A Longitudinal Study of Noise-Induced Hearing Loss in Aerobic Class Goers

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Abstract

Noise assessment of 105 aerobic classes and hearing assessment of 33 participants were conducted to evaluate the potential risk to noise induced hearing loss (NIHL) for aerobic class goers. Hearing levels were monitored over time for four comparison groups, including “High-Risk”, “Low-Risk”, “Control with HP”, and “Control without HP” groups. The “High-Risk” group included regular aerobic class goers who attended aerobic classes with an average noise level above 85 dBA and the “Low-Risk” group those attending aerobic classes with an average noise level below 85 dBA. The “Control with HP” group included non-gym goers asked to attend one high-risk aerobic class while wearing earplugs and the “Control without HP” group those asked to attend the aerobic class without hearing protection. Each comparison group consisted of healthy male and female adults, 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 one aerobic class and 48 hours and 30 days following the initial post-class test. Noise levels in the majority (78%) of the 105 aerobic classes examined were found to be higher than the 85 dBA. Signs of hearing deterioration immediately after participation of aerobic classes were most evident in the reduction of the DPOAEs measures. The “High-Risk” group exhibited the greatest reduction of DPOAEs amplitudes over time. The “Control without HP” group generally exhibited a larger degree of reduction in DPOAEs amplitudes immediately after the aerobic class as compared with the “Control with HP” group. This study provided empirical evidence showing that individuals who attended aerobic classes with excessively high noise level and did not wear hearing protectors, might be at risk of developing NIHL and that DPOAEs testing was a more sensitive tool than PTA in detecting early signs of hearing deterioration related to noise exposure.

Introduction

This study assessed the risk to noise-induced hearing loss (NIHL) in adults attending aerobic classes. It has been suggested that following an episode or a period of excessive noise exposure, changes in hearing may include reduced ability to detect sound and distortion of the perceived quality and clarity of auditory stimuli (Hetu & Fortin, 1995).

Noise-induced hearing loss is a preventable hearing disorder that affects people of all ages and demographics (Henderson, Subramaniam, & Boettcher, 1993).

Noise-induced hearing loss occurs slowly over time and the full effects may not be realized until after 10 to 15 years of chronic noise exposure (Miller, 1974). 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 (Melnick, 1991).

Acoustic trauma refers to a sudden, permanent sensorineural hearing loss caused by a single exposure to an intense sound, which is normally an impulse sound with a sound pressure level (SPL) of 130dBA (i.e., decibels measured on the “A” scale of a sound level meter) 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, Lindberg, & Smitley, 1972, p. 1249).

The effect of noise on hearing 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). Early detection of NIHL, as well as awareness of the effect of noise on the auditory function, is key to preventing NIHL or further hearing deterioration.

Hair Cells in the Cochlea

Noise-induced hearing loss is related to damage to the outer hair cells (OHCs) of the cochlea (Hall, 2000). The cochlea in each ear of mammals contains two sets of hair cells: inner hair cells (IHCs) and OHCs.

Both IHCs and OHCs are highly specialized sensory (afferent) transducers residing within the organ of Corti in the cochlea. Damage to IHCs is often associated with word recognition problems related to the degeneration of the neural signal (Prasher & Luxon, 1998).

Outer hair cells are active, muscle-like cells which assist in the amplification of sound transduction and provide “exquisite sensitivity” to increase the frequency resolution of the auditory system (Henderson et al., 1993).

Outer hair cells are more susceptible than IHCs to damage from noise exposure, acoustic trauma, ototoxic drugs, and other insults (Miller, 1974).

Noise Exposure

Noise exposure is the combination of SPL and duration (Royster, Royster, & Killion, 1991). As the SPL of the noise 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 SPL (measured in dBA) is normally calculated based on a conventional working schedule of eight-hour per day and five days per week.

For example, the New Zealand Occupational Safety and Health Service (2003) sets a level of no more than 85 dBA over eight hours 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 or non-occupational.

Individuals exposed to noise above 85 dBA for more than 40 hours a week have been shown to be at risk of developing of NIHL regardless of the noise type (Royster et al., 1991; Rintelmann et al., 1971; Yaremchuck & Kaczor, 1999; Williams, 2005).

In addition, noise has been considered a biological stressor that can cause the body to respond in ways that may lead to stress disorders, such as increased blood pressure and changes in blood chemistry (Suter & Franks, 1990).

Risk of Aerobic Class Goers to NIHL

Aerobics is a form of exercise set to music, with planned, structured, and repetitive bodily movements performed to improve or to maintain physical fitness.

The presence of dangerous noise levels during aerobic classes in gymnasiums has been reported (Clark & Calvert, 1991; Yaremchuck & Kaczor, 1999; Wilson & Herbstein, 2003).

