC are active, muscle-like cells which act as cochlear amplifier. Inner and outer hair cells are highly specialised sensory (afferent) transducers residing within the organ of Corti of each cochlea. Each organ of Corti contains 10,000 to 12,000 outer hair cells (OHC) and 3,000 to 4,000 inner hair cells (IHCs). Inner hair cells are myelinated and are the "true" auditory receptors (National Institute of Health, 2005). Each IHC has its own auditory nerve fibre. The Sterocilia converts IHC fluid-based energy into bioelectrical energy which is sent to the brain. Outer hair cells are not myelinated and up to 20 OHC may share a single auditory nerve fibre. The purpose of OHC is to amplify incoming sounds and provide "exquisite sensitivity" to increase frequency resolution in humans (Henderson et al., 1993). Outer hair cells are more susceptible to damage from noise exposure, acoustic trauma, ototoxic drugs and other insults (Miller, 1974). Outer hair cells damage is associated with poorer hearing thresholds, such as NIHL and presbyacusic. Inner hair cells damage is often associated with word recognition problems, secondary to the degeneration of the neural signal (Prasher & Luxon, 1998). In humans, when an IHC or OHC is damaged or dies, it is gone forever and the resultant hearing loss is permanent (Miller, 1974).

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1.1.4.2 Protecting Hair Cells

Preventing hair cell loss (through noise reduction) is arguably the best defence against NIHL.   Insult to the ear via noise exposure releases free radicals in the inner ear, which damages hair cells (Suter, 2002).   Glutathione (GSH, an antioxidant antagonistic to free radicals) has been considered to have the effect of limiting hair cell damage secondary to noise exposure in guinea pigs (Ohinata et al., 2000;   Yamasoba et al., 1998).   Henderson et al. (1997) reported that GSH was elevated in animals which underwent noise conditioning training and had achieved acquired resistance to noise.   These studies suggested that antioxidants are important in the prevention of NIHL and that pharmacological intervention may enhance prevention of NIHL. Researchers supported by the National Institute on Deafness and other Communication Disorders (NIDCD) in 2005 found that administration of antioxidants, aspirin, and vitamin E to guinea pigs for up to three days following noise exposure, had the effect of reducing hair cell damage (National Institute of Health, 2005).

Another fascinating avenue under exploration is the development of an antioxidant compound, taken orally, to prevent NIHL.   The "hearing pill" has been explored by the United States Marine Corps and others (Boswell, 2004). The primary compound within the pill is an amino acid (N-acetylcysteine) which facilitates the synthesis of antioxidants.   It is too early to report conclusive results, but the hearing pill may prove to be useful defence against NIHL (Shafer, 2005).

As scientists focus their energies on hair cell regeneration and protection, significant progress in non-humans has been demonstrated.   At this time, the only proven option is avoidance of, and protection from

prolonged and significant noise exposure.   In the next few decades, there is an excellent opportunity for advances in pharmacological and biological sciences to potentially impact the preservation and regeneration of human hearing (Ohinata et al., 2000).

In the last few years progress has been made in understanding basic mechanisms involved in damage to the inner ear and various potential therapeutic approaches have been developed.   It was shown that hair cell loss mediated by noise or toxic drugs may be prevented by antioxidants, inhibitors of intracellular stress pathways and neurotrophic factors or neurotransmission blockers.   Moreover, there is hope that once hair cells are lost, their regeneration can be induced or that stem cells can be used to build up new hair cells.   However, although tremendous progress has been made in recent years, most of the concepts are still in the "animal stage" and it is difficult to predict if any of these approaches will finally enter clinical practice (Bodmer, 2008).

1.1.5   Noisy Environment and NIHL

As the technology in the field of loudspeakers develops, the usage of a powerful sound amplification and delivery system may pose a potential hazard to unprotected hearing.   In the 1960s and 1970s, sound pressure levels over 115-120 dBA could not be produced by loudspeakers without the risk of damaging them.   During the past decades, however, loudspeakers have been developed that can produce sound pressure levels over 130 to 140 dBA at a distance of several meters.   This is the kind of equipment that is used by rock bands and pop groups these days (Gothe, Cynkier, Lind, Bloomberg, Svensson, and Ytterlind, 1991).   Most of the information on the subject comes from

related areas such as recreational noise that damages the cochlea temporarily or permanently and result in a hearing loss.   Some examples for recreational activity that can potentially damage peoples' hearing is the use of guns for hunting, regular music exposure such as playing a musical instrument or regular attendance in rock concerts, and regular use of personal stereo devices such as iPod and MP3 players (Hellstrom, Axelsson, & Costa, 1998; LePage & Murray, 1998;   Axelsson, 1996;   Williams, 2005;   Royster, Royster, & Killion, 1991).

Studies from several countries indicate an increased incidence of hearing impairment due to recreational noise, while others have found no such association (Quaranta, Portalatini, & Henderson, 1998).   Several studies have shown an association between shifts in hearing thresholds and exposure to excessive sound pressure levels from noisy recreational activities involving noisy toys, pop and rock concerts, or personal MP3 players (e.g., Jokitulppo et al., 1997;   Juman et al., 2004).   Other reports, however, yielded no evidence attributing hearing loss to high-level music exposure in non-professional listeners (Rintelmann et al., 1971;   Axelsson et al., 1994;   Hellstrom et al., 1998;   Mostafapour et al., 1998).   These conflicting findings may be due to different research designs and methodological differences on the detection of NIHL and suggest that a closer look at these methods is required.   Some examples of methodological differences are sample size, the lack of control groups, duration of monitoring and the number of assessments during the monitoring period.

Numerous studies have been published in the past regarding the effect of noise exposure from personal stereo player (PSP) on hearing.   Schmuziger et al. (2006b) conducted a long-term assessment of auditory changes related

to a single noise exposure during non-occupational activities. The researchers examined 42 participants who were divided into two groups based on their noise exposure of either continuous duration or single high-energy impulse. Audiometric data were available for each of these participants shortly after noise exposure and follow-up examinations took place one to sixteen years after the single exposure. The initial median hearing loss at 3-8 kHz measured in the group with continuous type of noise exposure was 9 dB HL. Hearing function at follow-up tests was found to return to the normal level. In contrast, the same initial temporary hearing loss was measured for the impulse-type noise group, but a residual hearing loss of 4 dB HL was found at follow-up. It is noteworthy that the majority of the participants from both groups reported tinnitus and hypersensitivity to sound (HSS) at follow-up, but with minimal impact on their lives. The researchers concluded that subtle changes of the cochlea were probably still present in the majority of participants after a single incidence of noise exposure even after a long period of recovery and speculated that "these subtle changes are most likely responsible for subjective audiological symptoms such as hypersensitivity to sound and tinnitus and are not detected by pure tone audiometry" (Schmuziger et al., 2006(b), p.53).

1.1.1.5.1 Noise in Aerobic Classes

Aerobics is a form of exercise set to music, with planned, structured, repetitive bodily movements performed to improve or to maintain physical fitness. Aerobic exercise classes, typically led by an instructor in the gymnasium setting, generally last for about an hour. The instructor directs participants while music is played in the background (Wilson & Herbstein,

2003).   The music tends to be loud to motivate participants.   Instructors often find themselves shouting commands to participants.   To overcome the strain of shouting over music, some instructors use microphones capable to amplify the instructor's voice to a level that is higher than the background music.   This may lead to the practice of using the amplification system at high loudness volume (Yaremchuck & Kaczor, 1999).

Aerobics has been identified as an at-risk activity in NIHL when loud music is played in classes (Wilson & Herbstein, 2003).   The presence of dangerous noise levels during aerobic classes in gymnasiums has been reported by Yaremchuck and Kaczor in 1999.   The researchers measured the sound pressure levels during aerobic class at five different gymnasiums for a total of 125 classes.   Twelve readings were obtained from each class, which lasted for 60 minutes.   The results showed that dangerous noise levels were present in the majority of classes, with 79 percent (92/125) of the readings found to be between 90 and 98 dBA and only 21 percent of the readings found to be below 90 dBA.

1.1.1.5.2   Noise and Exercise

Clark and Calvert (1991) found that participants in sports activities often view noisy environments as exciting and necessary to their enjoyment of a particular activity.   The researchers described this view as the "social noise phenomenon".   In other words, the louder the noise, the more successful the activity is considered to be.   They also found that noise was associated with power.   For instance, a motorcycle engine that is loud is associated with a more powerful delivery system.   According to Wilson and Herbstein (2003), attempts to reduce noise levels in gymnasiums through hearing conservation

"have generally failed, possibly because participants find the loud music enjoyable and motivating, and therefore not too loud" (p. 29).

Temporary threshold shift due to exposure to moderate to high levels of sound has been associated with changes in the amplitude and frequency content of TEOAEs (Kemp, 1982) and DPOAEs. According to Hall (2000), the effect of noise exposure on inducing TTS may be increased by exercise. The exact mechanism is unclear, but among the factors that might be involved are the amount of metabolic activity (and metabolic exhaustion), body temperature (more TTS with increased temperature), and release of bio-chemicals during the exercise. As previously mentioned, Engdahl (1996) conducted a study of eight normal hearing adults (three women and five men; age range: 25-33) with DPOAEs recorded post exposure to noise. Exercise on a stationary bicycle produced a heart rate approximating 60 per cent of maximal oxygen update. Band noise at a level of 102 dB SPL was presented by an audiometer for 10 minutes. Results from Engdahl's (1996) study revealed that DPOAE amplitude was reduced by noise exposure alone, in the frequency region of the noise, with recovery over a 20 minutes period. No significant correlation was found between TTS and DPOAE amplitude possibly because the TTS was minimal. It was concluded that physical exercise alone had no effect on auditory threshold or DPOAE findings but significantly increased the noise-induced TTS and the effect of noise exposure on the DPOAE amplitude.

1.1.6 Risk Factors and Prevention of NIHL

Cohen et al. (1970) coined the term "sociocusis" to describe the type of hazardous noise coming from non-occupational sources. More specifically,

the researchers are referring to recreational noise and the negative effects this noise has on hearing.   Examples of sociocusic sources are working tools, chain saws, unmuffled motorcycles, loud music, and hunting guns (Suter & Berger, 2002).

Noise is a biological stressor and can influence the entire physiological system.   It causes the body to respond in ways that may be harmful in the long run leading to biological changes leading to stress disorders (Suter & Franks, 1990).   According to Suter & Berger (2002), in the physiological dimension, the effects of prolonged exposure to noise revolves around cardiovascular effects such as increased blood pressure and changes in blood chemistry.   Properly fitted hearing protection devices will reduce the possibility of these effects and the prevention of occupational as well as recreational NIHL.

1.1.6.1   Risk Factors of Recreational NIHL

It has been shown that there is a correlation between the exposure to excessive sound pressure levels from non-occupational activities and shift in hearing thresholds (Meyer-Bisch, 1996;   Schmuziger et al., 2006).   In contrast, some reports have yielded no evidence of such correlation (Axelsson, Rosenhall & Zachau, 1994;   Hellstrom, 1991;   Hellstrom, Axelsson & Costa, 1998;   Mostafapour, Lahargoue, & Gates, 1998).   The susceptibility to acquired inner ear damage may also differ greatly among individuals. Inherited predispositions and middle ear infections may increase the harmful impacts of noise on hearing function (Suter & Franks, 1990).

Important aspects of auditory injury from noise exposure include

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additional symptoms, such as hypersensitivity to sound (HSS) or tinnitus (Anari et al., 1999; Lockwood, Salvi, & Burkard, 2002). These symptoms may persist even after the recovery from temporary threshold shift and become increasingly irritating to the patient (Suter & Berger, 2002). However, reports in the literature dealing with the consequences of recreational noise exposure have generally been more focused on the prevalence of such symptoms than on the severity of the psychological distress that may result from them (for example, Meyer-Bisch, 1996). Still, these additional symptoms are beyond the scope of this research and will not be discussed.

Estimating hearing risk due to recreational exposures, such as those due to music, is difficult because of their intermittent and irregular nature. According to Berger (2001) it appears that typical societal noise (transportation, recreational, home hobby, and other incidentals) approaches levels that cause hearing loss for those who are most susceptible. Based on findings from Engdahl's study (1996), it appears that exercise accentuates the risk of acquiring temporary, if not permanent, hearing loss due to noise. It is difficult to control music levels during exercise classes because of the common perception that louder music is more enjoyable, and therefore causes participants to work harder. However, in a recent study, Wilson and Herbstein (2003) found that ""Low-Risk"" sound pressure levels (by which they meant 85 dBA or quieter) could be used in aerobic classes without reducing loudness comfort, enjoyment or motivation to exercise for the majority of those involved.

1.1.6.2   Awareness Education and Hearing Protection Devices

Despite the potential risk associated with loud music playing during exercise classes, efforts to promote hearing conservation within the aerobics industry have been limited and largely unsuccessful possibly because participants often find loud music enjoyable and motivating (Wilson & Herbstein, 2003).   To obtain active participation and better understanding of the risks of noise to hearing, it is necessary to educate those exposed to noise either occupational noise or recreational noise.   Recommendations have been made by the Association of Health and Fitness Professionals (as outlined in their 'Code of Ethics for Group Fitness Instructors') that sound pressure levels should not exceed 90 dBA, and the amplified instructor's voice should not exceed 100 dBA.   Berger (2001) recommends that in order to be truly safe, noise levels during aerobic classes should be 5 dBA lower than those recommended by IDEA.   The awareness education program for hearing conservation often involves learning about noise-induced hearing loss (Prince, Colligan, Stephenson, and Bischoff, 2004), identification of "High-Risk" places and situations (Suter, 2002), and the use of hearing protection devices (Suter & Franks, 1990).   This is due to the reason that those who understand the risks of noise and the prevention role of hearing protection (HP) devices are more likely to participate for their own benefit rather than viewing the HCP as an imposition (Berger, 2001).

A hearing protection device is a device that can be worn by the user to reduce the level of sound entering the ear (Suter & Franks, 1990).   The three basic types of hearing protection devices are earplugs, earmuffs, and semi-inserts.   A properly selected, fitted and inserted earplug can provide considerable attenuation (noise reduction) and can be worn comfortably for many hours at a time.   These devices come in many shapes, sizes, and

material (Suter, 2002). If they are fitted and worn correctly, earplugs are often more comfortable than earmuffs for long wearing periods. They are cooler in hot weather, easier to wear in confined spaces, and more comfortable because of the lack of headband pressure. On the other hand, the attenuation of earplugs is more variable than that of earmuffs because they are more dependent on proper fitting and insertion practices. Also, some types of plugs tend to work loose simply from chewing or talking and need to be reinserted (Suter & Franks, 1990). Hearing protection devices are also varied in their attenuation rate. Based on a review of 22 field studies reported in Suter & Berger (2002), it was found that the labelled noise reduction rate (NRR), which was the level of attenuation of an HP device as measured in the manufacturer's laboratory ranged from 14 dB to 33 dB SPL. However, Suter & Berger (2002) noted that the level of attenuation measured in the field (field NRR) for a HP device was often not nearly as favourable as the specified laboratory NRR and therefore recommended to de-rate the HP device's expected attenuation level by 50 percent.

1.1.7 Architectural Acoustics

As aerobic classes typically take place in a gymnasium or an exercise room, the architectural acoustics needs to be considered as far as noise exposure is concerned. The acoustical environment in and around a room or a building is influenced by numerous interrelated and independent factors associated with the building planning-design-construction process. From the very outset of any building development, the selection of the site, the location of building on the site, and even the arrangement of spaces within the building can, and often does, influence the extent of the acoustical problems

involved.   The materials and construction elements that shape the finished spaces will also determine how sounds will be perceived in that space as well as how they will be transmitted to adjacent spaces.   The architects, engineers, building technologists, and constructors involved in the construction of a building all play a part in the control of the acoustical environment of the building (Gastmeier & Aitken, 1999).   The acoustics of a building is related to a system of sources, paths, and receivers of sound.   The building design has the greatest impact on the transmission paths.

The risk of developing hearing disorders due to noise exposure can be affected by a number of environmental factors, such as the size, shape, and acoustics of the room (Iannace et al., 2006).   Effective control of the acoustical environment in buildings involves at least a conceptual understanding of the basic properties of sound.   Such understanding is essential for those concerned with the complete building design and construction process that will influence the fundamental decisions required for the building to be constructed.   Solutions to acoustics problems require experienced judgment.   Even though acoustics is not the most important aspect of building construction, effective control of the acoustic environment is key to the production of good buildings (Yoo, 2001).   Studies of the acoustics in the rooms where aerobic classes take place will provide important information for future environmental modification to minimize the risk of noise-induced hearing loss if needed.   Therefore, before establishing a cause-effect relationship between noise exposure in aerobic classes and the hearing of aerobic class goers, it is recommended to assess the room acoustics by measurements of such parameters as reverberation time and SPL distribution.

1.1.7.1 Reverberation Time

Reverberant sound refers to the sound reflected from the surface of a room. Reverberation time is the time it takes for the reverberant sound to die away. The more absorbent a room, the shorter the reverberation time and thus less distortion or noise superimposed on the original sounds. As a standard measuring scheme, a measure of RT60 is used to indicate the time required for the sound energy to decay 60 dB from its original level. The reverberation time (RT60) of a room is a key parameter in quantifying the room acoustics. The concept of reverberation time and the related calculation procedure date back from the beginning of the 20th century, when it was developed by Wallace C. Sabine (Yoo, 2001). According to Gastmeier & Aitken (1999), RT60 is calculated as a function of the room volume at 500Hz (and/or 1000Hz), which is the centre of the crucial range for speech intelligibility. Speech intelligibility is expected to be reduced in highly reverberant environments (i.e., RT60 longer than 3.5 seconds). Evidence in the literature (Gastmeier & Aitken, 1999) suggests that gymnasiums typically suffer from an RT60 that is too long (ranging from 5 seconds to 8 seconds) resulting in high reverberating sound. Reduction in RT60 can be achieved with suitable absorptive treatment (Yoo, 2001).

1.1.7.2 Noise Dosemeter

The noise dosemeter is a small, integrating sound pressure level meter that calculates the noise dose automatically. The first dosemeter was designed in 1969 (Suter & Franks, 1990). The noise dosemeter can be clipped to the belt or to a shirt pocket with the microphone placed in the

vicinity of the head, preferably attached to the clothing at the neck area. Dose is a parameter used to quantify noise exposure over a period of time. The 100 percent dose is different in different countries because different countries are using different exchange rate and exposure levels. For example, In the United States, 100 percent dose is equal to 90 dBA noise level over an 8 hour period for 40 hours of work a week (Suter & Berger, 2002). In New Zealand, 100 percent dose is set as a criterion which is equivalent to an 85 dBA noise level over an 8 hour period for 40 hours of work a week.

Dosemeters are often used for the evaluation of industrial noise in the occupational setting. A literature review of studies in the field of NIHL revealed that most researchers have used sound level meter (SLM) to evaluate the noise levels in the different settings. For example, Yaremchuk & Kaczor (1999) used a portable SLM to evaluate the noise levels during aerobic classes in five different gyms. In Yaremchuk & Kaczor's (1999) study, readings from the SLM were taken at five minutes intervals to yield an average for each class. However, a recent study by Torre III & Howell (2008) has demonstrated the use of dosemeters, which were strapped to each of the 50 research participants with the microphone placed on the collar of the test ear side, in evaluating the noise exposure levels during aerobic classes.

1.1.8 Summary

Based on the literature review, there was strong evidence in support of a cause-effect relationship between NIHL and noise exposure, either occupational or recreational. Aerobic class goers have been identified as individuals at risk of NIHL because loud music is often played in aerobic class. However, there is a lack of empirical data in the literature demonstrating the

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effect of noise exposure in aerobic classes and the effect of certain preventing schemes. The insensitivity of the conventional hearing test, PTA, in detecting early signs of NIHL may be one of the reasons why the risk of NIHL for aerobic class goers is often underestimated or ignored. A review of the hearing tests and the auditory pathophysiology for NIHL suggested that testing of OAEs, sounds generated by the activity of OHC, might be more sensitive than PTA in reflecting the deterioration of OHC, which was the early sign of NIHL. The usefulness of DPOAEs in detecting the noise-induced damage to the inner ear has been demonstrated to some extent in the literature. However, better research design is needed to determine the risk and the development of NIHL in aerobic class goers, including assessment of the room acoustics of the place where aerobic classes take place, use of a longitudinal design, a control comparison groups, and a hearing test more sensitive to detecting the early signs of NIHL, and consideration of the effect of the use of hearing protection devices on NIHL.

1.2 Research Outline

This section outlines the research question, importance, aims, and hypotheses of the study.

1.2.1 Research Questions and Importance

In an attempt to assess the risk and the development of NIHL for aerobic class goers, two main research questions were raised in this study:

1. Are aerobic class goers without hearing protection at risk of

developing NIHL?

2. Is DPOAEs, test of the cochlea mechanics, more sensitive than PTA in detecting early signs of NIHL?

Studies of NIHL are important because hearing loss has significant implications on a person's well being and may affect their work performance. Environmental noise in the recreation centre is a significant but often overlooked public health issue to be addressed. There is currently no reliable information regarding the overall incidence and prevalence of NIHL in New Zealand. However, the fact that the annual payout for compensation claims for NIHL in 2007 was 38 million NZ dollars by the Accident Compensation Corporation (ACC), a government entity administering personal injury cover for all New Zealand citizens, residents, and visitors, and that the number of new NIHL claims increased from 3,000 in year 2001 to 5,000 in year 2008 (Thorne, Ameratunga, Stewart, Reid, Williams, Prudy, Dodd, Wallaart, 2008) indicated the increasing prevalence and costliness of this preventable problem.

In addition to the general concern for NIHL, reasons for considering the risk of NIHL for aerobic class goers are (i) the sound pressure levels generated during aerobic classes is often high, (ii) speakers used in gyms these days have the capacity to generate high sound pressure levels,
(iii) aerobic classes are becoming more and more popular these days and therefore more people are put at risk of developing hearing loss as a result. Evidence collected in this project will allow for an evaluation of the use of DPOAEs as a tool for early detection of NIHL. Identification of the risk of NIHL in noisy environment such as aerobic class and early detection of NIHL

will promote awareness of the need for hearing conservation. It will also facilitate the establishment of prevention schemes and/ or the introduction of noise control measures such as control of the reverberant sound to minimize potential hearing damage.

1.2.2 Aims of the Study

This study was aimed at monitoring changes of hearing levels of participants at various sessions post-exposure to pick up early signs of NIHL. As previously mentioned, the early destruction of the hair cells in the cochlea may not be reflected on the audiogram results (Jokitulppo et al., 1997). Therefore, this study employed both the objective measure of DPOAEs and subjective measure of PTA to assess the effects of noise exposure on the hearing of aerobic class goers. The purpose of this comparison was to investigate if the use of DPOAEs, an inner ear function test, could be used as a tool for early detection of NIHL when the loss was not detected in a normal pure tone audiometry test.