However, 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" (Wilson & Herbstein, 2003, p. 29). The insensitivity of the commonly used hearing test in detecting early signs of NIHL may be another reason why the risk of NIHL for aerobic class goers is often underestimated. For example, studies employing pure-tone audiometry (PTA), a conventional behavioral test of hearing, have failed to reveal any marked effect of recreational noise on hearing (Carter, Murray, Khan, & Waugh, 1984; Meyer-Bisch, 1996; Williams, 2005). As major advances in diagnostic audiology in recent years have enabled audiologists to conduct diagnostic procedures that rely on not only behavioural tests, such as PTA or speech audiometry, but also physiological measurements (Katz, Burkard, & Medwetsky, 2002), the risk of aerobic class goers to NIHL may be better assessed using a more sensitive test, such as test of otoacoustic emissions.

Distortion Product Otoacoustic Emissions

Otoacoustic emission (OAE) is a sound generated by the activity of the OHC with or without an evoking stimulus. Otoacoustic emissions can be measured in the ear canal with a microphone.

Table 1. Significant findings from results of ANOVAs performed on the pure-tone audiometric (PTA) and distortion product otoacoustic emissions (DPOAEs) measures obtained at different frequencies for the "High-Risk" (n = 9) and "Low-Risk" (n = 8) groups respectively.

		Left Ear		Right Ear	
		PTA	DPOAE	PTA	DPOAE
"High-Risk"					
2 kHz					
	χ^2	4.905	0.150	10.200	0.797
	df	3	3	3	3
	p	0.179	0.985	0.017$^{*,\xi}$	0.850
4 kHz					
	χ^2	8.727	1.950	5.136	8.250
	df	3	3	3	3
	p	0.033$^{*,\xi}$	0.583	0.162	0.041$^{*,\xi}$
8 kHz					
	χ^2	1.966	7.350	3.588	9.150
	df	3	3	3	3
	p	0.580	0.062	0.309	0.027$^{*,\xi}$
"Low-Risk"					
4 kHz					
	χ^2	3.000	3.000	0.200	11.280
	df	3	3	3	3
	p	0.392	0.369	0.978	**0.010***
8 kHz					
	χ^2	1.125	10.370	2.596	3.769
	df	3	3	3	3
	p	0.771	**0.016***	0.458	0.287

*significant at 0.05 level
ξ Post-hoc tests failed to reveal any significant difference in pairwise comparisons.

The presence of OAE has been found to indicate normal functioning of OHCs (Kemp, 1978; Hall, 2000). Middle ear disorders may affect OAE but are easily distinguishable from sensorineural hearing loss (Kemp, 1978). Clinically, OAE testing is used, in conjunction with other audiological assessments, mainly for assessing various retrocochlear lesions and ear pathologies like Meniere's disease (Royster et al., 1991).

It has been shown in animal studies that the effect of scattered damages to OHCs, when less than 20 percent of the total number of OHCs is affected, is not always evident in audiometric measurements (Bohne & Clark, 1982).

Clinically, the greater sensitivity of OAE to cochlear dysfunction has been shown by anecdotal reports of abnormal or absent OAE among patients with normal audiograms. It has been suggested that the absence of OAE may reflect an early stage of noise-induced auditory dysfunction when OHCs are deteriorating but the damage is still incomplete (Hall, 2000). As the primary reason people suffer from a permanent NIHL is a significant decline in the number (or functionality) of OHC resulting in reduced internal amplification (LePage & Murray, 1998), OAE testing may be more useful than pure-tone audiometry for early detection of NIHL.

Distortion product otoacoustic emissions (DPOAEs) is the sound emitted by the OHCs in response to two simultaneous tones of different frequencies. Studies have shown that the test of DPOAEs was useful for providing early warning for hearing loss. For example, in a study evaluating the clinical effectiveness of DPOAEs as a tool for screening for NIHL in 76 military personnel, it was found that DPOAEs were generally absent among participants with a history of noise exposure (Attias, Bresloff, Reshef-Haran, Horowitz, & Furman, 1998). Torre III and Howell (2008) examined the effects of noise in aerobic classes on hearing. Fifty participants (48 females and 2 males) underwent a hearing protocol including otoscopy, screening tympanometry, and a pre and post-aerobic class DPOAEs testing. Reduction of the DPOAEs strength following the aerobic class was found to be statistically significant for measures at the frequency of 6 kHz, with an average decrease of 1.4 dB SPL. These preliminary findings suggested that DPOAEs testing may be a viable tool for detecting early signs of NIHL and assessing the risk to NIHL.

Research Questions

In light of the paucity of empirical studies demonstrating the effect of noise exposure and hearing protection schemes in aerobic classes, this study employed a longitudinal group design and DPOAE testing, along with the conventional PTA tests, to assess the risk and the development of NIHL for aerobic class goers. The research questions were:

1. What is the evidence that individuals attending aerobic classes without any hearing protection scheme may be at risk of developing NIHL?

2. Is the DPOAE testing more sensitive than PTA tests in detecting early signs of NIHL?

Methodology

This study was structured into three phases. In the first phase, a sports hall normally used for aerobic classes was chosen for acoustic assessment,

Table 2. Significant findings from Results of ANOVAs performed on the PTA and DPOAEs measures obtained at different frequencies for the "Control without HP" (n = 10) and "Control with HP" (n = 6) groups.

		Left Ear		Right Ear	
		PTA	DPOAE	PTA	DPOAE
"Control without "HP"					
0.5 kHz					
	χ^2	8.872	---	9.447	---
	df	3	---	3	---
	p	$0.031^{*,\xi}$	---	$0.024^{*,\xi}$	---
1 kHz					
	χ^2	1.054	1.253	10.412	0.885
	df	3	3	3	3
	p	0.788	0.740	$0.015^{*,\xi}$	0.829
3 kHz					
	χ^2	6.892	2.241	9.250	6.266
	df	3	3	3	3
	p	0.075	0.524	$0.026^{*,\xi}$	0.099
4 kHz					
	χ^2	10.787	3.900	7.308	2.241
	df	3	3	3	3
	p	$0.013^{*,\xi}$	0.272	0.063	0.524
8 kHz					
	χ^2	3.471	3.150	8.887	6.450
	df	3	3	3	3
	p	0.325	0.369	$0.031^{*,\xi}$	0.092
"Control with HP"					
2 kHz					
	χ^2	1.244	10.200	0.500	3.000
	df	3	3	3	3
	p	0.742	**0.017***	0.919	0.392
3 kHz					
	χ^2	0.730	2.288	0.825	8.600
	df	3	3	3	3
	p	0.866	0.515	0.843	**0.035***
8 kHz					
	χ^2	1.653	11.400	1.971	3.800
	df	3	3	3	3
	p	0.647	**0.010***	0.578	0.284

*significant at 0.05 level
ξ Post-hoc tests failed to reveal any significant difference in pairwise comparisons.

including measurements of (1) reverberation time and (2) the noise levels of the hall when the noise environment of an aerobic class was simulated. The second phase included noise assessment of a selection of aerobic classes. The third phase encompassed an experiment to monitor the hearing of individuals assigned to different comparison groups before and immediately, hours, days, and months after attending an aerobic class.

Phase One: Acoustic Assessment of an Aerobic Class Setting

Reverberation time (RT) is the time it takes for a reverberant sound, which is the sound reflected from the surface of a room, to die away. The time required for the sound energy to drop to 60 dB below its original level (RT60) is normally used in the standard measurement procedure (Gastmeier & Aitken, 1999). The less absorbent a room, the longer the reverberation time (e.g., RT60 longer than 3.5 seconds), resulting in more noise to be superimposed on the original sounds and thus higher background noise or less intelligible speech (Sharland, 1972). The equipment used in this study for measuring RT60 of the sports hall (31.17 meters in width and 22.25 meters in length) included a microphone (Brüel & Kjær Type 4189), a modular precision sound analyzer (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 placement of the microphone attached to the sound analyzer followed the conventional RT measurement rule that microphone should be at least one meter away from any surface (e.g., walls or large piece of furniture) and at least one and a half meters away from any window. The background noise level in the chosen room was monitored using the sound analyzer before and during the RT measurement procedure. Pink noise was generated from the audio generator and delivered through the amplifier and loudspeaker system at a level of at least 10 dB above the background noise level. The range of frequencies tested for calculating the reverberation time was 0.08 to 10 kHz. The average reverberation time was derived from measures obtained with the sound analyzer placed at four different locations in the sports hall.

For measuring the noise level of the hall when the noise environment of an aerobic class was simulated, a sound level meter (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 tripod were used. The stereo system used for simulating the noise environment of an aerobic class was the one normally used in the chosen room for aerobic classes. These included a CD player (Pioneer CDJ100S), an amplifier (Crown XLS602), and four loudspeakers (JBL MRX512M). The sound level meter was placed on a tripod. The tripod was placed at least one meter from any major reflecting surface and at least one and a half meter away from windows. The microphone was secured at a height from 120 to 150 cm above the ground. A piece of music normally used in the aerobic class was played through the stereo system. The maximum output of the stereo system was played while the noise level was measured at 25 different locations evenly spaced out in the room. The measurement position where the highest SPL readout was obtained was marked. The safety limit of the volume control dial of the amplifier was identified by adjusting the volume control of the stereo system until the SPL readout at the marked position was shown as 97 dBA, which was the safety limit generally prescribed for continuous noise exposure for 30 minutes.