1.2.3 Hypotheses of the Study

Research conducted during the 80s and the 90s on animals and human have shown that excessive noise exposure gives rise to temporary emission shift. In a study of the effects of noise exposure on DPOAEs and hair cell loss of the cochlea in guinea pigs, Emmerich et al. (2000) also found a positive correlation between exposure to noise and damaged OHC as reflected by reduced DPOAEs levels. Based on the common finding from the experiments in animals as well as humans that DPOAEs (as well as TEOAEs) are altered by noise exposure, this study poses two hypotheses:

1. Participation without hearing protection in aerobic classes with a high level of noise may lead to temporary shift in hearing threshold showing signs of damage to the outer hair cells;

2. The test of DPOAEs is more sensitive than the conventional PTA in detecting early signs of NIHL within a 30 day period.

Chapter 2.

Acoustic Assessment of the Aerobic Class

This project included two stages of data collection and analysis process. The first stage of the study was aimed at (1) identifying the characteristics of a room typically used for aerobic classes and (2) establishing the average noise level in various course settings to allow for differentiation between aerobic classes posing high risk and those posing low risk of NIHL to the attendees. Acoustical measurements of the aerobic class included measurements of:

i) the reverberation time in one selected gym setting (a room used for aerobic classes in Gym A) when the aerobic class was not in session. We have simulated the noise level an aerobic class; and

ii) the noise level during aerobic classes taking places at different gyms.

2.1 Methodology

The instrumentation, procedure, and measurements used in the first stage of the study were described as follows.

2.1.1 Instrumentation

The equipment used for measuring the reverberation time in one selected gym setting included a microphone (Brüel & Kjær Type 4189), a modular precision sound analyser (Brüel & Kjær Type 2260), a sound level calibrator (Brüel & Kjær Type 4231), an amplifier (Brüel & Kjær lab 300), a loudspeaker (Brüel & Kjær Omni Power 4296), and a professional audio

generator (Neutrik Minirator Mr1).   The equipment used for measuring the noise level in the chosen gym setting included a sound level meter (SLM; Center 322 DC 9V 2 batteries), a standard 94 dB/1000 Hz sound calibrator (Lutron, model SC-941, IEC942, Class 2 standard, total harmonic distortion smaller than 2 percent), and a tri-pod.   For assessing the safety limit for noise level in the chosen gym setting, the stereo system normally used in the selected gym setting for aerobic classes was used to generate music to simulate the noise environment of an aerobic class.   The stereo system included a CD player (Pioneer, CDJ100S), an amplifier (Crown, XLS602), and four functional 2-way loudspeakers (JBL, MRX512M).   The equipment used for measuring the noise level in all gym settings included in this study was a data logging noise dosemeter (Extech model number 407355) with PC Interface.

2.1.2   Instrumentation Setup and Procedure

The instrumentation setup and the procedure involved in the first stage of the study are as follows.

2.1.2.1 Reverberation Time

Before obtaining measures to calculate the reverberation time of the chosen gym setting, the background noise level in that gym setting was measured using a sound analyser calibrated with sound calibrator before the commencement of measurements.   The microphone attached to the sound analyser was placed at least 1 meter away from any surface (e.g., walls or large pieces of furniture) and at least one and a half metre away from windows.   To generate noise to help assess the reverberation time of the

room, the output of the audio generator was connected to the amplifier. The output of the amplifier was connected to the loudspeaker. After selecting "pink noise" as the type of sound to be generated by the audio generator the experimenter set the sound playback level, through the volume control of the amplifier, to a level at least 10 dB above the background sound pressure level. The experimenter then placed the sound analyzer at six different positions in the Sports Hall and recorded from the sound analyzer the readout of RT60 at each of the four selected positions. The frequency range tested was 0.08 kHz to 10 kHz. During measurements, the sound source was stopped and the reverberation time was calculated by the SLM. In addition, the reverberation times were measured using two speaker positions. We measured reverberation time from each corner in addition to two measurements taken from the centre of the room. A diagram of the room tested including the six positions are marked by x in Appendix 1.

2.1.2.2 Noise Level with SLM

To assess the maximum noise level that could be played in the chosen gym setting, the measurement session was conducted when the gymnasium was cleared of people. During measurement, the SLM was placed on a tripod, with the tripod placed at least one meter from any major reflecting surface and at least one and a half metre away from windows and the microphone of the SLM secured at a height of between 120 to 150 centimetres above the ground level. A piece of music randomly selected from the music selection used in the aerobic class was then played through the stereo system as previously described. When the music was played back through the stereo system, the experimenters wore hearing protection devices (3M 1440; with

a NNR of 30 dB SPL). The experimenters set the volume control of the amplifier of the stereo system at the maximum level (Level 10) and then used the SLM to measure the SPL at 25 different locations in the sports hall (see Appendix 1). After identifying the location exposed to the highest pressure level, the volume of the amplifier was adjusted so that the sound level readout from the SLM placed in that position was at 97 dBA, which was the safety limit generally prescribed for a single session of 30 minutes exposure (see Appendix 2). This recording session was performed to gauge the safety level at which the stereo system could be played for an aerobic class in this particular gym setting.

2.1.2.3 Noise Level with Dosemeter

The noise dosemeter was used to assess the noise level during aerobic classes. The procedure taken to measure the noise level of the aerobic class was mainly based on the guidelines provided by International Organisation for Standardization (ISO 1996): "Description and measurement of environmental noise" and ISO 9612: "Guidelines for the measurement and assessment of exposure to noise in a working environment" standard measurement procedures, which form the basis for most national environmental and occupational noise (New Zealand Occupational Safety and Health Service, 2002). According to the ISO 1996 guidelines, the sound level meter needs to be placed on a tripod and the operator needs to stand half a meter behind and half meter to one side of the microphone. However, to avoid the Hawthorne effect, which states that participants' awareness of their behaviours or environments being observed may lead to changes in the condition of interest, the dosemeter was hidden in a bag and the microphone

was covertly placed outside the bag in the specified height to sense and measure the noise in the room during aerobic classes.   The dosemeter was calibrated every fortnight in accordance with ISO 1996 regulations.   A slow detector, giving an average reading for each one second of recording, A-weighted scale was used.

2.1.3   Measurements

The experimental measures obtained in the first stage of the study included reverberation time (in seconds), sound pressure level (in dBA), and an assessment of the surface material of the room.   The range of frequencies tested for calculating the reverberation time was 0.08 kHz to 10 kHz.   The average reverberation time was calculated as the average reverberation time of the four microphone positions.   The reverberation time, as previously described, reflected the time taken for a sound to drop to 60 dB below its original level.   The longer the reverberation time, speech becomes less intelligible and music becomes more cacophonous and produces higher background noise levels (Sharland, 1972).

2.2   Results and Discussion

The general features of the aerobic studios examined had a ceiling, a standard hard surface parquet floor, and a small area at the front for the instructor and the music system.   The music typically played during class contained modern-day rock and pop music songs with fast-paced portions collaged for use for the aerobic class.   The room (in Gym A) chosen for evaluation of both reverberation time and noise level was 31 meter long, 22 meters wide, and approximately 20 meters high.

2.2.1 Reverberation Time

Results from the acoustic assessment of the chosen gym setting revealed that the RT60 ranged from 0.95 seconds at 10 kHz to 7.2 seconds at 0.63 kHz (see Figure 1). The specific values obtained in the four microphone positions tested were shown in Appendix 3. As shown in Figure 1, the average reverberation time across the mid octave bands, particularly in the frequency range between 0.25 kHz to 2.5 kHz, were greater than the recommended maximum value of 2 seconds. Although there was a lack of published information regarding how the recommended RT60 has been established, Gastmeier & Aitken (1999) commented that approximately 2.4 seconds would provide an environment that is likely to be acceptable. Yoo (2001) recommended an RT60 of 1.8 seconds or lower. In any case, RT60 measurements obtained for the chosen gym setting were found to fail these recommendations, suggesting that the room examined was excessively reverberant. In particular, the high RT60 values at 0.63 kHz (7.2 seconds) and 1 kHz (6.21 seconds) may have serious implications on the noise levels in the room and the clarity of speech. As there was no sound damping or absorption structures such as hanging objects or holed plate found in the room examined, the reverberation time may be reduced if the interior surfaces of the room is covered with absorptive materials.

2.2.2 Noise Level

The safety limit for the noise level in the chosen gym setting was found when the volume control of the amplifier was set at Level 2. It has been informally observed during aerobic classes that instructors in this particular

gym setting often used the volume control at a level exceeding the identified safety limit, suggesting that this aerobic class might pose a risk of NIHL.   The SPL recorded at 25 different locations in the chosen gym setting when the amplifier was played at the maximum level had an average noise level of 107.2 dBA (SD = 1.74), ranging from 105.2 dBA to 110.8 dBA.   The SPL recorded when the volume control of the amplifier was set at Level 2 had an average of 97.6 dBA (SD = 1.47), ranging from 95.8 dBA to 99.4 dBA.   These results suggest that the volume control of the amplifier in Gym A may need to be maintained, in the absence of hearing protection, at least below Level 2 if music were to be continuously played for 30 minutes.

As for the noise level measured during aerobic classes across four gyms, the total number of classes measured was 105.   The average length of time of aerobic class in the 105 classes was 50 minutes.   The mean noise level for all classes measured was found to range from 73 dBA to 95.3 dBA.   Seventy eight percent (82/105) of the readings were above 85 dBA, and 7.6% (8/105) were above 100 dBA.   Only eight readings were below 80 dBA.   It was found that all values of 100 dBA or greater were from Gym B, which was also found to have the highest number of speakers per room during aerobic classes.

As there were only two measurements conducted in the fourth gym, data from this gym was later excluded from gym comparison.   The average noise levels during aerobic classes for each of the three gyms included for comparison were shown in Figure 2.

Although potentially hazardous noise levels during recreational activities have been widely documented, there are currently no regulations existing for acceptable levels of noise exposure during leisure activities.   Cohen, Antiaglia

and Jones (1970) recommended setting criteria for non-occupational noise conditions, with the safety level for non-occupational noise exposure set at 75 dBA as compared with the 85 dBA (and 90 dBA in North America) normally applied to the workplace. The present hearing conservation criteria set for occupational noise was determined under the assumption that quiet conditions would exist outside of the usual eight-hour work periods of the day to permit auditory recovery (Cohen et al., 1970). A review of the sound levels measured during the 105 classes demonstrated that noise levels during aerobic classes were higher than the recommended criteria set by Cohen et al. (1970) and violated this assumption.

2.2.3   Classification of High and Low Risk Aerobic Classes

In general, the nose levels in most aerobic classes were found to be higher than 85 dBA. However, as the noise level varied among aerobic classes, a distinction was made between high and low-risk classes for comparisons to be conducted in the second stage of the study. Based on the noise level measured, "High-Risk" classes were defined as classes with an average noise level exceeding 85 dBA. "Low-Risk" classes referred to classes with an average noise level lower than 85 dBA. The average noise levels during aerobic classes for the "High-Risk" and "Low-Risk" classes identified in the three gyms included for further analysis were shown in Figures 3 and 4 respectively.

The "High-Risk" classes identified included non-contact martial arts, high impact workout dancing to popular music, muscle workout using barbell with adjustable weights, and low impact workout using a step box. The "Low-Risk" classes identified included indoor cycling, boxing circuit, balance

classes, and low-impact aerobics.   As an example, Appendix 4 summarized the average noise levels across four different types of aerobic classes held in Gym B.   The first three types of classes, including high impact workout, non-contact martial arts, and muscle workout using barbell, were classified as "High-Risk" classes while the last one (indoor cycling) was classified as "Low-Risk" class.

2.2.4   Hawthorne Effect

In one of the gyms sampled (Gym A), a Hawthorne effect was observed while the noise level was being monitored during some aerobic classes.   The term "Hawthorne effect" dates back to a series of experiments on the productivity of an electric company in Chicago from 1924 to 1933.   Hawthorne is the name of the factory where the effect was first observed and described. The experiments were conducted by Mayo who published the results in 1933 (Draper, 2008).   Hawthorne effect refers to the effect due to the awareness of participants that they are the subject of an intervention or the feeling of being studied.   In this study, some instructors turned the volume down after being informed of the purpose of our research.   An average of an 8 dBA reduction in the noise level of the aerobic classes was observed from the measurements made after the date the instructors became aware of the research purpose (see Appendix 5).

Chapter 3.

Hearing Assessment of the Aerobic Class Goers

3.1   Methodology

The second stage of the study involved a series of hearing assessments of volunteers to monitor the effect of noise exposure on hearing, with post-exposure hearing tests taken at three post-exposure sessions in a one month period.   In addition, five participants of the "High-Risk" group were tested four months after the initial test to determine if the trend identified in the first month of monitoring persisted.

3.1.1   Participants

Participants in this study included regular aerobic class goers and non-gym goers.   An advertisement poster was posted around the University of Canterbury campus and the local gymnasiums calling for volunteers (Appendix 6).   The subject inclusion criteria were: i)   healthy adult aged between 18 and 50 years old, ii)   negative history of ear pathology, and iii) normal or no worse than a mild hearing loss, as verified through a PTA test (Appendix 7).   Exclusion criteria included: i)   the occurrence of acoustic trauma, ii)   excessive noise exposure during occupational activities, iii) previous ear surgery, iv)   a fracture of the skull, and v)   ingestion of potentially ototoxic drugs.

Regular aerobic class goers who had had at least six months of active participation in aerobic classes for at least once a week were included and divided into the "High-Risk" and "Low-Risk" groups.   Non-gym goers were

randomly assigned to the "Control without HP" and "Control with HP" groups.

A total of 35 participants were included in this study, excluding one participant from the "High-Risk" group due to pending middle ear surgery and one participant from the "Low-Risk" group due to participation in aerobic classes which was shorter than six month. The four comparison groups included: i) eight regular attendees of low-risk classes ("Low-Risk" group), ii) nine regular attendees of high-risk aerobic classes ("High-Risk" group), iii) six non-gym-goers sent to one high-risk aerobic class session with HP ("Control with HP" group), and iv) ten non-gym-goers sent to one high-risk aerobic class session without HP ("Control without HP" group). Table 1 listed the age, gender, and the duration of time of regular aerobics participation for each participant in the four groups. As an incentive, all participants were given a petrol voucher for their participation.

3.1.2 Participants' Task

If qualified based on the subject selection criteria as mentioned above, volunteers were provided with an information sheet detailing the aim of the study (Appendix 8) and invited to sign a consent form to indicate that they had read the description of the research and agreed to participate (Appendix 9). Volunteers were then asked to complete a short case history form detailing their basic demographics, current or previous ear problems, exposure to occupational or other recreational noise, frequency and duration of attending the class, and other background information (Appendix 10). The case history form included identification of hearing loss in the family before the age of 50, medical problems such as measles, mumps, diabetes and the use of medications that may affect OHC function, such as drugs

containing aminoglycosides and chemotherapeutic drugs (Robinette & Glattke, 2007).

All participants were instructed to keep a diary of noise exposure during the one-month monitoring period.   All participants were instructed to keep away from other sources of noise (e.g., clubs, rock concerts, lawn mowers, etc.) and provided with a pair of disposable earplugs (with a NRR of 22 dB SPL) to wear in noisy environment.   Participants were provided with a verbal explanation and a demonstration to show the correct way of inserting and removing earplugs for maximizing the noise attenuation provided by the HP device in noise attenuation.   Participants in the "High-Risk" and "Low-Risk" groups were instructed to maintain their regular participation in aerobic classes without wearing any HP device.   Non-gym goers were asked to participate in one "High-Risk" class (with or without a HP device as instructed) once at the beginning of the one-month monitoring period.   To ensure that participants followed the instructions, the experimenter became a member of the gyms and was present in most of the aerobic classes they participated.   Throughout the one-month monitoring period, all participants underwent four hearing assessment sessions, including tests of PTA and OAEs.

3.1.3   Instrumentation

The diagnostic assessment instrumentations included an otoscope (WelchAllyn reference model 23821), a clinical audiometer (Grason-Staler GSI61), a tympanometry (Tymptsar), and a Madsen Capella cochlear emissions analyser (DP1= $2f_1$-f_2; f_1= 65dB SPL, f_2= 55dB SPL; f_2/f_1 ratio= 1.22;   SNR= 6 dB).   The frequency separation of f_2 from f_1 is commonly

termed the f_2/f_1 ratio.   The most frequently measured DPOAEs is at the $2f_1-f_2$ frequency because it is the largest measurable DPOAEs in human ears (Robinette & Glattke, 2007).   The audiometer was calibrated according to the routine maintenance procedure followed by the Canterbury University Speech & Hearing clinic (i.e. once every two years).   The hearing assessments were performed in a sound treated room with the maximum allowable SPL maintained as specified by ANSI Standards S3.1.   The values specified by ANSI Standards were: 49 dB for 0.125 kHz, 35 dB for 0.25 kHz, 21 dB for 0.5 kHz, 26 dB for 1 kHz, 34 dB for 2 kHz, 37 dB for 4 kHz, and 37 dB for 8 kHz.

3.1.4   Procedure and Measurement

All hearing tests were conducted in the Speech and Hearing Clinic at the University of Canterbury University.   The order of testing was: i)   visual inspection of the ear canal and ear drum (otoscopy), ii)   basic hearing test (PTA), iii)   screening tympanometry, and iv)   inner ear function test (DPOAEs).   Participants had their ears inspected and their hearing tested prior to participating in a target class for the purpose of establishing their hearing level.   A "quiet period" of 14 hours prior to the baseline hearing assessment was required.   This was in accordance with the guidelines as outlined by the Hearing Conservation Amendment to the Occupational Safety and Health Administration (OSHA) from 1983.   A "quiet period" is defined by OSHA as a period of non-exposure to noise required prior to baseline hearing assessment (Suter, 2002).

Participants were tested at four different time points, including:

i)   Pre-exposure to noise (Time I),

ii)   immediately post-exposure (Time II),

iii)   24-48 hours post-exposure (Time III), which represents the end of the short recovery period, and

iv)   30 days post-exposure (Time IV), which represents the end of the extended recovery period.

In addition, five participants in the "High-Risk" group were tested four months post-exposure (Time V) to determine if the trends identified earlier were maintained.

The specific procedure used to obtain PTA and DPOAEs measures respectively were described as follows.

3.1.4.1 PTA

At the beginning of the PTA test, the experimenter explained to the participant the purpose of the hearing test and the need to respond by pushing a button when hearing a sound coming through the headphones or earphones.   Participants were notified that ears would be tested separately. Participants were asked to remove eyeglasses, or anything that might interfere with the proper seating of the headphones.   The experimenter then made sure that the headphones (or insert earphones) were placed on correct ears, with the headphones diaphragms sealing off the opening of the ear canal on both sides.   If using insert earphones, the experimenter made sure that the foam plug was inserted in a way that (1)   the outer edge of the insert phone was flush with the opening of the ear canal, (2)   the insertion depth was not too shallow, and (3)   the subject was comfortable (i.e., minimizing discomfort due to pressure from the headphone cushions pushing against earrings or the insert earphones in canals).

The range of frequencies tested in PTA was 0.25 kHz to 8 kHz. The Hughson-Westlake ascending method (Carhart & Jerger, 1959) was used to obtain participants' hearing thresholds. As all participants appeared to have normal hearing, the starting level was set at 30 dB HL. The sound level was reduced by 10 dB HL once a response occurred or increased in 5 dB HL steps until a response occurred. Once the first threshold was determined, the next frequency level was tested at a level of 15 dB HL higher than the threshold identified. The following frequencies were tested (in the order from first to last): 1, 1.5, 2, 3, 4, 6, 8, 1 kHz (retest for reliability check), 0.5, 0.75, and 0.25 kHz. The tone duration was 1 to 2 seconds, with at least 3 seconds between presentations. A hearing threshold was defined as the lowest hearing level at which responses occurred at least one-half of the ascending trials, with a minimum of two responses obtained out of three presentations at that level.

3.1.4.2 DPOAEs

Prior to the DPOAEs testing procedure, otoscopy and screening tympanometry would have been performed to determine the status of the external and middle ears. Before testing for DPOAEs, the experimenter explained the function of the test to participants in the following words: "The probe encompasses a small sensitive microphone and two speakers to detect small sounds produced by the inner ear in response to the sounds produced by the speakers. The test measures the activity level of the hair cells in response to sound". In addition, the experimenter emphasized the need for the participant to keep still and quiet and to minimize breathing noise and other bodily or clothing noise during the test.

An insertion probe with an appropriate size was chosen for the participant. The experimenter ensured that the probe was free of wax or debris and then inserted the probe as deeply as possible in the participant's ear canal without causing discomfort to the participant. A check for appropriate fitting was carried out by clicking on the "check-fit" screen of the cochlear emissions analyser. The OAEs cable was draped over the participant's shoulder in a position that minimized noise from the cable rubbing on clothing and hair.

The display of DPOAEs results for various response frequencies included (in graphical and tabular form) the amplitudes of the stimulus and DPOAEs (in real-ear dB SPL), the amplitude of the noise floor (in dB SPL), and the amplitude difference between OAE and the noise floor (in dB SPL).

Results from the immittance test of the middle ear were considered when interpreting the OAEs findings. According to Hall (2000), the presence of a negative middle ear pressure may impact the OAEs amplitude, particularly in the lower frequencies (smaller than 2 kHz).

The default test parameters on the Capella were set as the following values: L_1-L_2= 10 dB SPL [L_1= 65 dB SPL, L_2= 55dB SPL], f_2/f_1= 1.22, three points per octave. By convention, the lower frequency pure tone is referred to as the f_1 primary, and its level as L_1, whereas the higher-frequency primary is called f_2 and its associated level, L_2. Noise levels in the room were kept to a minimum during testing. Test time for participants was a little over two minutes for each DPgram. A DPgram is a graphic illustration of DPOAEs which displays the emission level as a function of frequency (Robinette & Glattke, 2007). An averaging process was continued to the maximum test time for all test frequencies (in half-octave steps from 1 to 8 kHz).

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There are no universally agreed criteria for defining the normality of DPOAEs or even its presence or absence. The absolute value of the noise floor was relevant in determining whether the measurement conditions were such that an OAE could be detected. A commonly used strategy for determining the presence of DPOAE, as outlined in Hall (2000), was to consider DPOAEs present if the amplitude was in the range between −10 to 30 dB SPL. This implied a substantial range including situations where the OAE signals might be depressed but could still be considered to be present. Since the difference between the DPOAE and noise floor levels is typically required to reach at least the range between 5 and 10 dB SPL (Robinette & Glattke, 2007), a more conservative approach is to consider an OAE present if its amplitude is greater than −10 dB SPL and its separation from the noise floor is at least 10 dB SPL (Hall, 2001). In this study, we chose to follow Hall's (2001) recommendation that DPOAEs be considered present in individual frequency bands if the SNR of the OAE is greater than 5dB SPL and the absolute amplitude of the OAE is greater than -10 dB SPL. These are the criteria commonly used in the clinical environment.

3.1.5   Statistical Analysis

A series of one-way Repeated Measures Analysis of Variances (ANOVAs) on Ranks were conducted on the experimental measures obtained from the four comparison groups separately to determine whether there was a "time" effect. Post-hoc pair comparisons using the Tukey test were performed if a significant effect was detected. The significance level was set at 0.05.

3.2   Results

Results from a series of one-way ANOVA on Ranks performed on the experimental measures for the four comparison groups separately were presented in Tables 2 to 5. For the experimental measures that were found to yield a significant session effect, the means of the measures obtained for each ear at each of the four different sessions for the subject group of interest were shown in Figures 5 to 10 respectively are described below. For better viewing of the relative sensitivity of the experimental measures assessed at each frequency to the session effect, the experimental measures averaged for each comparison group across the frequencies tested were also included in Appendices 27 to 30.

3.2.1 "High-Risk" Group

As shown in Table 2, a significant session effect was found for the "High-Risk" group in the PTA measures at 2 kHz for the right ear and at 4 kHz for the left ear and in the DPOAEs measures at 4 and 8 kHz for the right ear. Post-hoc tests failed to reveal any significant between-session difference. However, as shown in Figure 5, a general trend of hearing deterioration from Time I to Time II could be observed at these frequencies in the "High-Risk" group (Figure 5). Results showing the changes in PTA and DPOAEs measures at these frequencies for individuals from the "High-Risk" group were presented in Appendices 11 to 14.

3.2.1.1 PTA

As shown in Appendices 11 and 12, the PTA measures of all participants in the "High-Risk" remained at or above the normal limit throughout the monitoring period except for Participant 16, who exhibited

mild hearing loss at all times.   All participants in the "High-Risk" group showed signs of deterioration in the PTA measures from Time I to Time II at least at one frequency (either 2 or 4 kHz).   However, the shift of hearing threshold from Time I to Time II for the PTA measures in the "High-Risk" group was only 5 dB HL except for Participant 12, who exhibited a 10 dB HL shift at 2 kHz from Time I to Time II.   At Time III, only one participant (Participant 17) showed signs of deterioration in the PTA measures.   For PTA measures at 4 kHz, Participant 17 exhibited a shift of 10 dB from Time II to Time III, returned back to the baseline (Time I level) at Time IV, and deteriorated slightly (smaller than 5 dB HL) again from Time IV to Time V (Appendix 12).   At Time IV, none of the participants in the "High-Risk" group showed a reduction of PTA measures greater than 5 dB HL from the Time I baseline value.   However, at Time V, the PTA measures at 2 kHz for one participant (Participant 12) showed a reduction of more than 5 dB HL from the Time I baseline value (Appendix 11).

3.2.1.2   DPOAEs

Changes to DPOAEs measures post noise exposure were evident in the "High-Risk" group.   At Time I, as shown in Appendices 13 and 14, the DPOAEs measures of all participants in the "High-Risk" group remained at the normal range except for three participants (Participants 12, 16, and 20).   At Time II, all participants in the "High-Risk" group showed some signs of deterioration in the DPOAEs measures.   At 4 kHz for the right ear, Participants 18 and 20 showed a drastic drop of DPOAEs amplitudes from the normal range to below the normal limit at Time III and Time II respectively. At Time III, all participants in the "High-Risk" group showed signs of recovery

in the DPOAEs amplitudes except for one participant (Participant 18). At Time IV and V, all participants in the "High-Risk" group showed some signs of deterioration as compared with the Time I baseline value (Appendices 13 and 14). In average, the reduction in DPOAEs amplitude at 8 kHz for the "High-Risk" group four month post exposure (Time IV) was 11.47 dB SPL for the left ear and 13.04 dB SPL for the right ear.

3.2.2 "Low-Risk" Group

As shown in Table 3, a significant session effect in the "Low-Risk" group was only found on the DPOAEs amplitudes at 4 kHz for the right ear and at 8 kHz for the left ear. Post-hoc tests revealed that the average DPOAEs measures were not significantly different between Time I and Time II (Figure 6). However, the average DPOAEs measures assessed at 4 KHz for the right ear and at 8 KHz for the left ear of the "Low-Risk" group were significantly lower at Time IV than at Time I (Figure 6). Results showing the changes in DPOAEs measures at these frequencies for individuals from the "Low-Risk" group were presented in Appendices 15 and 16.

3.2.2.1 PTA

The maximum threshold shift in the average PTA measures from the "Low-Risk" group was found to be a reduction of 3.13 dB HL from Time I to Time II for the left ear at 2 kHz (Appendix 27). As threshold changes smaller than 5 dB HL was attributable to measurement variability, the PTA measures in the "Low-Risk" group could be considered unaffected over time across the frequency range in both ears. The PTA results for Participant 4's right ear demonstrated the relatively stable PTA measures over time, with the auditory

threshold remaining within a 5 dB HL range throughout the one month monitoring period (see Appendix 15). In particular, the PTA measure immediately post-exposure for the right ear at 4 kHz for Participant 4 was zero (Appendix 17) and this value stayed the same for the next assessment (Time III) and the one after (Time IV).

3.2.2.2   DPOAEs

Changes of DPOAEs measures post noise exposure were evident in the "Low-Risk" group but smaller as compared with the "High-Risk" group.   For example, the reduction in the average DPOAEs amplitudes recorded at 4 KHz for the left ear from Time I to Time II was 1.14 dB SPL for the "Low-Risk" group while that for the "High-Risk" group was 5.44 dB SPL (Appendix 28). The reduction in the average DPOAEs amplitudes recorded at 4 KHz for the right ear from Time I to Time II was 2.87 dB SPL for the "Low-Risk" group while that for the "High-Risk" group was 3.5 dB SPL (Appendix 30).   Likewise, the reduction in the average DPOAEs amplitudes recorded at 8 kHz for the left ear from Time I to Time II was 6.66 dB SPL for the "Low-Risk" group while that for the "High-Risk" group was 7.08 dB SPL (Appendix 30).

The general reduction in the DPOAEs amplitudes in the "Low-Risk" group was evident for both ears at all frequencies (except for 6 kHz for the left ear) after one month post-exposure, with the magnitude of the reduction from Time I to Time IV ranging from 2.77 (at 1 kHz) to 9.45 dB SPL (at 8 kHz) for the left ear (Appendix 28) and from 1.38 (at 1.5 kHz) to 5.83 dB SPL (at 4 kHz) for the right ear (Appendix 30).   At 8 kHz, the decrease in the DPOAEs amplitudes one month post-exposure averaged from the "Low-Risk" group

was also smaller than that from the "High-Risk" group, with an average reduction of 3.61 dB SPL from the baseline in the "Low-Risk" group (Figure 6) in comparison to 6.66 dB SPL in the "High-Risk" group (Figure 5)

As shown in Appendices 15 and 16, with DPOAEs amplitudes assessed at 4 KHz for the right ear and at 8 KHz for the left ear, all participants in the "Low-Risk" group showed some degree of deterioration from Time I to Time II. The DPOAEs amplitudes assessed at 8 KHz for the left ear of four participants, including two participants with normal DPOAEs amplitudes at Time I (Participants 4 and 6) and two with DPOAEs amplitudes below the normal range (Participants 7, and 8), were below the normal limit at Time II and remained below the normal limit all the way through Time IV despite some signs of recovery shown in Time III (Appendix 16).

3.2.3   "Control without HP" Group

As shown in Table 4, a significant session effect was found for the "Control without HP" group in the PTA measures at four frequencies (0.25, 0.5, 3, and 8 KHz) for the right ear and two frequencies (0.5 and 4 kHz) for the left ear.   A significant session effect on DPOAEs amplitudes was found only for the right ear at 8 KHz.   However, post-hoc tests failed to reveal any significant between-session difference on either PTA or DPOAEs measures (Figures 7 to 9).   Results showing the changes in PTA and DPOAEs measures at these frequencies for individuals from the "High-Risk" group were presented in Appendices 18 to 24.

3.2.3.1   PTA

The average PTA threshold shift immediately after attendance to one

high-risk class in the "Control without HP" group ranged from 1 to 3 dB HL in the right ear (Appendix 27) and 2 to 5 dB HL in the left ear (Appendix 29). Visual inspection of Appendices 18 to 23 revealed that all participants showed signs of deterioration in the PTA measures from Time I to Time II and the change exceeded 5 dB HL for six participants (60%), including Participants 32 (Appendices 19 and 22), 33 (Appendix 20), 34 (Appendices 22 and 23), 37 (Appendix 22), 38 (Appendix 22), and 39 (Appendices 21 and 23). Three participants (30%), including Participants 32 (Appendix 18, 19, and 22), 34 (Appendix 22, and 23), and 37 (Appendix 23), exhibited PTA measures falling from the normal range at Time I to below the normal limit at Time II. At Time III, only two participants (20%), including Participants 34 and 40, continued to show signs of further deterioration (Appendix 19). At Time IV, a threshold at least 10 dB HL lower than the baseline value (Time I) was found in three participants (30%), including Participants 33 (Appendix 20), 35 (Appendix 19), and 39 (Appendix 23).

3.2.3.2 DPOAEs

With the DPOAEs amplitudes assessed for the right ear at 8 KHz, nine participants (90%) in the "Control without HP" exhibited signs of deterioration from Time I to Time II (Appendix 24). In particular, the DPOAEs amplitudes obtained at 8 KHz from the left ear of Participant 34 showed a drastic drop from the normal range at Time I to below the normal limit at Time II and never returned to normal despite showing signs of recovery at Time III and IV. Two out of the three participants (Participants 33, 35, and 39) exhibiting below normal DPOAEs amplitude at 8 KHz for the left ear at Time I showed signs of deterioration at Time II and remained below the normal limit at Time

IV while the one left (i.e., Participant 35) showed signs of recovery over time and returned to the normal range at Time IV.   From Time II to Time III, three participants (30%), including Participants 33, 37, and 38, showed signs of deterioration (Appendix 24).   From Time III to Time IV, four Participants 32, 33, 38, and 39, showed signs of deterioration (Appendix 24).

3.2.4   "Control with HP" Group

As shown in Table 5, a significant session effect was found for the "Control with HP" group in the DPOAEs amplitudes at 3 kHz for the right ear and at 8 kHz for the left ear.   Post-hoc tests revealed that the only significant between-session difference on the DPOAEs amplitudes was between Time III and all the other sessions, with Time III measures exhibiting the poorest value (Figure 10).   This finding suggested that DPOAEs amplitudes of the control subjects showed a slight deterioration immediately after attendance to one high-risk aerobic class session but returned to baseline value at Time IV. Results showing the changes in DPOAEs amplitudes at these two frequencies for individuals from the "Control with HP" group were presented in Appendices 25 and 26.

3.2.4.1   PTA

The PTA measures obtained from the "Control with HP" group for both left and right ears after one aerobic class attendance remained stable around the normal range and did not show clinically significant change (Appendices 27 and 29).   For example, as shown in Appendix 27, the mean shift in the hearing threshold of the left ear from Time I to Time II for the "Control with HP" group ranged from 1.6 (at 0.5 kHz) to 2.5 dB HL (at 8 kHz), which was not

considered a clinically significant change.

3.2.4.2   DPOAEs

For the "Control with HP" group, DPOAEs amplitudes generally remained stable above the normal limit (Appendices 25 and 26) with the exception of 8 kHz in the left ear, where three participants (50%), including Participants 23, 27, and 28, fell from the normal range at Time I to below the normal limit at Time II (Appendix 26).   With the DPOAEs amplitudes assessed at 8 KHz for the left ear, all participants in the "Control with HP" group showed signs of hearing deterioration immediately after attending one high-risk class session and five participants (83%) continued to show signs of hearing deterioration from Time II to Time III (Appendix 26).   At Time IV, with the DPOAEs amplitudes assessed at 8 kHz for the left ear, four participants (67%) in the "Control with HP" group returned to the normal range and two participants (Participants 23 and 28) remained below the normal range (Appendix 26).

3.3   Summary of Main Findings

Generally, the hearing test results as previously described provided evidence showing that noise exposure in aerobic classes had a negative impact on hearing and that HP devices helped reduce the negative impact. There were six main findings:

1. **Session Effect**:   A general trend of hearing deterioration was found immediately after aerobic class.   Although TTS as shown in PTA measures were minor and generally clinically insignificant, a

reduction of DPOAEs amplitudes was observed in the majority of tests conducted immediately after the noise exposure in an aerobic class.

2. **Group difference**:   The post aerobic class hearing deterioration was shown in all subject groups, with the strongest reduction found in the "High-Risk" group, followed in order by the "Low-Risk" group, the "Control without HP" group, and the "Control with HP" group.   The "High-Risk" group exhibited the largest reduction of DPOAEs amplitudes over time.   In comparison, although the "Control without HP" group also exhibited a large reduction in DPOAEs amplitudes, this reduction was reduced after a one month recovery period.   After a one month recovery period, non-gym goers who served as the controls in this study generally showed a return of the hearing threshold to its pre-exposure level.

3. **Test Sensitivity**:   Changes to the PTA measures appeared to be relatively small across sessions.   Measures of DPOAEs were found to be more sensitive in differentiating pre-exposure hearing status and detecting subtle changes of hearing after noise exposure.

4. **Frequency Effect**:   The change to the amplitude of DPOAEs in response to noise exposure was particularly noticeable in the high frequencies, including 3, 4, and 8 kHz.

5. **Hearing Protection:**   The use of HP was found beneficial in

reducing the risks associated with noise during aerobic classes. In contrast, the "Control with HP" group showed no major changes to both PTA and DPOAEs measures at Time IV.

6. **Individual Difference**:   Individuals in the same subject group were found to vary in the degree and the rate of deterioration and recovery of the hearing.

Chapter 4.　DISCUSSION

This chapter provides a discussion of the findings in relation to the research question, previous research, clinical implications, limitation of the study, and future direction.　The purpose of this study was to evaluate noise levels during aerobic classes and to determine if regular participation in aerobic classes without HP may lead to NIHL.　Findings from the present study revealed that noise levels in most aerobic classes exceeded the 85 dBA safety level and thus might cause a hearing loss to regular aerobic class goers. These findings, together with measurement of DPOAEs levels immediately before and after participation in these classes, provided evidence showing that recreational noise during aerobic classes might be hazardous to the OHC function.　The continuing deterioration of hearing after participation in the "High-Risk" aerobic classes shown in this study suggested that the TES observed could potentially lead to a permanent loss of hearing especially among regular aerobic class goers.　The noise-induced TES may be reflected on a normal PTA long after the exposure.　However, PTA results in this study have generally failed to detect changes of hearing in response to noise exposure in aerobic classes.　The finding that testing of the DPOAEs amplitudes could reveal the latent damage to the cochlea as a result of noise exposure is consistent with previous studies (Attias et al., 1995;　Attias & Bresloff, 1996;　Attias et al., 1998;　Engdahl, 1996;　Sutton et al., 1994; Torre & Howell, 2008).　Specific findings for the experimental measures in this study are discussed in the following section.

4.1 The Sensitivity of DPOAEs and the Use of Hearing Protection

The findings that TES, instead of clinically significant TTS, was detected following participation in "High-Risk" aerobic classes supported the hypothesis that DPOAEs testing is more sensitive than the conventional PTA in detecting early signs of NIHL within a 30 day period. In other words, distortion product otoacoustic emissions were shown in this study to be more sensitive, as compared with the traditional test of hearing thresholds, to cochlear changes following noise exposure, suggestion that testing of DPOAEs is more appropriate for screening and monitoring ears at risk of NIHL. The objectivity of the measurements and the short test time required further enhance their usefulness as a cochlear measure.

Our findings suggest that there is a strong trend for the strength of the DPOAEs to decline with regular attendance in "High-Risk" aerobic classes. This is consistent with previous studies identified in chapter 1. Specifically, the decline in DPOAEs amplitudes measured from the "High-Risk" group was highly noticeable at 8 kHz in both ears, at 4 kHz in the left ear, and at 6 kHz in the right ear. The size of this decline was proportional to the level of exposure, with those attending "High-Risk" classes generally showing a sharper decrease in DPOAEs amplitude than the other three groups. Although attendees of "Low-Risk" classes also showed signs of hearing deterioration, the mean decline in the DPOAEs amplitudes was lower than the "High-Risk" group and the decline was observed at 8 kHz and 4 kHz in both ears, 3 kHz in the left ear, and 6 kHz in the right ear.

The finding that the DPOAEs amplitudes were reduced when measured

immediately after participation in an aerobic class supported the hypothesis that participation without hearing protection in aerobic classes with a high level of noise may lead to temporary shift in hearing threshold showing signs of damage to the outer hair cells. For the "Control with HP" group, a relatively stable PTA measures and clinically insignificant fluctuations were observed over time. As for the DPOAEs amplitudes measured from the "Control with HP" group, they remained relatively unaffected post class participation with the exception of the test at 3 and 8 kHz, which showed reduction some time after noise exposure. One possible explanation for the reduced amplitude post-exposure in the "Control with HP" group at these frequencies is that the NRR of the HP used at these frequencies is limited. Another explanation for the inconsistency in the results for this group is that the attenuation of an earplug may vary dependent on the adequacy of proper fitting and insertion practices. Even though the insertion of the earplugs was monitored by the researcher, their use was difficult to monitor because the placement of the earplugs was not as readily visible. It is also possible that the earplug in the participants' ears might have turned loose (due to chewing or exercising) at times and therefore were not effective in attenuating the high SPL.

Despite the speculation above, the post-exposure signs of hearing deterioration found in the "Control with HP" group generally returned to normal after one month of no further class participation and a trend of improvement in the DPOAEs strength was evident in the third and fourth hearing assessments for both groups of non-gym goers, who only went to the aerobic class once.

Overall, findings in this study suggested a link between noise exposure

in aerobic class and hearing deterioration.   Post-class deterioration in hearing was evident in participants of all groups.   Some measures have been taken in an attempt to minimize the effect of the extraneous factors, such as noise exposure outside the aerobic classes, to strengthen the internal validity of the study.   Participants were advised to avoid noisy environments and provided with a pair of earplugs to use when exposed to other potentially high level of recreational and non-occupational noise exposure (for example, rock concerts, lawn movers, power tools, car racing, clubbing, etcetera) during the monitoring period.   Although the participant's noise exposure outside the experimental setting was only monitored through self reporting, the inclusion of several comparison groups allowed for between-group comparisons against random variations and no apparent selection bias was found that could have threatened the subject equivalency between the comparison groups.

4.2 Noise Levels during Aerobic Classes

In terms of the noise levels in aerobic classes as assessed in the present study, they were generally consistent with previous research published.   In this study, the average noise level during an aerobic class was higher than 85 dBA in the three gyms tested.   Torre and Howell (2008) analyzed the noise levels in 12 aerobic classes and found them to range from 83.4 dBA to 90.7 dBA.   Britten, Burnett, and Cleveland (2008) reported an average SPL of 86 dBA in aerobic classes.   Yaremchuk & Kaczor (1999) measured the noise levels in 125 different aerobic classes from five different gyms and reported that the average noise level exceeded 90 dBA in 79 percent of the classes.   Findings from this study agreed with previous findings showing that the noise levels in aerobic classes were generally higher

than the safety level of 85 dBA for 8 hours duration.

The American Council on Exercise (ACE), a professional organisation for aerobics instructors, issued guidelines for safe music volume in fitness settings, recommending that the noise level be no higher than 70-80 dBA during aerobic classes. However, the results obtained in this research and previous research published show that these guidelines are rarely adhered to. Moreover, hearing loss is not the only problem. The American Council on Exercise has also documented that fitness instructors are damaging their voices from shouting over the background music. Although voice disorders are beyond the scope of this research, it is important to highlight the potential risk and investigate the matter in further research.

Lower SPL in aerobic classes may be achieved by either reducing the reverberant sound field (e.g., installing acoustic absorbers) or reducing the noise levels during class. Hearing conservation principles state that dangerous noise need to be controlled at the source, path, or at the receiving end (Suter & Berger, 2002). The engineering of some acoustic control mechanisms, which is essential to achieve an effective hearing conservation programme (HCP), is usually implemented in the workplace but should also be implemented in the recreational setting. The use of these controls in the gym setting would potentially reduce noise exposure to the point where the hazard to hearing is eliminated or is at least more manageable. Engineering controls are technologically feasible for most noise sources (Suter & Franks, 1990). It is highly likely that the application of a relatively simple noise control solutions will reduce the hazard in the various gymnasiums tested to the extent that the use of HP among those participating is no longer necessary.

For hearing conservation purposes, Suter & Franks (1990) define engineering controls as "any modification or replacement of equipment, or related physical change at the noise source or along the transmission path (with the exception of hearing protectors) that reduces the noise level at the person's ear" (p. 13). Typical engineering controls involve reducing noise at the source, interrupting the noise path, and reducing reverberation. Common examples of the implementation of such controls include erecting acoustical enclosures or barriers and the installation of sound absorbing material. One way of reducing the build-up of reverberant sound in the gym would be adding absorption to the surrounding space.

Noise is considered to be best controlled at the source because reducing the generation of noise usually has more widespread benefit than all other approaches that treat only specific locations in a room. Another approach would be path noise control. This is the reduction of noise exposure along the path between the source and participants in an aerobic class without interfering with the source itself. By inserting a noise control device in the path, the transmission of sound to the receiver is prevented or greatly reduced. This approach does not change the amount of noise that is produced, but it reduces the sound level which is received in the ear canal.

The most straightforward step towards the reduction of hazard to hearing in aerobic classes would be a reduction of the noise level to safety limits so the risk of NIHL is reduced, communication is improved, and noise-related problems (such as tinnitus) are also reduced. It is obvious that the practice of increasing sound levels to motivate participants during aerobic classes may put regular gym-goers, as well as instructors, at a greater risk of NIHL than non-regular participants due to the increased frequency of noise

exposure. Therefore, gym managers may need to regularly monitor the sound levels in various gym classes to ensure a safe environment with the cumulative effect of noise taken into account. Since the risk of developing NIHL in aerobic classes has been clearly demonstrated in this study through sensitive measures, decision makers at either national or international level may need to play a key role in introducing regulations and criteria for recreational noise as this is a health and safety matter that should be addressed.