Phase Two: Classification of Aerobic Classes Based on Noise Measurement

In the second phase of the study, a total of 105 aerobic classes were randomly selected from four gymnasiums in the local area (Christchurch, New Zealand) for noise assessment. The instrument used for measuring the noise level included a data logging noise dosemeter (Extech model 407355), with a setting of an A-weighted decibel scale and a slow detector to yield an average reading for every second of recording. The noise measurement procedure in this study generally followed the guidelines provided by the International Organization for Standardization (ISO) in a 1996 report, which forms the basis of measurement procedures 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 fortnightly in accordance with ISO 1996 regulations.

Phase Three: Monitoring the Hearing of Aerobic Class Goers

The third phase of the study involved a series of hearing assessments of volunteering participants to monitor the effect of noise exposure in an aerobic class on hearing. After obtaining approvals from an institutional ethical review board and related personnel, advisements were posted around the gymnasiums and flyers were distributed in a university campus to

Figure 1. The average reverberation time (in seconds) for the sports hall. The dotted line (RT60 = 2 seconds) represents the recommended maximum RT60 for general-purpose auditorium.

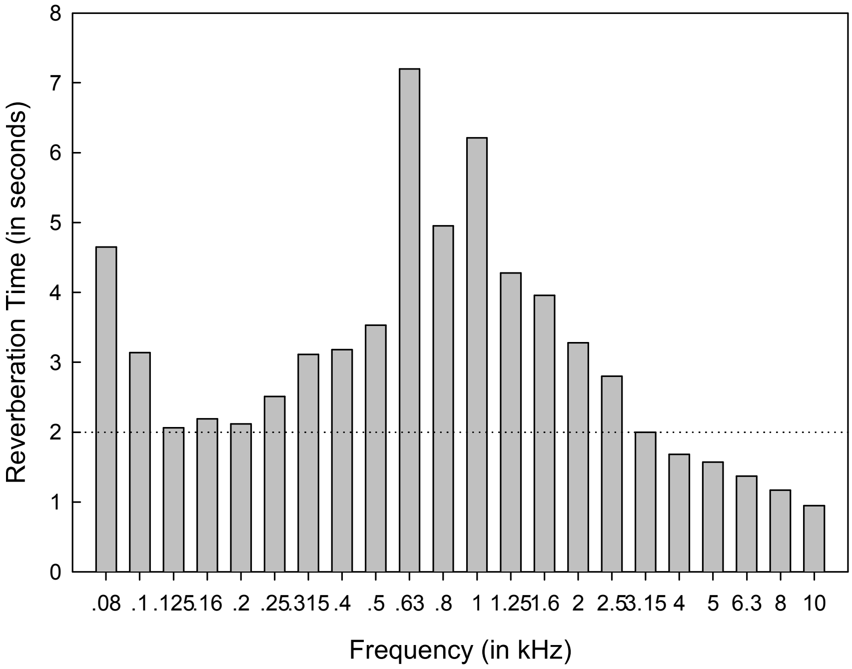


Figure 2. Means and standard deviations of the PTA and DPOAEs measures obtained at different time points from the "High-Risk" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss.)