4.3   Findings of the Study in Relation to Previous Research

In general, the results of this study indicate that a relationship exists between NIHL and DPOAEs. The findings suggest that there is a strong trend for the strength of the otoacoustic emissions to decline with continuing attendance in aerobic classes without using HP. The decline was most noticeable immediately post-exposure in the majority of tests conducted in all comparison groups but the level and the progression of the decline are affected by the level and frequency of noise exposure. Since the design of our study did exclude the effects of other forms of noise to which people may also be exposed from other occupational and non-occupational settings during the monitoring period, the cause-effect relationship between noise exposure in the aerobic class and the sign of NIHL was strongly suggested.

As NIHL in groups of people (but not individuals) exposed to noise can be predicted with knowledge of the noise level and duration (Henderson et al., 1993), variability in the amount of noise-induced TES across individuals was noted in this study. The 5 to 8 db SPL decrease in DPOAEs levels immediately post-exposure in the present study is generally consistent with

the level that has been reported in previous research (Engdahl, 1996; Attias et al., 1998). However, a similar research published by Torre & Howell (2008) showed a considerably lower (1.4 db SPL) decrease in DPOAEs amplitude after noise exposure in aerobic classes. The discrepancy among studies in the reported level of DPOAEs reduction after noise exposure in aerobic classes may be related to methodological differences such as the variation in the levels and duration of noise exposure in the aerobic classes and the susceptibility of individual participants. According to Henderson et al. (1993) and Hall (2000), non-auditory predictors of susceptibility to hearing loss, which include factors such as eye color, age, smoking, middle-ear muscles characteristics, and exposure to drugs or chemicals, can affect the susceptibility of individuals to NIHL to some extent. In addition, susceptibility may also be due to inherent characteristics (i.e. genetic) and consumption of ototoxic drugs (Henderson et al., 1993). As consuming ototoxic drugs was set as an exclusion criterion in this research, it is reasonable to assume that research participants who did not show reduction in DPOAEs amplitude might have developed a noise resistant mechanism that protects their cochlea. Currently, there is no clinical test to detect those individuals most at risk for NIHL Robinette & Glattke (2007). However, this study provided evidence showing that some people are more susceptible to NIHL. The results are further proof for the reaction of the outer hair cells to noise which leads to stiffness of the basilar membrane. At this stage, it is still impossible to differentiate vulnerable inner ears from stable ones. The question as to whether a stable inner ear is due to a resilient cochlea, the development of physiological mechanism, genetics, or the fact that being physically fit has a protective benefit against hearing loss remains unknown at

this stage.

Despite individual differences, results obtained in this study generally suggested that the noise exposure experienced by participants in "High-Risk" aerobic classes caused a sub-clinical damage to their (audiometrically) normal ears. Most importantly, the present study has demonstrated that the DPOAEs measures closely reflected the cochlear alternations following noise exposure. Findings from the majority of the cases in this study showed that the cochlear alterations were not detected by the pure tone audiometric measurements. In other words, TES were unaccompanied by PTA TTS in most cases. This finding is supported by a study published by Attias et al. (1998) showing that ears with history of noise exposure had significantly reduced DPOAEs amplitude in comparison to the age-matched normal hearing controls. Other research in the field of OAEs techniques and NIHL has also proved that DPOAEs and TEOAEs are able to detect sub-clinical damage to the cochlea (Lucertini et al., 2002; Probst et al., 1987; Attias et al., 1995, LePage & Murray, 1998), which has been referred to as noise-induced otoacoustic emission loss with or without hearing loss (Attias et al., 1995).

4.4   Clinical Implications

Findings from the current study offer some clinical implications for those regularly attending aerobic classes in the gym. The current study confirms that regular attendance in aerobic classes can potentially cause a hearing loss over time. The hearing loss may not show up initially in a normal PTA test but more sophisticated methods of assessment such as DPOAEs may show reduction in amplitude particularly in the high frequency region immediately post-exposure. The present finding of a continuous

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reduction in the strength of DPOAEs post-exposure over time has also demonstrated the usefulness of DPOAEs measures in detecting preclinical NIHL and susceptibility to NIHL.

This study employed a longitudinal research design to examine the temporal relationship among exposure to noise, changes in hearing, and changes in DPOAEs in gym and non-gym goers.   We gained access to people who are already recreationally noise-exposed and compared their hearing levels pre and post exposure to (at various time points) with those of demographically matched control groups with and without HP.   Although the time constraint of the study did not allow for following up the progression of a hearing loss which usually takes many years to develop, the finding of the reduced DPOAEs post-exposure over time among participants of the "High-Risk" group suggested that regular-goers to the gym are at risk of developing a permanent hearing loss if HP are not used.

4.5   Limitations of the Study and Future Direction

There are a number of limitations to the generalisation of the present findings.   The number of subjects included in this study was small and thus the observations made in this study may not be representative of the clinical population.   Studies consisting of a larger sample size are needed for follow-up studies to increase the generalizability of the finding.   Future studies may include more subjects in each group and a variety of individuals predisposed with different levels of hearing loss to allow for a comparison of the noise effect on different subject type and thus identify patients who are most susceptible to gym noise.

In addition, future studies involving a longer duration of hearing

monitoring period are necessary to investigate the long-term effect of gym noise on hearing.   One more effect that should be taken into account in any future research is the Hawthorne effect.   Encountering the effect during the first phase of the research decreased the internal validity of the results and made the classification of classes to "High-Risk" and "Low-Risk" more challenging.   Therefore, we recommend that measurements of noise levels for research in the field of NIHL are to be conducted covertly and with minimal involvement of staff members in the gym.

As for the acoustic assessment of the hearing environment of the aerobic class, although noise dosemeter provided the best opportunity for measuring noise in real-life setting, such as during aerobic classes, there were some limitations to the method used.   One of them is the fact that noise levels received at the tympanic membrane are not equal to those at the outside of the ear canal so the measured noise level is not necessarily the noise level received by participants.   Therefore, the noise level measured was not necessarily a true reflection of the noise received in the participants' ear canals.   One way of overcoming this problem is by placing a probe microphone in a participant's ear canal to measure the actual noise levels received.   However, this was not feasible in this research because participants were exercising and there was no way of keeping the microphone steel in their canal while using real ear measures equipment to measure the noise received in the canal.

Furthermore, as no frequency analysis of the music used during aerobic classes was completed, it is unknown how characteristics of the music used during the aerobic classes involved in the present study affected DPOAEs in specific frequencies.   Frequency analysis was not completed because the

music varied from class to class and even within each class. More specifically, the instructors rarely have a set play-list of music for each class, and the cool-down music may be completely different. Therefore, it was not feasible to conduct a meaningful frequency analysis in the present study.

4.6 Conclusion

In summary, this study highlighted some important points related to the hearing health. Firstly, it can be concluded that noise levels in most aerobic classes are high and can potentially cause a hearing loss among regular aerobic class goers especially if these individuals are also subjected to occupational noise during their working day. Secondly, the noise-induced hearing loss can initially be manifested by TES which may not be reflected on a standard PTA test. Therefore, the risk of recreational NIHL can be underestimated due to the difficulty in its early detection. It is important that professionals, as well as the general public, are advised of the risk and taught how to protect their hearing. Although the results in this study obtained are inconclusive due to the methodological constraints as discussed, this study has demonstrated that early warning for NIHL is available through DPOAEs testing. The testing of DPOAEs offers new precision in determining the status of the cochlea in comparison to the PTA test. Lastly, in light of the increasing popularity of aerobic classes, the risks of noise exposure during these activities need to be assessed and brought to the attention of the relevant government bodies so that legislation is undertaken to set guidelines for recreational noise activities to prevent premature hearing loss among regular aerobic class goers and individuals exposed to recreational noise on a regular basis. Individuals participating in aerobic classes should be made

aware of the harmful effects of noisy background conditions.

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Table 1. Participants Information for individuals in the four comparison groups, including the "Low-Risk", "High-Risk", "Control with HP" ("Control+HP"), and "Control without HP" ("Control-HP") groups.

Classification	Subject	Gender	Age	Duration of aerobic class attendance (Y:M)	Gym	Hearing Status
Low-Risk	1	Female	21	0:10 months	A	Normal
	2	Female	30	1:6 months	A	Normal
	3	Female	28	0:11 months	A	Normal
	4	Female	25	2:4 months	A	Normal
	5	Female	29	10:1 months	A	Normal
	6	Male	21	1:5 months	A	Normal
	7	Male	33	0:8 months	A	Normal
	8	Male	35	0:8 months	A	Mild hearing loss*
	9 (excluded)	Male	23	0:2 months	C	Normal
High-Risk	11	Female	21	4:0 months	A	Normal
	12	Female	34	3:11 months	B	Normal
	13	Female	18	0:8 months	A	Normal
	14 (excluded)	Female	26	0:6 months	B	Mild hearing loss*
	15	Female	32	5:6 months	A	Normal
	16	Male	34	0:8 months	A	Mild hearing loss*
	17	Male	23	3:0 months	B	Normal
	18	Male	23	1:7 months	B	Normal
	19	Male	23	0:8 months	B	Normal
	20	Male	48	16:0 months	A	Normal
Control+HP	21	Female	25	Never attended	B	Normal
	22	Female	20	Never attended	A	Normal
	23	Female	43	Never attended	A	Normal
	26	Male	22	Never attended	B	Normal
	27	Male	29	Never attended	B	Normal
	28	Male	21	Never attended	B	Normal
Control-HP	31	Female	40	Never attended	A	Normal
	32	Female	22	Never attended	B	Mild hearing loss*
	33	Female	30	Never attended	B	Normal
	34	Female	47	Never attended	B	Mild hearing loss*
	35	Female	22	Never attended	B	Normal
	36	Male	21	Never attended	A	Normal
	37	Male	21	Never attended	B	Normal
	38	Male	22	Never attended	A	Normal
	39	Male	50	Never attended	A	Mild hearing loss*
	40	Male	32	Never attended	A	Normal

Table 2. Results of one-way RM ANOVAs on Ranks for PTA and DPOAEs measures obtained from the "High-Risk" group.

|	*n=8*	0.25 kHz	0.5 kHz	0.75 kHz	1.0 kHz	1.5 kHz	2.0 kHz	3.0 kHz	4.0 kHz	6.0 kHz	8.0 kHz
Right Ear											
PTA	p	0.779	0.723	0.520	0.750	0.861	0.017*	0.727	0.162	0.944	0.309
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	1.091	1.326	2.263	1.212	0.750	10.200	1.308	5.136	0.382	3.588
DPOAEs	p	-	-	-	0.903	0.979	0.850	0.062	0.041*	0.172	0.027*
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	0.570	0.192	0.797	7.329	8.250	5.000	9.150
Left Ear											
PTA	p	0.454	0.930	0.109	0.299	0.349	0.179	0.200	0.033*	0.315	0.580
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	2.619	0.447	6.059	3.675	3.293	4.905	4.642	8.727	3.545	1.966
DPOAEs	p	-	-	-	0.952	0.583	0.985	0.092	0.583	0.583	0.062
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	0.342	1.950	0.150	6.450	1.950	1.950	7.350

*Significant at 0.05 level

Table 3. Results of one-way RM ANOVAs on Ranks for PTA and DPOAEs measures obtained from the "Low-Risk" group.

	n=8	0.25 kHz	0.5 kHz	0.75 kHz	1.0 kHz	1.5 kHz	2.0 kHz	3.0 kHz	4.0 kHz	6.0 kHz	8.0 kHz
Right Ear											
PTA	p	0.457	0.464	1.000	0.791	0.925	0.599	0.355	0.978	0.173	0.458
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	2.605	2.563	0.000	1.043	0.474	1.875	3.245	0.200	4.980	2.596
DPOAEs	p	-	-		0.392	0.098	0.415	0.193	0.010*	0.080	0.287
	df	-	-		3	3	3	3	3	3	3
	Chi-sq.	-	-		3.000	6.300	2.850	4.731	11.28	6.750	3.769
Left Ear											
PTA	p	0.874	0.907	0.549	0.537	0.769	0.299	0.459	0.392	0.510	0.771
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	0.698	0.556	2.114	2.176	1.133	3.672	2.591	3.000	2.314	1.125
DPOAEs	p	-	-	-	0.292	0.125	0.808	0.096	0.369	0.526	0.016*
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	3.731	5.734	0.974	6.346	3.150	2.231	10.37

*Significant at 0.05 level

Table 4. Results of one-way RM ANOVAs on Ranks for PTA and DPOAEs measures obtained from the "Control without HP" group.

	n=9	0.25 kHz	0.5 kHz	0.75 kHz	1.0 kHz	1.5 kHz	2.0 kHz	3.0 kHz	4.0 kHz	6.0 kHz	8.0 kHz
Right Ear											
PTA	p	0.025*	0.017*	0.138	0.112	0.238	0.142	0.022*	0.063	0.967	0.031*
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	9.333	10.26	5.512	6.000	4.222	5.444	9.643	7.308	0.263	8.887
DPOAEs	p	-	-	-	0.542	0.435	0.482	0.110	0.381	0.102	0.040*
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	2.148	2.733	2.461	6.034	3.067	6.200	8.333
Left Ear											
PTA	p	0.061	0.012*	0.274	0.788	0.770	0.529	0.075	0.022*	0.866	0.325
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	7.380	10.93	3.889	1.054	1.131	2.217	6.892	9.655	0.730	3.471
DPOAEs	p	-	-	-	0.482	0.615	0.101	0.402	0.586	0.570	0.644
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	2.461	1.800	6.236	2.933	1.933	2.011	1.667

*Significant at 0.05 level

Table 5. Results of one-way RM ANOVAs on Ranks for PTA and DPOAEs measures obtained from the "Control with HP" group.

	n=6	0.25 kHz	0.5 kHz	0.75 kHz	1.0 kHz	1.5 kHz	2.0 kHz	3.0 kHz	4.0 kHz	6.0 kHz	8.0 kHz
Right Ear											
PTA	p	0.607	0.392	0.439	0.666	0.995	0.919	0.843	0.854	0.597	0.578
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	1.839	3.000	2.707	1.571	0.073	0.500	0.825	0.780	1.884	1.971
DPOAEs	p	-	-	-	0.572	0.334	0.392	0.035*	0.172	0.392	0.284
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	2.000	3.400	3.000	8.600	5.000	3.000	3.800
Left Ear											
PTA	p	0.522	0.347	0.212	0.771	0.968	0.742	0.866	0.644	0.484	0.647
	df	3	3	3	3	3	3	3	3	3	3
	Chi-sq.	2.25	3.308	4.500	1.125	0.257	1.244	0.730	1.667	2.455	1.653
DPOAEs	p	-	-	-	0.284	0.222	0.742	0.515	0.457	0.615	0.010*
	df	-	-	-	3	3	3	3	3	3	3
	Chi-sq.	-	-	-	3.800	4.397	1.244	2.288	2.600	1.800	11.40

*Significant at 0.05 level

Figure 1.   The average reverberation time (in seconds) for the chosen room in Gym
A.   [The dotted line (RT60 = 2 seconds) represents the recommended
maximum RT60 for general purpose auditorium for both speech and
music (Sharland, 1972).]
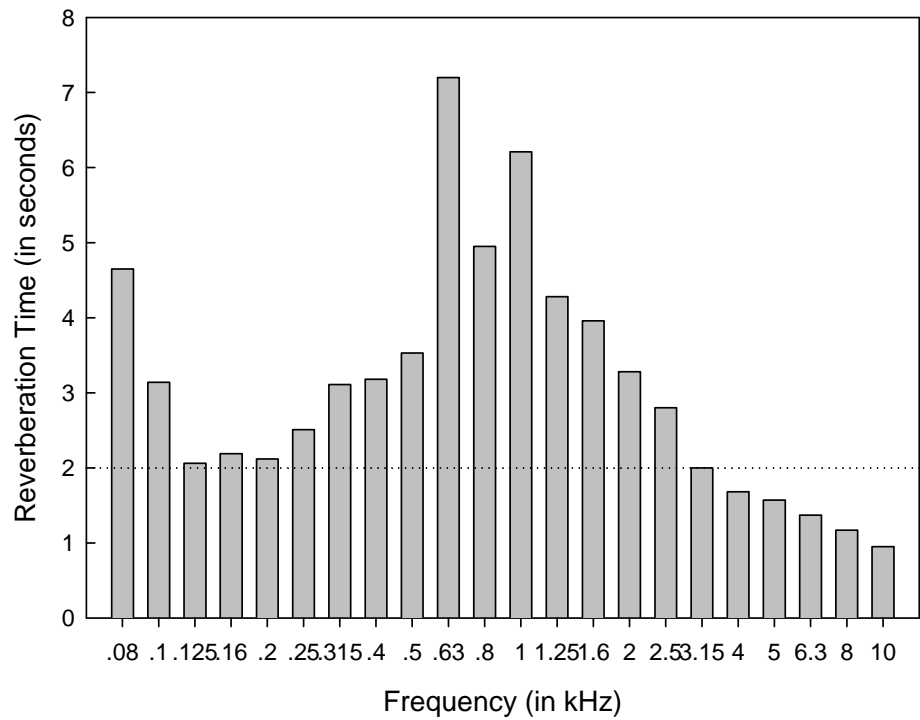
Figure 2. The average noise level during aerobic classes in each of the three gyms included for comparison.
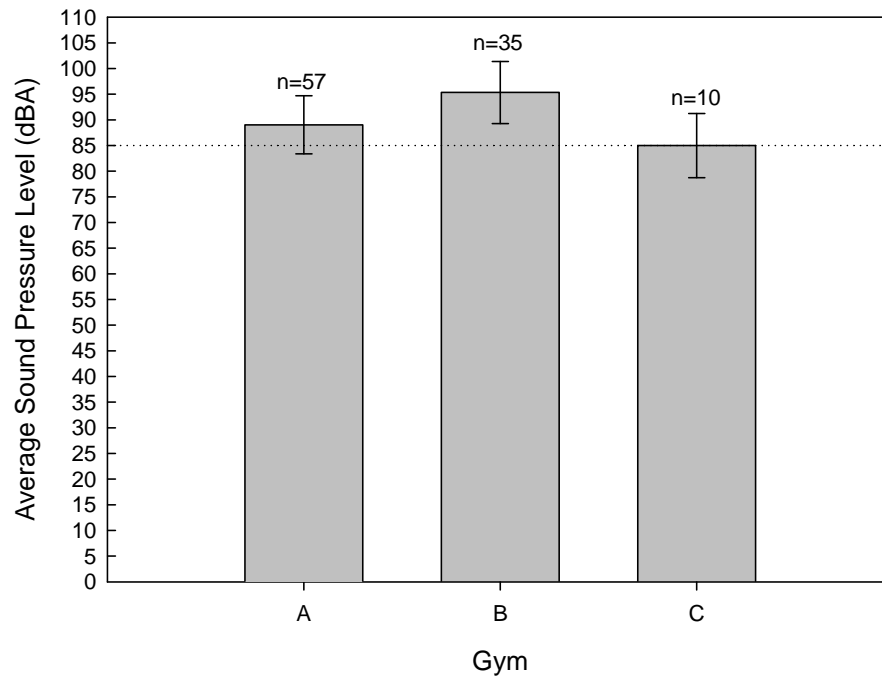
Figure 3. The average noise level in the "High-Risk" classes identified in three different gyms.
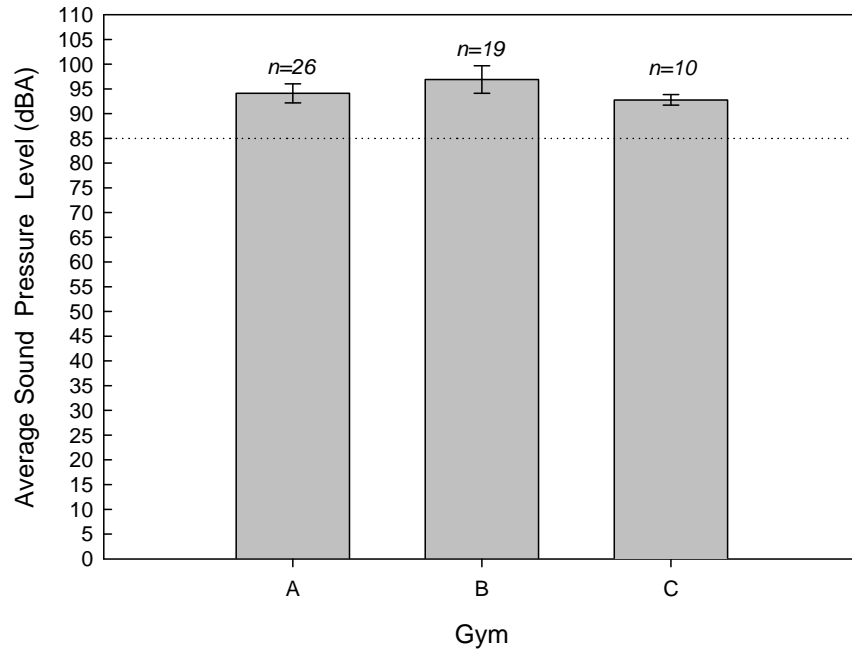
Figure 4. The average noise level in the "Low-Risk" classes identified in three different gyms.
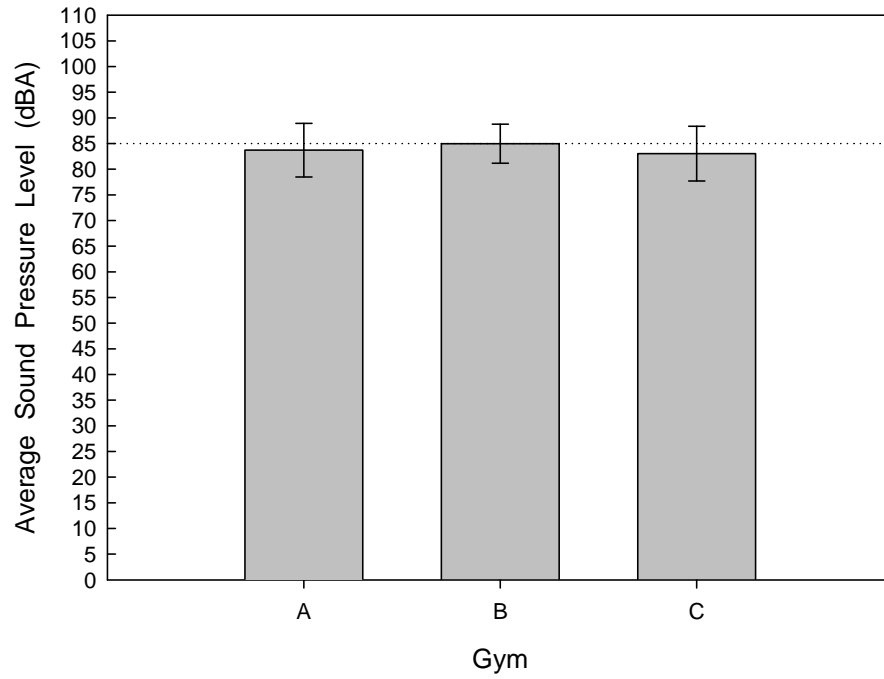
Figure 5. Means and standard deviations of the PTA and DPOAEs measures obtained at different times from the "High-Risk" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss.)

Figure 5.1 PTA measures (right ear) at 2 kHz

Figure 5.2 PTA measures (left ear) at 4 kHz

Figure 5.3 DPOAEs amplitudes (right ear) at 4 kHz

Figure 5.4 DPOAEs amplitudes (right ear) at 8 kHz
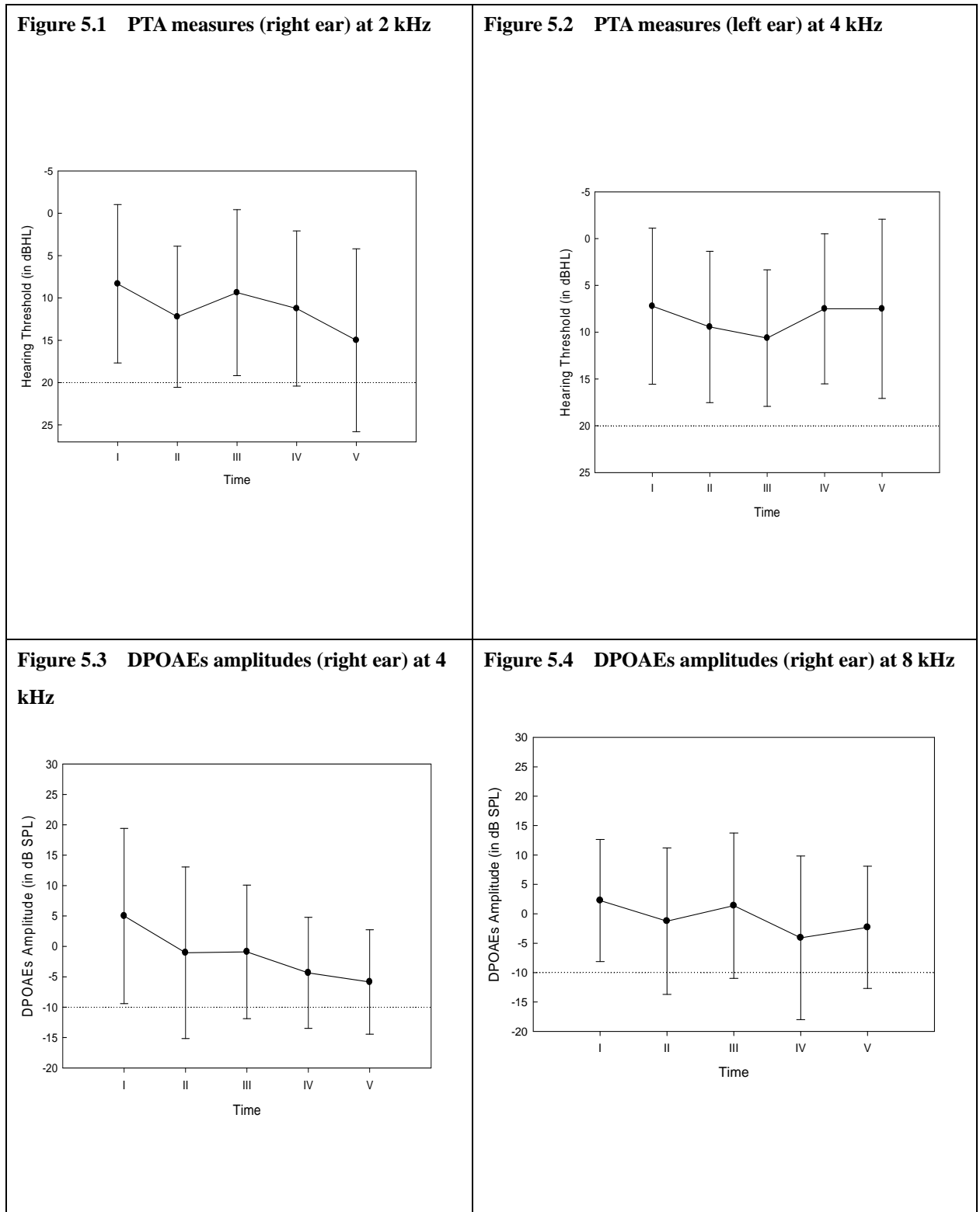
Figure 6. Means and standard deviations of the DPOAEs amplitudes obtained at
different times from the "Low-Risk" group.   (The dotted line represents
the normal limit, with below-line values indicating hearing loss.)

Figure 6.1   DPOAEs amplitudes (right ear) at 4 kHz
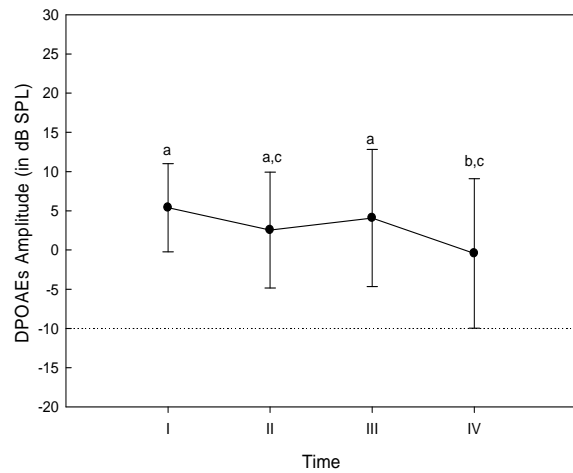
Figure 6.2   DPOAEs amplitudes (left ear) at 8 kHz
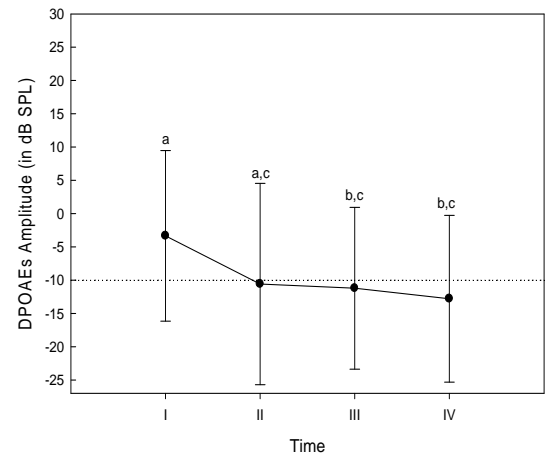
Figure 7. Means and standard deviations of the PTA measures (right ear) obtained at different times from the "Control without HP" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss.)

Figure 8.1   PTA measures (right ear) at 0.25 kHz

Figure 8.2   PTA measures (right ear) at 0.5 kHz

Figure 8.3   PTA measures (right ear) at 3 kHz

Figure 8.4   PTA measures (right ear) at 8 kHz
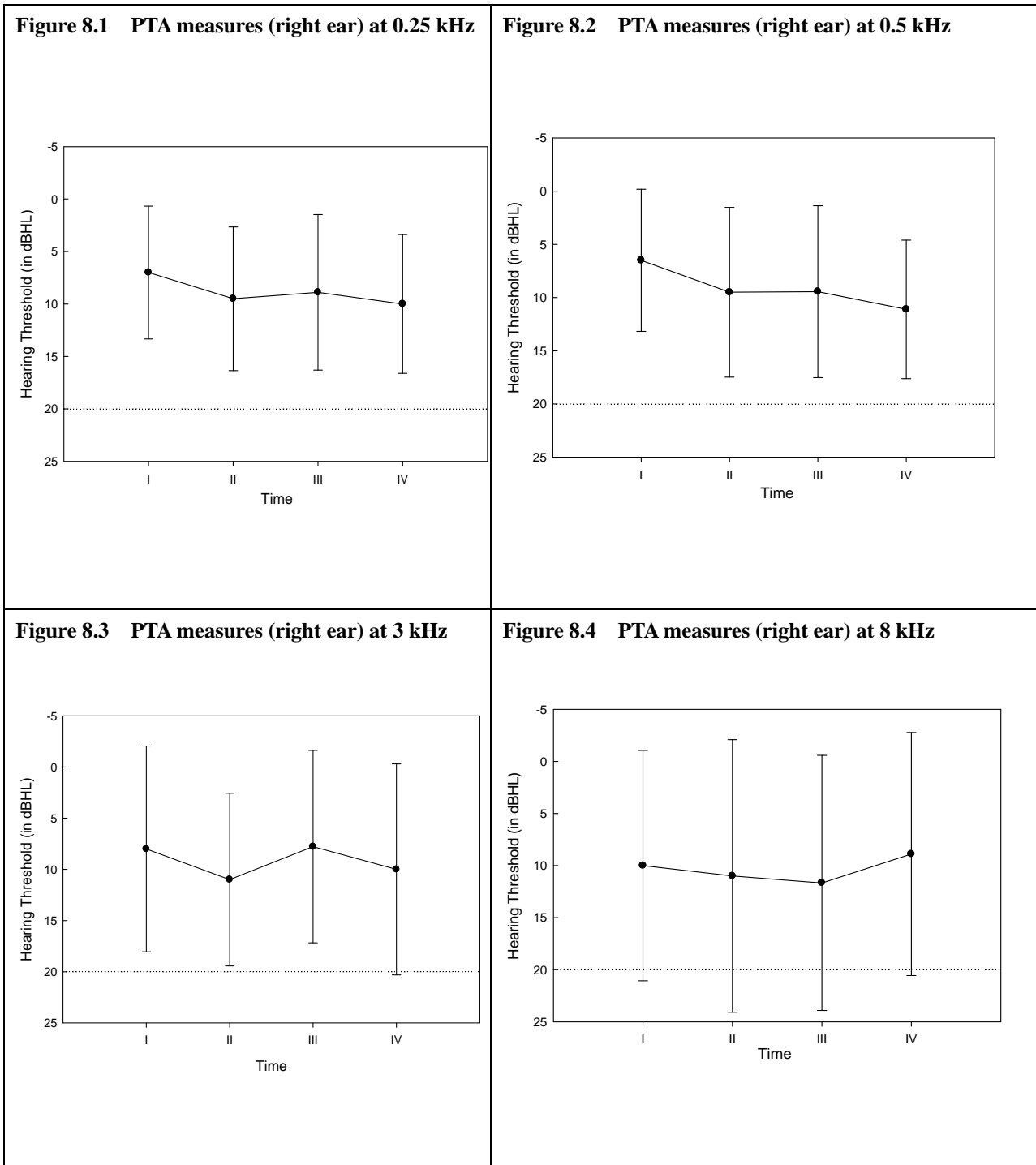
Figure 8.   Means and standard deviations of the PTA measures (left ear) obtained at different times from the "Control without HP" group.   The dotted line represents the normal limit, with below-line values indicating hearing loss.

| Figure 9.1   PTA measures (left ear) at 0.5 kHz | Figure 9.2   PTA measures (left ear) at 4 kHz |
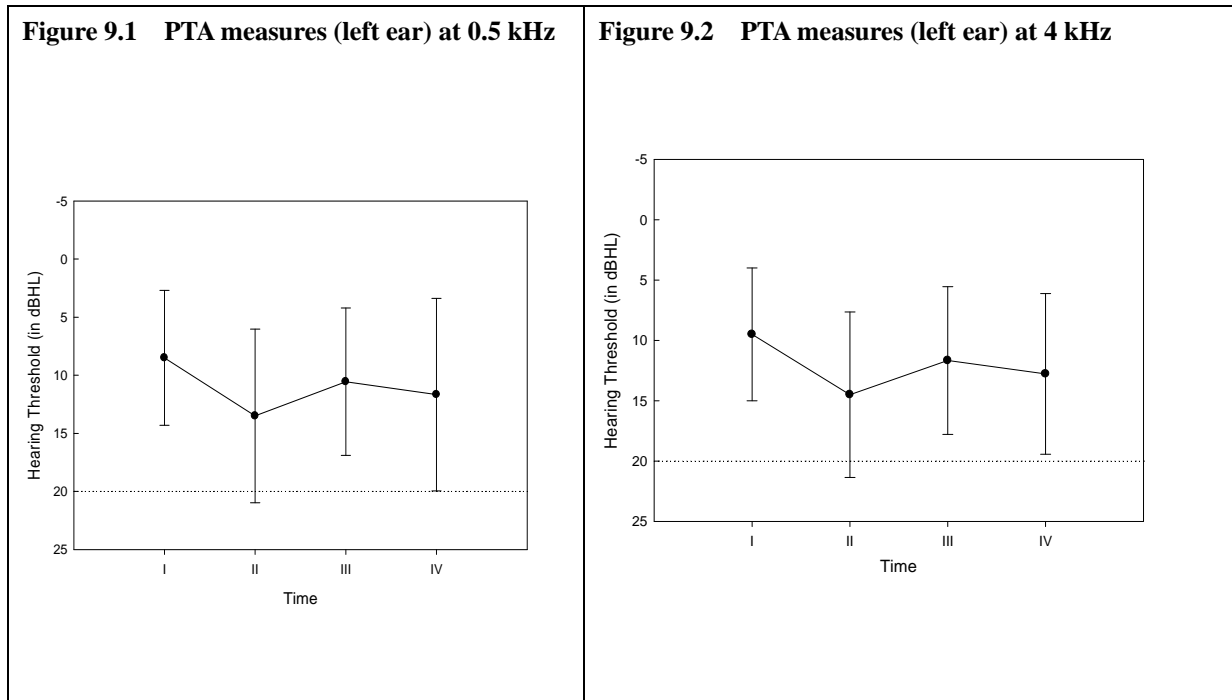
Figure 9.   Means and standard deviations of the DPOAEs amplitudes (right ear) obtained for 8 kHz at different times from the "Control without HP" group.   (The dotted line represents the normal limit, with below-line values indicating hearing loss.)
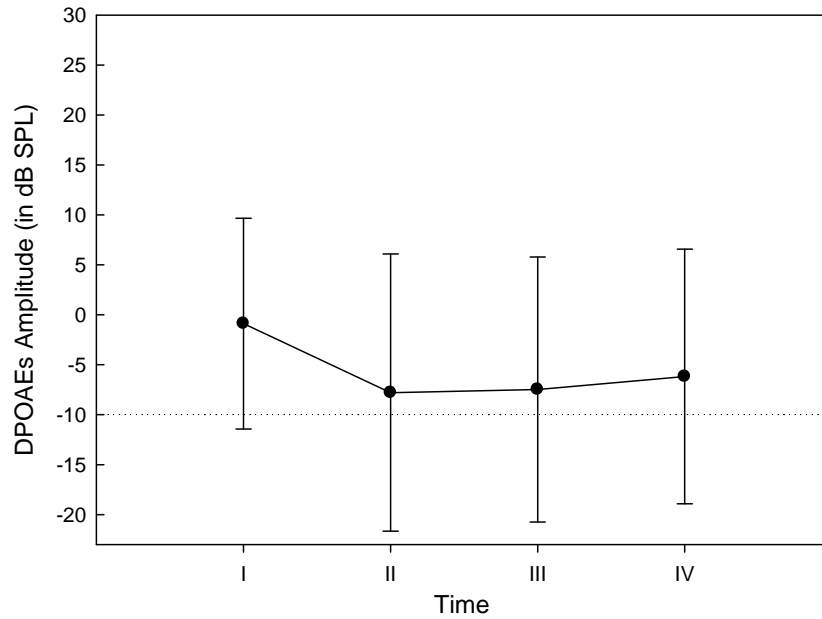
Figure 10. Means and standard deviations of the DPOAEs amplitudes obtained at different times from the "Control with HP" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss.)

Figure 7.1 DPOAEs amplitudes (right ear) at 3 kHz

Figure 7.2 DPOAEs amplitudes (left ear) at 8 kHz
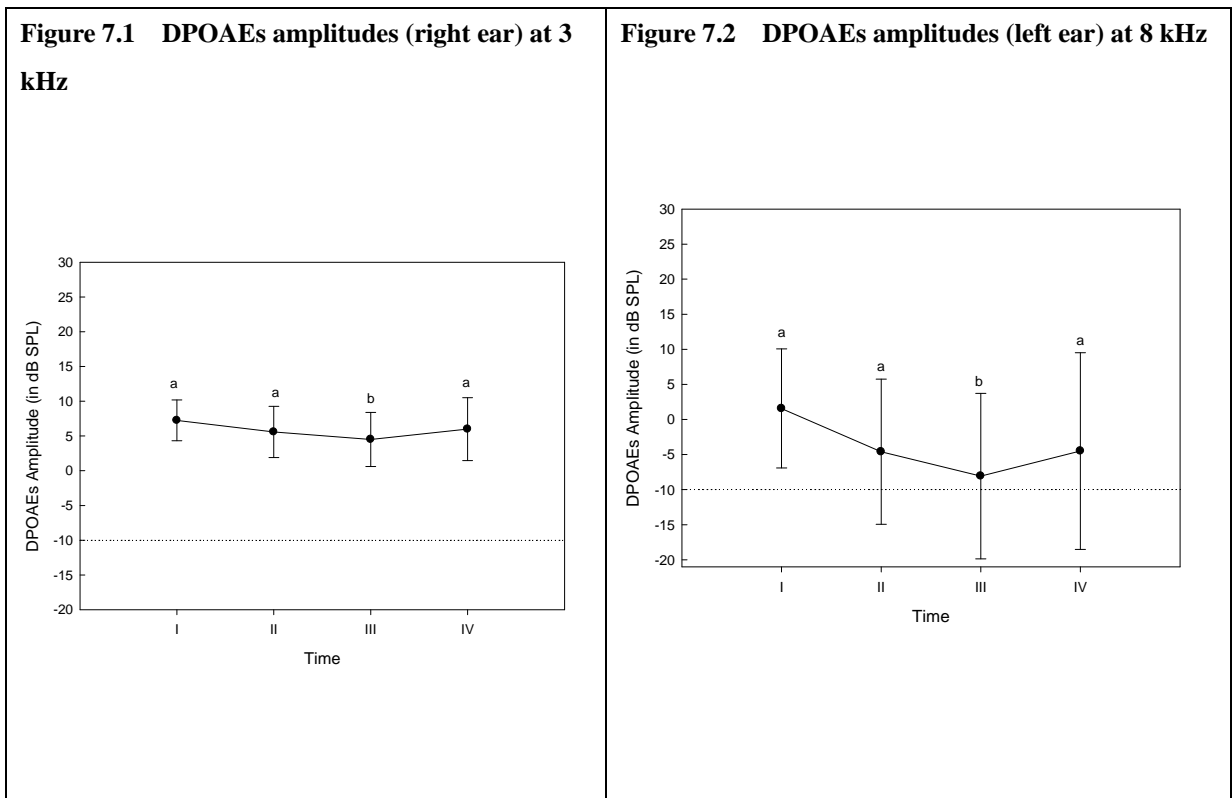
Appendix 1

A schematic representation of the measuring points (shown as numbers in circles) and the placement of all(functional and dysfunctional)speakers (shown as "S" in squares) in Gym A's sports hall.   The three speakers at the back were dysfunctional during measurement.   X represents the placement of the reverberation equipment during measurement.   Note the four points.

University Sports Hall
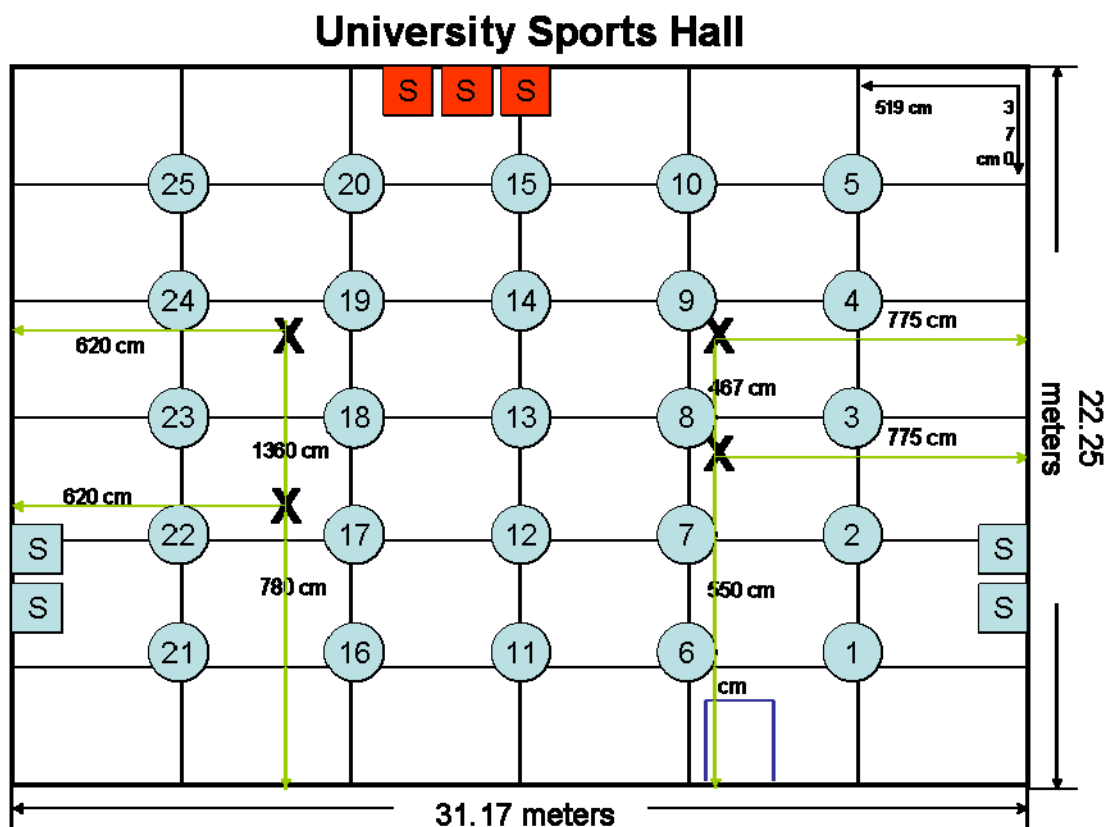
Appendix 2

Damage Risk Criteria: Combinations of noise exposure levels and durations for occupational noise exposure (Suter & Berger, 2002).