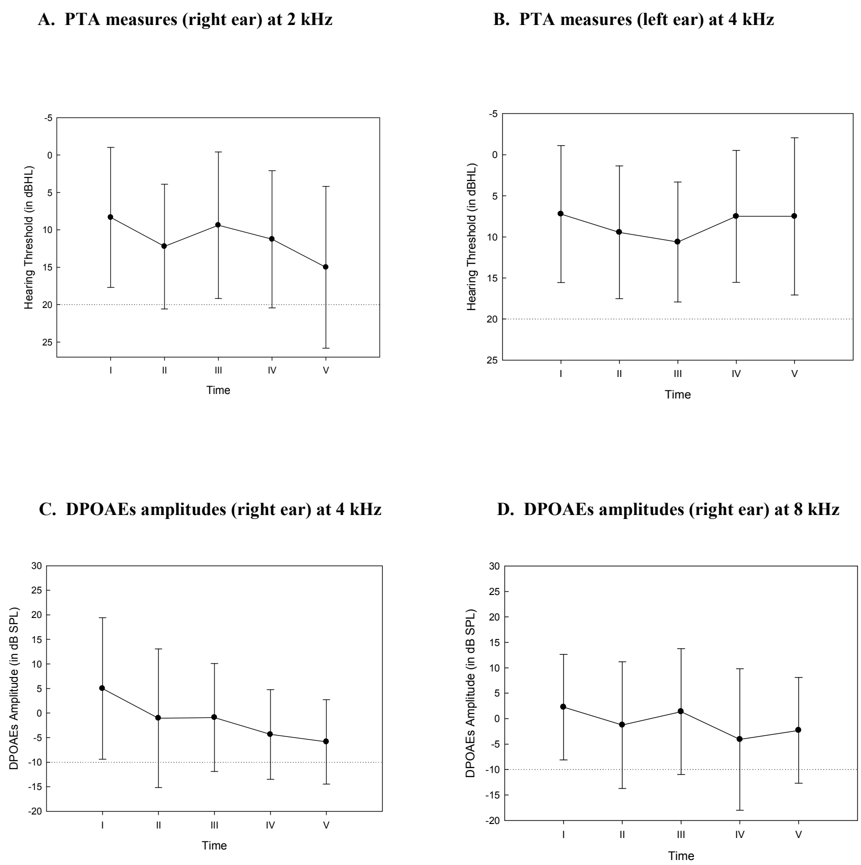
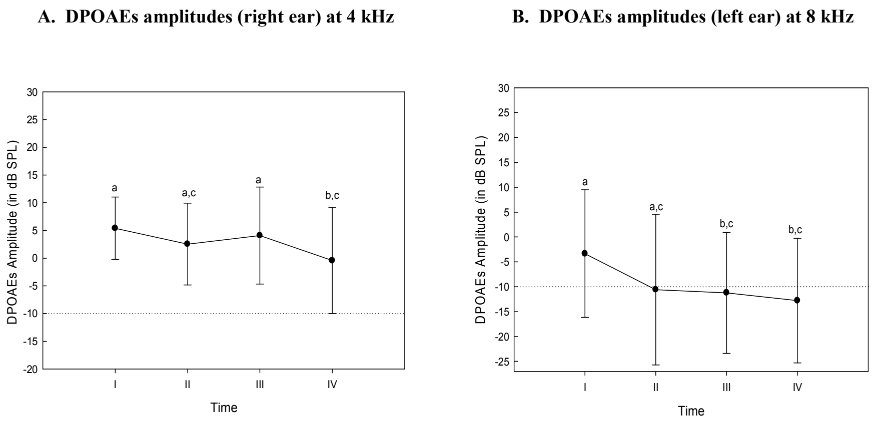


Figure 3. Means and standard deviations of the DPOAEs amplitudes obtained at different time points from the "Low-Risk" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss. Significantly different group means were labeled with