Exposure Level (in dBA)	Hours	Minutes	Seconds	Exposure Level (in dBA)	Hours	Minutes	Seconds
80	25	24	0	106	0	3	45
81	20	10	0	107	0	2	59
82	16	0	0	108	0	2	22
83	12	42	0	109	0	1	53
84	10	5	0	110	0	1	29
85	8	0	0	111	0	1	11
86	6	21	0	112	0	0	56
87	5	2	0	113	0	0	45
88	4	0	0	114	0	0	35
89	3	10	0	115	0	0	28
90	2	31	0	116	0	0	22
91	2	0	0	117	0	0	18
92	1	35	0	118	0	0	14
93	1	16	0	119	0	0	11
94	1	0	0	120	0	0	9
95	0	47	37	121	0	0	7
96	0	37	48	122	0	0	6
97	0	30	0	123	0	0	4
98	0	23	49	124	0	0	3
99	0	18	59	125	0	0	3
100	0	15	0	126	0	0	2
101	0	11	54	127	0	0	1
102	0	9	27	128	0	0	1
103	0	7	30	129	0	0	1
104	0	5	57	130-140	0	0	<1
105	0	4	43				

Appendix 3.

Results of RT60 measurements in Gym A at four positions for different frequencies

(1/3 octave band centre frequency).

Freq. (kHz)	Position 1 (s)	Position 2 (s)	Position 3 (s)	Position 4 (s)
0.08	1.49	2.33	10.93	3.83
0.1	1.55	7.18	2.42	1.41
0.125	2.5	1.89	1.4	2.45
0.16	2.17	2.38	2.01	2.2
0.2	2.31	2.2	2.32	1.64
0.25	2.48	2.61	2.14	2.79
0.315	3.4	3.17	2.98	2.88
0.4	3.11	2.89	3.27	3.45
0.5	3.39	3.74	3.53	3.47
0.63	3.7	3.42	3.89	3.65
0.8	3.99	4.02	4.17	4.03
1.0	3.91	4.2	4.23	4.12
1.25	4.47	4.53	4.07	4.06
1.6	4.29	4.14	3.8	3.61
2.0	3.3	3.6	3.13	3.08
2.5	2.59	3.1	2.68	2.83
3.15	1.96	2.04	2.11	1.87
4.0	1.73	1.75	1.68	1.57
5.0	1.51	1.66	1.58	1.52
6.3	1.35	1.36	1.41	1.37
8.0	1.15	1.23	1.11	1.2
10.0	0.96	1.03	0.85	0.96

Appendix 4

The average noise level (in dBA) in different aerobic classes in 'Gym B'.

Class	n	Mean	Median	S.D.
High impact workout	14	97.94	98.42	3.63
Non-contact martial arts	9	96.65	97.61	4.75
Muscle workout using barbell	7	96.42	97.11	3.13
Indoor cycling	2	82.90	82.9	7.49

Appendix 5

A comparison of the average noise level measured in the same aerobic class before
and after the date instructor became aware of the purpose of the study.
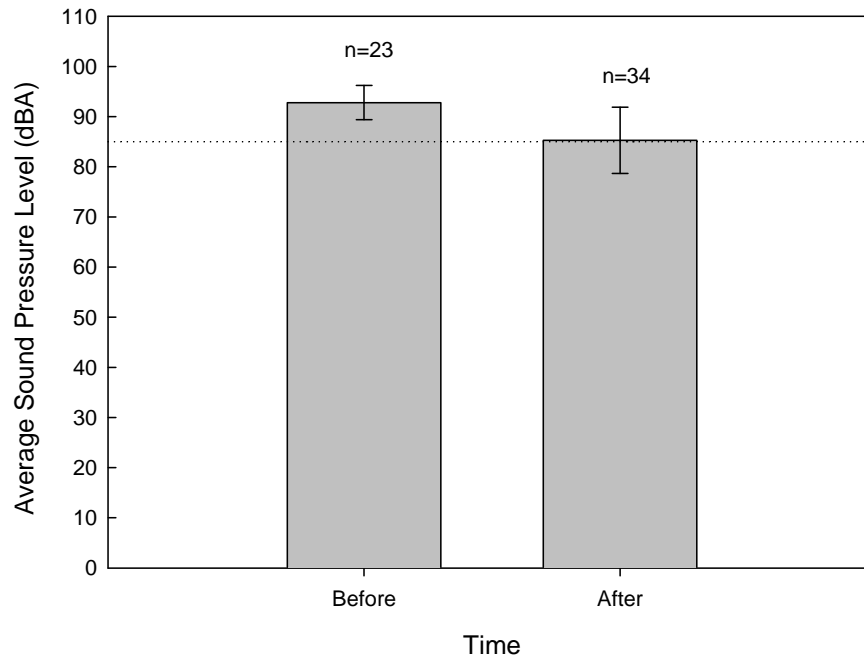
FREE PETROL!! CAN YOU HEAR THAT?

We are looking for participants for a study to assess hearing.   We will test your hearing before and after a gymnasium class (immediately after, 2 days after, and 30 days after) and provide you with a $10 petrol voucher.   All free!!

There are no risks associated with the hearing test.   Tests will be performed in the University's Speech and Hearing clinic on campus.   The test should take less than 15 minutes for each session.

Interested?   Make sure you are meeting the following criteria and contact us:

1   Older than 18 years of age;

2   are in good health;

3   have no history of hearing disorders or ear pathologies.

Please contact:

Mr. Eyal Goel

Masters Student for Audiology

The Dept. of Communication Disorders

Email: eyalgoel@yahoo.co.uk

Mobile phone: 021 153 2712

Free hearing test +petrol	021 153 2712	eyalgoel@yahoo.co.uk	Free hearing test +petrol	021 153 2712	eyalgoel@yahoo.co.uk	Free hearing test +petrol	021 153 2712	eyalgoel@yahoo.co.uk	Free hearing test +petrol	021 153 2712	eyalgoel@yahoo.co.uk	Free hearing test +petrol	021 153 2712	eyalgoel@yahoo.co.uk	Free hearing test +petrol	021 153 2712	eyalgoel@yahoo.co.uk

Appendix 7

The recommended scale for classification of the severity of hearing loss (Jerger and Jerger, 1980).

Hearing Threshold (in dBHL)	Degree of Hearing Loss
(-10) to 20	Normal hearing
21 to 40	Mild hearing loss
41 to 55	Moderate hearing loss
56 to 70	Moderately-severe hearing loss
71 to 90	Severe hearing loss
>91	Profound hearing loss

University of Canterbury
The Department of Communication Disorders

Project Title: Monitoring Noise-Induced Hearing Loss in Gymnasium Goers: A Longitudinal Study with Distortion Product Otoacoustic Emissions and Pure Tone Audiometry.

Investigators: Mr. Eyal Goel and Dr. Emily Lin

To: Potential research participants

You are invited cordially to participate in a research project related to noise-induced hearing loss.   This information sheet is to be administrated to research participants before their participation in audiometric and otoacoustic emissions (OAEs) testing in the University of Canterbury Speech and Hearing Clinic.   Information from the study will be used to decide if changes can be observed to allow for early identification of hearing losses caused by noise.   The study has been approved by the Human Ethic Committee of Canterbury University, Christchurch.

If you agree to participate, we will ask you some questions about you.   Your hearing will be tested before and immediately after your participation in a gymnasium class. It will also be tested 24-48 hours after participation and 30 days after.   Comparisons will be made between the results to find out if the OAEs test can be used as a predictable tool for early detection of hearing loss caused by noise.   You will be given a petrol voucher (NZD10) for your participation.

Your hearing tests results will be kept confidential.   Only you and the research team will be able to look at them.   The results will be used to find out which one of the different tests is best for identifying noise-induced hearing loss before it causes problems.   We will show you your test results and explain their significance.   The results of the project will be published in a journal article and you can be assured of the complete confidentiality of data gathered in this investigation.

The project is being implemented by a master student for audiology, Mr. Eyal Goel,

who will be under supervision of Dr. Emily Lin. Emily and Eyal will be pleased to discuss any concerns you may have about participation in the project.

Sincerely

Eyal Goel   Emily Lin, Ph.D.
Master of Audiology student   Lecturer
E-mail: eyalgoel@yaho.co.uk   E-mail: emily.lin@canterbury.ac.nz
Telephone: 021-153 2712   Telephone: 03-366-7001 x7080

Appendix 9

Consent Form

Researcher's name: Mr. Eyal Goel and Dr. Emily Lin

Contact Address: Department of Communication Disorders

University of Canterbury

Private Bag 4800

Christchurch

Date:

CONSENT FORM

"Monitoring Noise-Induced Hearing Loss in Gymnasium Goers: A Longitudinal Study with Distortion Product Otoacoustic Emissions & Pure Tone Audiometry"

I have read and understood the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I also understand that I may, at anytime, withdraw from the project, including withdrawal of any information I have provided.

(Please sign your name on the signature line below. Your signature indicates that you have read the above and agree to participate in this project.)

Name (please print): _____

Signature: _____

Date: _____

Appendix 10

Noise-induced Hearing Loss Research- Questionnaire for Participants

Date: _____

Name: _____ Gender: _____ Date of Birth: _____

Phone Number: _____ Email Address: _____

1. Are you a student in Canterbury University?   *Yes*   *No*

2. Have you been exposed to loud noise in the past 48 hours?   *Yes*   *No*

3. Do you use earplugs during gymnasium classes to protect your hearing?   *Yes*   *No*

4. Do you think you have a hearing loss/ difficulty   *Yes*   *No*

5. Have you ever suffered balance/vertigo problems?   *Yes*   *No*

6. Have you ever had a head injury?   *Yes*   *No*

7. Have you suffered any of the following (please circle):

    Meningitis   Measles   Diabetes   Mumps   Heart and blood pressure

8. Have you ever experienced problems with your hearing? For example, muffled hearing, painful ears,

    ringing ears (tinnitus)?   If yes, how many times a month?

                Yes (Times a month: _____ *)*   *No*

9.   Do you have history of middle ear problems?   *Yes*   *No*
    When: _____

10. Have you had an ear surgery?   *Yes*   *No*
    When: _____

11. Are you taking any medications?   *Yes*   *No*
    What: _____

12. Do you have family history of hearing loss?   *Yes*   *No*

   Who: _____   *Age of onset and cause (if known):* _____

13. Do you smoke? If yes, how many a day?   *Yes* _____   *No*

14. How long have you been attending aerobic classes for?   _____

15. How many times a week do you attend an aerobic class? 0   *1   2   3   4   5   6   7*
   (How long have you been attending aerobic classes for? _____ *)*

## *Thank you for your efforts in filling out this form.*
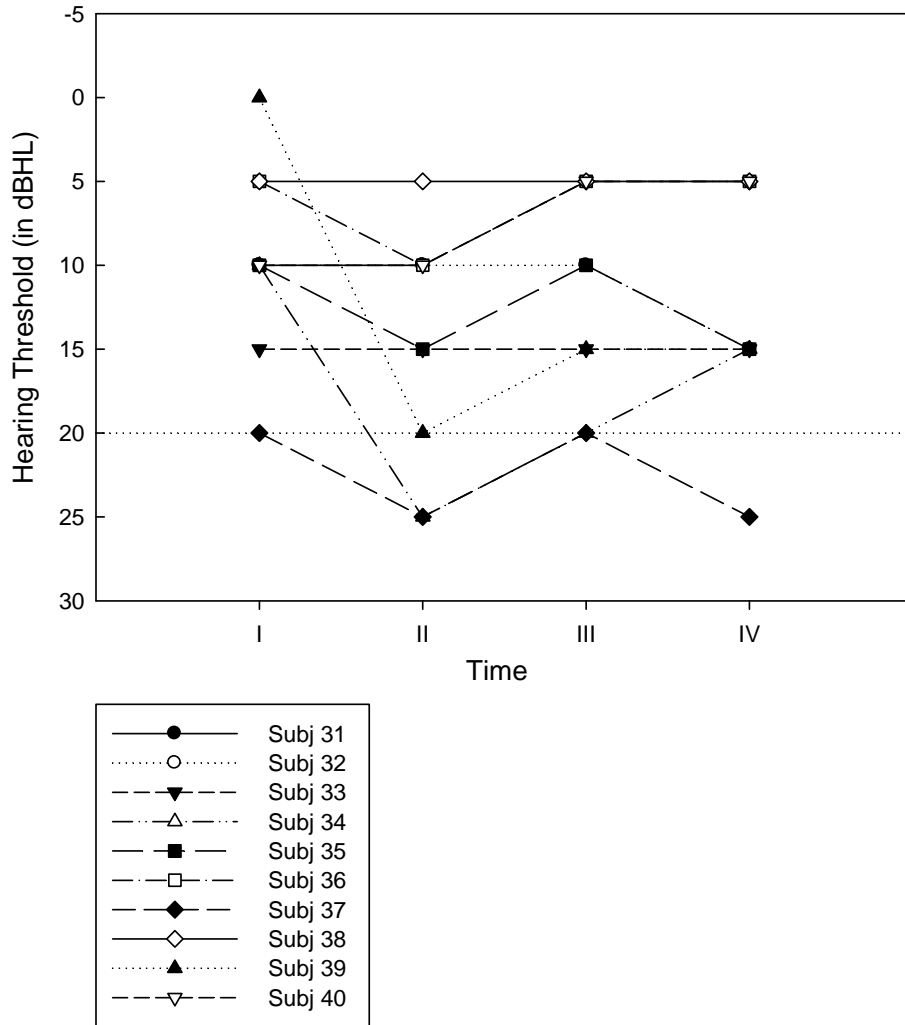
Appendix 11

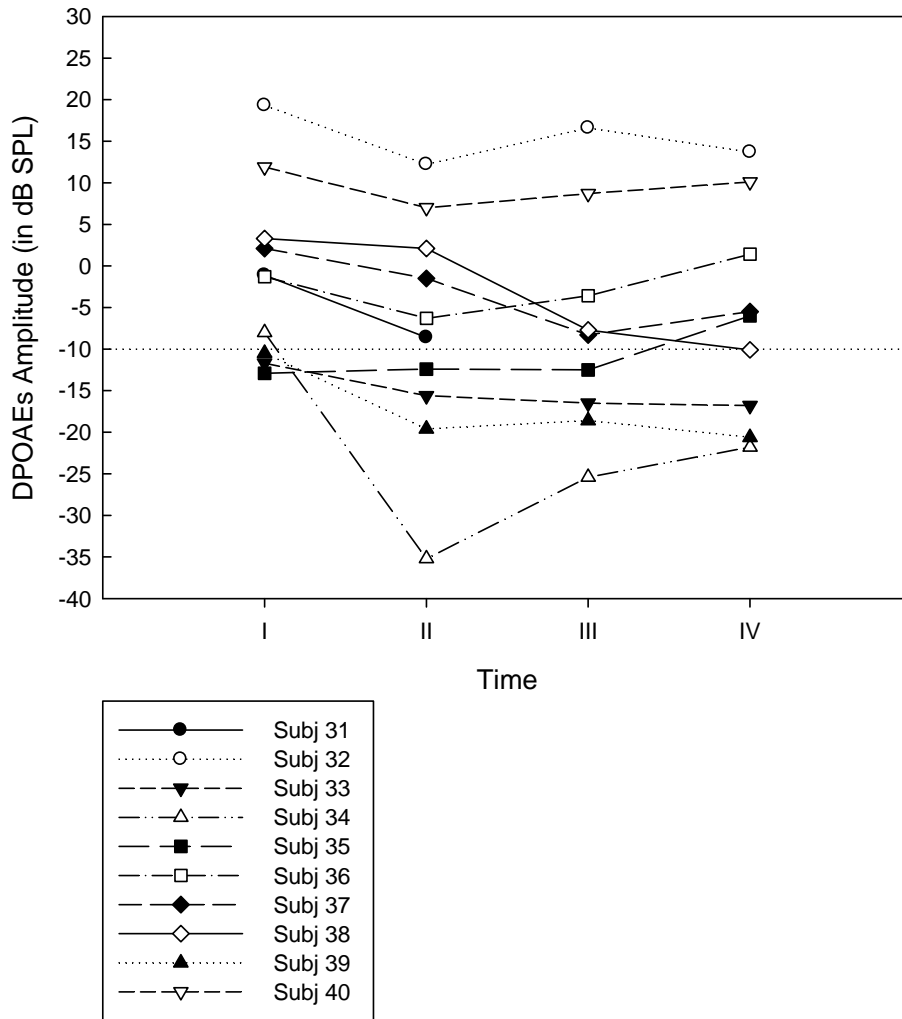PTA measures (right ear) for individuals in the "High-Risk" group at 2 kHz
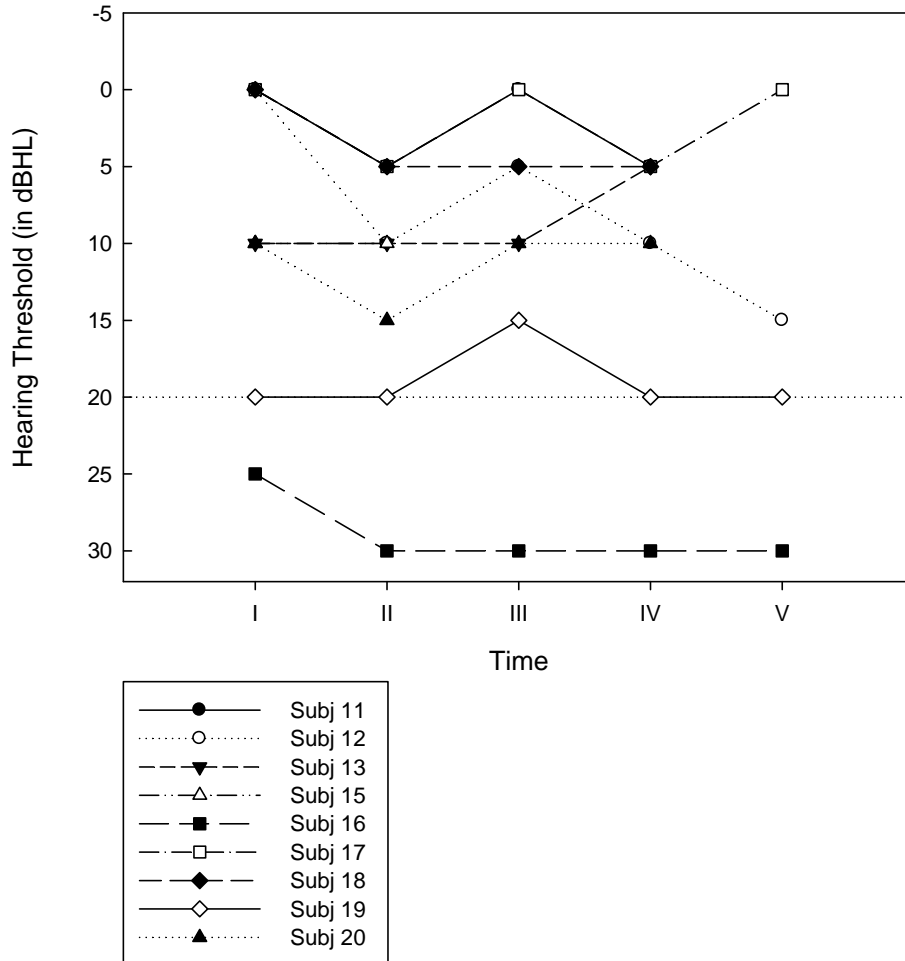
Appendix 12

PTA measures (left ear) for individuals in the "High-Risk" group at 4 kHz
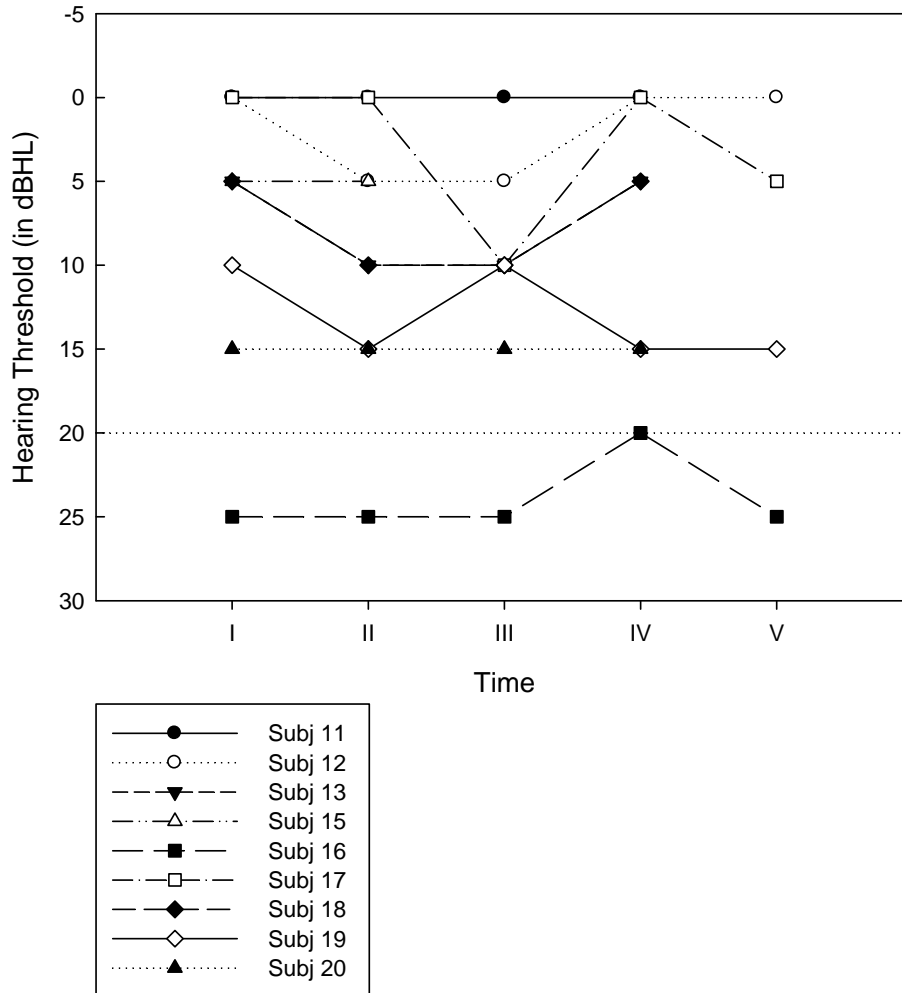
Appendix 13

DPOAEs amplitudes (right ear) for individuals in the "High-Risk" group at 4 kHz
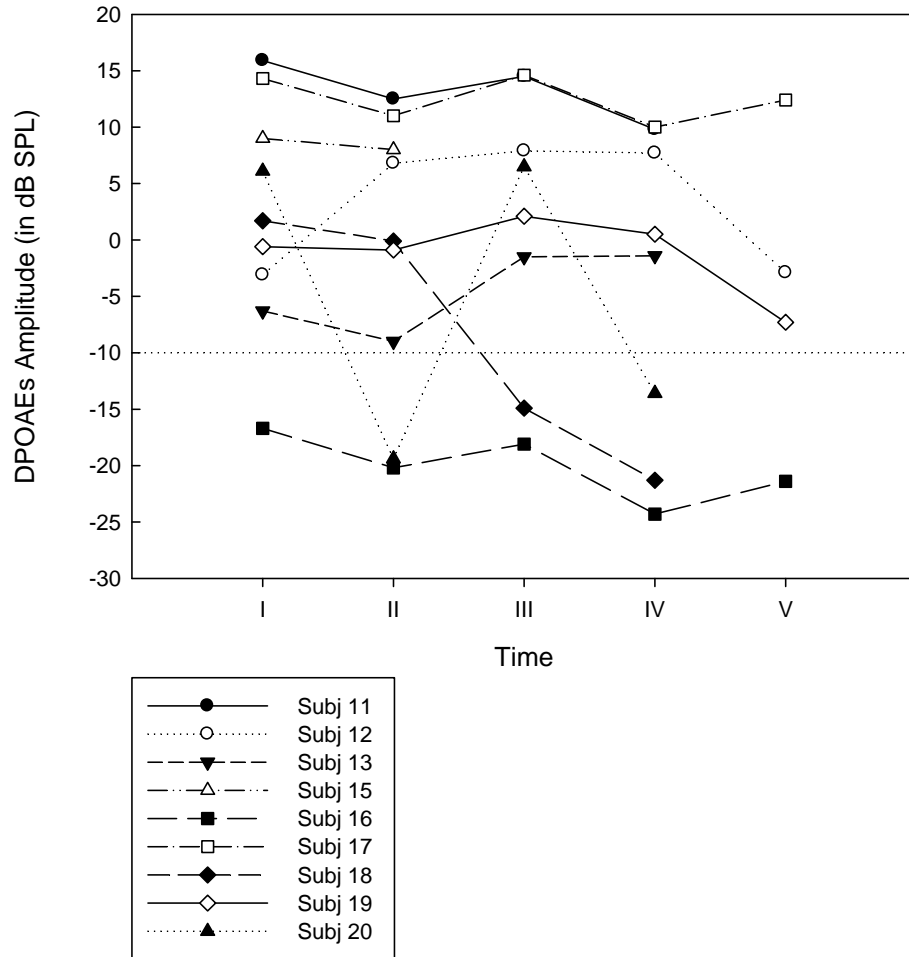
Appendix 14

DPOAEs amplitudes (right ear) for individuals in the "High-Risk" group at 8 kHz
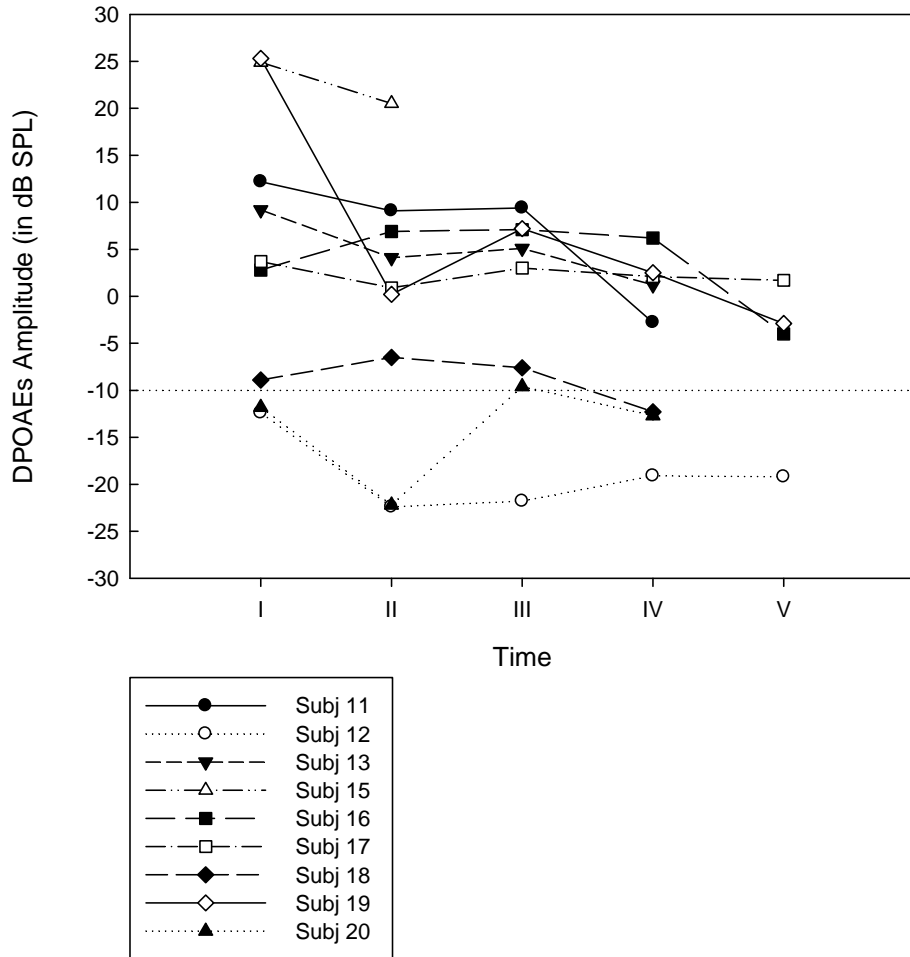
Appendix 15

DPOAEs amplitudes (right ear) for individuals in the "Low-Risk" group at 4 kHz
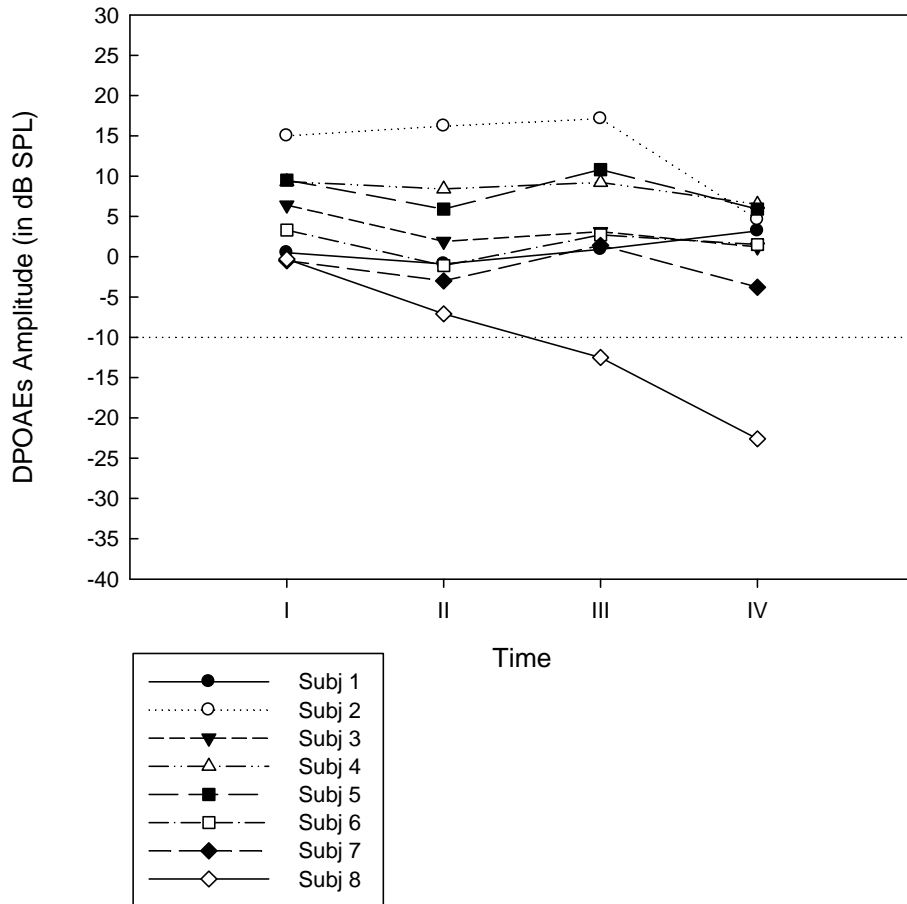
Appendix 16

DPOAEs amplitudes (left ear) for individuals in the "Low-Risk" group at 8 kHz
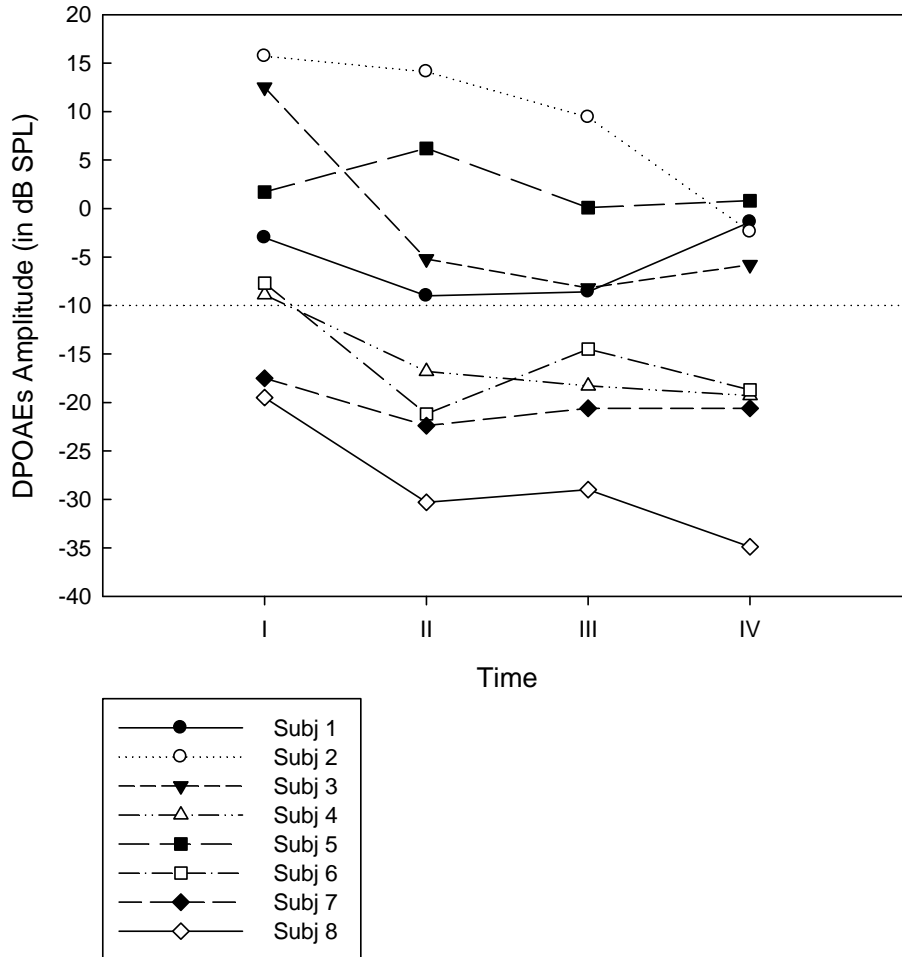
Appendix 17

PTA measures (right ear) for Participant 4 (from the "Low-Risk" group)
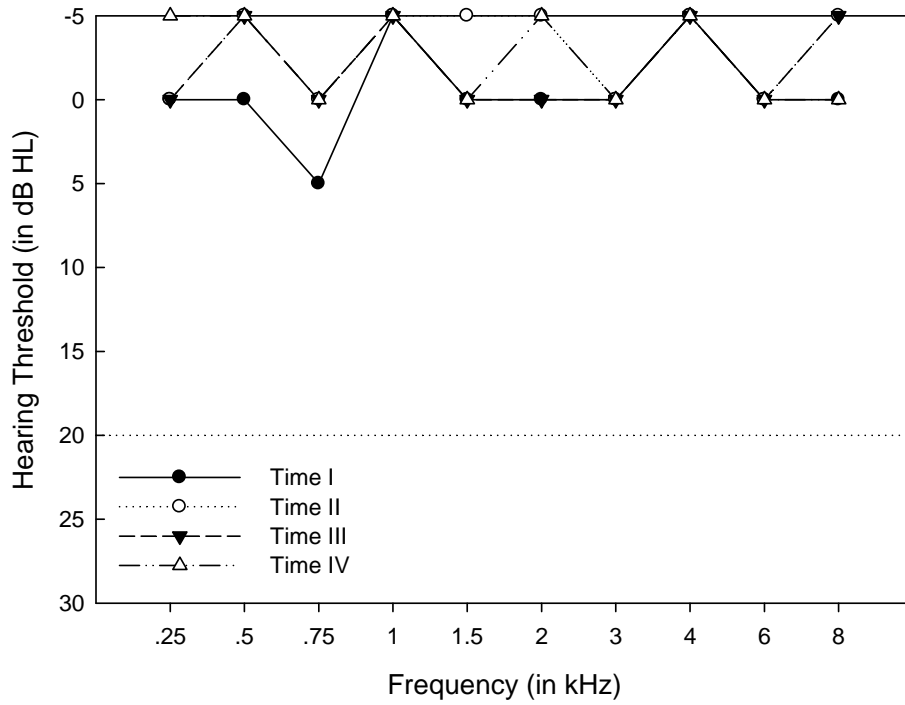
PTA measures (right ear) for individuals in the "Control without HP" group at 0.25 kHz
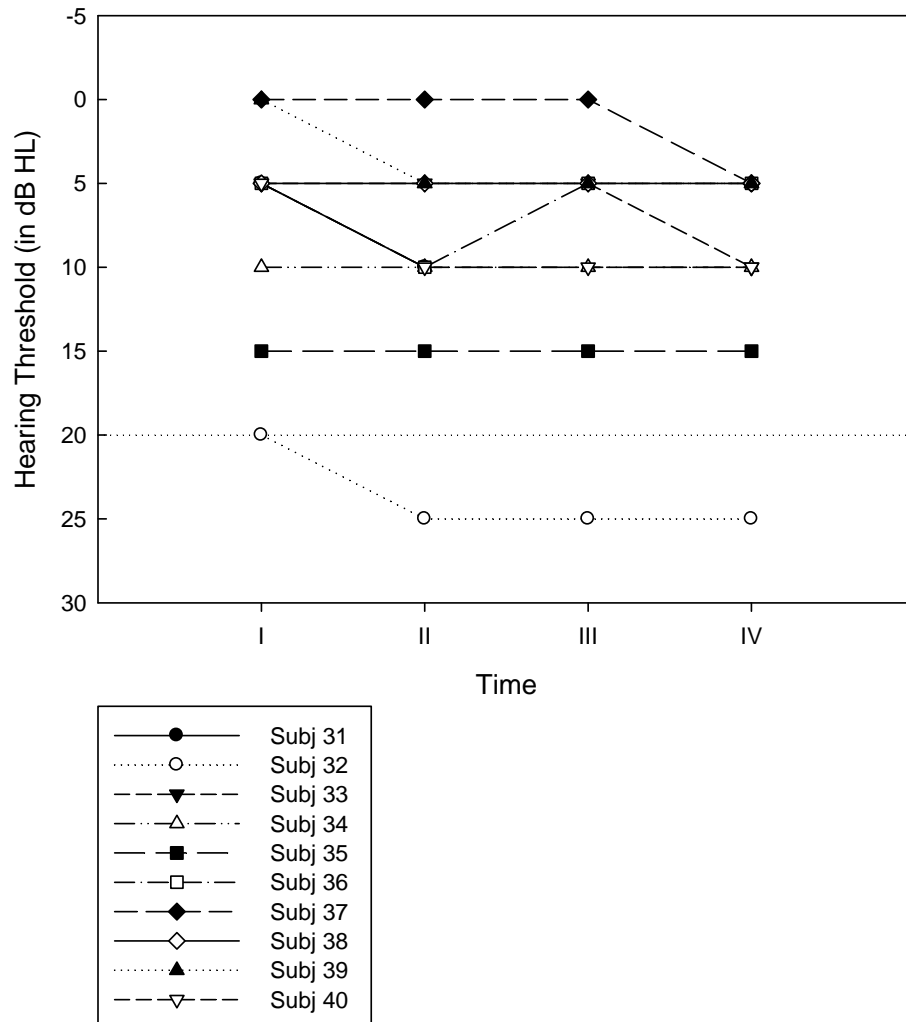
PTA measures (right ear) for individuals in the "Control without HP" group at 0.5 kHz
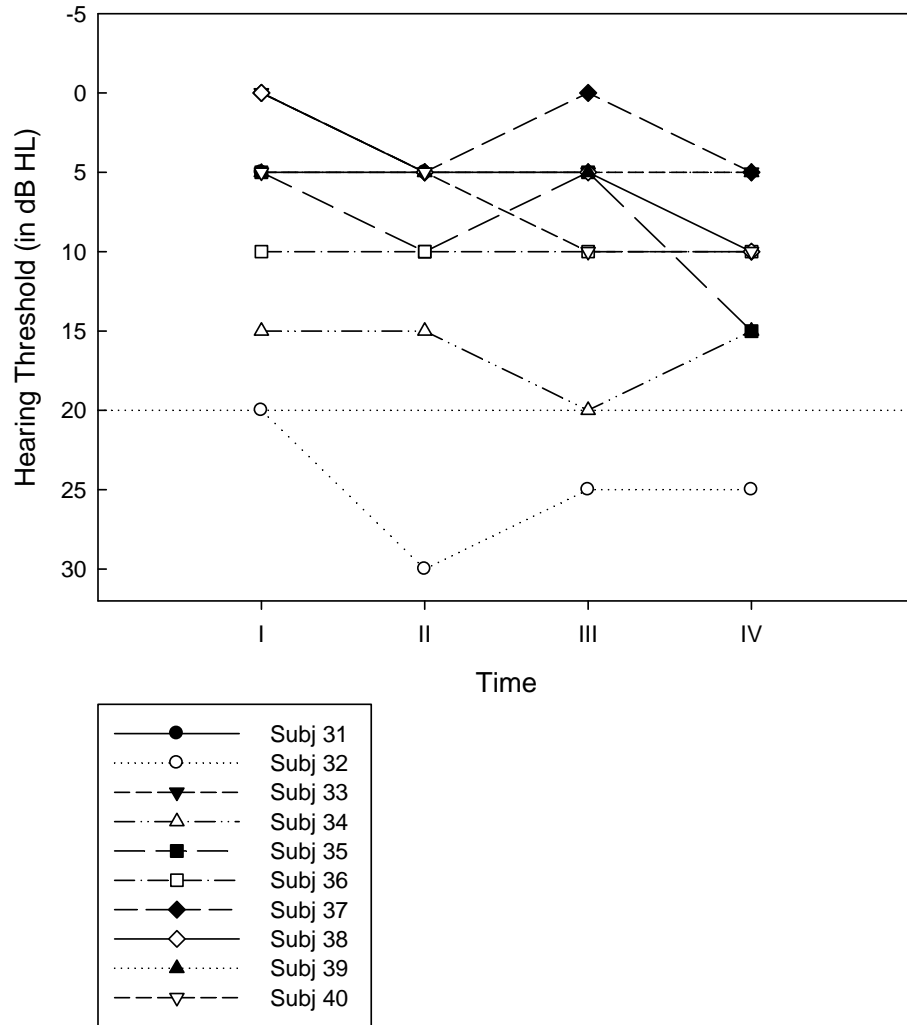
Appendix 20

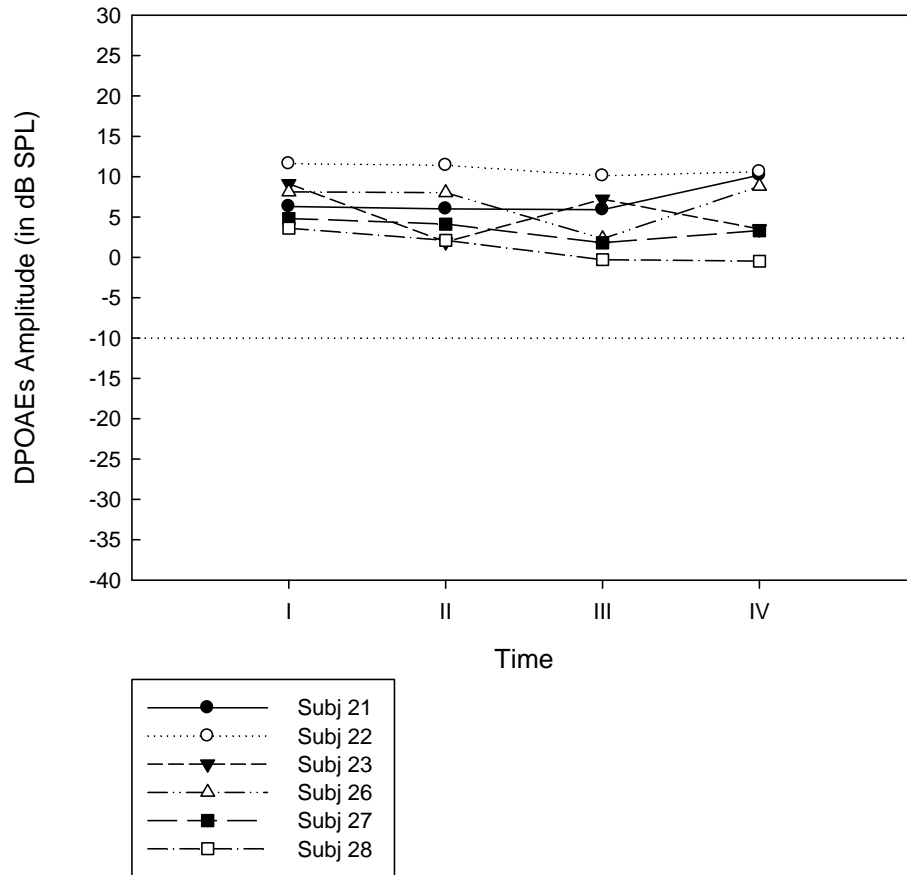PTA measures (right ear) for individuals in the "Control without HP" group at 3 kHz
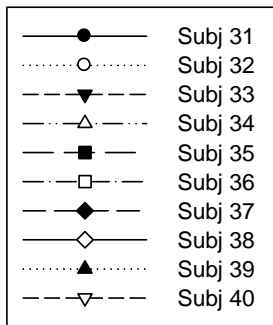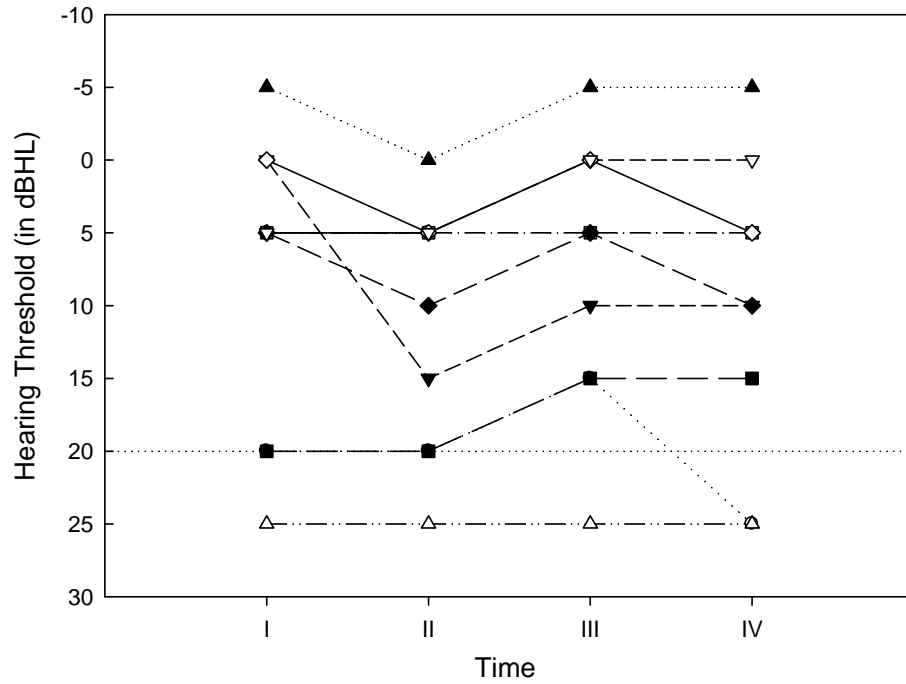
Appendix 21