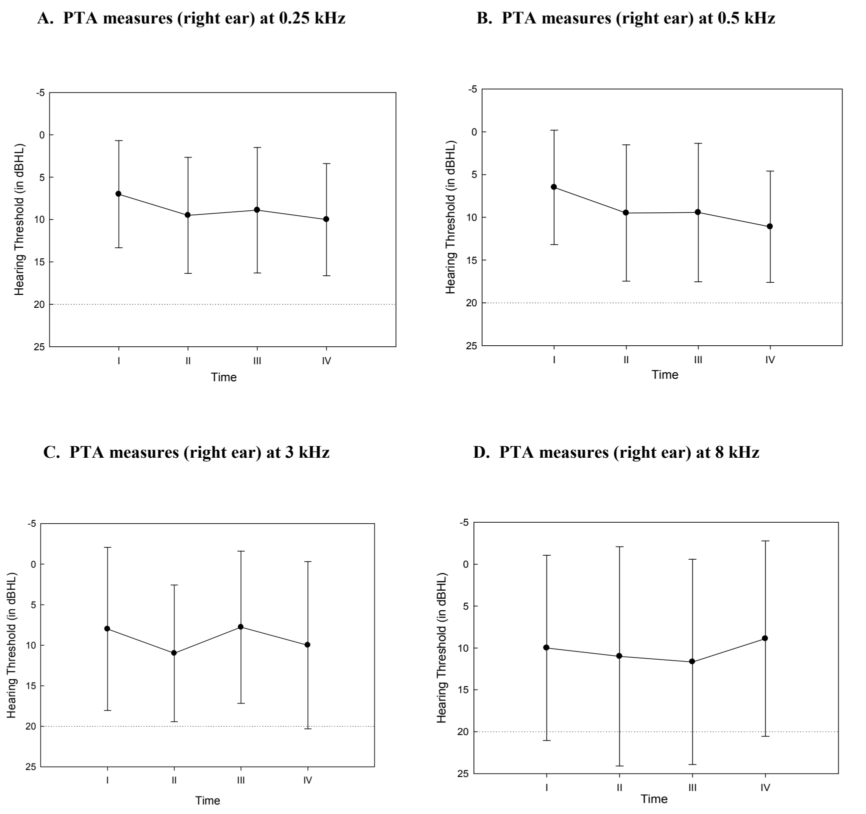


recruit regular aerobic class goers and individuals who usually do not work out in the gymnasium. The subject inclusion criteria were: i) healthy adult aged between 18 and 50 years old, ii) negative history of ear pathology, and iii) normal or no worse than a mild hearing loss, as verified through a PTA test. Exclusion criteria were: i) past history or present sign of acoustic trauma, ii) excessive noise exposure during occupational activities, iii) previous history of ear surgery, iv) a fracture of the skull, and v) ingestion of potentially ototoxic drugs.

The operational definition of "non-gym goers" was individuals who reportedly had never taken any aerobic class and had never, or rarely, been to the gymnasium in recent years. "Regular aerobic class goers" referred to individuals who had been attending aerobic classes at least once a week for at least six months. As the noise levels of aerobic classes were found in the previous phase of the study to vary among classes, a distinction was made between high and low-risk classes. Aerobic classes with an average noise level above 85 dBA were classified as high-risk and those below 85 dBA as low-risk. Regular aerobic class goers recruited from high-risk aerobic classes were classified as the "High-Risk" group and those from the low-risk classes as "Low-Risk". Non-gym goers were randomly assigned to the "Control without Hearing Protection (HP)" and "Control with HP" groups.

A total of 33 participants were recruited from May to September in 2008. There were nine participants (4 females and 5 males, aged from 18 to 48 years) in the "High-Risk" group, eight (5 females and 3 males, aged from 21 to 35) in the "Low-Risk" group, ten (5 females and 5 males, aged from 21 to 50) in the "Control without HP" group, and six (3 females and 3 males, aged from 20 and 43) in the "Control with HP" group. Result of a one-way Analysis of Variance (ANOVA) showed that there was no significant age difference between the

Figure 4. Means and standard deviations of the PTA measures (right ear) obtained at different time points from the "Control without HP" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss.)



four comparison groups [F(3, 29) = 0.279, p = 0.84].

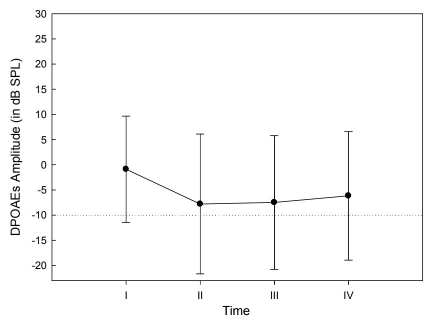
All participants were instructed to keep a diary of noise exposure during the experimental period and keep away from other sources of noise (e.g., clubs, rock concerts, and lawn mowers). In addition, all participants were provided with a pair of disposable earplugs (NRR22, i.e., Noise Reduction Rating = 22 dBA) to wear in noisy environment outside the experimental setting. 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 attend one session of high-risk aerobic class, with those assigned to the "Control without HP" group instructed to wear no HP device and those to the "Control with HP" group instructed to wear earplugs during the class. To ensure that participants followed the instructions, one of the experimenters was present in most of the aerobic classes where participants attended. All non-gym goers were then asked to keep away from gymnasiums throughout the rest of the experimental period.

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= 2f1-f2; f1= 65dB SPL, f2= 55dB SPL; f2/f1 ratio= 1.22; SNR= 6 dB). The hearing assessments were performed in a sound treated room with the maximum allowable SPL maintained as specified by ANSI Standards S3.1.

Throughout the one-month monitoring period, all participants underwent four sessions of hearing assessment, including tests of PTA and DPOAEs. All hearing tests were conducted in the Speech and Hearing Clinic at the University of Canterbury. 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 baseline 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 & Berger, 2002).

Participants were tested at four different time points, including: baseline measures (Time I), immediately after an aerobic class (Time II), 24-48 hours post-exposure (Time III), which represents the end of the short recovery period, and 30 days post-exposure (Time IV), which represents the end of the extended recovery period. In addition, five participants from the "High-Risk" group were tested four months post-exposure (Time V) to determine if the trend of hearing change were maintained. The length of time between the baseline (Time I) and the initial post-exposure measurement sessions (Time II) measurement sessions ranged from 0 to 65 days (Mean = 11.9 days, SD = 16.5, n = 33). Result from a one-way ANOVA on Ranks showed no significant difference on the measure of the time lag between Time I and II between the four comparison groups (H = 2.498, df = 3, p = 0.476).

Figure 5. Means and standard deviations of the DPOAEs amplitudes (right ear) obtained for 8 kHz at different time points from the "Control without HP" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss.)