PTA measures (right ear) for individuals in the "Control without HP" group at 8 kHz
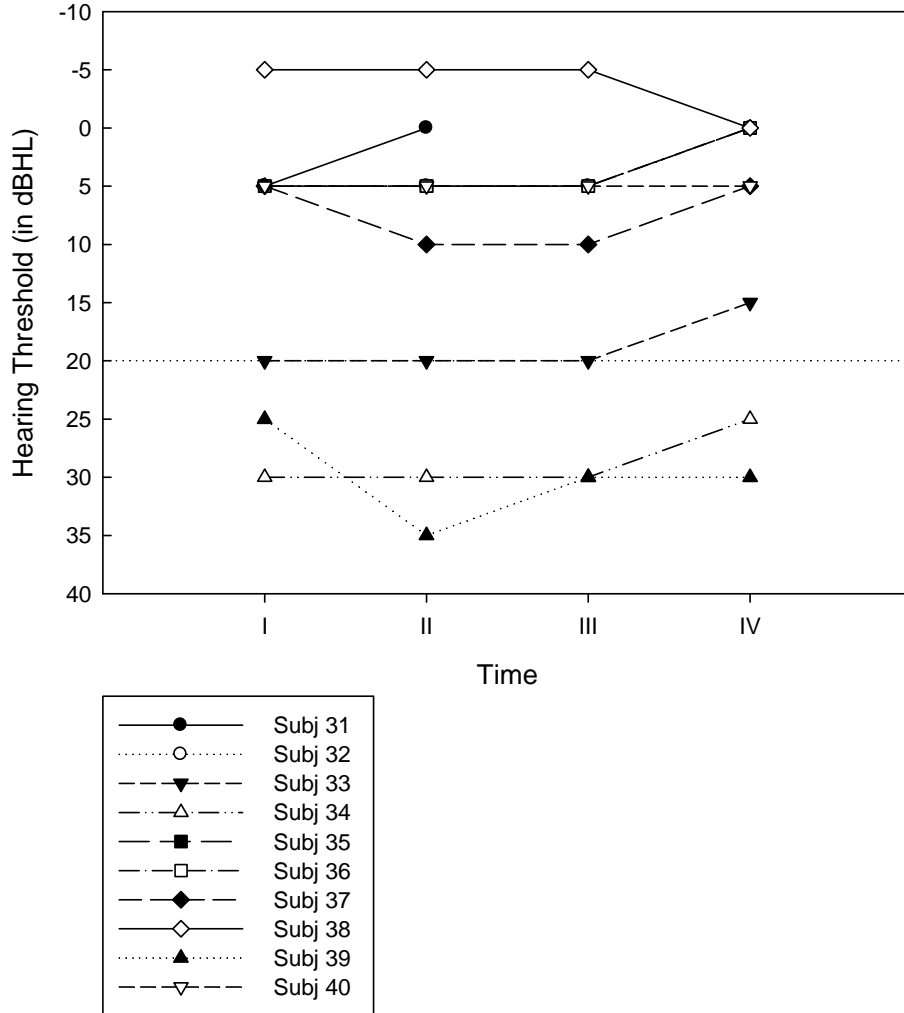
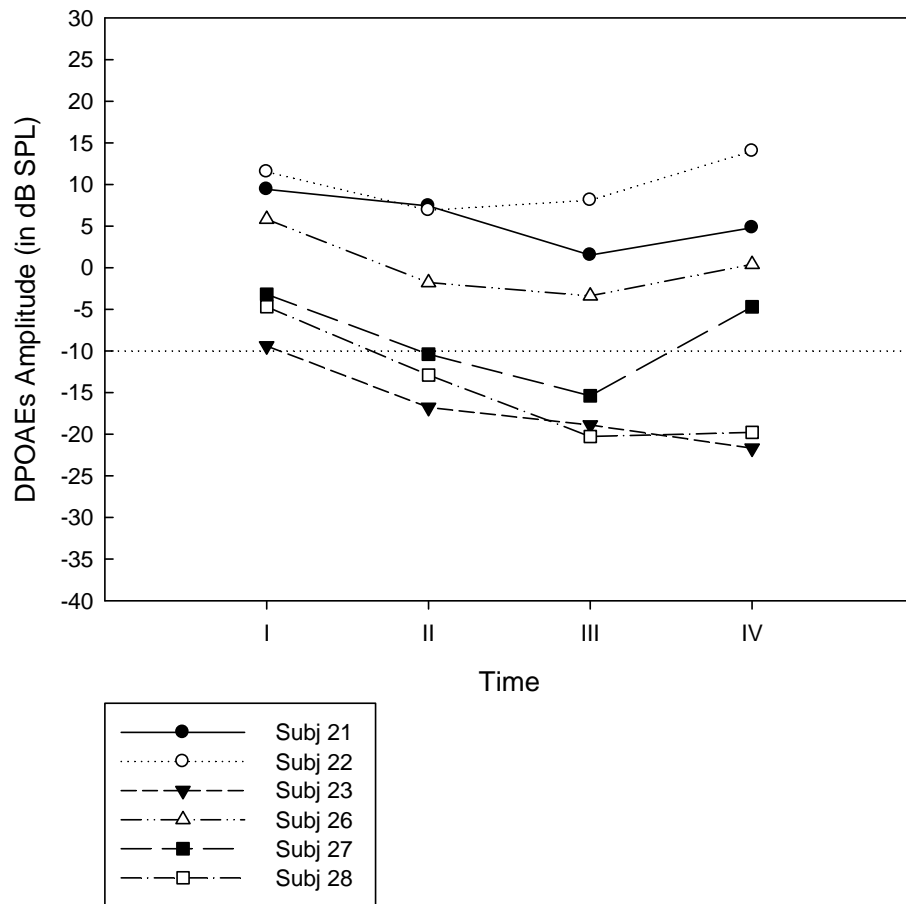# Appendix 22

PTA measures (left ear) for individuals in the "Control without HP" group at 0.5 kHz
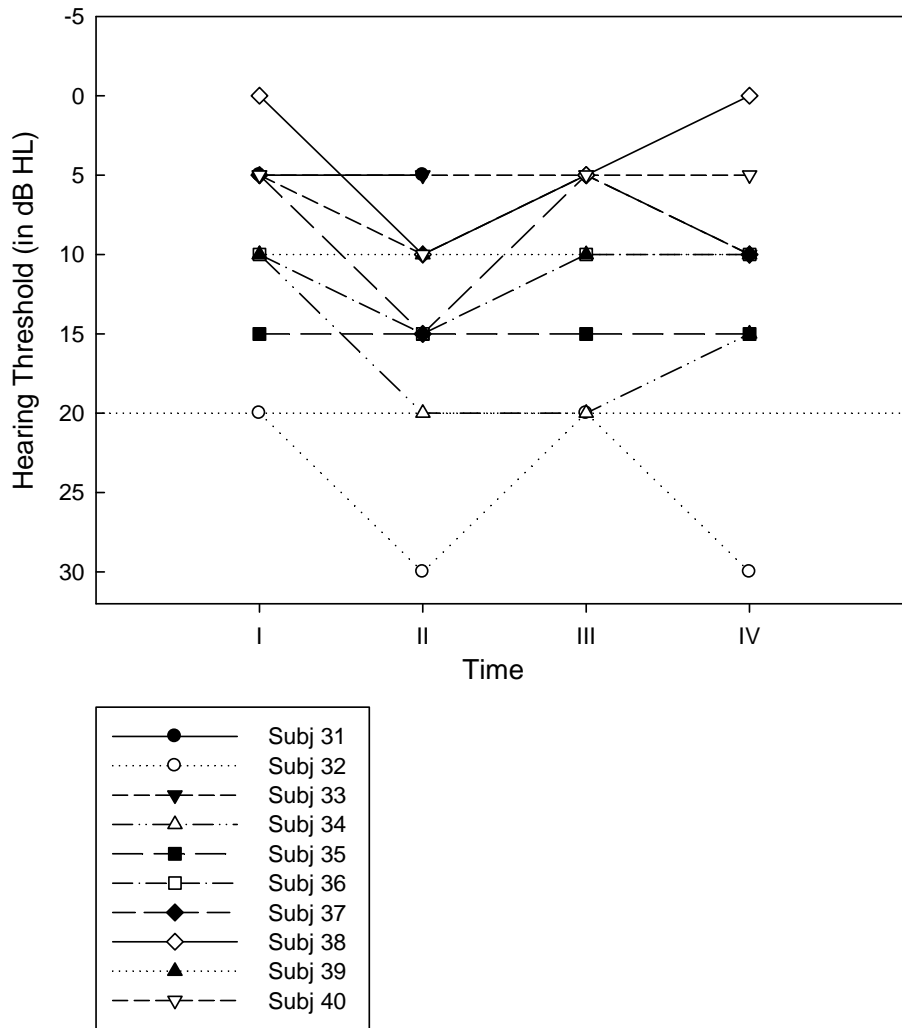
Appendix 23

PTA measures (left ear) for individuals in the "Control without HP" group at 4 kHz

Appendix 24

DPOAEs amplitudes (right ear) for individuals in the "Control without HP" group at 8 kHz

Appendix 25

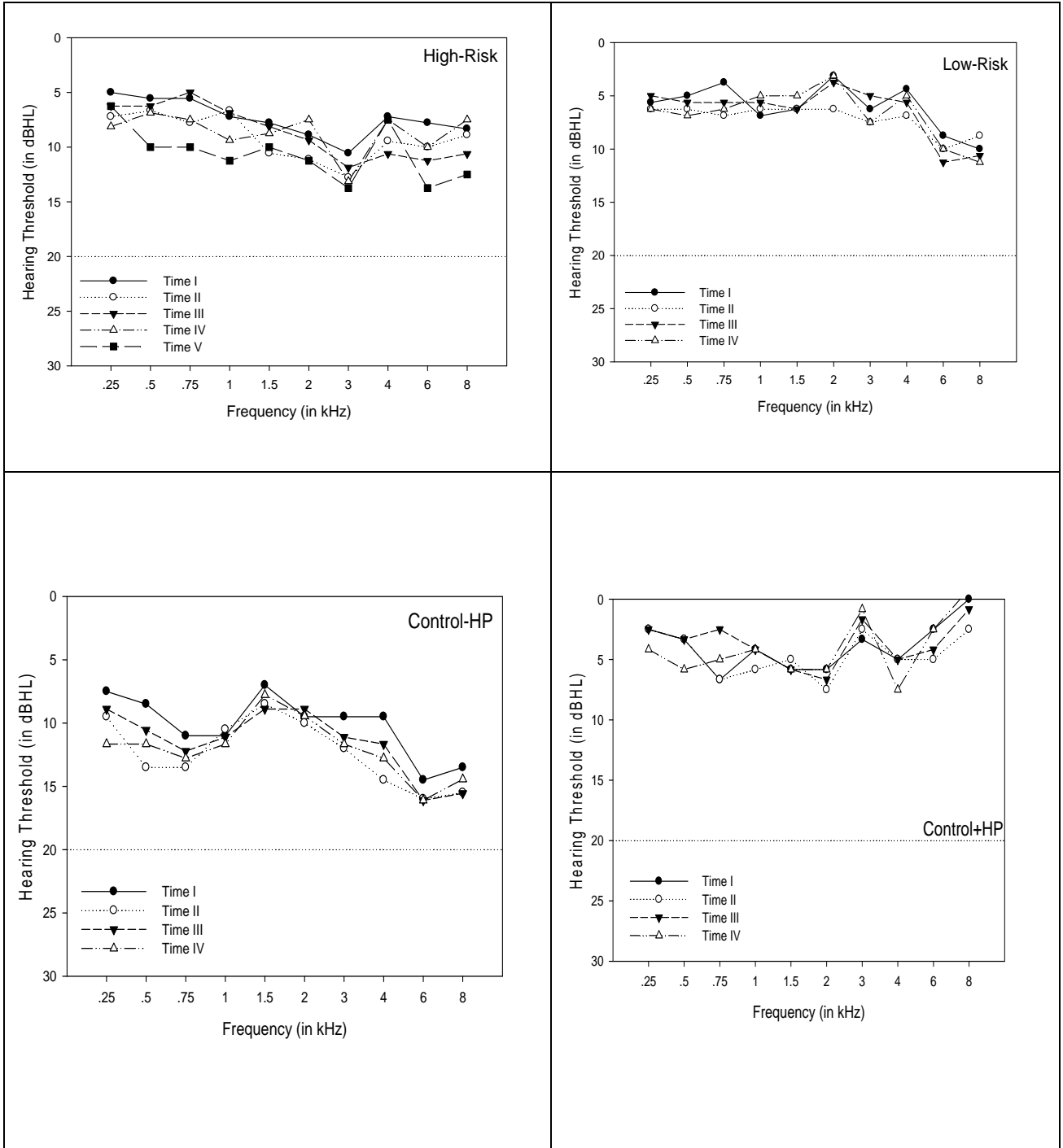DPOAEs amplitudes (right ear) for individuals in the "Control with HP" group at 3 kHz

Appendix 26

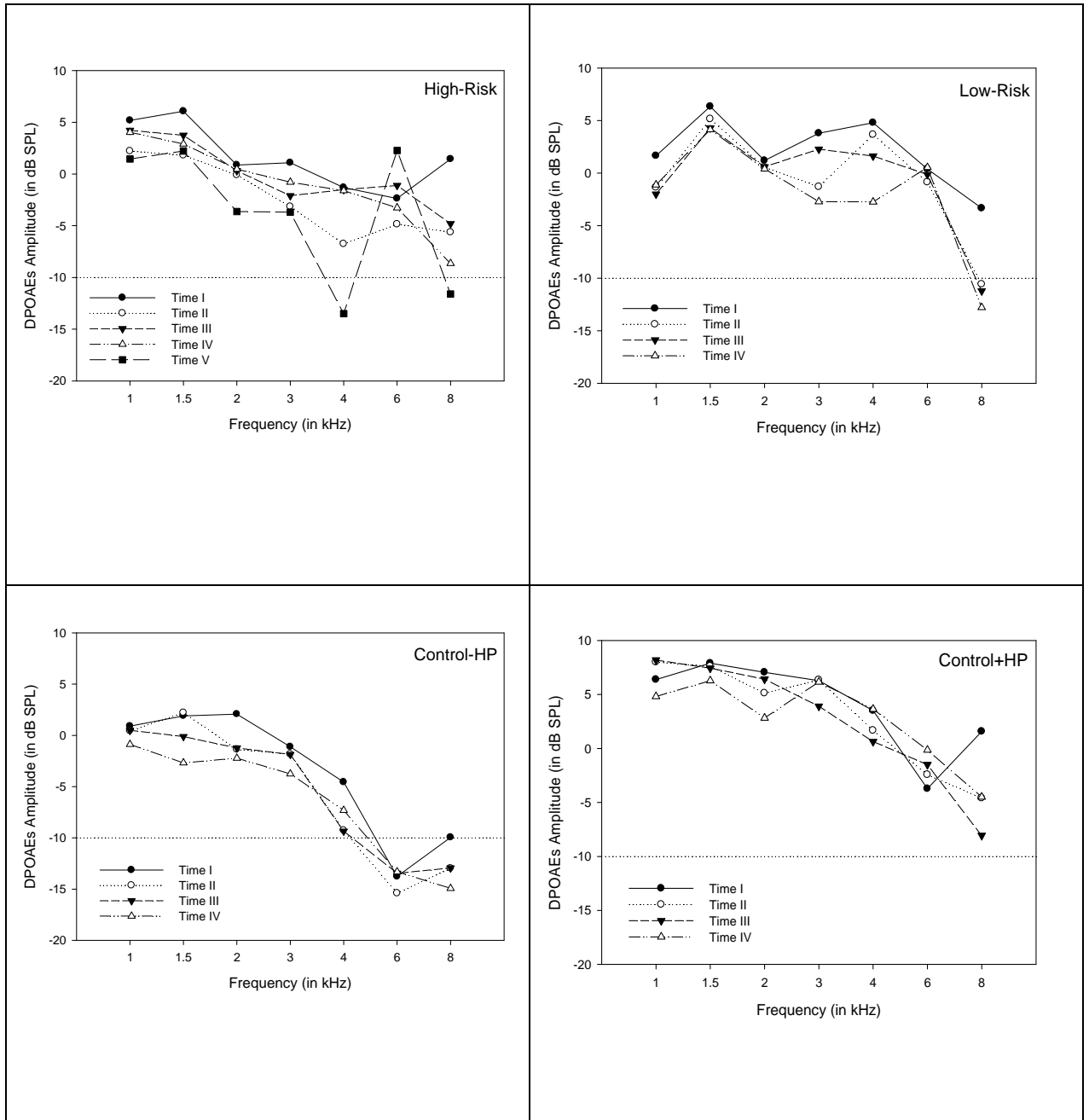DPOAEs amplitudes (left ear) for individuals in the "Control with HP" group at 8 kHz

Subj 21
Subj 22
Subj 23
Subj 26
Subj 27
Subj 28

Appendix 27

Mean PTA measures of the left ear for the four comparison groups
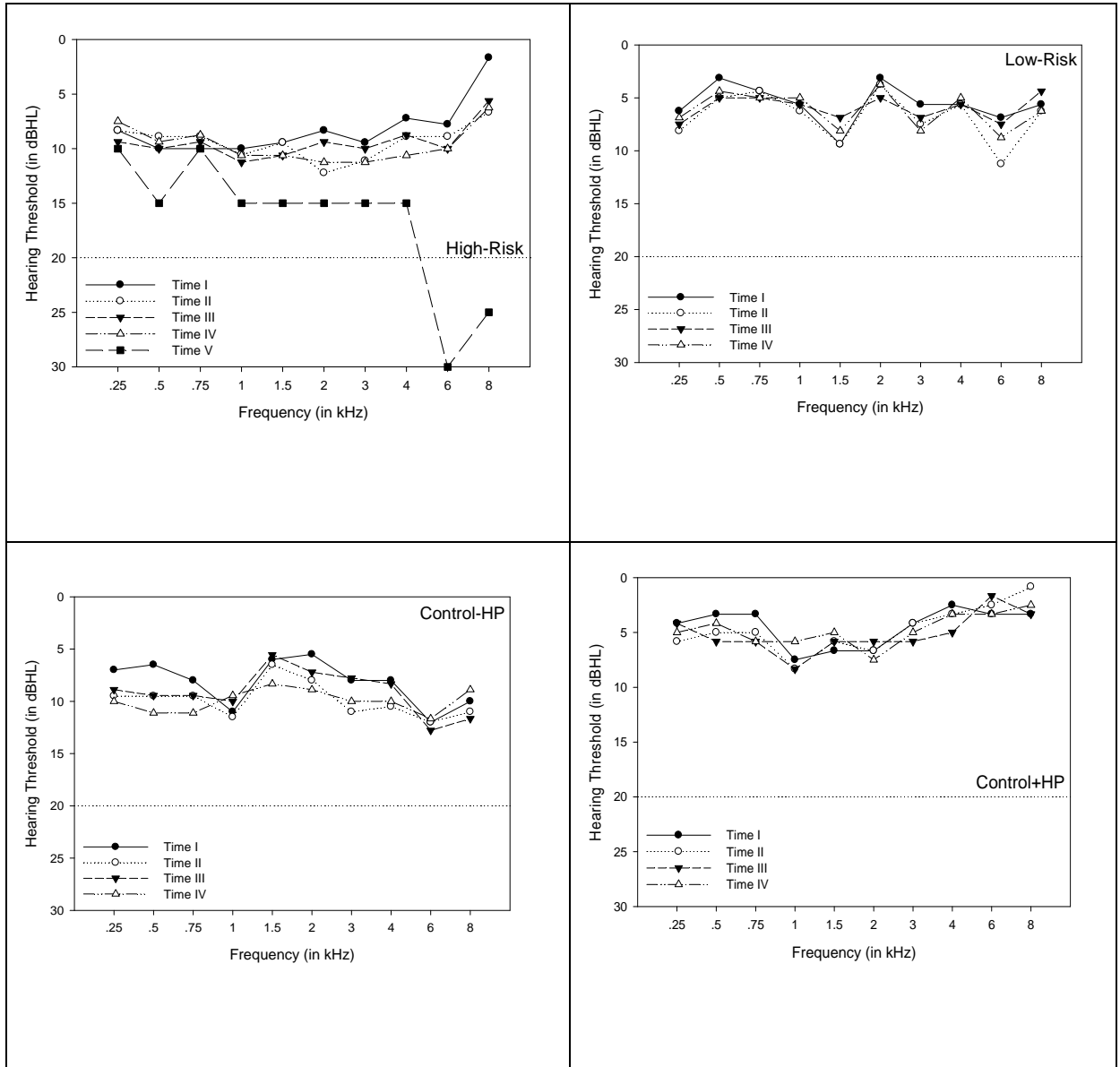
Appendix 28

Mean DPOAEs measures of the left ear for the four comparison groups

Appendix 29

Mean PTA measures of the right ear for the four comparison groups

Appendix 30

Mean DPOAEs measures of the right ear for the four comparison groups