A series of one-way Repeated Measures (RM) Analysis of Variances (ANOVAs) on Ranks were conducted on the PTA and DPOAEs 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.

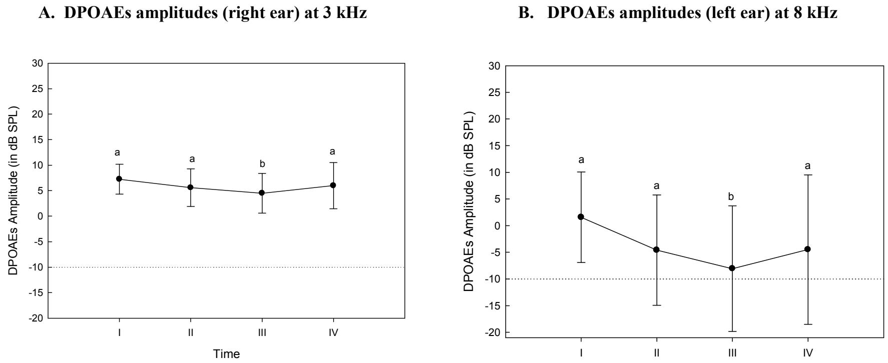
Results

Measures obtained from the three phases of the study were used to describe the room acoustics of a typical aerobic class setting, the noise levels of the sampled aerobic classes, and the effect of noise exposure in aerobic classes on the hearing of participants in the four comparison groups.

Room Acoustics

Results from the acoustic assessment of the chosen sports hall revealed that the RT60 measures ranged from 0.95 seconds at 10 kHz to 7.2 seconds at 0.63 kHz. As shown in Figure 1, the average reverberation time across the mid octave bands, especially in the frequency range from 0.25 to 2.5 kHz, were higher than the normally recommended maximum value of 2 seconds (Sharland, 1972). Although there was a lack of published information regarding how the recommended RT60 has been established, Gastmeier and Aitken (1999) commented that approximately 2.4 seconds would provide an environment that is like to be acceptable. Yoo (2001) recommended an RT60 of 1.8 seconds or lower. Therefore, the present finding suggested that the room examined was excessively reverberant. In particular, the high RT60 value at 0.63 kHz (7.2 seconds) and 1 kHz (6.21 seconds) might have serious implications regarding the negative impact of noise on the clarity of speech. The SPL recorded in the sports hall when the stereo system was played at the maximum level showed an average of 107.2 dBA (SD = 1.74), with the measures ranging from 105.2 to 110.8 dBA in the 25 different measurement locations. The SPL recorded when the volume control was set at the predetermined safety limit showed an average of 97.6 dBA (SD = 1.47), with measures ranging from 95.8 to 99.4 dBA. These findings indicated that

Figure 6. Means and standard deviations of the DPOAEs amplitudes obtained at different time points from the "Control with HP" group. (The dotted line represents the normal limit, with below-line values indicating hearing loss. Significantly different group means were labeled with different letters.)



reduction of the reverberation time of the sports hall needed to be considered and that the stereo system used in the room needed to be controlled to avoid the noise levels in aerobic classes from exceeding the safety limit.

Noise Levels of Aerobic Classes

The noise levels in the sampled aerobic classes, which generally lasted for approximately 50 minutes, was found to range from 73 dBA to 95 dBA. Seventy eight percent (82/105) of the classes measured were above 85 dBA, and 7.6% (8/105) were above 100 dBA. Only eight classes were below 80 dBA. As noise levels 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. The high-risk classes included classes for 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 included classes for indoor cycling, boxing circuit, balance classes, and low-impact aerobics.

Effect of Noise Exposure in Aerobic Classes on Hearing

Results from a series of one-way RM ANOVAs one Ranks performed on the PTA and DPOAEs measures were shown for the four comparison groups separately in Tables 1 to 2. For the experimental measures found in the ANOVA tests to yield a significant "time" effect, the means and standard deviations of the experimental measures averaged for each time point in each subject group were shown in Figures 2 to 6.

As shown from Figures 2 to 6, Time II measures tended to be poorer (i.e., an increase in the hearing threshold level for PTA measures and a decrease in values for DPOAEs measures) than Time I measures across all subject groups, suggesting that hearing showed signs of deterioration immediately after noise exposure in the aerobic class. However, post-hoc tests failed to reveal any significant Time I-Time II difference on both PTA and DPOAEs measures probably due to great between-subject variations and small sample size.

The TTS as shown in PTA measures were minor and generally clinically insignificant, with no increase, from Time I to Time II, of the number of participants falling below the 20 dB cutoff point across all groups. The maximum PTA difference between Time I and Time II for individuals was found to be 15 dB (PTA right ear at 3 kHz) for the "Control without HP" and 10 dB (PTA right ear at 2 kHz) for the "High-Risk" group.

A reduction of DPOAEs amplitudes was observed in the majority of tests conducted immediately after the noise exposure in an aerobic class. The maximum reduction of DPOAE values from Time I to Time II was found to be 27.2 dB (DPOAE right ear at 8 kHz) for the "Control without HP" group, 25.5 dB (DPOAE right ear at 4 kHz) for the "High-Risk" group, 8.2 dB (DPOAE right ear at 8 kHz) for the "Control with HP" group, and 6.8 dB (DPOAE right ear at 4 kHz) for the "Low-Risk" group. These findings showed that the DPOAEs measures for both "Control with HP" and "Low-Risk" groups were relatively unaffected immediately after participation of an aerobic class.

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.

A visual analysis of Figures 5 and 6 comparing Time IV and Time I measures revealed that following a one-month recovery period, non-gym goers who served as the controls in this study generally showed a return of the DPOAEs values to its pre-exposure level. Changes to the PTA measures appeared to be relatively small across sessions.

In summary, measures of DPOAEs were found to be more sensitive than PTA measures in detecting subtle changes of hearing after noise exposure. The reduction of the DPOAEs amplitude following noise exposure in the aerobic class was particularly noticeable in high frequencies, including 3, 4, and 8 kHz. The use of HP was found beneficialin reducing the risks associated with noise during aerobic classes. Individuals within the same group were found to vary in the degree and the rate of deterioration and recovery of the hearing.

Discussion

The finding that noise levels in most aerobic classes exceeded the safety limit and thus might cause a hearing loss to regular aerobic class goers agreed with previous studies. For example, Torre III and Howell (2008) analyzed the noise levels in 12 aerobic classes and found them to range from 83.4 dBA to 90.7 dBA. Yaremchuk & Kaczor (1999) measured the noise levels in 125 different aerobic classes from five different gymnasiums and reported that the average noise level exceeded 90 dBA in 79 percent of the classes. 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. However, the hearing conservation criteria normally 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).

Results from the noise assessment of 105 aerobic classes in this study showed that noise levels during aerobic classes were generally higher than the recommended criteria set by Cohen et al. (1970) and thus violated this assumption.

These findings, together with measurement of the DPOAEs levels of participants immediately after participation in aerobic class, provided evidence showing that recreational noise during aerobic classes might be hazardous to the OHC function.

In particular, the continuing deterioration of hearing after participation in the high-risk classes shown in this study suggested that the temporary emissions shift (TES) observed could potentially lead to a permanent loss of hearing especially among regular aerobic class goers.

While the PTA results in this study have generally failed to detect changes of hearing in response to noise exposure in aerobic classes, the noise-induced TES may be observed not only at the early stage of NIHL but also long after the exposure.

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 (Sutton, Lonsbury-Martin, Martin, & Whitehead, 1994; Attias, Furst, Furman, Reshef-Haran, Horowitz, & Bresloff, 1995; Attias & Bresloff, 1996; Attias et al., 1998; Torre III & Howell, 2008). Specifically, the decline in DPOAEs amplitudes measured from the "High-Risk" group was highly noticeable at 4, 6, and 8 kHz. The size of this decline was related 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.

As participants' noise exposure outside the experimental setting was only monitored in this study through self-reporting, the validity of using Time III and IV observations to determine the cause-effect relationship between noise exposure in the aerobic class and the development of NIHL might be weakened.

Although the inclusion of several comparison groups allowed for between-group comparisons and no apparent subject selection bias was identified that could have threatened the subject equivalency between the comparison groups, a larger sample size was needed to ensure adequate cancellation of the effects of extraneous factors.

A more objective approach in assessing the noise exposure of the participants outside the experimental setting throughout the experimental period would also be useful to tease out the potential history effect in a longitudinal study. Future studies may include more participants 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 hearing for different subject types and thus identify individuals who are most susceptible to gym noise.

The current study confirms that regular attendance in aerobic classes can potentially cause a hearing loss over time. Despite the methodological constraints as discussed, this study has demonstrated that early warning for NIHL is available through DPOAEs testing.

The present finding of a continuous 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.

Conclusion

This study provided evidence showing that noise levels in most aerobic classes were exceedingly high and could potentially cause a hearing loss among regular aerobic class goers.

Early signs of NIHL appeared to be more evident through DPOAEs testing than through conventional PTA tests.

Therefore, DPOAEs testing should be considered in screening individuals susceptible to NIHL. In addition, the professionals and the general public need to advised of the danger of recreational noise and taught how to protect their hearing.

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